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***Entitlements to continued life and the
evaluation of population health***

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Entitlements to continued life and the evaluation of population health*

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Abstract

We analyze the implications of axioms formalizing entitlements to continued life for the evaluation of population health, when combined with basic structural axioms. A straightforward implication of our analysis is that if the scope of equal entitlements to continued life is not limited, concerns for morbidity (and not just mortality) are dismissed in the evaluation of population health. Nevertheless, with axioms formalizing a more limited scope of equal entitlement to continued life, we provide several characterization results of focal population health evaluation functions, ranging from *lifetime utilitarianism* to *generalized healthy years equivalent utilitarianism*.

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1 Introduction

Entitlements to continued life have been a major theme in the public debate, notably during the aftermath of the COVID-19 outbreak. Earlier than that, the so-called Affordable Care Act (also known as “Obamacare”) already made a strong case in favor of equal entitlements to continued life, as expressed in the following excerpt (e.g., Basu et al., 2020):

The Secretary shall not use evidence or findings from comparative clinical effectiveness research conducted under section 1181 in determining coverage, reimbursement, or incentive programs under title XVIII in a manner that treats extending the life of an elderly, disabled, or terminally ill individual as of lower value than extending the life of an individual who is younger, nondisabled, or not terminally ill.

Equal entitlements to continued life have also been scrutinized in academic research. One of the strongest defenders is John Harris, who, in a series of contributions that date back to the 80’s and spanned for more than 20 years, argued ethical concerns for a fundamental right to continued life to which all individuals are entitled to the same extent (e.g., Harris, 1985; 1997; 1999; 2005). Harris’ arguments led to the conclusion that, even if some lives are not lived at perfect health, lives are in fact equally valuable, as long as they are valued by those living those lives. Under certain circumstances, such a conclusion has also been endorsed by part of the health economics community.¹ For instance, recent empirical evidence suggests that choices about which patient to treat are influenced more by the sizes of the gains achievable from treatment than by patients’ life expectancy or quality-of-life in absence of treatment (e.g., Shah et al., 2015). Somewhat related, the National Institute for Health and Care Excellence (NICE), the organization responsible for producing advice on the use of health technologies in the British National Health Service, indicates that it may be appropriate to recommend the use of treatments for terminal illness that offer an extension to life even if their base case cost-effectiveness estimates exceed the range normally considered acceptable (e.g., Rawlins and Culyer, 2004).

Another argument usually considered to defend equal entitlement to continued life is the recurrent argument within political philosophy that welfare interpersonal comparisons are incommensurate, and, therefore, that it is wrong to discriminate on the basis of health states. Nevertheless, such an argument has been contested (e.g., Singer et al., 1995; McKie et al., 1997) and debated (e.g., Grimley Evans, 1997; Williams, 1997).

¹Notable exceptions do exist (e.g., Williams, 1992; Edlin et al., 2013).

We provide in this paper a new perspective on the concept of equal entitlement to continued life, in connection with the evaluation of population health, a topic receiving increasing attention within economic design (e.g., Herrero and Moreno-Terner, 2008; Calo-Blanco, 2016, 2020; Chambers and Moreno-Terner, 2019; Immorlica, 2019). To do so, we consider the axiomatic approach to the evaluation of population health, introduced by Hougard et al., (2013), and also considered by Moreno-Terner and Østerdal (2017). In such an approach, the health of an individual in the population is defined according to the two standard dimensions (quality of life and quantity of life), but one of them (quality of life) receives a special treatment, as no restrictions are made regarding its mathematical structure. A distinguishing feature of this approach is that it does not make assumptions about individual preferences over quantity and quality of life. In doing so, we depart from the strand of the literature on population health evaluation in which the analysis relies on individual preferences on quantity and quality of life (e.g., Østerdal, 2005; Harvey and Østerdal, 2010), and also from the popular strand of the (health economics) literature in which the analysis relies on a generic individual health utility concept (e.g., Wagstaff, 1991; Bleichrodt, 1997; Dolan, 1998). Thus, we circumvent basing our analysis on the concept of individual health preferences, which has faced recurrent criticisms over its conceptual foundation and elicitation procedures, particularly in the context of population health evaluation (e.g. Dolan, 2000).

We formalize equal entitlement to continued life as an axiom of social preferences for population health evaluations in the model described above. More precisely, we consider a cohort of individuals and aim to evaluate the effects of alternative health care policies for such a cohort, on the grounds of the resulting distributions of health (that the policies would generate for the cohort). In such a scenario, equal entitlement to continued life is formalized as the axiom stating that if two distributions of health only differ in granting an amount of extra years to one or another individual, then they are considered equally good by the social planner (as all lives are valued equally). The combination of such an axiom with some basic structural axioms characterizes the population health evaluation function that ranks distributions according to the unweighted aggregation (across agents in the population) of lifetimes in the distribution. Such a function does not include any concern whatsoever for the quality of life at which individuals in the population experience those lifetimes, which is in contrast with some traditional forms of evaluation for health distributions, such as the so-called Quality Adjusted Life Years (e.g., Pliskin et al., 1980), in short QALYs, and the so-called Healthy Years Equivalent (e.g., Mehrez and Gafni, 1989), in short HYE. In other words, under the presence of some basic

structural axioms, endorsing the principle of equal entitlement to continued life in its full force drives towards dismissing morbidity concerns in the evaluation of population health. The result just described is closely related to a result in Hasman and Østerdal (2004), which establishes a general incompatibility between a specific form of the equal entitlement to continued life principle and the weak Pareto principle.²

The main aim of the paper is to distill weaker axioms limiting the scope of equal entitlement to continued life, and explore their implications. To wit, axioms in which the extra years are not granted to arbitrary individuals, but to individuals sharing some features. As we show, some of the axioms keep driving towards *lifetime utilitarianism*. Some others do allow for more general population health evaluation functions, dubbed *generalized lifetime utilitarianism*. That is, the unweighted aggregation (across agents in the population) of lifetimes in the distribution, after being submitted to an increasing and continuous function.

The idea of equal entitlement to continued life, as introduced above, prevents any form of discrimination against individuals with worse quality of life, when it comes to allocate extra life years. Now, some political philosophers have endorsed going a step ahead, arguing that justice requires that a positive discrimination in favor of the worst-off be allowed. The most extreme position is advocated by Rawls (1971), with his so-called *difference principle*, for whom differences in primary goods are only morally acceptable if they maximize the level of primary goods achieved by the worst-off individual. Parfit (1997) coined the term *prioritarianism* for the view that the worse off should be given priority over the better off, but that they need not necessarily receive the extreme priority that characterizes the difference principle. A comprehensive endorsement of the prioritarian evaluation of outcomes and policies is provided by Adler (2012). There are several ways in which the principle of prioritarianism could be formalized (e.g., Moreno-Ternerero and Roemer, 2008). In a welfarist setting, prioritarianism is usually characterized as a strictly concave social welfare function (e.g., Roemer, 2004). In a non-welfarist setting of resource allocation, it can be formalized as an axiom of *no-domination* (e.g., Moreno-Ternerero and Roemer, 2006; 2012), which implies that less capable agents to transform resources into outcomes cannot receive less resources.

In our setting, we can formalize prioritarianism by means of similar axioms to those in the non-welfarist setting of resource allocation, but regarding the hypothetical allocation of extra life years. More precisely, we can unambiguously say that an agent is worse off than another

²This can only be formalized in a context where individual preferences on quality and quantity of life are an ingredient of the model, which is not the case of this paper.

if the latter dominates the former in both quality and quantity of life. Our *worst-off priority* axiom formalizes the idea that extra life years should not be valued less when awarded to a worst-off agent, so defined. We also consider another weaker axiom in which the principle is restricted to (pairs of) agents at perfect health.

We show that the combination of the worst-off priority axiom with some basic structural axioms characterizes *concave lifetime utilitarianism*. That is, the population health evaluation function referring to the unweighted aggregation (across agents in the population) of lifetimes in the distribution, after being submitted to a concave (increasing and continuous) function. Thus, as with the case of equal entitlement to continued life, morbidity concerns are excluded from the evaluation of the distribution of health. Nevertheless, mortality concerns are allowed to be included in a more general and egalitarian-oriented form.

Based on the results mentioned above, one might wonder whether all population health evaluation functions including a concern for morbidity are also excluded when principles related to *prioritarian value of life* are imposed. It turns out that is not the case, as the family of population health evaluation functions arising upon aggregating individual HYE_s, after being submitted to a concave (increasing and continuous) function, can also be characterized resorting to an axiom connected to the principle of priority. More precisely, the last result of the paper states that, if we consider the weaker worst-off priority axiom outlined above, combined with the basic structural axioms mentioned above, we characterize the family of population health evaluation functions arising upon aggregating individual HYE_s, after being submitted to a concave (increasing and continuous) function.

The rest of the paper is organized as follows. In Section 2, we introduce the model, the focal population health evaluation functions, and the basic structural axioms we consider for our analysis. In Section 3, we introduce the axioms of equal entitlement to continued life and explore their implications. As a result, we characterize population health evaluations that dismiss morbidity concerns. In Section 4, we move to extend the analysis to the case of prioritarian (rather than equal) entitlement to continued life. Here we also characterize population health evaluations that dismiss morbidity concerns and others that do capture them. Section 5 discusses some further insights, ranging from the tightness of our characterization results to variations and possible extensions of our model. We conclude in Section 6.

2 The model

The content of this section mostly follows Hougaard et al., (2013). Let us consider a cohort of individuals (in brief, “population”) that we identify with the set $N = \{1, \dots, n\}$, where $n \geq 3$. Imagine a policy maker who has to evaluate several alternative health policies for such a population. Each policy is characterized by a given distribution of health it generates for the population. The health of each individual in the population is described by a duplet indicating the level achieved in two parameters: quality of life and quantity of life (gained). Assume that there exists a set of possible health states (describing quality of life), A , defined generally enough to encompass all possible health states for everybody in the population. We emphasize that A is an abstract set without any particular mathematical structure. Quantity of life (gained) is simply described by the set of nonnegative real numbers, i.e., $T = [0, +\infty)$. Formally, let $h_i = (a_i, t_i) \in A \times T$ denote the health duplet of individual i . In words, h_i indicates that agent i will be experiencing (from the moment the policy is implemented) t_i units of time (e.g., days, months, years) each experienced at quality a_i .³ A population health distribution (or, simply, a health profile) $h = [h_1, \dots, h_n] = [(a_1, t_1), \dots, (a_n, t_n)]$ specifies the health duplet of each individual in the population. We denote the set of all possible health profiles by H .⁴ Even though we do not impose a specific mathematical structure on the set A , we assume that it contains a specific element, a_* , which we refer to as *perfect health* and which is univocally identified, as a “superior” state, by the policy maker.

2.1 Population health evaluation functions

The policy maker’s preferences (or social preferences) over health profiles are expressed by a preference relation \succsim , to be read as “at least as preferred as”. As usual, \succ denotes strict preference and \sim denotes indifference. We assume that the relation \succsim is a weak order. A *population health evaluation function* is a real-valued function $P : H \rightarrow \mathbb{R}$. We say that P represents \succsim if $P(h) \geq P(h') \Leftrightarrow h \succsim h'$, for each pair $h, h' \in H$.

Instances of population health evaluation functions are the following. First, the so-called *lifetime utilitarianism*, which evaluates population health distributions by means of the aggre-

³The running interpretation is then that agents only experience chronic health states, although it could alternatively be interpreted that a_i reflects an average level of quality at which lifespan t_i is experienced.

⁴For ease of exposition, we establish the notational convention that $h_S \equiv (h_i)_{i \in S}$, for each $S \subset N$.

gate lifetime the distribution yields.⁵ Formally,

$$P^t[h_1, \dots, h_n] = P^t[(a_1, t_1), \dots, (a_n, t_n)] = \sum_{i=1}^n t_i. \quad (1)$$

Second, a more general form of lifetime aggregation in which lifetimes are submitted to an arbitrary increasing and continuous function.

$$P^{gt}[h_1, \dots, h_n] = P^{gt}[(a_1, t_1), \dots, (a_n, t_n)] = \sum_{i=1}^n g(t_i), \quad (2)$$

where $g : \mathbb{R}_+ \rightarrow \mathbb{R}$ is a strictly increasing and continuous function. We refer to P^{gt} as *generalized lifetime utilitarianism*. If the function g is also assumed to be concave, we shall refer to it as *concave lifetime utilitarianism*. Such a population health evaluation function endorses a concern (aversion) for the inequality of lifetimes in the population.

The following one, which we call *QALY utilitarianism*, evaluates population health distributions by means of the unweighted aggregation of individual QALYs in society, or, in other words, by the weighted (through health levels) aggregate time span the distribution yields. Formally,

$$P^q[h_1, \dots, h_n] = P^q[(a_1, t_1), \dots, (a_n, t_n)] = \sum_{i=1}^n q(a_i)t_i, \quad (3)$$

where $q : A \rightarrow [0, 1]$ is a function satisfying $0 \leq q(a_i) \leq q(a_*) = 1$, for each $a_i \in A$.

More generally, one could evaluate population health distributions by means of the unweighted aggregation of individual Healthy Years Equivalent (HYES) in society. Formally,

$$P^h[h_1, \dots, h_n] = P^h[(a_1, t_1), \dots, (a_n, t_n)] = \sum_{i=1}^n f(a_i, t_i), \quad (4)$$

where $f : A \times T \rightarrow T$ is a function indicating the HYES for each individual, i.e.,

- f is continuous with respect to its second variable,
- $0 \leq f(a_i, t_i) \leq t_i$, for each $(a_i, t_i) \in A \times T$, and
- For each $h = [h_1, \dots, h_n] = [(a_1, t_1), \dots, (a_n, t_n)] \in H$,

$$h \sim [(a_*, f(a_i, t_i))_{i \in N}].$$

We refer to P^h as *HYE utilitarianism*.

⁵This reflects the traditional view for the evaluation of the impact of health care only in terms of its effect on mortality.

Generalizing further, one could consider to submit HYE's first to a strictly increasing and continuous function. Formally,

$$P^{gh}[h_1, \dots, h_n] = P^{gh}[(a_1, t_1), \dots, (a_n, t_n)] = \sum_{i=1}^n g(f(a_i, t_i)), \quad (5)$$

where $g : \mathbb{R}_+ \rightarrow \mathbb{R}$ is a strictly increasing and continuous function, and $f : A \times T \rightarrow T$ is a function indicating the *healthy years equivalent* for each individual, as described above. We refer to P^{gh} as *generalized HYE's utilitarianism*. If the function g is also assumed to be concave, hence capturing an aversion for the inequality of HYE's in the population, we shall refer to it as *concave HYE utilitarianism*.

2.2 Basic structural axioms

We now list the basic structural axioms for social preferences that we consider in this paper.

First, the axiom of **anonymity**, which represents a standard formalization of the principle of impartiality in axiomatic work. It says, in our context, that the evaluation of the population health should depend only on the list of quality-quantity duplets, not on who holds them. Formally,

Anonymity: $h \sim h_\pi$ for each $h \in H$, and each permutation π of the set N .

The second axiom, **separability**, says that if the distribution of health in a population changes only for a subgroup of agents in the population, the relative evaluation of the two distributions should only depend on that subgroup. In other words, it imposes that the trade-off between agent i 's and agent j 's assignments does not depend on agent k 's assignment. The axiom underlies the use of incremental analysis in cost-effectiveness analysis (the standard currency in the economic evaluation of health care programs). Formally,

Separability: $[h_S, h_{N \setminus S}] \succsim [h'_S, h_{N \setminus S}] \Leftrightarrow [h_S, h'_{N \setminus S}] \succsim [h'_S, h'_{N \setminus S}]$, for each $S \subseteq N$, and each pair $h, h' \in H$.

Third is the standard axiom of **continuity**, which says that, for fixed distributions of health states, small changes in lifetimes cannot provide large changes in the evaluation of the population health distribution. Formally,

Continuity: Let $h, h' \in H$, and $h^{(k)}$ be a sequence in H such that, for each $i \in N$, $h_i^{(k)} = (a_i, t_i^{(k)}) \rightarrow (a_i, t_i) = h_i$. If $h^{(k)} \succsim h'$ for each k then $h \succsim h'$, and if $h' \succsim h^{(k)}$ for each k then $h' \succsim h$.

The next two axioms introduce some structure on the domain of health states.

The first one, **perfect health superiority**, simply says that replacing the health status of an agent by that of perfect health cannot render population health worse. Formally,

Perfect health superiority : $[(a_*, t_i), h_{N \setminus \{i\}}] \succsim h$, for each $h = [h_1, \dots, h_n] \in H$ and $i \in N$.

The second one, **time monotonicity at perfect health**, says that if each agent is at perfect health, increasing lifetime for some is a strict improvement.

Time monotonicity at perfect health: If $t_i \geq t'_i$, for each $i \in N$, with at least one strict inequality, then $[(a_*, t_1), \dots, (a_*, t_n)] \succ [(a_*, t'_1), \dots, (a_*, t'_n)]$.

The next two axioms are somewhat dual to the previous two, as they convey principles referring to the bottom of the domain of health profiles.

The first one, **positive lifetime desirability**, says that the health of the population is not worse if any agent moves from zero lifetime to positive lifetime (for a given health state). In particular, the axiom implies that all health states are worth living.

Positive lifetime desirability: $h \succsim [h_{N \setminus \{i\}}, (a_i, 0)]$, for each $h = [h_1, \dots, h_n] \in H$ and $i \in N$.

The last basic axiom, **social zero condition**, says that if an agent gets zero lifetime, then her health state is irrelevant for the social desirability of the health distribution. Formally,

Social zero condition: For each $h \in H$ and each $i \in N$ such that $t_i = 0$, and each $a'_i \in A$, $h \sim [h_{N \setminus \{i\}}, (a'_i, 0)]$.

In what follows, we refer to the set of axioms introduced above as the **basic structural axioms** (in short, **BASIC**). All the population health evaluation functions listed above satisfy all these axioms.

3 Equal entitlement to continued life

We now add to the previous list of basic structural axioms the axiom modeling the notion of equal entitlement to continued life, informally discussed at the introduction. In words, the axiom of **equal entitlement to continued life** says that a certain amount of additional life years to individual i is socially seen as just as good as the same amount of additional life years to individual j , regardless of health states.⁶ Note that the axiom implicitly assumes that all

⁶Hasman and Østerdal (2004) define a similar axiom in their model. As mentioned in the Introduction, Theorem 1 below is closely related to a result in Hasman and Østerdal (2004) which, in a model with both

health states are worth living, and, therefore, that this additional lifetime would be valued by all agents.

Equal entitlement to continued life: For each $h \in H$, each $c > 0$, and each pair $i, j \in N$,

$$[(a_i, t_i + c), (a_j, t_j), h_{N \setminus \{i, j\}}] \sim [(a_i, t_i), (a_j, t_j + c), h_{N \setminus \{i, j\}}].$$

This is a strong axiom. As the next result states, its combination with the basic structural axioms characterizes *lifetime utilitarianism*.

Theorem 1 *The following statements are equivalent:*

1. \succsim is represented by a population health evaluation function satisfying (1).
2. \succsim satisfies equal entitlement to continued life and BASIC.

Proof. We focus on the non-trivial implication. Formally, assume \succsim satisfies *equal entitlement to continued life* and the *basic structural axioms*. Then, by Theorem 1 in Hougaard et al., (2013), the *basic structural axioms* imply that \succsim can be represented by a separable population health evaluation function as in (5). Now, let $c > 0$, $h \in H$, and $i, j \in N$ be such that $a_i = a_*$. By *equal entitlement to continued life*,

$$[(a_*, 0), (a_j, c), h_{N \setminus \{i, j\}}] \sim [(a_*, c), (a_j, 0), h_{N \setminus \{i, j\}}].$$

Equivalently,

$$g(f(a_*, 0)) + g(f(a_j, c)) = g(f(a_*, c)) + g(f(a_j, 0)).$$

As $f(a_*, 0) = f(a_j, 0) = 0$, it follows that

$$g(f(a_j, c)) = g(c).$$

As g is an increasing function, this leads to the fact that

$$f(a_j, c) = c,$$

for each $c > 0$ and each $a_j \in A$. As mentioned above, $f(a_j, 0) = 0$, for each $a_j \in A$. Altogether, we obtain that \succsim can be represented by a population health evaluation function satisfying (2).

Now, let $h \in H$ and $i, j \in N$, such that $a_i = a_*$. Then, by *equal entitlement to continued life*,

$$[(a_*, t_i), (a_j, t_j + c), h_{N \setminus \{i, j\}}] \sim [(a_*, t_i + c), (a_j, t_j), h_{N \setminus \{i, j\}}],$$

individual and social preferences, establishes a general incompatibility between a specific form of the equal entitlement to continued life principle and the weak Pareto principle.

which translates into

$$g(t_i) + g(t_j + c) = g(t_i + c) + g(t_j),$$

for each $t_i, t_j \in T$, and $c > 0$. It follows from here that

$$g\left(\frac{x+y}{2}\right) = \frac{g(x) + g(y)}{2},$$

for each $x, y \geq 0$. As g is continuous and strictly increasing, it follows from Theorem 1 in Aczel (2006, p. 43) that there exist $\alpha > 0$ and β such that $g(x) = \alpha x + \beta$, for each $x > 0$. Consequently, \succsim is indeed represented by a population health evaluation function satisfying (1), as desired. \square

As its proof indicates, Theorem 1 relies on Theorem 1 in Hougard et al., (2013), which characterizes the family of population health evaluation functions satisfying BASIC. The proof of Theorem 1 shows that, when the axiom of *equal entitlement to continued life* is added to BASIC, the family shrinks to *lifetime utilitarianism*. Now, Theorem 1 could be stated more strongly. To wit, the characterization of *lifetime utilitarianism* is also obtained restricting the *equal entitlement to continued life* axiom to the case in which one of the agents being compared experiences zero lifetime, or perfect health (or both things happen simultaneously). On the other hand, as shown in Section 5.1, some of the basic structural axioms can be dismissed in the characterization of *lifetime utilitarianism* when keeping the full force of the *equal entitlement to continued life* axiom.

In what follows, we limit the scope of the axiom in ways that allow for weaker implications. First, we restrict the principle to agents experiencing the same quantity of life.

Equal entitlement to continued life for equal lifetimes: For each $h \in H$, each $c > 0$, and each pair $i, j \in N$, such that $t_i = t_j = t$,

$$[(a_i, t + c), (a_j, t), h_{N \setminus \{i, j\}}] \sim [(a_i, t), (a_j, t + c), h_{N \setminus \{i, j\}}].$$

When combined with the basic structural axioms, this axiom has weaker implications than *equal entitlement to continued life*. More precisely, as the next result states, the combination characterizes *generalized lifetime utilitarianism*. Thus, morbidity concerns are also excluded, but mortality concerns are valued more generally.

Theorem 2 *The following statements hold:*

1. \succsim is represented by a population health evaluation function satisfying (2).

2. \succsim satisfies equal entitlement to continued life for equal lifetimes and BASIC.

Proof. We focus on the non-trivial implication. Formally, assume \succsim satisfies *equal entitlement to continued life for equal lifetimes* and the *basic structural axioms*. Then, as in the previous proof, \succsim can be represented as in (5).

Now, let $c > 0$, $h \in H$, and $i, j \in N$. By *equal entitlement to continued life for equal lifetimes*,

$$[(a_i, c), (a_j, 0), h_{N \setminus \{i, j\}}] \sim [(a_i, 0), (a_j, c), h_{N \setminus \{i, j\}}].$$

Equivalently,

$$g(0) + g(f(a_j, c)) = g(0) + g(f(a_i, c)).$$

From here, it follows that, by the strict monotonicity of g ,

$$f(a_j, c) = f(a_i, c), \quad \text{for each } c > 0, \text{ and } a_i, a_j \in A.$$

As $f(a_*, t) = t$, for each $t \in T$, we deduce from the above that $f(a_i, t) = t$, for each $a_i \in A$ and $t \in T$, from where it follows that \succsim is indeed represented by a population health evaluation function satisfying (2). \square

As its proof indicates, Theorem 2 also relies on Theorem 1 in Hougaard et al., (2013), which characterizes the family of population health evaluation functions satisfying BASIC. The proof of Theorem 2 shows that, when the axiom of *equal entitlement to continued life for equal lifetimes* is added to BASIC, the family shrinks to *generalized lifetime utilitarianism*. Now, as with Theorem 1, Theorem 2 could also be stated more strongly. To wit, the characterization of *generalized lifetime utilitarianism* is also obtained restricting the *equal entitlement to continued life for equal lifetimes* axiom further to the case in which the common lifetime is precisely zero, or to the case in which one of the agents enjoys perfect health.

The counterpart natural option to *equal entitlement to continued life for equal lifetimes* would be to restrict the principle to agents experiencing the same quality of life. More precisely, *time invariance at common health* says that the planner should be indifferent between adding (the same amount of) lifetime to one agent or another, provided both experience the same health status, although probably different lifetimes.⁷ Formally,

⁷Thus, the axiom conveys an absence of lifetime discrimination: an individual is not less worthy of treatment on the sole grounds that she has a longer lifetime. As a matter of fact, the axiom is very similar, although not identical, to the so-called non-age dependence axiom in Østerdal (2005).

Time invariance at common health: For each $h \in H$, each $c > 0$, and each pair $i, j \in N$, such that $a_i = a_j = a$,

$$[(a, t_i + c), (a, t_j), h_{N \setminus \{i, j\}}] \sim [(a, t_i), (a, t_j + c), h_{N \setminus \{i, j\}}].$$

Hougaard et al., (2013) show that the combination of this axiom with the basic structural axioms characterizes *QALY utilitarianism*. Thus, alternative population health evaluation functions including morbidity concerns can indeed be characterized when the scope of the *equal entitlement to continued life* axiom is limited in a proper way.

A further weakening of the axiom along these lines occurs when the common health state is precisely the perfect health state. Formally,

Time invariance at perfect health: For each $h \in H$, each $c > 0$, and each pair $i, j \in N$, such that $a_i = a_j = a_*$,

$$[(a_*, t_i + c), (a_*, t_j), h_{N \setminus \{i, j\}}] \sim [(a_*, t_i), (a_*, t_j + c), h_{N \setminus \{i, j\}}].$$

Hougaard et al., (2013) also show that the combination of this axiom with the basic structural axioms characterizes *HYE utilitarianism*.

4 Priority of the worst-off for the entitlement to continued life

We propose in this section an alternative to the previous analysis of the concept of equal entitlement to continued life. More precisely, we formalize a *prioritarian* view for the entitlement to continued life. To do so, we begin formalizing the axiom of *worst-off priority*, which says that a certain amount of additional life years to an individual is socially seen at least as good as the same amount of additional life years to another (better-off) individual, who is enjoying perfect health, and a higher lifetime. Formally,

Worst-off priority: For each $c > 0$, each $h \in H$, and each pair $i, j \in N$, such that $t_i \geq t_j$,

$$[(a_*, t_i), (a_j, t_j + c), h_{N \setminus \{i, j\}}] \succeq [(a_*, t_i + c), (a_j, t_j), h_{N \setminus \{i, j\}}].$$

As the next result states, adding this axiom to the set of basic structural axioms we characterize a general form of lifetime aggregation in which lifetimes are submitted to an arbitrary increasing continuous and *concave* function. In other words, we obtain *concave lifetime utilitarianism*.

Theorem 3 *The following statements are equivalent:*

1. \succsim is represented by a population health evaluation function satisfying (2), with a concave function g .
2. \succsim satisfies *worst-off priority* and *BASIC*.

Proof. We focus on the non-trivial implication. Formally, assume \succsim satisfies *worst-off priority*, and the *basic structural axioms*. Then, as in the proof of the previous results, \succsim can be represented as in (5).

Now, let $c > 0$, $h \in H$, and $i, j \in N$ be such that $a_i = a_*$. By *worst-off priority*,

$$[(a_*, 0), (a_j, c), h_{N \setminus \{i, j\}}] \succsim [(a_*, c), (a_j, 0), h_{N \setminus \{i, j\}}].$$

Equivalently,

$$g(f(a_*, 0)) + g(f(a_j, c)) \geq g(f(a_*, c)) + g(f(a_j, 0)),$$

i.e.,

$$g(f(a_j, c)) \geq g(c),$$

As $0 \leq f(a_j, c) \leq c$ (by definition of f), and g is an increasing function, it follows that

$$f(a_j, c) = c,$$

for each $c > 0$ and each $a_j \in A$. By definition, $f(a_j, 0) = 0$, for each $a_j \in A$. Altogether, we obtain that \succsim can be represented by (2).

Now, let $h \in H$ and $i, j \in N$, be such that $t_i \geq t_j$ and $a_i = a_*$. Then, by *worst-off priority*,

$$[(a_*, t_i), (a_j, t_j + c), h_{N \setminus \{i, j\}}] \succsim [(a_*, t_i + c), (a_j, t_j), h_{N \setminus \{i, j\}}],$$

which translates into

$$g(t_i) + g(t_j + c) \geq g(t_i + c) + g(t_j),$$

for each $t_i, t_j \in T$, such that $t_i \geq t_j$, and $c > 0$. As g is continuous, it follows from the above that g is concave. \square

As its proof indicates, Theorem 3 also relies on Theorem 1 in Hougaard et al., (2013), which characterizes the family of population health evaluation functions satisfying BASIC. The proof of Theorem 3 shows that, when the axiom of *worst-off priority* is added to BASIC, the family shrinks to *concave lifetime utilitarianism*. It then follows that, even though worst-off priority

(which is, after all, a weakening of the axiom of equal entitlement to continued life) allows for other more general forms of population health evaluation functions, these also involve dismissing any concern whatsoever over quality of life.

The last axiom we consider will have different implications. It is an alternative axiom to model prioritarianism, which weakens the previous one, as it only applies to agents enjoying perfect health. More precisely, **worst-off priority at perfect health** says that, among agents at perfect health, we prioritize those with lower lifetimes (hence, worst-off) when it comes to allocate extra additional life years. Formally,

Worst-off priority at perfect health: For each $c > 0$, each $h \in H$, and each pair $i, j \in N$, such that $t_i \geq t_j$,

$$[(a_*, t_i), (a_*, t_j + c), h_{N \setminus \{i, j\}}] \succsim [(a_*, t_i + c), (a_*, t_j), h_{N \setminus \{i, j\}}].$$

As stated in the next result, the combination of this axiom with the set of basic structural axioms characterizes *concave HYE utilitarianism*.

Theorem 4 *The following statements are equivalent:*

1. \succsim is represented by a population health evaluation function satisfying (5), with a concave function g .
2. \succsim satisfies worst-off priority at perfect health and BASIC.

Proof. We focus on the non-trivial implication. Formally, assume \succsim satisfies *worst-off priority at perfect health*, and the *basic structural axioms*. Then, as in the previous proofs, \succsim can be represented as in (5). Now, let $c > 0$, $h \in H$, and $i, j \in N$, be such that $a_i = a_j = a_*$, and $t_i \geq t_j$. By *worst-off priority at perfect health*,

$$[(a_*, t_i), (a_*, t_j + c), h_{N \setminus \{i, j\}}] \succsim [(a_*, t_i + c), (a_*, t_j), h_{N \setminus \{i, j\}}].$$

Equivalently,

$$g(f(a_*, t_i)) + g(f(a_*, t_j + c)) \geq g(f(a_*, t_i + c)) + g(f(a_*, t_j)),$$

i.e.,

$$g(t_j + c) - g(t_j) \geq g(t_i + c) - g(t_i), \quad \text{for each } c > 0, \text{ and } t_i \geq t_j.$$

It then follows from here, as argued in the previous proof, that g is concave. \square

As with the previous results, the proof of Theorem 4 also relies on Theorem 1 in Hougaard et al., (2013). The proof of Theorem 4 shows that, when the axiom of *worst-off priority at perfect health* is added to BASIC, the family shrinks to *concave HYE utilitarianism*. Whereas *equal entitlement to continued life* and *worst-off priority* imply that the “healthy years equivalent function” is independent of individual health states, *worst-off priority at perfect health* has no implications on such a function. Its only effect on the separable structure of the population health evaluation function is to make each of its arguments enter after being submitted to a concave function.⁸

5 Further insights

5.1 Independence of the axioms

The four theorems we present in this paper have a common structure. They all consider BASIC, i.e., the pack of basic structural axioms we introduced in Section 2.1, and add an additional axiom to it. Each of the four added axioms drives towards a specific population health evaluation function. For each of the four theorems, we can consider a (separable) population health evaluation function as in (5), thus satisfying BASIC, but with a different functional form than the one characterized in the corresponding theorem. That would be enough to show that the additional axiom is essential for the theorem. For instance, QALY utilitarianism is an example of a separable population health evaluation function, thus satisfying BASIC, which violates *equal entitlement to continued life*, *equal entitlement to continued life for equal lifetimes* and *worst-off priority*. It does satisfy *worst-off priority at perfect health* though. But its slight modification in which individual QALYs are first squared (before being aggregated) violates this axiom (while satisfying BASIC too). As for BASIC, it is also essential for each of the theorems. To show this, one only needs to consider non-separable population health evaluation functions, i.e., outside the family (5), satisfying each of the additional axioms. For instance, we can consider the following population health evaluation function.

$$P^\varphi[h_1, \dots, h_n] = P[(a_1, t_1), \dots, (a_n, t_n)] = \varphi(a_1, \dots, a_n) \sum_{i=1}^n t_i, \quad (6)$$

where $\varphi : A^n \rightarrow \mathbb{R}_+$. P^φ satisfies the additional axioms (but not BASIC), as desired.

⁸*Equal entitlement to continued life* has a stronger effect, in such a step, making that function linear, instead of concave.

Note that our model imposes a minimal mathematical structure for the set of available health states A . Thus, we cannot specify further the structure of g (except, perhaps, that it reaches a maximum at a_*). Now, if we would assume, for instance, that all health states could be ranked, we could consider $\varphi(a_1, \dots, a_n) = \min\{a_1, \dots, a_n\}$ or a suitable transformation of it. The resulting population health evaluation function would be consistent with equal entitlement to continued life, as well as prioritizing individuals with worse health. It is left for further research to explore the normative foundations of some of these non-separable population health evaluation functions.

Somewhat related to the above, one might wonder whether the whole BASIC pack is needed for the results we present. The answer is no. As mentioned above, Theorem 1 can indeed be refined to consider only two of the axioms within BASIC. More precisely, we have the following result.

Theorem 5 *The following statements are equivalent:*

1. \succsim is represented by a population health evaluation function satisfying (1).
2. \succsim satisfies equal entitlement to continued life, time monotonicity at perfect health, and the social zero condition.

Proof. We focus on its non-trivial implication. Formally, assume \succsim satisfies *equal entitlement to continued life*, the *social zero condition* and *time monotonicity at perfect health*. Let P be a population health evaluation function representing \succsim and let $h = [(a_1, t_1), \dots, (a_n, t_n)] \in H$. By iterated application of *equal entitlement to continued life*, and the transitivity of \succsim ,

$$h \sim [(a_1, t_1 + \dots + t_n), (a_k, 0)_{k \neq 1}].$$

By iterated application of the *social zero condition*, and the transitivity of \succsim ,

$$[(a_1, t_1 + \dots + t_n), (a_k, 0)_{k \neq 1}] \sim [(a_1, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1}].$$

By *equal entitlement to continued life*,

$$[(a_1, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1}] \sim [(a_1, 0), (a_*, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1, 2}].$$

By the *social zero condition*,

$$[(a_1, 0), (a_*, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1, 2}] \sim [(a_*, 0), (a_*, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1, 2}].$$

Finally, by *equal entitlement to continued life*,

$$[(a_*, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1}] \sim [(a_*, 0), (a_*, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1, 2}].$$

Altogether, by the transitivity of \succsim , we obtain,

$$h \sim [(a_*, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1}],$$

from which we conclude that \succsim depends only on $t_1 + \dots + t_n$.

Let now $h' = [(a'_1, t'_1), \dots, (a'_n, t'_n)] \in H$. By the above argument,

$$h' \sim [(a_*, t'_1 + \dots + t'_n), (a_*, 0)_{k \neq 1}].$$

Thus, by *time monotonicity at perfect health*,

$$h' \sim [(a_*, t'_1 + \dots + t'_n), (a_*, 0)_{k \neq 1}] \succsim [(a_*, t_1 + \dots + t_n), (a_*, 0)_{k \neq 1}] \sim h.$$

if and only if

$$\sum_{i=1}^n t'_i \geq \sum_{i=1}^n t_i.$$

Transitivity concludes. □

Parallel results cannot be obtained for the remaining results in the paper. For instance, consider the following population health evaluation function.

$$P[h_1, \dots, h_n] = P[(a_1, t_1), \dots, (a_n, t_n)] = |Z(h)| + \sum_{i \in Z(h)} t_i, \quad (7)$$

where $Z(h) = \{i \in N : t_i \neq 0\}$ and $|Z(h)|$ denotes its cardinality. This function satisfies *equal entitlement to continued life for equal lifetimes*, *time monotonicity at perfect health*, and the *social zero condition*.

5.2 Variations of the model

A (crucial) modeling assumption in our work is the existence of a focal health state considered as perfect health. One might conjecture that the existence of a focal *worst health state* might also suffice to replicate our analysis. This is not the case. On the one hand, some (health) states might be considered worse than death, which might call to consider negative lifetimes (something not allowed in our model). On the other hand, if we endorse the axiom of *positive lifetime desirability* (which is part of our BASIC pack), death would be considered the worst

state. But this cannot be considered as the *dual* state to perfect health (a_* in our model) as the former is connected to lifetime, whereas the latter is independent of it.

Our analysis could be extended to the case of multidimensional health.⁹ More precisely, if individuals would be defined by a n -tuple, rather than just a duplet, with one of the dimensions referring to lifetime, then we could extend our analysis with respect to a $n - 1$ dimensional state, relying on (multidimensional) *healthy years equivalent*.

We acknowledge that our work has been set in a context without uncertainty. In other words, and following Broome (1993), we consider a formulation of the population health evaluation problem which contains no explicit element of risk, and in which we obtain characterizations of population health evaluation functions without assumptions on the policy maker's (or individuals') risk attitudes. It is left for further research to extend our analysis in that direction. Fleurbaey et al., (2021) have recently focused on the fact that risk about the timing of death generates inequalities not only among the descendants of the deceased (inequalities in bequests), but, also, among the deceased themselves (inequalities in consumption and longevity. More precisely, they study the optimal taxation of accidental bequests in an economy where individuals care about what they leave to their offspring in case of premature death. They show that the utilitarian social criterion supports a fully confiscatory tax, whereas an ex-post egalitarian criterion (giving priority to the unlucky short-lived) supports to subsidize accidental bequests.

To conclude, we mention that our framework could be connected to the (sizable) literature on bankruptcy problems, initiated by O'Neill (1982) and recently surveyed by Thomson (2019). This literature deals with a classic allocation problem in which one has to distribute a perfectly divisible and homogeneous good when there is not enough to cover all agents' demands (claims). It encompasses many different situations (such as the bankruptcy of a firm, the division of an estate to the creditors of a deceased, or the collection of a given amount of taxes, just to name a few) and it goes as far back as the history of economic thought. Formally, a bankruptcy problem is defined by (N, c, E) , where N is the set of agents, $c = (c_i)_{i \in N}$ is the claims vector, and $E \leq \sum_{i=1}^n c_i$ is the endowment (to be allocated among agents in N). Under the presence of BASIC, we can naturally associate a bankruptcy problem to a population health distribution. Formally, for each

$$h = [h_1, \dots, h_n] = [(a_1, t_1) \dots, (a_n, t_n)],$$

⁹This is, for instance, the case of the well-known EQ-5D system, which comprises the following five dimensions: mobility, self-care, usual activities, pain/discomfort and anxiety/depression.

let

$$B(h) = (N, (t_i)_{i \in N}, E),$$

where

$$E = \sum_{i=1}^n f(a_i, t_i),$$

and $f : A \times T \rightarrow T$ is the HYE function.¹⁰

$B(h)$ is a well-defined bankruptcy problem. A focal solution to it would be precisely to assign each agent the corresponding amount of HYE, i.e., $f(a_i, t_i)$.¹¹ Now, in a context of (health care) resource allocation, where individuals transform resources into life expectancy, one might conceive alternative solutions (for instance, resorting to traditional rules, such as the constrained equal awards, constrained equal losses, proportional, or Talmud rules). This would, de facto, implement a reallocation of HYE aiming to prioritize certain individuals depending on their relative abilities to transform (health care) resources into life expectancy.

6 Conclusion

We have explored in this paper axioms formalizing several principles of entitlement to additional life years, in the context of the evaluation of health distributions. The unconstrained principle of equal entitlement to additional life years is extremely strong. Its combination with some basic structural axioms leads to evaluating health distributions by the aggregate lifetime they offer, dismissing any concern whatsoever for the morbidity associated to health distributions. In other words, the principle of equal entitlement to additional life years favors life saving procedures with respect to life enhancing procedures, as endorsed by Harris (1999). Nevertheless, if the scope of the principle is reduced to individuals sharing some characteristics, more general population health evaluation functions can be recovered. Instances are the functions arising after aggregating a generic function of lifetimes, or even aggregating quality adjusted life years, or healthy years equivalent.

¹⁰Note that, under the presence of BASIC,

$$h = [h_1, \dots, h_n] = [(a_1, t_1), \dots, (a_n, t_n)] \sim [(a_*, f(a_1, t_1)), \dots, (a_*, f(a_n, t_n))].$$

¹¹This can actually be rationalized by considering the image of any of traditional bankruptcy rule via the *composition operator* (e.g., Hougaard et al., 2012) associated to the HYE function.

Another related principle we have explored is that of prioritarian entitlement to continued life, conveying the idea that worst-off individuals are prioritized in the allocation of additional life years. Two axioms formalizing that principle have been considered. One turns out to exhibit strong implications too as it leads towards *generalized lifetime utilitarianism*. Another has weaker implications, leading to characterize *concave HYE utilitarianism*. This is a more general (and equity-oriented) population health evaluation function, which conveys a concave aggregation of healthy years equivalent.

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