The Cost-Effectiveness Criterion and the Treatment of Health Gains and Losses versus Additional Years of Life

By Qinwan Zhang

(6135121)

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Supervisor: Professor Victoria Barham

ECO 6999

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Abstract

In publicly-funded health care system with limited health care resources, the government needs to determine which of all available treatments it is willing to fund. Cost-effectiveness analysis (CEA) has been developed as a solution to this problem, and it helps policy makers choose between alternative treatments. A feature of the standard CEA model is that each person is weighted equally, irrespective of their initial state of health or the nature of the health improvement or life extension due to treatment. This paper extends the standard CEA to examine whether assigning different weights to health treatments which enable patients to avoid illness or death versus treatments which prolong life matters to funding decisions, particularly at the end of life. I study a two-period individual expected utility function and derive the incremental cost-effectiveness ratio for each treatment and determine the implications for funding decisions.The analysis reveals that the incremental cost-effectiveness ratio of each treatment in a model with different weights may generate different funding rules from those derived from the standard model.

Contents

1 Introduction

In publicly-funded health care systems with limited health care resources, the government needs to determine which of all available treatments it is willing to fund. Moreover, it is important that the approach to determining which treatments to fund provide meaningful ongoing guidance to policy makers. This is important because the health budget will vary across time, implying that there may be changing real resources for dealing with health problems. Another and more important problem is that the technology changes over time. There are always new treatments and procedure available and the costs and expected benefits of existing treatments will also change over time because of updated technology. Generally speaking, there are a lot of ways that governments could decide. For example, researchers can ask for doctors' opinions. However, relying on expert advice has some problems. For example, how would the government choose when doctors disagree about which treatments to fund? The procedure for comparing alternative treatments known as cost-effectiveness analysis (CEA) has been developed as a transparent procedure for ranking alternative health care treatments and guiding the allocation of public health care budgets. It has become an important tool for health policy making.

One of the features of CEA is that it weighs the expected health gains to individuals equally, regardless of their age, or past health history. This may mean that CEA will tend to deny care for older individuals, because the expected benefits of providing them with care are lower. This may be viewed as a desirable feature of CEA, because it has been suggested that many health systems overspend resources on individuals with terminal illnesses. However, there is evidence that the public prefers to weight health improvement more heavily than life extension.[1] If the allocation of health resources is to reflect public preferences, we need to weigh treatments that aim at life extension less heavily than those that aim

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[1] This idea is based on Pinto-Prades et al. (2014).

at health improvement. In this paper I examine how introducing differential weights for health improvements versus life extension affects the incremental cost-effectiveness ratio of each treatment and funding decisions.

The rest of this paper is organized as follows. Section 2 is largely expository in nature, and reviews key papers in the literature that provide insight into CEA, identifying important weaknesses with CEA. Section 3 is analytical. I first introduces a model of health resource allocation which is similar to those used elsewhere in the literature, in which all expected health improvements are equally weighted. Subsequently, I extend this basic model to introduce different weights for different treatments. Section 4 concludes.

2 Cost-effectiveness Analysis

Since there are limited health resources, the government needs to determine which of all available treatments it is willing to fund. The approach to measuring and comparing the cost and effectiveness of alternative medical treatments which has become known as cost-effectiveness analysis (CEA) has been developed over several decades; my presentation of the underlying methodology is based on Weinstein et al. (1996).

CEA is a tool for comparing the tradeoffs associated with alternative health interventions, and specifically the way in which these interventions differ with respect to the consumption of resources and their impact on health. In the case of a specific health intervention the average cost-effectiveness ratio is calculated in the following way: it is the cost divided by the expected health benefits, measured in terms of quality-adjusted life years(QALYs), gained with this specific health intervention and takes the form: $\frac{C_j}{E_j}$, where C_j denotes the costs and E_j the expected health benefits (QALYs) gained with intervention j.

In situations where there is more than one possible treatment for a given medical con-

4

dition, the average cost-effectiveness ratio cannot help solve the funding decisions through ranking alternatives, according to (Johannesson & Weinstein, 1993). They state that the average cost-effectiveness ratio compares a specific treatment with no treatment at all. When there is more than one possible treatment for a single health problem, these alternatives are mutually exclusive. In this case, we cannot say that one treatment with lowest average cost-effectiveness (CE) ratio should be funded since these alternatives are dependent and average cost-effectiveness ratio compares a particular treatment with no treatment at all. For example, if two treatments are dependent, then investing on one treatment will affect the possibility of investing on the other, since the health resource is limited. Therefore, the incremental cost-effectiveness ratio, which captures the amount of cost increasing if choosing one particular treatment, compares two alternatives for the single health problem. More specifically, the government will choose the treatment with lowest incremental cost-effectiveness ratio. For example, if the average CE ratio of one treatment is lower than the other one, but the cost of this treatment is so expensive, then the government will not choose this one if facing limited health resources. In this case, using average CE ratio cannot get the right answer. However, using incremental CE ratio will solve this problem because of its definition. Therefore, it is crucial to use the incremental CE ratio rather than simply comparing the cost-effectiveness of the different procedures. As explained by Weinstein et al. (1996), the incremental CE ratio can be expressed as:

$$CE \, ratio = \frac{C_1 - C_2}{E_1 - E_2} \tag{1}$$

where C_j denotes the costs and E_j the expected improvement in health (QALYs) associated with interventions j, and $j \in [1, 2]$, where 1 and 2 denote the health alternatives for a single problem. This incremental CE ratio (ICER) can determine which intervention is more effective than its alternative, since it is the incremental cost divided by incremental

benefit between two alternatives. Once again, the government will fund the treatment with ICER which is lower than threshold over the other alternative. This result is supported by McGregor and Caro (2006), who introduce two methods, the League Table and the acceptability threshold to show how to select one of many health interventions. The authors use the ICER rather than average CE ratio under those methods. Therefore, ICER, instead of average CE ratio, is used to solve the health problem: how to choose one treatment to fund over many other alternatives if there exist limited health resources.

As explained by Culyer et al. (2007), the use of CEA is justified by the fact that this approach maximizes the expected health gains per public health dollar spent. In the United Kingdom, the National Institute for Health and Clinical Excellence (NICE) determines a maximum CE threshold for funding procedures. Procedures with a CE ratio less than the threshold can be used in clinical settings; procedures which have a CE ratio greater than the threshold are not funded. The application of CEA has made the determination of funding decisions more objective, and ensures that health dollars are allocated efficiently.

2.1   The Role of QALYs

Whereas the costs associated with particular procedures are relatively straightforward to measure, to better understand the CE ratio it is important to understand the way that QALYs are calculated, and the strengths and weaknesses of this measure of benefits. The denominator of the cost-effectiveness ratio measures the expected increase in quality-adjusted life years generated by a particular procedure. As explained by Garber (2000), the QALY is a single index which takes both life expectancy and quality of life into account. This index measures the benefit of an additional year of life, of a given quality. Perfect health with an additional year is normalized to 1, and death is normalized to 0. There are states of health which are considered worse than death, and an additional year of life in

these states of health gives a negative QALY. For simplification, the QALY is equal to the value that time duration at the certain health state times the utility score for this health state. More formally, for a given individual, who may experience i different health states, the expected QALY is measured by:

$$QALY = \sum_{i=current\ age}^{Maximum\ age} F_i \delta^i q_i \tag{2}$$

, where F_i denotes the probability that people will survive at health state i; δ^i refers to the discount factor; q_i denotes the benefits to the individual of an additional life year associated with the health state i.

The measurement of QALYs is not without controversy. As pointed out by Whitehead and Ali (2010), a number of methodologies are used for measuring expected benefits: "the visual analogue scale (VAS), the time trade-off (TTO) and the standard gamble (SG)" (p. 8). For the VAS, they state that individuals are asked to assess the given health state by giving its utility between 0 to 100, where 0 denotes the worst health state, and 1 denotes perfect health. In contrast, under the TTO, the authors explain that individuals are asked to choose one of two alternatives that are presented, which captures individuals' willingness to sacrifice length of life to get more years in the healthy state. Finally, with the SG approach, individuals are asked to choose between current health states under certainty and a gamble in which they obtain either full health or death. Each approach has its own strength and weakness. Carr-Hill (1989) argues that it is hard to meaningfully compare the outcomes associated with the different responses, since some of them focus on improving health while others aims at prolonging life. As Carr-Hill (1989) observes, these approaches implicitly rely on the assumption of constant risk aversion, implying that risk aversion does not vary with health status.

Loomes and McKenzie (1989) also addresses the problem of constant risk aversion when calculating the QALYs. Therefore, the authors introduce one alternative using the SG method that does not require those assumptions. They argue that, however, this approach allows individuals to face two alternatives under the standard gamble method: Y years in less healthy state or Y years in perfect health state with probability p, and dead with probability $1 - p$. Individuals are required to choose the value of p so that they are indifferent with two alternatives. They observe that the probability will vary for each value of Y if individuals' attitude to risk depends on the number of years spent in a given health state. Therefore, this alternative still has a problem even though it does not require previous two assumptions.

Whitehead and Ali (2010) and Carr-Hill (1989) note that it is not clear who should be asked the health valuation questions - doctors? patients? members of the public?. The issue of *who* specifically should be surveyed to establish the expected health benefits of alternative procedures is also considered by Weyler and Gandjour (2011). The authors conduct a study with 176 students in Germany to determine whether we need to use preferences of patients or non patients based on the standard gamble (SG) model. This paper compares preferences between those who have experienced depression and those who have not, and it finds that there are 110 students who have presented maximum endurable time (MET) preference, which implies that individuals prefer to live no longer than maximum endurable time, and in the short-term, the utility score for individuals without experience of depression is no larger than that for those with experiences of depression, but in the long-term, they have presented fewer MET preference even though they have lower utility score of depression. In this case, it implies that for the long-term, individuals without experience of depression underestimate the influence of depression since they take depression as worse

health state but have less MET preference.[2] Therefore, it is preferable to use preferences of individuals with experience of depression when calculating the QALY associated with the treatment of depression since the general public is likely to underestimate the effect of depression, which will misrepresent the preferences.

Broome (1993) examines whether quality-adjusted life years can be a good measurement of the benefits associated with health treatments. He states that we need to use a cardinal scale of benefits in order to compare different alternatives, but QALYs provide a cardinal measure of expected benefits only when two conditions are met: one is that if one individual receives more total benefit than the other, then this individual has a better life, and the other is that whether an individual's life is good at any period depends only on the life quality in the specific period.[3]

Nord (1994) is concerned with whether or not QALYs is a proper measure of quality of life, and he argues that the standard interpretation has a major problem: it cannot be tested since the quality of life necessarily reflects individual preferences. He proposes an alternative interpretation: that it be interpreted as the number of years individuals are willing to sacrifice in order to improve their health status. He claims that this is a question that can be tested by asking individuals about how they are willing to trade off life expectancy versus health improvement. However, a weakness, as he points out, is that it still cannot capture how individuals value the trade-off between avoiding death and life years gained or health improvements. To see why this is so, this author argues that it is impossible to compare the benefits when individuals are asked to make a choice between life saved versus situations where they must evaluate a possible health improvement without any life year gains. The reason is that the initial health status when offered these choices

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[2]If one individual value a given state much lower, then this individual needs to have more MET preference, since they do not want to tolerate more time than maximum endurable time

[3]The author notes that these conditions are not always true, since for example, the first assumption only considers the total amount of benefit but ignores the distribution of benefits over time.

are different. More specifically, the initial health status is higher if there is an evaluation of health improvement than of life saved. Since one person cannot be in two different initial health states at the same time, one cannot trade off life saved versus any other outcomes. Therefore, Nord suggests a third interpretation of QALYs from the perspective of social valuation. Unlike the previous interpretations, this one includes two trade-offs: the one between life years gained and quality of life gained, like in the second interpretation, and the other between quality of life and the number of people saved. Nord concludes that QALYs have empirical meaning only when interpreted from the society's perspective.

The actual importance of the QALY is studied by Chapman et al. (2004), who compare the costs per unadjusted life year with costs per QALY in CEA to establish whether there is a substantive difference between those two methods. They explain that if those two methods yield the same result, then it is unnecessary to use QALYs, which are expensive to measure. They use data from a cost utility analysis database, which contains 228 articles published before 1998, and includes 63 studies that report both costs per unadjusted life year and costs per QALY for the same intervention. The authors compare those two ratios in terms of the medians, means, and the differences between these ratios. The authors find that in most cases, the differences are small. However, in some cases the difference is large. They conclude that if treatments that have higher expected effect on the life expectancy than on the life quality, the costs per QALY can be replaced by costs per life years, which is cheaper.[4]Therefore, whether QALY is necessary depends on the relative impact between life quality and life expectancy associated with the health conditions.

In conclusion, if the government only cares about the aggregate health gains, then this goal can be achieved by maximizing the total expected health gains per dollar spent, and

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[4]For example, if we study chronic conditions, then we need to use costs per QALY, since chronic conditions have a larger impact on the life quality than life expectancy. However, if we study palliative treatments, then we can abandon costs per QALY, since these treatments aim at life extension.

QALYs play a crucial role in this calculation. However, the measurement of QALYs is not without controversy. I now turn to a more careful examination of the social welfare function that is justified by the usefulness of CEA.

2.2 Welfare Foundation of CEA

As explained above, CEA has been developed to provide guidance to health policy makers. The development of CEA has been largely ad hoc, and can be contrasted with the approach most natural for economists, which is cost-benefit analysis (CBA). As explained by Phelps and Mushlin (1991), the major difference between cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA) is that CBA measures the costs and benefits into dollars whereas CEA ranks alternatives in terms of health gains per dollar, without monetizing the value of those changes in health.

To compare the equivalence of the ranking of treatments generated under CBA and CEA is first discussed by Garber and Phelps (1997). If CEA rankings differ than CBA rankings, then it is not meaningful from a welfare-economics point of view.The authors assume that an individual is risk neutral, has fixed time preferences, and a utility function that is separable in health and consumptions. Under these conditions, they show that CEA and CBA are equivalent. In addition, they show that at the optimum the incremental CE ratio is equalized for all treatments.

Meltzer and Smith (2011) also research the equivalence of CEA and CBA, and they use lifetime utility function. Unlike Garber and Phelps (1997), who find that future costs do not alter the cost-effectiveness ratio of each intervention, this paper finds that the result of Garber and Phelps (1997) holds only when the sum of consumption and medical costs equals to the earning of each individual at all ages. Therefore, Meltzer and Smith (2011) conclude that future costs cannot be ignored since they alter the incremental cost-effectiveness ratio

11

and thus change the ranking of health interventions. More specifically, ignoring future costs allows policy makers to favour life extension rather than health improvement.

Meltzer (1997) also studies the equivalence of CEA and CBA. Unlike Garber and Phelps (1997), this paper uses lifetime expected utility. The author finds that as long as future medical and non-medical expenditures, as well as all consumptions and earnings, are included in the lifetime utility model, then CEA yields the same result as CBA. Further insight is provided by Bleichrodt and Quiggin (1999), who take an axiomatic approach. They assume that utility depends only on consumption and health and prove that if and only if utility is multiplicative in health and consumption, and if consumption is constant over time, will CEA and CBA be equivalent. Like Bleichrodt and Quiggin (1999), Canning (2013) also takes an axiomatic approach. However, unlike those authors, he assumes that there is a life metric utility function that can represent the individual's preference, and that social preferences must satisfy three axioms : the Pareto principle, which states that society prefers states where make at least one individual better off and no one worse off; anonymity, which states that society only considers the distribution of utility but ignores which individual obtains which utility; and a third axiom which states that if we change the way of valuing health state by adding a fixed constant, then it cannot alter the social preference. He shows that CEA is equivalent to CBA, where the measurement of health outcome is healthy life equivalents rather than QALYs if individuals live at less healthy state.

In summary, the appropriateness of using CEA can be questioned as it was developed as a practical tool, rather than being derived from a welfare economics analysis. However, under some assumptions, it can rank treatments in the same way as CBA. Even though different models have different conditions, generally speaking, the conditions are the person is risk neutral and has fixed time preference, and the utility function needs to be separable

12

in health and consumption.

2.3   The Objective Function: Should Governments Maximize Total Expected Health Gains

As explained above, the widespread application of CEA criterion is justified by appealing to the fact that this maximizes the expected health gains generated per public health dollar spent. Not surprisingly, however, the appropriateness of this objective has been called into question.

In a thoughtful paper, Dolan and Olsen (2001) identify some alternative measures of total health benefits that should potentially be considered in developing health care policy. The first measure is total number of QALYs, and, as discussed above, this means that the government should maximize the expected benefits. However, if the government is also concerned about equity, other measures are relevant. A second alternative is the number of expected QALYs if individuals do not receive treatment; this measure of health benefits is particularly important for individuals with severe illness. They argue that the government needs to distribute QALYs to these persons in order to decrease health inequality. Another factor that could affect the distribution of QALYs is past health history. If an individual's past health care needs are due to his own unhealthy action, should that individual receive the same treatment? Secondly, if an individual's current need for health care is due to unhealthy actions such as drinking and smoking issues, should he get less weight than others? Finally, the authors ask whether the government needs to give less weight to those who have required more health care in the past. The authors conclude that if the government is concerned with equity, then past health and treatment history should affect the way in which health care spending- and therefore QALYs- are allocated at present.

The claim that equity concerns should influence funding decisions is investigated empir-

ically by Dolan and Tsuchiya (2005). They surveyed 100 individuals in order to determine how age, past health, future life expectancy and future health in the absence of treatments would influence public preferences regarding access to treatment. The authors find that people prefer to give the priority to the young over the old and to those with poor past health. A similar approach is taken by Lancsar et al. (2011), who find that the public wants to give more weight to very young and very old individuals, since younger individuals have more years in their future and older ones face the risk of death. In addition, these researchers suggest that the public is willing to give more weight to individuals with less severe health conditions than those who are very sick, since these with less severe health conditions are more likely to recover well than those who face severe illness.

Relatedly, Pinto-Prades et al. (2014) investigate the public preference for life expectancy gained for individuals who are at the end of life and health gains for those with temporary health problems, and the trade-off between health gains with temporary health problems and increases in life quality for those who are at the end of life. The authors find that the public is willing to give more weight for treatments which occur at the end of life. In addition, the finding is that the general population weight quality of life more than increases in life expectancy.

The papers discussed above suggest that there should be trade-off between equity and efficiency of health care dollars. This new ideal is supported by empirical research which should concern a public preference by giving greater priority to the very young and very old. According to Pinto-Prades et al. (2014), the public values the quality of life more than life extension. This implies that there should be different weights on QALYs associated with different kinds of treatments. In particular, greater weight should be attached to treatments which enable individuals to avoid death, which allows individuals to transition from death to healthy, or to improve their health, as compared to treatments which extend

life, which allows individuals to transition from death to sick. In the next section, I develop a model which fills this gap in the cost-effectiveness literature.

3 Model

3.1 Basic Model

I consider an economy in which people live for only two periods, period 1 and period 2. There exist three states of health: healthy (H), sick (S) and dead (D), and everyone is healthy in the initial state, period 0. The utility function has two arguments: consumption of a private good and health, and it is additive. Hence the utility function takes the form: $U(C) + U(H)$, where C is consumption level, and H is health states. In addition, there is an exogenous probability of transitioning from healthy, in state 0, to either sick or dead in period 1. The probability of a healthy person transitioning to sick or dead is constant across periods. π_{ij} denotes the probability of transitioning from health state i to health state j. For example, π_{12} denotes the probability of transitioning from healthy to sick. In the absence of medical treatments, $\pi_{21} = \pi_{32} = \pi_{31} = 0$, since people cannot spontaneously recover. If an individual dies, then this is a permanent transition. The modelling strategy used here differs from that of Garber and Phelps (1997), for example, because the likelihood of transitioning from one health state to another and, in particular, the likelihood of surviving until the next period depend on an individual's status in each period.

The likelihood of transitionary to the health states "sick" or "dead" is affected by accessing medical treatment. M_{ij}^t denotes treatments administered in period t to an individual in health state i to enable them to transition to health state j, and β_{ij}^t denotes that the probability of treatments will be successful. For example, $\beta_{21}^1 \left(M_{21}^1 \right)$ is the probabil-

15

ity that an individual transitioning to sick will be successfully treated, enabling them to remain healthy in period 1. β_{31}^1 (M_{31}^1) is the probability that an individual facing death is successfully treated and remains healthy in period 1. I assume the β functions are concave in medical expenditures, where $\beta_{ij}^t(M_{ij}^t) = 0$ if $M_{ij}^t = 0$, $(\beta_{ij}^t)' > 0$ and $\beta_{ij}^t(\infty) < 1$. This tells us that people cannot be cured if they do not get any treatment, but if infinite resources are allocated to medical treatment then there is no guarantee of a cure.

I also assume that life-time income and total budget for medical treatment are exogenous, and are publicly-funded, that is, funded by equal per capita taxes. Additionally, all people who are sick and have the same health status are treated equally. Since we only have two periods, and the focus is on the allocation of the health care budget, we ignore discounting.

It is important to be able to determine the number of people in each health state in each period. $P(\phi_j^t), j \in [H, S, D]$ is the number of people in health state j in period t. For example, $P(\phi_H^1)$ is the number of healthy individuals in period 1. I denote by $\lambda_j^t, j \in [H, S, D]$ is the proportion of people who are transitioning between two specific health state in period t, and to whom the treatment M_j^t is administered in period t. For example, λ_{31}^1 denotes the number of individuals who are transitioning from healthy to dead in period 1, and to whom the treatment M_{31}^1 is administered in period 1, while $1 - \lambda_{31}^1$ is the proportion of people who have the same transition, but to whom the treatment M_{32}^1 is administered in period 1. λ_{31}^2 is the number of people who are transitioning from health to dead in period 2, and to whom the treatment M_{31}^2 is administered in period 2, while $1 - \lambda_{31}^2$ is the number of people who have the same transition, but to whom the treatment M_{32}^2 is administered in period 2. λ_{32}^2 is the proportion of people who are transitioning from sick to death in period 2, but to whom the treatment M_{31}^2 is administered in period 2, while $1 - \lambda_{32}^2$ is the proportion of people who have the same transition, but to whom the

treatment M_{32}^2 is administered in period 2. In addition, C^t denotes the consumption level in period t.

Assuming that the mass of individuals in the society in period 0 is normalized to one, the population of healthy individuals in period 1 is determined by:

$$P(\phi_H^1) = \pi_{11} + \pi_{12} * \beta_{21}^1(M_{21}^1) + \pi_{13} * \beta_{31}^1(M_{31}^1) * \lambda_{31}^1 \tag{3}$$

Similarly, $P(\phi_S^1)$, the population of sick individuals, takes the following form:

$$P(\phi_S^1) = \pi_{12} * (1 - \beta_{21}^1(M_{21}^1)) + \pi_{13} * \beta_{32}^1(M_{32}^1) * (1 - \lambda_{31}^1) \tag{4}$$

Finally and similarly, the population of dead individuals, $P(\phi_D^1)$, takes the following form:

$$P(\phi_D^1) = \pi_{13} * [(1 - \lambda_{31}^1) * (1 - \beta_{32}^1(M_{32}^1)) + \lambda_{31}^1 * (1 - \beta_{31}^1(M_{31}^1))] \tag{5}$$

I now turn to the analysis of optimal resource allocation in this economy. I first derive optimal policy prescriptions when all expected QALYs are equally weighted, and then show how these results are modified when differential weights are introduced.

3.1.1 Maximizing Expected Social Welfare

In the economy considered here, expected social welfare is appropriately represented as the expected utility of a representative individual in the initial state. For clarity, it is useful to separate expected utility in period 1 and period 2. The expected utility function

in period 1 is:

$$E(U_1) = \pi_{11} * (U(C^1) + V(H)) + \pi_{12} * [\beta_{21}^1(M_{21}^1) * (U(C^1) + V(H)) + (1 - \beta_{21}^1(M_{21}^1)) * (U(C^1) + V(S))] +$$

$$\pi_{13} * \lambda_{31}^1 * [\beta_{31}^1(M_{31}^1)(U(C^1) + V(H)) + (1 - \beta_{31}^1(M_{31}^1))(U(C^1) + V(D))] +$$

$$\pi_{13} * (1 - \lambda_{31}^1) * [\beta_{32}^1(M_{32}^1) * (U(C^1) + V(S)) + (1 - \beta_{32}^1(M_{32}^1)) * (U(C^1) + V(D))]$$

After simplification, this can be rewritten as:

$$E(U_1) = \pi_{11}[U(C^1) + V(H)] + \pi_{12}[U(C^1) + \beta_{21}^1(M_{21}^1)V(H) + (1 - \beta_{21}^1(M_{21}^1))V(S)] + \pi_{13} * \lambda_{31}^1[U(C^1) +$$

$$\beta_{31}^1(M_{31}^1) * V(H) + (1 - \beta_{31}^1(M_{31}^1))V(D)] + \pi_{13} * (1 - \lambda_{31}^1)[U(C^1) + \beta_{32}^1(M_{32}^1)V(S) +$$

$$(1 - \beta_{32}^1(M_{32}^1)) * V(D)]$$

Similarly for period 2:

$$E(U_2) = P(\phi_H^1) * \pi_{11}(U(C^2) + V(H)) + P(\phi_H^1) * \pi_{12} + P(\phi_S^1) * \pi_{22})[\beta_{21}^2(M_{21}^2) * (U(C^2) + V(H)) +$$

$$(1 - \beta_{21}^2(M_{21}^2)) * (U(C^2) + V(S))] + P(\phi_H^1) * \pi_{13} * \lambda_{31}^2[\beta_{31}^2(M_{31}^2) * (U(C^2) + V(H)) +$$

$$(1 - \beta_{31}^2(M_{32}^2)) * U(C^2) + V(D))] + P(\phi_H^1) * \pi_{13} * (1 - \lambda_{31}^2)[\beta_{32}^2(M_{32}^2) *$$

$$(U(C^2) + V(S)) + (1 - \beta_{32}^2(M_{32}^2)) * (U(C^2) + V(D))] + P(\phi_S^1) * \pi_{23} * \lambda_{32}^2[\beta_{31}^2(M_{31}^2) *$$

$$(U(C^2) + V(H)) + (1 - \beta_{31}^2(M_{32}^2)) * (U(C^2) + V(D))] + P(\phi_S^1) * \pi_{23} * (1 - \lambda_{32}^2) * [\beta_{32}^2(M_{32}^2) *$$

$$(U(C^2) + V(S)) + (1 - \beta_{32}^2(M_{32}^2)) * (U(C^2) + V(D))]$$

This can be simplified as following:

$$
\begin{aligned}
E(U_2) =& P(\phi_H^1) * \pi_{11}(U(C^2) + V(H)) + (P(\phi_H^1) * \pi_{12} + P(\phi_S^1) * \pi_{22})[U(C^2) + \beta_{21}^2(M_{21}^2)V(H) + \\
& (1 - \beta_{21}^2(M_{21}^2))V(S)] + P(\phi_H^1) * \pi_{13} * \lambda_{31}^2[U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D)] + \\
& P(\phi_H^1) * \pi_{13} * (1 - \lambda_{31}^2)[U(C^2) + \beta_{32}^2(M_{32}^2) * V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D)] + P(\phi_S^1) * \pi_{23} * \lambda_{32}^2 \\
& [U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D)] + P(\phi_S^1) * \pi_{23} * (1 - \lambda_{32}^2)[U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + \\
& (1 - \beta_{32}^2(M_{32}^2))V(D)]
\end{aligned}
$$

The objective of the social planner is to maximize social welfare subject to the resource constraints. Following the convention in the cost-effectiveness literature to treat the health care budget as exogenous, there are separate budget constraints for consumptions and for health care expenditures. I therefore require that total consumption in period 1 and period 2 not exceed lifetime income, Y, and also the total medical treatment costs, M, cannot be less than expected total treatment costs in period 1 and period 2. Therefore, the two budget constraints are expressed as:

$$Y \geq C^1 + C^2 \tag{6}$$

$$M \geq M^1 + M^2 \tag{7}$$

where C^1 and C^2 denote consumption in period 1 and period 2, respectively; M^1 and M^2 refer to the medical treatment costs in period 1 and period 2, respectively. More precisely:

$$
\begin{aligned}
M^1 =& \pi_{12}(M_{21}^1) + \pi_{13}\lambda_{31}^1(M_{31}^1) + \pi_{13}(1 - \lambda_{31}^1)(M_{32}^1) \\
M^2 =& (P(\phi_H^1)\pi_{12} + P(\phi_S^1)\pi_{22})(M_{21}^2) + P(\phi_H^1)\pi_{13}[\lambda_{31}^2(M_{31}^2) + (1 - \lambda_{31}^2)(M_{32}^2)] + \\
& P(\phi_S^1)\pi_{23}[\lambda_{32}^2(M_{31}^2) + (1 - \lambda_{32}^2)(M_{32}^2)]
\end{aligned}
$$

Therefore, we obtain:

$$L = E(U_1) + E(U_2) + \psi(Y - C^1 - C^2) + \mu(M - M^1 - M^2)$$

We can use the equations of the expected utility function and medical treatment costs in both periods to get the Lagrangian function and rearrange it as following:

$$
\begin{aligned}
L =& \pi_{12}[U(C^1) + \beta_{21}^1(M_{21}^1)V(H) + (1 - \beta_{21}^1(M_{21}^1))V(S) - \mu(M_{21}^1)] + \pi_{13} * \lambda_{31}^1[U(C^1) + \beta_{31}^1(M_{31}^1)* \\
& V(H) + (1 - \beta_{31}^1(M_{31}^1))V(D) - \mu(M_{31}^1)] + \pi_{13} * (1 - \lambda_{31}^1)[U(C^1) + \beta_{32}^1(M_{32}^1)V(S) + (1 - \beta_{32}^1(M_{32}^1))* \\
& V(D) - \mu(M_{32}^1)] + \pi_{11}[U(C^1) + V(H)] + (P(\phi_H^1) * \pi_{12} + P(\phi_S^1) * \pi_{22})[U(C^2) + \beta_{21}^2(M_{21}^2)V(H) + \\
& (1 - \beta_{21}^2(M_{21}^2))V(S) - \mu(M_{21}^2)] + P(\phi_H^1) * \pi_{13}\lambda_{31}^2[U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D) - \\
& \mu(M_{31}^2)] + P(\phi_H^1) * \pi_{13} * (1 - \lambda_{31}^2)[U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D) - \mu(M_{32}^2)] + \\
& P(\phi_S^1) * \pi_{23} * \lambda_{32}^2[U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D) - \mu(M_{31}^2)] + P(\phi_S^1) * \pi_{23} * (1 - \lambda_{32}^2)* \\
& [U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D) - \mu(M_{32}^2)] + P(\phi_H^1) * \pi_{11}(U(C^2) + V(H)) + \\
& \mu(M) + \psi(Y - C^1 - C^2)
\end{aligned}
$$

The social welfare maximum can then be found by optimizing the Lagrangian function with respect to the choice variables, C^1, C^2, M_{21}^1, M_{31}^1, M_{32}^1, M_{21}^2, M_{31}^2, M_{32}^2, λ_{31}^1, λ_{31}^2, λ_{32}^2, μ and ψ. Taking the derivatives in terms of each treatment in the second period provides the first order conditions:

$$M_{21}^2 : (\beta_{21}^2)'(V(H) - V(S)) = \mu \tag{8}$$

$$M_{31}^2 : (\beta_{31}^2)'(V(H) - V(D)) = \mu \tag{9}$$

$$M_{32}^2 : (\beta_{32}^2)'(V(S) - V(D)) = \mu \tag{10}$$

20

Secondly, we need to take the derivatives in terms of each treatment in period 1. Based on the equation (3), (4), and (5), we know that each treatment in period 1 affects the expected utility function not only in period 1 but also in period 2, unlike second period treatments, which affect only in the current period. The first order conditions for each treatment in the first period takes the following form:

$$M_{21}^1 : (\beta_{21}^1)' [(\pi_{12} - \pi_{22})\alpha_1 + \pi_{13}\lambda_{31}^2\alpha_2 + \pi_{13}(1 - \lambda_{31}^2)\alpha_3 - \pi_{23} * \lambda_{32}^2\alpha_2 - \pi_{23}(1 - \lambda_{32}^2)*$$

$$\alpha_3 + \pi_{11}\alpha_4 + V(H) - V(S)] = \mu$$

$$M_{31}^1 : (\beta_{31}^1)' [\pi_{12}\alpha_1 + \pi_{13}\lambda_{31}^2\alpha_2 + \pi_{13}(1 - \lambda_{31}^2)\alpha_3 + \pi_{11}\alpha_4 + V(H) - V(D)] = \mu$$

$$M_{32}^1 : (\beta_{32}^1)' [\pi_{22}\alpha_1 + \pi_{23}\lambda_{32}^2\alpha_2 + \pi_{23}(1 - \lambda_{32}^2)\alpha_3 + V(S) - V(D)] = \mu$$

, where

$$\alpha_1 = U(C^2) + \beta_{21}^2(M_{21}^2)V(H) + (1 - \beta_{21}^2(M_{21}^2))V(S) - \mu(M_{21}^2)$$

$$\alpha_2 = U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D) - \mu(M_{31}^2)$$

$$\alpha_3 = U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D) - \mu(M_{32}^2)$$

$$\alpha_4 = U(C^2) + V(H)$$

I now take the derivative in terms of the second period λs, and I get the first conditions:

$$\lambda_{32}^2 : \beta_{31}^2(M_{31}^2)V(H) - \beta_{32}^2(M_{32}^2)V(S) - (\beta_{31}^2(M_{31}^2) - \beta_{32}^2(M_{32}^2))V(D) - \mu((M_{31}^2) - (M_{32}^2)) = 0$$

$$(11)$$

$$\lambda_{31}^2 : \beta_{31}^2(M_{31}^2)V(H) - \beta_{32}^2(M_{32}^2)V(S) - (\beta_{31}^2(M_{31}^2) - \beta_{32}^2(M_{32}^2))V(D) - \mu((M_{31}^2) - (M_{32}^2)) = 0$$

$$(12)$$

Based on the equations (11) and (12), we can see that those two first order conditions are

21

exactly the same. I believe that the value of λ_{32}^2 is equal to λ_{31}^2, since the λs are determined by first order conditions. I also notice that the left-hand side of each equation is a constant term. If the constant is larger than zero, this means that the objective function will rise as the λ increases. Since the goal is to maximize the objective function, in this case, we choose λ to be equal to 1. If the constant is smaller than zero, then the objective function will fall as the λ rises. In this case, we choose λ to be 0. Since the first order conditions suggest that this constant is equal to 0, which means we can choose λ to be anything between 0 to 1. I will take an extreme example in my model, which is choosing λ to be 0 or 1. Since these two values of λ yield the similar result,[5] let's choose the λ to be 1 and simplify the first order conditions in terms of second period treatments as following:

$$M_{21}^1 : (\beta_{21}^1)' [(\pi_{12} - \pi_{22})\alpha_1 + (\pi_{13} - \pi_{23})\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(S)] = \mu \qquad (13)$$

$$M_{31}^1 : (\beta_{31}^1)' [\pi_{12}\alpha_1 + \pi_{13}\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(D)] = \mu \qquad (14)$$

$$M_{32}^1 : (\beta_{32}^1)' [\pi_{22}\alpha_1 + \pi_{23}\alpha_2 + V(S) - V(D)] = \mu \qquad (15)$$

Now, I turn to derivation in terms of consumption level.

$$C^1 : (\pi_{11} + \pi_{12} + \pi_{13}) * U(C^1)' = \psi$$

$$C^2 : (P(\phi_H^1)(\pi_{11} + \pi_{12} + \pi_{13}) + P(\phi_S^1)(\pi_{22} + \pi_{23}))U(C^2)' = \psi$$

---

[5]If $\lambda = 0$, then it means that all individuals, who are transitioning from healthy to dead or sick to dead, are taking medical treatments that allow them to transition from death to sick, and if $\lambda = 1$, then all individuals, who are transitioning from healthy to dead or sick to dead, are taking medical treatments that allow them to transition from death to healthy.

This can be simplified as:

$$C^1 : U(C^1)' = \psi$$

$$C^2 : (P(\phi_H^1) + P(\phi_S^1))U(C^2)' = \psi$$

I take the derivative with respect to μ and ψ, and I get:

$$\mu : M = M^1 + M^2$$

$$\psi : Y = C^1 + C^2$$

3.1.2 Interpretation

Based on the definition of cost-effectiveness ratio, this captures the benefit of a treatment for additional cost on the treatment. I first focus on the first order conditions for the second period treatments. Based on equations (8),(9) and (10), the left-hand side terms for these three equations are equalized. For equation (8), the left-hand side term refers to expected utility change for those who are transitioning from healthy to sick if there is an additional dollar of spending on the treatment M_{21}^2. Similarly, for equation (9), the left-hand side term captures the expected utility change for individuals who are transitioning from healthy to dead if there is an extra dollar of spending on the treatment M_{31}^2. Likewise, for (10) equation, the left-hand side term tells us the change in expected utility for people who are transitioning from sick and dead if there is an additional dollar of spending on the treatment M_{32}^2. Therefore, the left-hand side term of each equation captures the incremental cost-effectiveness ratio of each treatment. The right-hand side term of equations (8), (9) and (10) are all equal to μ, which is the shadow price. In other words, the marginal utility is equal to μ if there is an additional unit of health resources.

23

Since the left-hand side terms are equalized, the incremental cost-effectiveness ratio is the same for all second period treatments.

I now turn to the first order conditions for the first period treatments. Based on equations (13), (14) and (15), the left-hand side terms of these equations are equalized. In this case, there are two perspectives: the future costs can be ignored since it cannot alter the ranking of health treatments, as Garber and Phelps (1997) suggested. In this case, the first order conditions for period 1 treatments are identical to that for period 2 treatments. Under this circumstance, the interpretations are the same those for second period treatments. Therefore, the incremental cost-effectiveness ratio is equalized for each treatment in each period. In contrast, the alternative perspective is supported by Meltzer and Smith (2011), who argued that future effect cannot be ignored since it will change the incremental cost-effectiveness ratio and funding decisions. In this case, an example on equation (13), the left-hand side term captures the incremental expected social welfare change from an additional dollar on treatment M_{21}^1, which is provided to healthy individuals at the beginning of period 1 who are transitioning to sick. This differs with M_{21}^2, since M_{21}^2 is a treatment, which is provided to either healthy or sick individuals at the beginning of period 2 who are transitioning to sick. The left-hand side term in equation (14) refers to the expected social welfare change if spending an extra dollar on treatment M_{31}^1, which is provided to healthy individuals at the beginning of period 1 who are transitioning to dead. This treatment differs with M_{31}^2, since M_{31}^2 refers to the treatment, which is provided to either healthy or sick individuals at the beginning of period 2 who are transitioning to dead. For the (15) equation, the left-hand side term tells us the change in the social welfare from the last dollar on treatment M_{32}^1, which is provided to healthy people at the beginning of period 1 who are transitioning to dead. However, M_{32}^2 is different, since it is provided to either healthy or sick people at the beginning of period 2 who are transitioning to dead.

The right-hand side term for equations (13), (14) and (15) equals to μ, which refers to the marginal utility of an additional unit of health resources. I notice that regardless of whether future costs are included, the left-hand side of each of these first order conditions captures the incremental cost-effectiveness ratio of the treatments. This leads to the conclusion that at an optimal solution, the incremental cost-effectiveness ratio is equalized for all medical treatments.

It is important to understand that although the optimal solution requires that incremental cost-effectiveness ratio be equalized across treatments, this does not imply that the likelihood of successful treatments is equalized. Moreover, through examining the second period treatment, I notice that at an optimum, it must be true that:

$$(\beta_{21}^2)^{'}(V(H) - V(S)) = (\beta_{31}^2)^{'}(V(H) - V(D)) \tag{16}$$

$$(\beta_{31}^2)^{'}(V(H) - V(D)) = (\beta_{32}^2)^{'}(V(S) - V(D)) \tag{17}$$

$$(\beta_{32}^2)^{'}(V(S) - V(D)) = (\beta_{21}^2)^{'}(V(H) - V(S)) \tag{18}$$

Since we know that $V(S) > V(D)$, as the utility of being sick is greater than utility of being death, then $V(H) - V(S) < V(H) - V(D)$, meaning that the utility change between being health and sick is smaller than the utility change between being healthy and dead. From equation (16), we conclude that $(\beta_{21}^2)^{'} > (\beta_{31}^2)^{'}$. Since the β function is concave, and $\beta(M)^{'} > 0$, then if the β function depends only on the total amount spent on treatment and not on the initial health state then it must be true that $M_{21}^2 < M_{31}^2$ when they are chosen optimally. Likewise, $V(H) > V(S)$, as the utility of being healthy is greater than utility of being sick, and so $V(H) - V(D) > V(S) - V(D)$. From (17) equation, $(\beta_{31}^2)^{'} < (\beta_{32}^2)^{'}$. Since the β function is concave, and $\beta(M)^{'} > 0$, then if the β function is independent of the initial health state it must be true that $M_{31}^2 > M_{32}^2$ when they are chosen optimally.

Also, by a similar argument, it can be seen that the government needs to invest more in M_{31}^2 than in M_{32}^2 and M_{21}^2 in order to maximize expected social welfare. Combining these results, if the utility difference between healthy and sick is smaller than that between sick and dead, and if the likelihood of success depends only on the total amount spent, then the government optimally invests more in treatment M_{32}^2 than in M_{21}^2. However, if the utility difference between healthy and sick is larger than that between sick and dead, then the government will invest more in treatment M_{21}^2 than in M_{32}^2.

For equation (13), (14) and (15), the first order conditions for the first period treatments, we get:

$$(\beta_{21}^1)' [(\pi_{12} - \pi_{22})\alpha_1 + (\pi_{13} - \pi_{23})\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(S)] =$$
$$(\beta_{31}^1)' [\pi_{12}\alpha_1 + \pi_{13}\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(D)]$$
$$(\beta_{31}^1)' [\pi_{12}\alpha_1 + \pi_{13}\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(D)] = (\beta_{32}^1)' [\pi_{22}\alpha_1 + \pi_{23}\alpha_2 + V(S) - V(D)]$$
$$(\beta_{32}^1)' [\pi_{22}\alpha_1 + \pi_{23}\alpha_2 + V(S) - V(D)] = (\beta_{21}^1)' [(\pi_{12} - \pi_{22})\alpha_1 + (\pi_{13} - \pi_{23})\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(S)]$$

Similarly, from the first equation, if $V(D) - V(S) - \pi_{22}\alpha_1 - \pi_{23}\alpha_2 > 0$, then $(\beta_{21}^1)' < (\beta_{31}^1)'$. Since the β function is concave, and $\beta(M)' > 0$, $M_{21}^1 > M_{31}^1$, when they are chosen optimally. Therefore, the government will fund M_{21}^1 more to maximize social welfare. On the other hand, if $V(D) - V(S) - \pi_{22}\alpha_1 - \pi_{23}\alpha_2 < 0$, then $(\beta_{21}^1)' > (\beta_{31}^1)'$. Since the β function is concave, and $\beta(M)' > 0$, $M_{31}^1 > M_{21}^1$ when they are chosen optimally. Hence, the government will fund M_{31}^1 more to maximize the expected social welfare. In addition, if $V(D) - V(S) - \pi_{22}\alpha_1 - \pi_{23}\alpha_2 = 0$, then $(\beta_{21}^1)' = (\beta_{31}^1)'$. Since the β function is concave, and $\beta(M)' > 0$, $M_{31}^1 = M_{21}^1$ when they are chosen optimally. Therefore, the government will fund the same amount of dollars for both treatments to satisfy the conditions for social welfare maximization. From the second equation, if $(\pi_{12} - \pi_{22})\alpha_1 + (\pi_{13} - \pi_{23})\alpha_2 +$

$\pi_{11}\alpha_4 + V(H) - V(S) > 0$, then $(\beta_{31}^1)' < (\beta_{32}^1)'$. Since the β function is concave, and $\beta(M)' > 0$, $M_{31}^1 > M_{32}^1$ when they are chosen optimally. Hence, the government will fund M_{31}^1 more to maximize expected social welfare. On the other hand, if $(\pi_{12} - \pi_{22})\alpha_1 + (\pi_{13} - \pi_{23})\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(S) < 0$, then $(\beta_{31}^1)' > (\beta_{32}^1)'$. Since the β function is concave, and $\beta(M)' > 0$, $M_{32}^1 > M_{31}^1$ when they are chosen optimally. Therefore, the government is willing to fund more on treatment M_{32}^1 to satisfy the conditions for social welfare maximization. In addition, if $(\pi_{12} - \pi_{22})\alpha_1 + (\pi_{13} - \pi_{23})\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(S) = 0$, then $(\beta_{31}^1)' = (\beta_{32}^1)'$. Since the β function is concave, and $\beta(M)' > 0$, $M_{31}^1 = M_{32}^1$. Hence, the government will put the same amount of money on both treatments to maximize expected social welfare. Similarly, from the third equation, if $(2\pi_{22} - \pi_{12})\alpha_1 + (2\pi_{23} - \pi_{13})\alpha_2 - \pi_{11}\alpha_4 + 2V(S) - V(D) - V(H) > 0$, then $(\beta_{32}^1)' < (\beta_{21}^1)'$. Since the β function is concave, and $\beta(M)' > 0$, $M_{32}^1 > M_{21}^1$ when they are chosen optimally. Hence, the government will fund M_{32}^1 more to satisfy the conditions for social welfare maximization. On the other hand, if $(2\pi_{22} - \pi_{12})\alpha_1 + (2\pi_{23} - \pi_{13})\alpha_2 - \pi_{11}\alpha_4 + 2V(S) - V(D) - V(H) < 0$, then $(\beta_{32}^1)' > (\beta_{21}^1)'$, and the government is willing to put more money on M_{21}^1 than M_{32}^1, since β function is concave, and $\beta(M)' > 0$, which leads to $M_{21}^1 > M_{32}^1$ when they are chosen optimally. In addition, if $(2\pi_{22} - \pi_{12})\alpha_1 + (2\pi_{23} - \pi_{13})\alpha_2 - \pi_{11}\alpha_4 + 2V(S) - V(D) - V(H) = 0$, then $(\beta_{32}^1)' = (\beta_{21}^1)'$. Since β function is concave, and $\beta(M)' > 0$, $M_{21}^1 = M_{32}^1$. Hence, policy makers will fund the same amount of money on both treatments to maximize social welfare.

Simply saying, from my basic model I notice that the incremental cost-effectiveness ratio is equalized for all health treatments even when we consider future effects, which is consistent with Garber and Phelps (1997). However, taking future effects into account may alter the funding decisions, which is also suggested by Meltzer and Smith (2011). Since Pinto-Prades et al. (2014) suggested that the public prefers to assign different weights to

27

different health treatments, more specifically, the public values quality of life more than life extension, my next discussion is based on this issue, and I assign different weights to different health treatments.

3.2 Model with weights

Since in my model I have three different health treatments: treatments that aim at avoiding death, avoiding sickness and extending life, I assign different weights to these treatments. Pinto-Prades et al. (2014) argue that the public values improvements in the quality of life more than life extending treatments which do not improve health. Consequently, I assume that the weights for avoiding death or avoiding sickness are both higher than life extension.

I now propose three weights that are used in my model. There are weights of utility in terms of avoiding death, avoiding sickness and extending life. For example, treatment M_{31}^1 and M_{31}^2 are the ones that avoid death in period 1 and period 2. M_{31}^1 and M_{31}^2 are the treatments that allow people to transition from death to health, which can be taken as the treatment for avoiding death. In this case, I will give the weight of utility $\hat{\rho}$, in terms of the treatments. Treatments M_{21}^1 and M_{21}^2 are the ones that avoid sickness in both periods, since they allows individuals to transition from sick to health. Those can be taken as the treatments for avoiding sickness, I will propose the weight of utility, $\tilde{\rho}$. Finally, I have treatments M_{32}^1 and M_{32}^2, which helps people transition from death to sick. In this case, those treatments can be taken as the ones with life extension, since people who receive this treatment will still be sick. I will give the weight of utility, $\bar{\rho}$.

3.2.1   Maximizing Expected Social Welfare

In the economy considered here, expected social welfare is appropriately represented as the expected utility of a representative individual in the initial state. As above, in the standard model, it is useful to separate expected utility in period 1 and period 2. The expected utility function in period 1 is:

$$
\begin{aligned}
E(U_1^w) =& \pi_{11}[U(C^1) + V(H)] + \tilde{\rho}\pi_{12}[U(C^1) + \beta_{21}^1(M_{21}^1)V(H) + (1 - \beta_{21}^1(M_{21}^1))V(S)] + \hat{\rho}\pi_{13} * \lambda_{31}^1 \\
& [U(C^1) + \beta_{31}^1(M_{31}^1) * V(H) + (1 - \beta_{31}^1(M_{31}^1))V(D)] + \bar{\rho}\pi_{13} * (1 - \lambda_{31}^1)[U(C^1) + \\
& \beta_{32}^1(M_{32}^1)V(S) + (1 - \beta_{32}^1(M_{32}^1)) * V(D)]
\end{aligned}
$$

Similarly for period 2:

$$
\begin{aligned}
E(U_2^w) =& P(\phi_H^1) * \pi_{11}(U(C^2) + V(H)) + \tilde{\rho}(P(\phi_H^1) * \pi_{12} + P(\phi_S^1) * \pi_{22})[U(C^2) + \beta_{21}^2(M_{21}^2)V(H) + \\
& (1 - \beta_{21}^2(M_{21}^2))V(S)] + \hat{\rho}P(\phi_H^1) * \pi_{13} * \lambda_{31}^2[U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D)] + \\
& \bar{\rho}P(\phi_H^1) * \pi_{13} * (1 - \lambda_{31}^2) * [U(C^2) + \beta_{32}^2(M_{32}^2) * V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D)] + \hat{\rho}P(\phi_S^1) * \\
& \pi_{23} * \lambda_{32}^2[U(C^2) + \beta_{31}^2(M_{31}^2) * V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D)] + \bar{\rho}P(\phi_S^1) * \pi_{23} * (1 - \lambda_{32}^2) \\
& [U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D)]
\end{aligned}
$$

As before, we assume that the objective of the social planner is to maximize social welfare subject to the resource constraints. However, the Lagrangian function is now expressed as:

$$
\begin{aligned}
L =& \tilde{\rho}\pi_{12}[U(C^1) + \beta_{21}^1(M_{21}^1)V(H) + (1 - \beta_{21}^1(M_{21}^1))V(S) - \frac{1}{\tilde{\rho}}\mu(M_{21}^1)] + \hat{\rho}\pi_{13} * \lambda_{31}^1[U(C^1) + \beta_{31}^1(M_{31}^1)* \\
& V(H) + (1 - \beta_{31}^1(M_{31}^1))V(D) - \frac{1}{\hat{\rho}}\mu(M_{31}^1)] + \bar{\rho}\pi_{13} * (1 - \lambda_{31}^1)[U(C^1) + \beta_{32}^1(M_{32}^1)V(S) + (1 - \beta_{32}^1(M_{32}^1))* \\
& V(D) - \frac{1}{\bar{\rho}}\mu(M_{32}^1)] + \pi_{11}[U(C^1) + V(H)] + \tilde{\rho}(P(\phi_H^1) * \pi_{12} + P(\phi_S^1) * \pi_{22})[U(C^2) + \beta_{21}^2(M_{21}^2)V(H)+ \\
& (1 - \beta_{21}^2(M_{21}^2))V(S) - \frac{1}{\tilde{\rho}}\mu(M_{21}^2)] + \hat{\rho}P(\phi_H^1) * \pi_{13}\lambda_{31}^2[U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D)- \\
& \frac{1}{\hat{\rho}}\mu(M_{31}^2)] + \bar{\rho}P(\phi_H^1) * \pi_{13} * (1 - \lambda_{31}^2)[U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D) - \frac{1}{\bar{\rho}}\mu(M_{32}^2)]+ \\
& \hat{\rho}P(\phi_S^1) * \pi_{23} * \lambda_{32}^2[U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D) - \frac{1}{\hat{\rho}}\mu(M_{31}^2)] + \bar{\rho}P(\phi_S^1) * \pi_{23} * (1 - \lambda_{32}^2)* \\
& [U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D) - \frac{1}{\bar{\rho}}\mu(M_{32}^2)] + P(\phi_H^1) * \pi_{11}(U(C^2) + V(H))+ \\
& \mu(M) + \psi(Y - C^1 - C^2)
\end{aligned}
$$

The social welfare maximum can be found by optimizing the Lagrangian function in terms of the choice variables C^1, C^2, M_{21}^1, M_{31}^1, M_{32}^1, M_{21}^2, M_{31}^2, M_{32}^2, λ_{31}^1, λ_{31}^2, λ_{32}^2, μ and ψ. Firstly, taking the derivatives with respect to each second period treatment provides the first order conditions:

$$M_{21}^2 : \tilde{\rho}(\beta_{21}^2)'(V(H) - V(S)) = \mu \tag{19}$$

$$M_{31}^2 : \hat{\rho}(\beta_{31}^2)'(V(H) - V(D)) = \mu \tag{20}$$

$$M_{32}^2 : \bar{\rho}(\beta_{32}^2)'(V(S) - V(D)) = \mu \tag{21}$$

The first order conditions for λ_{32}^2 and λ_{31}^2 takes for the following form:

$$\lambda_{32}^2 : \hat{\rho}[\beta_{31}^2(M_{31}^2)V(H) - \beta_{32}^2(M_{32}^2)V(S) - (\beta_{31}^2(M_{31}^2) - \beta_{32}^2(M_{32}^2))V(D)] - \mu((M_{31}^2) - (M_{32}^2)) = 0$$
$$(22)$$

$$\lambda_{31}^2 : \hat{\rho}[\beta_{31}^2(M_{31}^2)V(H) - \beta_{32}^2(M_{32}^2)V(S) - (\beta_{31}^2(M_{31}^2) - \beta_{32}^2(M_{32}^2))V(D)] - \mu((M_{31}^2) - (M_{32}^2)) = 0$$
$$(23)$$

From equations (22) and (23), we notice that these two equations are exactly the same, and the left-hand side terms for those equations are constants. Like the situations as in the basic model without weights, we can choose λ_{32}^2 and λ_{31}^2 to be between 0 and 1. Like the choice in the basic model, I choose those λs to be 1. The same reason as before. Therefore, the first order conditions for second period treatments takes the following form:

$$M_{21}^1 : (\beta_{21}^1)'[\tilde{\rho}((\pi_{12} - \pi_{22})\hat{\alpha}_1 + V(H) - V(S)) + \hat{\rho}(\pi_{13} - \pi_{23})\hat{\alpha}_2 + \pi_{11}\hat{\alpha}_4 + V(H) - V(S)] = \mu$$
$$(24)$$

$$M_{31}^1 : (\beta_{31}^1)'[\tilde{\rho}\pi_{12}\hat{\alpha}_1 + \hat{\rho}(\pi_{13}\hat{\alpha}_2 + V(H) - V(D)) + \pi_{11}\hat{\alpha}_4] = \mu \qquad (25)$$

$$M_{32}^1 : (\beta_{32}^1)'[\tilde{\rho}\pi_{22}\hat{\alpha}_1 + \hat{\rho}\pi_{23}\hat{\alpha}_2 + \bar{\rho}(V(S) - V(D))] = \mu \qquad (26)$$

where each α takes the following form:

$$\hat{\alpha}_1 = U(C^2) + \beta_{21}^2(M_{21}^2)V(H) + (1 - \beta_{21}^2(M_{21}^2))V(S) - \frac{1}{\hat{\rho}}\mu(M_{21}^2)$$

$$\hat{\alpha}_2 = U(C^2) + \beta_{31}^2(M_{31}^2)V(H) + (1 - \beta_{31}^2(M_{31}^2))V(D) - \frac{1}{\hat{\rho}}\mu(M_{31}^2)$$

$$\hat{\alpha}_3 = U(C^2) + \beta_{32}^2(M_{32}^2)V(S) + (1 - \beta_{32}^2(M_{32}^2))V(D) - \frac{1}{\hat{\rho}}\mu(M_{32}^2)$$

$$\hat{\alpha}_4 = U(C^2) + V(H)$$

I now take derivatives with respect to consumption level in each period:

$$C^1 : [\tilde{\rho}\pi_{12} + \hat{\rho}\pi_{13}\lambda^1_{31} + \bar{\rho}\pi_{13}(1 - \lambda^1_{31}) + \pi_{11}]U(C^1)' = \psi$$

$$C^2 : [P(\phi^1_H)(\tilde{\rho}\pi_{12} + \hat{\rho}\pi_{13}\lambda^2_{31} + \bar{\rho}\pi_{13}(1 - \lambda^2_{31}) + \pi_{11}) + P(\phi^1_S)(\tilde{\rho}\pi_{22} + \hat{\rho}\pi_{23}\lambda^2_{32} + \bar{\rho}\pi_{23}(1 - \lambda^2_{32}))]U(C^2)' = \psi$$

The first order conditions for μ and ψ are expressed as:

$$\mu : M = M^1 + M^2$$

$$\psi : Y = C^1 + C^2$$

3.2.2 Interpretation with weights

Based on the definition of cost-effectiveness ratio, which captures the benefit of a treatment for additional cost on the treatment. I firstly look close to the first order conditions, equations (19), (20) and (21) for the second period treatments, and I notice that the left-hand side terms of each equation are equalized. For equation (19), the left-hand side term refers that the weighted expected utility change for those who are transitioning from healthy and sick if spending the last dollar on the treatment M^2_{21}. For equation (20), the left-hand side term captures the weighted expected utility change for individuals who are transitioning from healthy to dead if there is an additional dollar of spending on treatment M^2_{31}. Finally, the left-hand side term of equation (21) reveals that the weighted expected utility change for people who are transitioning from sick to dead if spending an extra dollar on the treatment M^2_{32}. Since the cost-effectiveness ratio captures the outcomes of a treatment per unit of its cost, the left-hand side term of each condition can be taken as the incremental cost-effectiveness ratio for each treatment. The right-hand side term of each equation is equal to μ, which is the shadow price of additional health resources. In other words, μ

32

captures the marginal utility of having an additional unit of health resources. Therefore, the incremental cost-effectiveness ratio is equalized for all second period treatments.

I now move to the first order conditions for the first period treatments. There are two perspectives: the future costs can be ignored since it cannot alter the ranking of health treatments, as Garber and Phelps (1997) suggested. In this case, the first order condition of each first period treatment is the same as for each second period treatment. In contrast, the alternative perspective is supported by Meltzer and Smith (2011), who argued that future effect cannot be ignored since it can alter funding decisions. In this case, when we look at equations (24),(25) and (26), we notice that the left-hand side term of each equation equals to the incremental cost-effectiveness ratio, based on its definition. The left-hand side term of equation (24) captures the weighted expected social welfare change from an additional dollar of spending on the treatment M_{21}^1, which is provided to a healthy person at the beginning of period 1 who are transitioning from to sick. This differs with M_{21}^2, which is provided to either a healthy or sick person at the beginning of period 2 who are transitioning to sick. For equation (25), the left-hand side term reveals the weighted expected social welfare change if spending the last dollar on the treatment M_{31}^1,which is provided to a healthy person at the beginning of period 1 who are transitioning from to dead. This differs with M_{31}^2, which is provided to either a healthy or sick person at the beginning of period 2 who are transitioning to dead. Finally, the left-hand side term of (26) suggests that the weighted change in expected social welfare if there is an additional dollar of spending on the treatment M_{32}^1, which is provided to a healthy person at the beginning of period 1 who are transitioning from healthy to dead. This differs with M_{32}^2, which is provided to either a healthy or sick person at the beginning of period 2 who are transitioning to dead.The right-hand side of each equation is equal to μ, which is the shadow price of additional unit of health resources. In other words, this term denote the

marginal utility of having an extra unit of health resources. Therefore, I conclude that the incremental cost-effectiveness ratio is equalized for all first period treatments. In addition, I notice that regardless of whether future costs are included, the left-hand side of each first order condition captures the incremental cost-effectiveness ratio and leads to be equalized for all treatments.

Since it is important to understand that although the optimal solution requires that incremental cost-effectiveness ratio be equalized across treatments, this does not imply that the likelihood of successful treatments is equalized. Moreover, through examining the second period treatment, I notice that at an optimum, it must be true that:

$$\tilde{\rho}(\beta_{21}^2)'(V(H) - V(S)) = \hat{\rho}(\beta_{31}^2)'(V(H) - V(D)) \tag{27}$$

$$\hat{\rho}(\beta_{31}^2)'(V(H) - V(D)) = \bar{\rho}(\beta_{32}^2)'(V(S) - V(D)) \tag{28}$$

$$\bar{\rho}(\beta_{32}^2)'(V(S) - V(D)) = \tilde{\rho}(\beta_{21}^2)'(V(H) - V(S)) \tag{29}$$

Since $V(D) < V(S)$, as the utility of being dead is greater than that of being sick, then $V(H) - V(S) < V(H) - V(D)$. From equation (27), we get that $\tilde{\rho}(\beta_{21}^2)' > \hat{\rho}(\beta_{31}^2)'$. If we believe that $\tilde{\rho} \leq \hat{\rho}$, which suggests that avoiding death is more important than avoiding sickness, then $(\beta_{21}^2)' > (\beta_{31}^2)'$. Since β function is concave, and $\beta(M)' > 0$, then if β is independent of the initial health state it must be true that $M_{31}^2 > M_{21}^2$ when they are chosen optimally. This is consistent with the result in the basic model without weights. On the other hand, if we weight avoiding sickness more than avoiding death, then there is a possibility that $(\beta_{21}^2)' < (\beta_{31}^2)'$. Since β function is concave, and $\beta(M)' > 0$, $M_{21}^2 > M_{31}^2$. Hence, the government is willing to invest more on M_{21}^2 than the other one to satisfy the conditions for weighted social welfare maximization. In this case, introducing the weights will alter the investment decisions that the government makes. Since $V(H) > V(S)$, as the

utility of being healthy is larger than that of being sick, then $V(H) - V(D) > V(S) - V(D)$. From equation (28), we know that $\hat{\rho}(\beta_{31}^2)' < \bar{\rho}(\beta_{32}^2)'$. Since I assume that avoiding sickness or death needs to be weighted more heavily than life extension, $\hat{\rho} > \bar{\rho}$. Hence, $(\beta_{31}^2)' < (\beta_{32}^2)'$. Since β function is concave, and $\beta(M)' > 0$, $M_{31}^2 > M_{32}^2$. Therefore, policy makers are willing to invest more on the avoiding death treatments than extending life ones, which is consistent with the basic model. If $(V(S) - V(D)) > (V(H) - V(S))$, then $\bar{\rho}(\beta_{32}^2)' < \tilde{\rho}(\beta_{21}^2)'$. Since I assume the weight for avoiding sickness is higher than that for extending life, then $\bar{\rho} < \tilde{\rho}$, which leads to two possibilities. One is that $(\beta_{32}^2)' < (\beta_{21}^2)'$, which suggests that $M_{32}^2 > M_{21}^2$ when they are chosen optimally because β function is concave, and $\beta(M)' > 0$. Hence the government is willing to invest more on M_{32}^2 to maximize weighted social welfare. The other possibility is that $(\beta_{32}^2)' > (\beta_{21}^2)'$, which suggests that $M_{32}^2 < M_{21}^2$ when they are chosen optimally because β function is concave, and $\beta(M)' > 0$. Hence the government is willing to invest more on M_{21}^2 to maximize weighted social welfare. On the other hand, if $(V(S) - V(D)) < (V(H) - V(S))$, then $\bar{\rho}(\beta_{32}^2)' > \tilde{\rho}(\beta_{21}^2)'$. Since I assume the weight for avoiding sickness is higher than that for extending life, then $\bar{\rho} < \tilde{\rho}$, which leads to $(\beta_{32}^2)' > (\beta_{21}^2)'$. Since β function is concave, and $\beta(M)' > 0$, $M_{21}^2 > M_{32}^2$. Hence, the government wants to fund more on M_{21}^2 than the other one for social welfare maximization. Therefore, it is possible that introducing weights alter the investment decisions that the government makes.

I now turn to the first order condition for each first period treatment:

$$(\beta_{21}^1)'[\tilde{\rho}((\pi_{12} - \pi_{22})\hat{\alpha}_1 + V(H) - V(S)) + \hat{\rho}(\pi_{13} - \pi_{23})\hat{\alpha}_2 + \pi_{11}\hat{\alpha}_4 + V(H) - V(S)] =$$
$$(\beta_{31}^1)'[\tilde{\rho}\pi_{12}\hat{\alpha}_1 + \hat{\rho}(\pi_{13}\hat{\alpha}_2 + V(H) - V(D)) + \pi_{11}\hat{\alpha}_4]$$

$$(\beta_{32}^1)^{'}[\tilde{\rho}\pi_{22}\hat{\alpha_1} + \hat{\rho}\pi_{23}\hat{\alpha_2} + \bar{\rho}(V(S) - V(D))] = (\beta_{21}^1)^{'}[\tilde{\rho}((\pi_{12} - \pi_{22})\hat{\alpha_1} + V(H) - V(S)) +$$

$$\hat{\rho}(\pi_{13} - \pi_{23})\hat{\alpha_2} + \pi_{11}\hat{\alpha_4} + V(H) - V(S)]$$

$$(\beta_{31}^1)^{'}[\tilde{\rho}\pi_{12}\hat{\alpha_1} + \hat{\rho}(\pi_{13}\hat{\alpha_2} + V(H) - V(D)) + \pi_{11}\hat{\alpha_4}] = (\beta_{32}^1)^{'}[\tilde{\rho}\pi_{22}\hat{\alpha_1} + \hat{\rho}\pi_{23}\hat{\alpha_2} + \bar{\rho}(V(S) - V(D))]$$

$$(30)$$

I will take equation (30) as an example. My goal is to compare the efficiency of the avoiding death treatment and the life extension treatment. Mathematically, I want to determine the sign of $(\beta_{31}^1)^{'} - (\beta_{32}^1)^{'}$. If this sign is positive, then $M_{32}^1 > M_{31}^1$ when they are chosen optimally because β function is concave, and $\beta(M)^{'} > 0$. Therefore, policy makers want to invest M_{32}^1 more to maximizing weighted social welfare. On the other hand, if this sign is negative, then $M_{32}^1 < M_{31}^1$ when they are chosen optimally because β function is concave, and $\beta(M)^{'} > 0$. Therefore, the government is willing to fund more on M_{31}^1 for weighted social welfare maximization. In addition, if this sign is equal to 0, then $M_{32}^1 = M_{31}^1$ whey they are chosen optimally, which allows the government to invest the same amount of money on both treatments. In order to determine this sign, we need to determine the sign of $\tilde{\rho}(\pi_{12} - \pi_{22})\hat{\alpha_1} + \hat{\rho}(\pi_{13} - \pi_{23})\hat{\alpha_2} + \hat{\rho}V(H) - \bar{\rho}V(S) - (\bar{\rho} + \hat{\rho})V(D))$. However, this sign is determined by three weights, $\hat{\rho}$, $\bar{\rho}$ and $\tilde{\rho}$. Although the weight for avoiding sickness or death is greater than that for extending life, we are not sure if the weight for avoiding sickness is greater than avoiding death. Therefore, investment decisions for each treatment depend on three weights, and different magnitude of weights may yield different investment decisions. Combining the first order conditions of treatments in both period, we conclude that introducing weights may alter the investment decisions.

3.3 Comparisons

In this section, I compare the results and interpretations in terms of the basic model with equal weight and the model with different weights. The purpose is to investigate whether introducing weights alters the results and interpretations. If it does, then introducing weights plays an important role in making decisions in the health care system. Based on the results for the basic model and the model with different weights, the incremental cost-effectiveness ratio is equalized for all treatments in both periods for both models when choosing each treatment optimally. The only difference is that the two models may generate different funding decisions. I firstly focus on second period treatments.

For the basic model with the equal weight, it has two possibilities. If the utility difference between sick and dead is greater than that between healthy and sick, then policy makers are willing to invest M_{31}^2 more than M_{32}^2, which is funded more than M_{21}^2. On the other hand, if the utility difference between sick and dead is smaller than that between healthy and sick, then the government wants to fund M_{31}^2 more than M_{21}^2, which is invested more than M_{32}^2. In either case, the government will fund avoiding death treatments more than others. However, for the model with different weights, if weighting avoiding sickness more heavily than avoiding death, then there is a possibility that the government is willing to fund more on avoiding sickness treatments than avoiding death ones, which is not consistent with what we have found in the basic model. Therefore, it is possible to change funding decisions if assigning different weights to different health interventions.

I now turn to first period treatments. Even though the basic model and model with different weights cannot guarantee which treatment the government is willing to invest more since it depends on the utility of each health state, it is enough to investigate whether introducing different weights matters. For the basic model, funding decisions depend on other factors that are independent with weights. For example, if the sign of $(\pi_{12} - \pi_{22})\alpha_1 +$

$(\pi_{13} - \pi_{23})\alpha_2 + \pi_{11}\alpha_4 + V(H) - V(S)$ is positive, then the government will invest more on treatment of avoiding death than that of extending life. Therefore, the decision depends on the sign of that constant term. However, for the model with different weights, funding decisions depend on the sign of $\tilde{\rho}(\pi_{12} - \pi_{22})\hat{\alpha_1} + \hat{\rho}(\pi_{13} - \pi_{23})\hat{\alpha_2} + \hat{\rho}V(H) - \bar{\rho}V(S) - (\bar{\rho} + \hat{\rho})V(D))$, which can be also taken as a constant term that depends on the other factors and three weights. In other words, different weights probably influences funding decisions. Therefore, introducing different weights matters in terms of determining which treatment the government is willing to fund.

4   Conclusions

This paper examines whether assigning different weights to health treatments change the results in terms of health treatments rankings and funding decisions, and this is significant since Pinto-Prades et al. (2014) suggested that the public values different treatments differently. In order to do this, I derive the incremental CE ratio for each treatment through maximizing expected utility function with 2-periods in the basic model with equal weights and the one with different weights for health treatments. I find that incremental CE ratio is equalized for all health treatments and equal to the shadow price of an additional health resources in the basic model even when taking future effects into account, which is supported by Garber and Phelps (1997). The same result is applied in the model with different weights for health treatment, implying that when we taking different weights into account, the ranking of health treatments does not change because the incremental CE ratio of each treatment is the same as in the basic model, in other words, they are all equally desirable at the margin, and this ratio is equal to the shadow price of an additional unit of health resources. However, this paper finds that there is a possibility that assigning different weights to health treatments changes funding decisions. In other words, even though

different weight does not change the incremental CE ratio, it does alter funding decisions since people do not treat treatments equally valuable. These findings in this paper fill gap in the issues that are mentioned in Pinto-Prades et al. (2014).

However, this paper has some unanswered questions. This paper uses expected utility theory, which is not necessarily the best way to evaluate health state. In particular, Rasiel et al. (2005) argues that expected utility theory cannot explain risk seeking behaviour when facing risky prospect at the end of life, and the assessment is made by individuals. The other question that is unanswered in this paper is that whether assigning different weight to individuals changes the results, since Lancsar et al. (2011) suggested that people give young individuals priority of health care. Further research can focus on these issues.

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