Is the Distribution of Cardiovascular Risks Really Improving ? A Robust Analysis for France.

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Abstract

In this paper, we appraise the recent evolution of the distribution of individuals'risk of cardiovascular diseases (CVD) in France among both men and women using new normative criteria. An individual risk of CVD is described by a probability of getting such a disease. Building on the framework of Gravel and Tarroux (2015), we assume that individuals, who differ by their income, have Von Neuman-Morgenstern (VNM) preferences over such risks. We appeal to Harsanyi's aggregation theorem to provide empirically implementable dominance criteria that coincide with the unanimity, taken over a large class of such individual preferences, of anonymous and Pareto-inclusive VNM social rankings of distributions of individuals' risk of CVD. The implementable criteria that we obtain are Sequential headcount poverty dominance and Sequential headcount affluence dominance. We apply these criteria to the distribution of cardiovascular risks among French men and women on the 2006-2010 period. Probabilities of CVD are assigned to individuals on the basis of a logit model estimated on both the men and the women samples for each of the two years. Our main empirical result is that men and women were differently affected by evolution in the distribution of CVD risks between 2006 and 2010. Specifically, the distribution improved for women but did not improve for men.

Keywords: Risk, Dominance, *ex ante* Social Welfare, State-Dependent Expected Utility, Poverty, Health, Cardiovascular diseases.

JEL classification numbers: C81, D3, D63, D81, I32, J63, J64

1 Introduction

Despite clear progress in prevention and treatment, Cardiovascular Diseases (CVD) remain the primary cause of mortality worldwide. While about three quarter of the deaths caused by CVD occur in low or intermediary income countries, individuals living in high income countries are nonetheless affected quite severely by these diseases. In France

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for example, they remain the second cause of mortality after cancer (see e.g. Petersen, Peto, Peto, Rayner, Leal, Luengo-Fernandez, and Gray (2005)). Even when they do not kill, CVD have major negative impact on individual well-being. Cerebrovascular accidents for instance - which count for a significant fraction of CVD - are the first source of acquired permanent physical handicap among French adults. There are many factors that influence the individual probability of suffering from a CVD. Well-known among them are tobacco use, high blood pressure, high cholesterol, physical inactivity, diabetes, poor diet, stress and, of course, aging. The prevalence of CVD in low income countries suggests a connection between CVD and socioeconomic conditions. As is well-known in the epidemiological literature (see e.g. Kaplan and Keil (1993) or Diez-Roux, Link, and Northridge (2000) for the specific case of CVD or Smith (1999) and Cutler, Deaton, and Lleras-Muney (2006) for a broader discussion of the relationship between health and socioeconomic conditions). In France, Jusot (2006) has provided convincing evidence of a robust negative relation between the probability of dying and income.

Another source of inequality in the probability of suffering from a CVD appears to be gender. It is widely established in effect that men are more affected than female by CVD, even though this gender gap tends to shrink with age (see e.g. Haring, Ulrich, Volzke, Nauck, Dorr, Felix, and Wallaschofski (2012), Rogers, BG, Onge, and Krueger (2010) or Vartiainen and Puska (1999)). When combined with the well-known fact that women tend to be in lower socioeconomic conditions than men, this gender difference in exposure to CVD risk raises the more general question of the overall gender differential fairness in terms of exposure to both CVD risks and poor socioeconomic condition. Is the exposure to CVD and poor economic condition more unfairly distributed among men than among women ? Have the steady improvement in both protection against CVD risk and overall economic situation observed until the recent economic crisis affected differently the male and the female population ? These are some of the questions addressed in this paper.

Answering these questions requires normative criteria for evaluating the "overall fairness" of a particular distribution of exposure to CVD risk in a population of individuals who differ also by their socioeconomic conditions. The current paper uses a dominance approach for making this evaluation. While there are many studies in the literature that have used dominance criteria for evaluating distributions of health outcomes (see e.g. Arndt, Distante, Hussain, Osterdal, Huong, and Ibraimo (2012), Duclos, Sahn, and Younger (2006), Hussain, Jorgensen, and Osterdal (2016)), most of them have taken the *ex post* perspective of making the evaluation *after* the occurence of the health outomes. By contrast the current paper starts from the *ex ante* view point that health matters are risky and, as such, may affect individuals' well being from their mere possibility of occurence, even if they do not occur. It does so by using the general approach developed in Gravel and Tarroux (2015). The starting point of this approach is the observation that, when envisaged from the view point of an individual who faces it, a CVD risk can be described by a *probability distribution* over a set of *pairs* made of a state of health (e.g. dead, extremely severe impairment, mildly severe impairment, etc.) *and* of a pecuniary consequence (income net of medical expenditure) associated with that state. We assume that individuals evaluate these risks by a Von Neumann-Morgenstern (VNM) preference. The approach implemented in this paper views distributions of individual CVD risks as alternative *Socially Risky Situations* (SRS) (see e.g. Fleurbaey (2010)). On what principles could an "ethical observer" base his/her evaluation of any such SRS ?

Three come to mind relatively naturally. *First*, the ethical observer should treat individuals' situations somewhat symmetrically. We formulate this "anonymity" principle by requiring that simply changing the name of the individual who ends up for sure in a given state with a given income (if there is such an individual) is a matter of social indifference. The *second* principle that the ethical observer would satisfy is the (Paretian) respect for unanimity. If all individuals in the society agree on the ranking of two SRS, then the ethical observer should respect this agreement. The *last*, possibly more contentious, principle, is that the ethical observer should himself/herself appraise SRS with VNM preferences, just like the individuals do. This principle is clearly more contentious when imposed at the social level than at the individual one. At the individual level, VNM assumptions on preferences can be defended or criticized on the basis of their positive empirical plausibility. The expected utility model has, indeed, empirically falsifiable implications on individual behavior (for example the purchase of health insurance). Hence, appraising the plausibility of VNM assumptions on preferences over lotteries amount to empirically verifying whether or not actual individuals' behavior satisfy these implications. No such positive defense of VNM properties can be provided when applied to an "ethical observer" who summarizes the normative principles that are deemed legitimate for evaluating SRS. As it happens, the normative appeal of the VNM assumptions when applied to social evaluation has been seriously questioned since at least Diamond (1967).

Be it as it may, the three principles together have strong implications on the normative evaluation of SRS. Indeed, as shown by Harsanyi (1955) some fifty years ago, they force the normative comparison of any two such situations to result from summing, across individuals, their expected VNM utilities - that depend upon both their income and their final health state - that must be calculated (thanks to the anonymity condition) by the *same* utility function. This leaves open the choice of the expected utility function used by these individuals. In the current paper as well as in Gravel and Tarroux (2015), the (very) prudent attitude is taken of seeking for criteria that command unanimity over a (significantly) large class of individual VNM preferences.

What class of individual VNM preferences can be considered "significantly large" for our purpose ? In Gravel and Tarroux (2015), two such classes were considered. The first of them comprises all VNM preferences that could be represented by an expected utility function with a (positive) marginal utility of income that is *decreasing* with respect to the health states (ordered from the worst to the best). Gravel and Tarroux (2015) then identified an operational statistical criterion for comparing any two SRS in the same way than would all anonymous, Paretian and VNM social judgements based on this class of individual VNM that they call Sequential Expected Headcount Poverty (SEHP) dominance. According to this criterion, a SRS A is (weakly) better than a SRS B if, for any income poverty line and any state of health, the *expected* number of individuals who are *both* below the line *and* in a worse state is no greater in A than in B. The second, and more restricted, class of VNM preferences considered by Gravel and Tarroux (2015) consists of those preferences of the first class who satisfy, in addition, the property of *risk aversion* (the expected utility function that represents these preferences is concave in income), along with the property that the decrease in the marginal utility of income with respect to income be itself decreasing with respect to the health states. Gravel and Tarroux (2015) then identify an implementable criterion that coincides with the unanimity, over this class of VNM preferences, of all Pareto-inclusive VNM social preferences that they call "*Sequential Expected Poverty Gap*" (SEPG) dominance. This criterion works just like the SEHP one, but with poverty gap, rather than headcount poverty, used as the poverty measure.

Yet, it is unclear that the properties considered by Gravel and Tarroux (2015) are plausible when applied to individual preferences over health-related risks. Particularly questionable is the assumption that the marginal utility of income be decreasing with respect to health. For one thing, this is at odds with empirical evidence (see e.g. Viscusi and Evans (1990)) based on health-insurance purchased at an actuarially fair premium. Indeed, any VNM individual whose expected utility function exhibits a marginal utility of income that is decreasing with health would choose to over insure when faced with the possibility of purchasing insurance at an actuarially fair premium. Yet, in practice, it is *under*- rather than *over* - insurance that seems to be more common.

In this paper, we characterize an alternative dominance criterion to those considered in Gravel and Tarroux (2015). Noticing the health-insurance purchasing behavior of actual individuals, we make the assumption that the marginal utility of income *increases* with respect to the health state. Yet we keep the (more conventional) assumption that the marginal utility of income be positive and, possibly, decreasing with respect to income (at any given state). We accordingly consider the class individual VNM preferences that are such that the positive marginal utility of income be increasing with the health-states (ordered from the worst to the best). We find that the implementable criterion that coincides with the unanimity of all anonymous, Paretian and VNM aggregation of preferences in this class is the criterion that we call *Sequential Expected Headcount Affluence* (SEHA) dominance. According to this criterion, a distribution of risk of health A is better than B if for every poverty line and every state of health, the expected number of people who are both richer than this poverty line and in a weakly better state of health than that state is larger in A than in B.

We finally put our criteria to work by appraising the trend in the distributions of individual risks of CVD in France over the period 2006-2010. We do this by estimating, for samples of male and female individuals taken for each of the two years 2006 and 2010, a Logit model that explains the fact, for an individual, to be the victim of a CVD. The estimation of this model for both women and men enables us to assign to each individual of the sample in the two years an individual probability of having a CVD (as a function of his/her observable characteristics), and to compare the evolution of the distribution of these risks between the two years for the two genders. As it happens, and for obvious reasons, our criteria do not enable one to rank in one way or another the distributions of individual exposures to CVD risks among males and females. This lack of conclusiveness is not surprising because, as recalled above, women tend on the one hand to poorer than men and, on the other hand, to be better protected than men against the risk of CVD. Since the two dominance relations go in opposite directions, there is no overall dominance of one gender over the other. However, it turns out that the distribution of individuals' exposures to cardiovascular risks among women has improved as per both the SEHP and the SEHA criterion over the period 2006-2010 while no such improvement has been recorded for men. We interpret this result as indicative of a clear improvement in both the economic situation and protection against cardiovascular risk of women. Such a clear improvement has not been recorded for males over the same period.

The plan of the rest of the paper is as follows. The next section presents the theoretical framework and the criteria used to compare distributions of exposures to CVD risks. The third section discusses the empirical analysis and the fourth section concludes.

2 Theory

2.1 Normative criteria

Our criteria apply to societies made of a *given* number, n say, of individuals[1], indexed by i, with $i \in N = \{1, ..., n\}$. These societies expose their members to risks of *Cardiovascular Diseases (CVD)* in which any individual can fall into a finite number, l say, of mutually exclusive *health states*, indexed by h (with $h \in \Omega = \{1, ..., l\}$). We assume that health states are ordered from the worst (death) to the best (perfect health) so that state h is weakly worse than state $h+1$ for every $h = 1, ..., l-1$. Individuals receive income (possibly randomly) along with their health state We interpret this income as the amount of money that the individual has available to spend on anything else than health expenses brought about by the health condition associated with that state. We assume throughout that these income are strictly positive. In order to keep the formalism simple, we assume that the set $\mathbb{I}$ of all conceivable income levels can be written as $\mathbb{I} = \{1, ..., m\}$ for some (possibly very large) integer m. Hence, income is assumed to be available in integer quantities (say in cents).

We call *Socially Risky Situation (SRS)* a specific pattern of exposures of individuals to these cardiovascular risks. Formally, we model a SRS as a probability distribution - or *lottery* $-$ p on the set $\mathbb{X} = (\Omega \times \mathbb{I})^n$ of all logically conceivable vectors of state-income pairs, one such pair for every individual. A typical element x of $\mathbb{X}$ writes:

$$x = (h_1^x, y_1^x, ..., h_n^x, y_n^x) \tag{1}$$

where, for $i = 1, ..., n$, $h_i^x \in \Omega$ denotes the health state of i in situation x and $y_i^x \in \mathbb{I}$ denotes i's income in that state. In our finite framework, a lottery p is simply an element of the $(lm)^n - 1$ dimensional simplex, the xth component of which, denoted p_x, being interpreted as the probability that the society falls into state x under the SRS p. We abuse notation and, for any $a \in \mathbb{X}$, we denote simply by a the "non-risky" SRS p that gives a for sure and that is defined by $p_x = 1$ if $x = a$ and and $p_x = 0$ otherwise. We denote by $\mathbb{L}$ the set of all lotteries on $\mathbb{X}$. For a SRS $p \in \mathbb{L}$, we denote by $\pi_i^p(h, y)$ the probability that individual i be in state h with an income of y in that socially risky prospect. This probability is formally defined by:

$$\pi_i^p(h, y) = \sum_{\{x: h_i^x = h,\ y_i^x = y\}} p_x \tag{2}$$

Every individual $i \in N$ is assumed to have a VNM preference ordering[2] $\succsim_i$ on $\mathbb{L}$, with asymmetric (strict preference) and symmetric (indifference) factors $\succ_i$ and $\sim_i$ respectively. This means that there exists a function $\Phi_i : (\Omega \times \mathbb{I})^n \to \mathbb{R}$ such that, for every SRS p and q in $\mathbb{L}$, one has:

$$p \succsim_i q \Leftrightarrow \sum_{x \in \mathbb{X}} p_x \Phi_i(h_1^x, y_1^x, ..., h_n^x, y_n^x) \geq \sum_{x \in \mathbb{X}} q_x \Phi_i(h_1^x, y_1^x, ..., h_n^x, y_n^x) \tag{3}$$

We refer to the numerical representation of $\succsim_i$provided by (3) as to the expected utility representation. We further assume that each individual is *selfish* and cares only about his/her own risk of health and not at all about that of his/her fellow co-citizens. We also

[1] The generalization to societies involving different numbers of individuals is immediate.

[2] An ordering is a reflexive, complete and transitive binary relation.

assume that no individual is indifferent to everything so that, for every i, one can find at least two SRS p and q for which $p \succ_i q$. These two assumptions imply that, for every individual i, one has in fact:

$$p \succsim_i q \Leftrightarrow \sum_{h\in\Omega}\sum_{y\in\mathbb{I}} \pi_i^p(h,y)U_i(h,y) \geq \sum_{h\in\Omega}\sum_{y\in\mathbb{I}} \pi_i^q(h,y)U_i(h,y) \tag{4}$$

for some function $U_i : \Omega \times \mathbb{I} \to \mathbb{R}$ that is *not* constant.

SRS in $\mathbb{L}$ are evaluated by some ethical analyst who uses a *social ordering* $\succsim$ (with asymmetric and symmetric factors $\succ$ and $\sim$ respectively) that satisfies the VNM properties and the strong Pareto principle with respect to individual preferences. In the same fashion as in (3), the fact that $\succsim$ satisfies the VNM properties means that there exists a function $W : (\Omega \times \mathbb{I})^n \to \mathbb{R}$ such that, for every SRS p and q in $\mathbb{L}$, one has:

$$p \succsim q \Leftrightarrow \sum_{x\in\mathbb{X}} p_x W(h_1^x, y_1^x, ..., h_n^x, y_n^x) \geq \sum_{x\in\mathbb{X}} q_x W(h_1^x, y_1^x, ..., h_n^x, y_n^x) \tag{5}$$

The fact that $\succsim$ satisfies the strong Pareto principle means that if p and q are two SRS in $\mathbb{L}$ for which $p \succsim_i q$ holds for every individual i, then $p \succsim q$ and if, furthermore, there is an individual h for which $p \succ_h q$, then $p \succ q$. We also assume that the social ordering $\succsim$ on $\mathbb{L}$ used by the ethicist is *anonymous* so that it considers any two "non-risky" SRS that differ only by a permutation of two individuals state-income pairs as socially equivalent. Put differently, if a SRS brings one person for sure in a state with a given income level, it does not matter who this person is. The formal definition of anonymity is as follows.

Condition 1 *(anonymity) Let x and x' be two "non-risky" social situations in $\mathbb{X}$ such that, for two individuals h and $i \in N$, one has $(h_h^x, y_h^x) = (h_i^{x'}, y_i^{x'})$, $(h_i^x, y_i^x) = (h_h^{x'}, y_h^{x'})$ and $(h_g^x, y_g^x) = (h_g^{x'}, y_g^{x'})$ for all $g \in N$ such that $g \neq h, i$. Then $x \sim x'$.*

By virtue of a version of Harsanyi (1955)'s aggregation theorem stated as theorem 2 in Weymark (1993), any anonymous VNM social ordering of $\mathbb{L}$ that satisfies the strong Pareto principle with respect to individual VNM preferences can be written uniquely (up to an affine transformation) as a weighted sum of individuals expected utilities. Moreover, the anonymity condition forces the individual preferences and the individual weights to be the same across individuals. The formal statement of this state of affairs is as in the following proposition, proved in the Appendix.

Proposition 1 *Let $(\succsim_1, ..., \succsim_n)$ be a profile of selfish VNM individual preference orderings on $\mathbb{L}$ and let $\succsim$ be an anonymous VNM social ordering of $\mathbb{L}$ that satisfies the strong Pareto principle. Then, for every two SRS p and q in $\mathbb{L}$, one has:*

$$p \succsim q \Leftrightarrow \sum_{i\in N}\sum_{h\in\Omega}\sum_{y\in\mathbb{I}} \pi_i^p(h,y)U(h,y) \geq \sum_{i\in N}\sum_{h\in\Omega}\sum_{y\in\mathbb{I}} \pi_i^q(h,y)U(h,y) \tag{6}$$

for some function $U : \Omega \times \mathbb{I} \to \mathbb{R}$ whose expectation, taken over the probabilities $\pi_i^p(h,y)$ for $h \in \Omega$ and $y \in : \mathbb{I}$, numerically represents individual i's preferences.

This proposition says that the possibilities of obtaining an anonymous Paretian aggregation of a given profile of selfish individual VNM preferences into a social preference that satisfies itself the VNM requirement are somewhat limited. Indeed, in order for such an aggregation to be possible, the individual VNM selfish preferences must be the same (thanks to the anonymity condition), and must be aggregated by a simple symmetric summation of the individual VNM expected utilities.

There are obviously many such selfish VNM preferences that individuals can have. When basing social evaluation of SRS on the respect of those identical selfish VNM preferences, it seems therefore important to avoid an excessive dependence of the evaluation on the choice of the individual preferences. In this paper, we adopt the dominance viewpoint that seeks consensus over a large spectrum of those individual preferences. That is, we want to obtain a social ranking of lotteries in $\mathbb{L}$ that would be agreed upon by *all* social orderings that can be written as per (6) for some utility functions U taken from some (reasonably large) class. Specifically, we define normative dominance with respect to a class of expected utility functions as follows.

Definition 1 (Normative dominance) *SRS p normatively dominates SRS q for a class $\mathbb{U}$ of functions $U : \Omega \times \mathbb{I} \to \mathbb{R}$, denoted $p \succsim_{\mathbb{U}} q$, if inequality (6) holds for all functions U in the class.*

In this paper, we apply this general definition of normative dominance to specific classes of VNM preferences. In order to define them formally in the discrete setting considered herein, we first introduce the following properties of the expected utility representation of such VNM preferences.

P1 For every state $h = 1, ..., l-1$, one has:
(i) $U(h, y) \leq U(h+1, y)$ for every income $y \in \{1, ..., m\}$ and
(ii) $U(h+1, y+1) - U(h+1, y) \geq U(h, y+1) - U(h, y) > 0$ for every income $y \in \{1, ..., m-1\}$

P2 For every state $h = 1, ..., l-1$, one has:
(i) $U(h, y) \leq U(h+1, y)$ for every income $y \in \{1, ..., m\}$ and
(ii) $U(h, y+1) - U(h, y) \geq U(h+1, y+1) - U(h+1, y) > 0$ for every income $y \in \{1, ..., m-1\}$

We denote by $\mathbb{U}^+$ the class of all state-dependent utility functions satisfying property **P1** and by $\mathbb{U}^-$ the class of utility functions who satisfy **P2**.

In words, individuals with VNM preferences whose expected utility representation lies in $\mathbb{U}^+$ or $\mathbb{U}^-$ all prefer being for sure healthy than being for sure non healthy (given income) and all prefer having more income for sure than less (given health). However individuals with preferences for risk represented by a utility function in $\mathbb{U}^+$ differ from those with utility in $\mathbb{U}^-$ in the way they valuate an additional dollar received in the bad health state as compared to that received in the good one (when they have the same income in both states). Individuals with utility in $\mathbb{U}^+$ value more receiving for sure an extra dollar when healthy then when ill. Those with utility in $\mathbb{U}^-$ value more the extra dollar received when ill than when healthy. The class $\mathbb{U}^-$ of utility functions was considered in Gravel and Tarroux (2015). The class $\mathbb{U}^+$ of such utility may seem perhaps more appropriate for describing the insurance purchasing behavior of individuals who face risk of health.

To see why, consider an individual endowed with an income of y and exposed to a probability π to have a health problem that can be insured at an actuarially fair premium of $r = \frac{\pi}{1-\pi}$. Assuming that the health problem, if it arises, generates a financial loss of L, one can write the health insurance purchase decision of that individual as:

$$\max_{I \geq 0} (1-\pi) U(2, w - \frac{\pi I}{1-\pi}) + \pi U(1, w - L + I)$$

Because any purchase of a strictly positive amount I^* of insurance will satisfy the first order condition of this program[3], one has:

$$\partial U(2, w - \frac{\pi I^*}{1-\pi})/\partial y = \partial U(1, w - L + I^*)/\partial y$$

If the marginal utility of income is larger in state 2 than in state 1 (as postulated in **P1**), then this equality can only hold if $w - L + I^* \geq w - \frac{\pi I^*}{1-\pi}$ and, therefore, if $I^* \leq (1-\pi)L$. Hence, a VNM individual with preference for risk satisfying **P1** who can purchase a health insurance at an actuarially fair premium would choose to purchase *less* insurance than the expected financial loss incurred in case of a health problem. Put differently, the individual would choose to under insure him(her)self. The converse conclusion would obviously obtain if were was assuming instead a VNM preference numerically represented by a utility function in $\mathbb{U}^-$. There seems to be some empirical evidence (see e.g. Viscusi and Evans (1990)) that under-health insurance is much more prevalent than over health insurance. We therefore believe that assumption P1 is not astonishingly unreasonable concerning individual preferences for risks of health. Yet, we shall provide the analysis here by considering in turns the two families of utility function.

2.2 Implementable criteria and their characterization

In this paper, we propose two implementable criteria that coincide, respectively, with normative dominance defined with respect to the class $\mathbb{U}^+$ and $\mathbb{U}^-$.

The *first* of these is the *Sequential Expected Headcount Affluence* (SEHA) dominance criterion. It is defined as follows.

Definition 2 (Sequential Expected Headcount Affluence dominance) *For p and $q \in \mathbb{L}$, we say that p SEHA dominates q, denoted $p \succsim_{SEHA} q$ if, for every affluence line $t \in \mathbb{I}$ and every health state $h \in \Omega$, one has:*

$$\sum_{i \in N} \sum_{h \geq h} \sum_{y \geq t} \pi_i^p(h, y) \geq \sum_{i \in N} \sum_{h \geq h} \sum_{y \geq t} \pi_i^q(h, y) \tag{7}$$

In words, socially risky prospect p dominates socially risky prospect q for the SEHA criterion if, for every health state h and monetary affluence line t, the *expected number* of individuals who are *both* in a weakly **better** state than h *and* **richer** than t is no smaller in p than in q. As the SEHA criterion requires inequality (7) to hold for every affluence line, it implies, by choosing a small enough such line, that, for every health state h, the expected number of individuals in weakly better state than h be no smaller in the dominating situation than in the dominated one. In the same spirit, since the SEHA criterion requires inequality (7) to holds for $h = 1$, it implies the expected number of rich people irrespective of their health be no smaller in the dominating situation than in the dominated one.

The *second* implementable criterion was called Sequential Expected Headcount Poverty Dominance in Gravel and Tarroux (2015). It is defined as follows.

[3] We are cheating a bit here with respect to the discrete setting in which the rest of the analysis is conducted by considering a differentiable framework.

Definition 3 (Sequential Expected Headcount Poverty dominance) *For p and $q \in \mathbb{L}$, we say that p SEHP dominates q, denoted $p \succsim_{SEHP} q$ if, for every poverty line $t \in \mathbb{I}$ and every state $k \in \Omega$, one has:*

$$\sum_{i \in N} \sum_{h \leq k} \sum_{y \leq t} p(i,h,y) \leq \sum_{i \in N} \sum_{h \leq k} \sum_{y \leq t} q(i,h,y) \tag{8}$$

In words, SRS p dominates SRS q for the SEHP criterion if, for every state k and monetary poverty line t, the *expected numbers* of individuals who are *both* in a weakly **worse** state than k *and* poorer than t is no greater in p than in q. Just like for the SEHA criterion, since the SEHP criterion requires inequality (8) to hold for every poverty line, it implies, by choosing a large enough poverty line, that, for every state k, the expected number of individuals in states weakly worse than k be no greater in the dominating situation than in the dominated one. In the same spirit, since the SEHP criterion requires inequality (8) to hold for $k = l$, it implies the expected number of poor irrespective of the state - a statistic commonly known as headcount poverty in the literature - to be no greater in the dominating situation than in the dominated one. Notice that requiring the fraction of poor irrespective of the health state to be lower in the dominating distribution than in the dominated one for any poverty line is equivalent to requiring the fraction of rich irrespective of the health state to be higher in the dominating distribution than in the dominated one for any (affluence) line. Hence, one requirement of the dominance test is common to both the SEHA and the SEHP dominance criteria.

We now provide the normative foundations for each of these criteria by showing that it coincides with the ranking of SRS that commands unanimity over all anonymous Paretian and VNM social rankings who assume that individual VNM preferences can be represented by expected utility functions in one the two classes defined above.

The first theorem establishes an equivalence between normative dominance for the class $\mathbb{U}^+$ and SEHA dominance. The proof of the first theorem has been relegated in appendix A. The proof the second theorem can be found in Gravel and Tarroux (2015).

Theorem 1 *Let p and q be two socially risky prospects in $\mathbb{L}$. Then $p \succsim_{\mathbb{U}_1} q$ if and only if $p \succsim_{SEHA} q$.*

The second theorem establishes the equivalence between normative dominance over the class$\mathbb{U}^-$ and SEHP dominance dominance.

Theorem 2 *Let p and q be two socially risky prospects in $\mathbb{L}$. Then $p \succsim_{\mathbb{U}_2} q$ if and only if $p \succsim_{SEHP} q$.*

3 Empirical Analysis

3.1 Data description

We now apply this framework to the comparisons of SRS related to CVD. We use for this purpose data from the French *Enquête sur la Santé et la Protection Sociale (ESPS)*. The ESPS is a panel survey that follows a sample of about 8000 households containing all together 22 000 individuals are that representative of about 95% of the inland European France (excluding outer sea regions such New Caledonia, Reunion Island, etc.). The survey is not fully representative of the inland European French population because it overrepresents the poor households who are eligible to Universal Medical Coverage (*Couverture Maladie Universelle*) program. This program provides free medical care to poor individuals who do not have access to standard social security medical insurance provided to common employed or unemployed individuals. Because of this, it is a bit biased toward extremely poor households. Informations on individual characteristics (age, gender, education level, marital and professional or social status, smoking behavior, etc.) and household structure (type of the household, number of persons in the household, etc.) are included in the survey. Detailed information on individual health, medical consumption, and insurance is also provided by this data set, that contains also information on the household monthly net income. Yet, the information on that income is not very precise. Among other things, the household is only asked to report its net monthly income that sums all the net income earned by its members. We here convert household income into individual one using "modified OECD" equivalence scale.[4] On the other hand, the health information, reported for each individual of the household, is quite comprehensive and detailed. Individuals interviewed in the ESPS are asked whether each member of the household has been suffering in the last year of a large collection of possible diseases. We focus here on somewhat serious CVD that impact significantly the life quality of those that they affect. We consider specifically the following CVD: Angina, myocardial infarction, coronary insufficiency, chronic ischemic cardiomyopathy, acute or chronic pericarditis, valvulopathies (including mitral insufficiency), aortic aneurism, obstructive cardiomyopathy, primary and secondary cardiomyopathy, heart rythm disorders, heart failure, hemorrhagic stroke, non hemorrhagic stroke, carotid artery stenosis or trombosis, cerebral arteriosclerosis and arteriopathy (including peripheral arteries diseases). We are aware that this list is somewhat heterogenous and, perhaps, arbitrary to some extent. We have included cardiovascular diseases that strike us as significantly affecting the quality of life, and have excluded others, such as hypertension, that rarely generate perceivable symptoms, but that are known to increase significantly the risk of suffering from other CVD in the future. In the analysis conducted below, we define a cardiovascular risk as the probability that an individual suffers from one, or several, of those diseases in the year of survey. Hence, in terms of the theoretical model of the previous section, we consider only two health state: suffering from a CVD, and not suffering from it. We should emphasize that the information we have on the fact that a given individual suffers from one of those CVD results from the declaration of the person, and not from the appraisal of a physician or a health professional. We should also notice that this definition of a cardiovascular risk does not include the very important case of people who die from the disease. Hence, our analysis deals with the probability of suffering from at least one of these CVD and being alive.[5] We further limit the samples to the individuals above the age of 20 who provide information on their income and on their health. These restrictions lead us to work with a sample of about 10 000 individuals per year, more or less equally split between men and women. Descriptive statistics on our samples are provided in Figure 1

[4]According to this scale, the first adult of the household counts for 1, any other member above 14 counts for 0.5 and any member below 14 counts for 0.3.

[5]See Gravel, Mukhopadhyay, and Tarroux (2008) for an early use of the Gravel and Tarroux (2015) methodology to the appraisal of distributions of mortality risks.

	2006		2010	
	MEN	WOMEN	MEN	WOMEN
Sample size	5182	5611	4323	4811
Fraction of the sample suffering from CVD	9.6%	8.7%	10.1%	8.4%
Average monthly disposable income (euros)	1480.49	1413.97	1541.03	1474.52
Interdecile ratio	3.8	3.9	3.8	3.9

Figure 1: Descriptive Statistics

3.2 Model estimation

The first step of the analysis is to assign to each individual of the sample a probability of suffering, in a given year, of one of the above CVD, based on this individual's observable characteristics. For this sake, we estimate a Logit model that explains the fact, for a given individual, of suffering from one of the above CVD by a set of observables. These observables include demographic (age, sex, marital status, household type and composition), socioeconomic variables (income level, the highest level of education, occupational status, region of residence) and behavioral variables that may influence the individual probability of suffering from a cardiovascular disease (e.g. physical activity, smoking, consuming alcohol, obesity, etc.).

We estimate the Logit model separately for men and women for each of the two years 2006 and 2010. The estimated model is the following:

$$y_i^* = X_i\beta + \varepsilon_i \tag{9}$$

where, for every i, y_i^* is the binary variable ($= 0$ if the individual does not report one of the above CVD), β is the vector of parameters (including a constant term) that are to be estimated, X_i is the values of the observable characteristics of individual i (assumed to be measured by non-negative numbers) and ε_i is an individual error term identically and independently distributed across individuals according to the logistic distribution $L(a) = \frac{1}{1+exp(-a)}$ for some positive number a. For each individual $i \in [1, n]$, the probability π_i of suffering from a cardiovascular disease conditional on X_i is defined by:

$$\begin{aligned} \pi_i &= L(X_i\beta) \\ &= \frac{1}{1+exp(-X_i\beta)} \end{aligned} \tag{10}$$

while the (complementary) probability of not suffering from a cardiovascular disease is:

$$1 - \pi_i = \frac{1}{1+exp(X_i\beta)}$$

A nice feature of the Logit model is that:

$$\ln(\frac{\pi_i}{1-\pi_i}) = X_i\beta$$

Hence the parameters β reflect the impact that changes in the values of the explanatory variables X_i can have on the probability of occurrence of cardiovascular disease. The estimated parameters of the model are the values that maximize the following likelihood function:

$$V = \prod_{h=1}^{k} (L(X_{hi}\beta))^{Y_i}(1 - L(X_{hi}\beta))^{1-Y_i}$$

Explanatory variable	men 2006	women 2006	men 2010	women 2010
Age	0.08	0.07	0.02	0.04
Age squared	0.00002**	0.0003**	0.00007**	0.0004**
No hypertension	-0.619***	-0.97***	-0.714***	-0.517***
No cholesterol	-0.973***	-0.599***	-0.393***	-0.582***
No diabetes	-0.49***	-0.446***	-0.45***	-0.354***
Smoke	0.13	0.441**	0.124	0.365
No education	0.116	-0.112	-0.252	-0.864
Primary education	-0.139	-0.068	0.211	-0.115
Secondary education	0.01	-0.13	-0.025	-0.21
Income below Median	0.267**	0.082*	0.081*	0.025*
Inactive	0.192*	0.278	0.488***	0.201
Craft person/retailer	-0.194	-0.188	0.119	0.607*
Executive	-0.36	-0.255	0.397	0.296
Liberal profession	0.238	-0.113	0.51	0.792
Foreperson	-0.486	-0.116*	0.179	0.655
Professor/teacher	-0.181	-0.802**	0.623	-0.458*
Farmer	-0.32	-0.453*	-0.014*	0.278
Qualified worker	-0.039	-0.188	0.417	0.197
Technician	-0.309	-0.483	0.21	0.595
Intermediary	0.13	-0.457*	0.366	0.23
Other profession	-0.238	–0.184	0.071	0.256
Mediterranean	-0.035	0.191	-0.055	0.236
Centre east	-0.209	0.301	-0.257	0.24
South West	-0.022	0.192	-0.034	0.241
West	-0.42	-0.007	-0.177	0.221
East	-0.098	0.26	-0.024	0.25
North	0.026	0.465**	0.401	0.268*
Parisian basin	-0.11	0.135	0.025	0.218

Table 1: results of the Logit estimates[6]

The results of the estimation of the Logit model for men and women and for the years 2006 and 2010 are presented in Table 1. A first thing to note about this table is the somewhat small number of variables that are statistically significant. Among those are the standard health predictors of CVD such as hypertension, cholesterol, diabetes and, of course, age (the only explanatory variable that is measured in a non-dichotomic fashion). On the other hand, smoking does not have a significant effect on the occurrence of CVD except, possibly, for women in 2006. This weak effect of smoking, that seems to be at odd with folk evidence, can perhaps be explained by the fact that people who declare suffering from one of the above CVD may have decided to quit smoking after having the disease. If

[6]Coefficients significant at the 1%, 5% and 10% level are indicated by ***, ** and * respectively.

this is the case, it is possible that this inverse causality (having a CVD induces quitting smoking) mitigates the more conventional causal effect that smoking can have on the occurrence of CVD. The stronger impact that smoking seems to have on the occurrence of CVD among women than among men is in line with recent epidemiological evidence (see e.g.Huxley and Woodward (2011)). Somewhat surprisingly, the education level (the reference being a post-secondary education) does not seem to have a significant effect on the occurrence of CVD. Perhaps this is due to the fact that education is highly correlated with income, which do have a significant effect on the occurrence of CVD. Indeed, the fact of having an income below the median increases significantly the occurrence of having a CVD for both males and females in the year 2006 and 2010. Less strong -notably for women - but nonetheless significant, is the impact of being professionally inactive on the CVD risks. It is interesting to notice that the strong effect of professional inactivity on the occurrence of CVD observed for men does not seem to be present for women. The professional status of the individual - the reference being an unqualified worker - does not seem to explain significantly the occurrence of CVD. The few exceptions to this are the fact of being a farmer (which significantly protects 2006 men against CVD) and the fact of being a professor or a teacher (which significantly reduces the occurrence of CVD among women for the two years). One can also observe the occasional (and mild) effect of being a Craft or a fore person for women in one of the two years. The place of residence of the person (the reference being the Paris metropolitan area) does not seem either to affect significantly the occurrence of cardiovascular disease, with the noticeable exception of the North region for women (who is an important predictor of the occurrence of CVD).

Despite the lack of statistical significance (at least at the 10% level) of some of the explanatory variables, the model performs plausibly. A way to see this is to use the estimated values of the parameters provided in Table 1 to assign to every individual of the sample his or her probability of suffering from a CVD, as a function of his/her characteristics, using formula (10) (applied to the estimated values of the vector of parameters β). The relationship that is thus estimated between the probability of getting a CVD for a representative individual of a given type and his/her age is represented on Figure below for active non-smoking men and women that are free from hypertension, high cholesterol and diabetes, whose income is below the median, who live in the North region and who are qualified workers. As can be seen, the probability of getting a CVD, increases non-linearly with age, with a net convex inflexion taking place in the mid forties, and a net concave inflexion happening in the mid or late eighties (the probability of getting a CVD while staying alive ceases to increase above ninety). An interesting feature of Figure 2 is that the probability of suffering from CVD at any given age seems higher for women than for men when one controls the other characteristics (including of course the risks factors such cholesterol, hypertension, diabetes and (non) smoking). How can this be reconciled with the fact, shown in Figure 1, that the average probability of suffering from CVD is higher for men than for women ? Simply by noting that men tend to be more exposed to major risks factors such as diabetes, cholesterol and high blood pressure than women, while the latter are more prone to suffering from CVD given their risk factors. The Epidemiological literature (see Wenger (2012) for a recent survey) has, indeed, well documented that the cardiovascular consequences of suffering from a metabolic or cholesterol disorders for instance were more severe for women than for men (see Gami, Witt, Howard, Erwin, Gami, Somers, and Montori (2007)). Hence, given risks factors and age, northern French women appear to be more at risk to suffer from a CVD than men of the same age with the same risk factors.

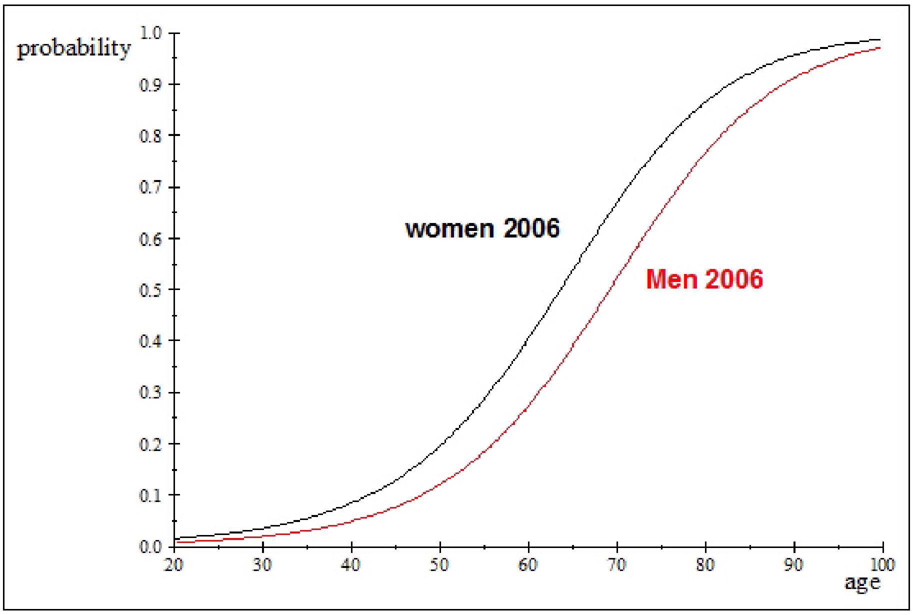

Figure 2: Individual probability of having a CVD for representative men and women of given characteristics.

3.3 Comparing Distributions of Exposures to CVD by the SEHA and the SEHP criteria

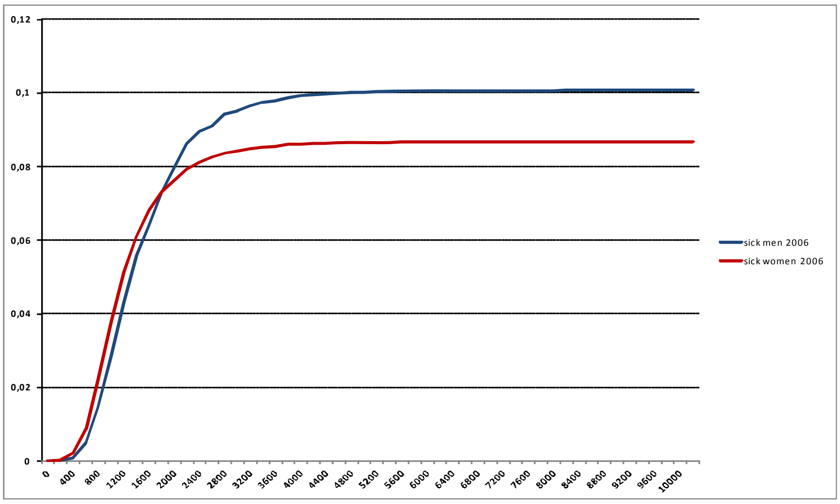

Figure 3: Expected headcount poverty curves for sick women and men, 2006

Figure 3 shows, for 2006, the expected headcount poverty curves among French Men and Women suffering from a CVD. Remember that each of these curves shows the expected probability, for an individual in the corresponding population, to be *both* sick *and* weakly poorer than the poverty line indicated on the horizontal line. As can be seen, for sufficiently low poverty lines, this probability is higher for women than for men (who

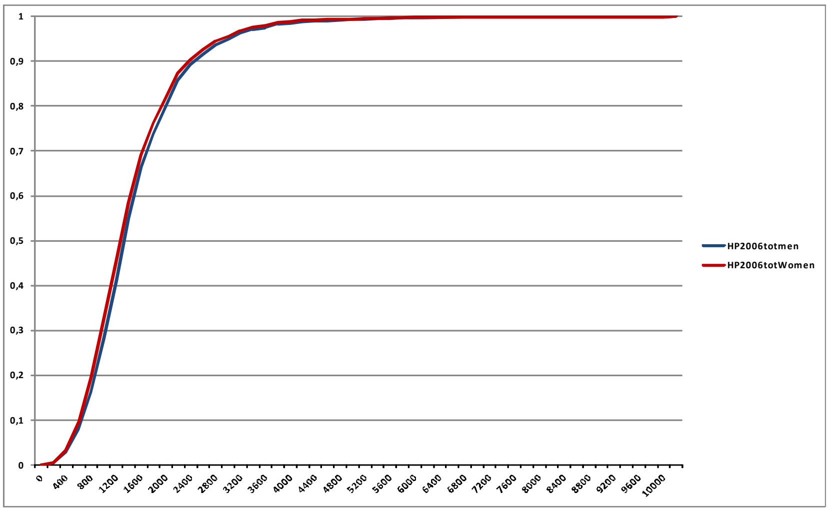

Figure 4: Expected headcount poverty curves in the total population of men and women, 2006

tend to be overall poorer than men). However, when the poverty line becomes sufficiently large (somewhere near 1500 euros a month), the probability of being both poor and sick becomes larger for men than for women. Hence, the expected headcount poverty curves cross at that poverty line. The reason for this is the fact, indicated in Figure 1 above, that the overall probability of suffering from a CVD is larger for men than women. This fact is recalled to our attention in Figure 3 where each of the two curves reaches a plateau (for a large enough poverty line below which everybody is poor) corresponding to the total probability of suffering from a CVD. Figure 4 shows the expected headcount poverty curves for the total population of men and women. As can be seen, the curve for men tends to lie everywhere below that for women. This reflects the fact that, in the whole population - made of those who suffer from a CVD and those who do not - a higher fraction of women than men lies below any poverty line. As the SEHP criterion requires the absence of crossing among any of the two pairs of curves of Figures 3 and 4, we conclude therefore that men and women's exposures to CVD risks were non-comparable in 2006. The same conclusion can be obtained from the examination of Figures 5 and 6 who show the same curves for the year 2010. The qualitative conclusion of absence of dominance of one gender over the other is also obtained for that year from the fact that the two expected headcount poverty curves for men and women sufferers (shown in Figure 5) cross (while no such crossing is obtained for the total headcount poverty curves). Notice however that the crossing of the two curves in Figure 5 for 2010 is less radical than what it was in 2006. Indeed, for a wide spectrum of income poverty lines, the probability for a women to have an income below this line and to be affected by a CVD is significantly smaller than what is for men. This reflects the somewhat important improvement that women have experienced, over the period 2006 - 2010 in their exposure to CVD risks as compared to men.

As shown on Figures 7 and 8, the SEHA dominance criterion does not provide any help in obtaining more conclusive verdict on this matter. These figures depict indeed, for the years 2006 and 2010 respectively, the probability of being *both* more affluent than any income level shown on the horizontal line *and* in good health for men and women. Clearly, for low enough income level with respect to which everybody is rich, the probability of

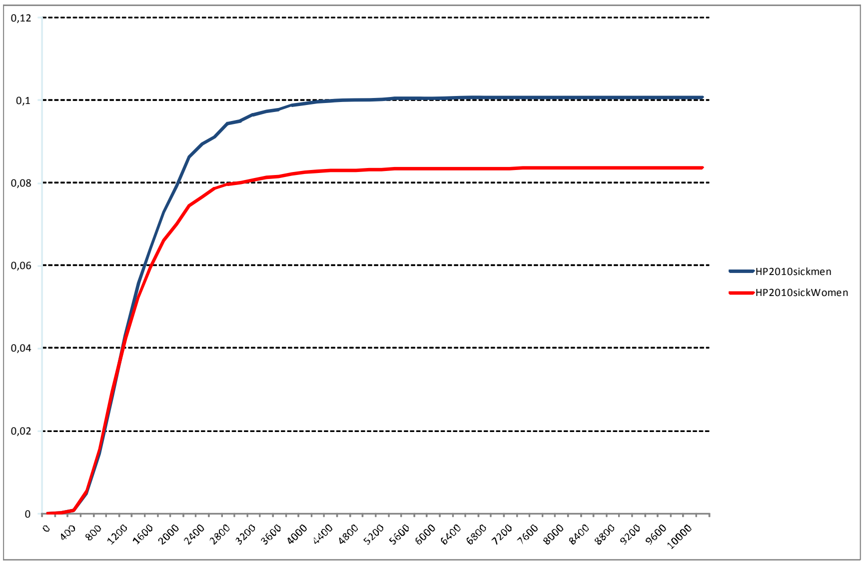

Figure 5: Expected headcount poverty curves for sick men and women, 2010.

being both more affluent than this level and exempt from CVD coincides with the overall probability of being exempt from CVD, that is larger for women than for men for the two years. Hence the female curves of Figures 7 and 8 are above the male one for low enough affluence line. When the affluence line becomes larger than, roughly, 800 euros a month, the probability of being both richer than this line and exempt from cardiovascular disease becomes larger for men than women. Albeit this may not be well visible on the figures due to the convergences of the two curves for large affluence line, there happens to be another crossing for large affluence lines (somewhere above 5800 euros a month). Hence, if the affluence line is sufficiently large, women are more likely to be both richer than this line and exempt from cardiovascular diseases then men. Since Figures 4 and 6 have already shown that French men face a lower overall probability of having an income lower than any poverty line than French women (irrespective of health), there is no need to check for the crossing (or not) of the two overall affluence curves as theoretically required by inequality (7).

Hence, it happens that men and women's exposures to risk can not be compared by our criteria. There are VNM preferences represented by functions in the class $\mathbb{U}^{+} \cup \mathbb{U}^{-}$ defined above, which, if aggregated by a Paretian VNM and anonymous ethicist, would lead to the conclusion that the distribution of CVD is better among women than among men while there are some VNM preferences in the class for which the opposite conclusion holds. A way of reducing such disagreements would be to reduce the class of possible VNM preferences considered by the ethicist. For instance, Gravel and Tarroux (2015) have considered a subclass of $\mathbb{U}^{-}$ made of VNM preferences that also exhibit risk aversion that is decreasing with respect to health. They have identified an operational dominance criterion that coincides with the unanimity of judgements made on this restricted class that they called sequential expected poverty gap dominance. Would such a criterion, that is more discriminatory than the SEHP one, be helpful here in ranking conclusively the distributions of CVD risk of men and women ? The answer to this question is negative. The reason for this is that even the more discriminatory sequential expected poverty gap criterion requires, among other things, that total poverty irrespective of the health state

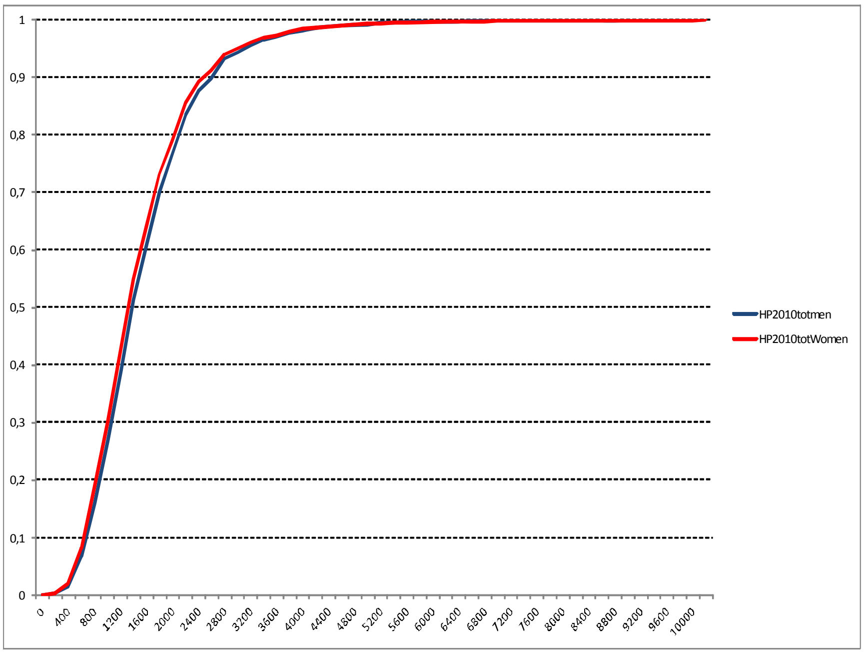

Figure 6: Expected headcount poverty curves in the total population of men and women, 2010.

(measured by the poverty gap or the headcount) be smaller in the dominating distribution than in the dominated one for all poverty lines. It also requires that the overall probability of suffering from a CVD irrespective of income be smaller in the dominating distribution than in the dominated one. For men and women, these two requirements work in opposite directions. Women have an overall probability of suffering from CVD irrespective of their income lower than men, but, irrespective of their health state, they suffer from more income poverty then men.

It happens, however, that women's exposures to CVD risks have unquestionably improved over the period 2010 as per the SEHP criterion, while no such improvement has been observed for men. Consider indeed Figure 9, showing the probability for a woman of both suffering from a CVD and having an income lower than any poverty line for the two years 2006-2010. As can be seen, the 2010 curve lies everywhere below that of 2006. Hence, no matter what is the poverty line, it is less probable for a woman in 2010 to suffer from a CVD and being poor than it was in 2006. Consider now Figure 10, which shows the headcount poverty curves of women irrespective of the health state for the two same years. Again - but perhaps less clearly due to the proximity of the two curves - no matter what is the poverty line, the fraction of women who are poor for that poverty line is lower in 2010 than 2006. Hence, the distribution of CVD risks among women has unquestionably improved on the period 2006-2010 for the SEHP. This means that all NM and anonymous ethical evaluation of the French women exposures to CVD risks that respect - in the Pareto sense - individual VNM preferences represented by a function in the class $\mathbb{U}^-$ individuals will conclude in an improvement of their exposures over the period 2006-2010. This unanimity actually extends to VNM preferences represented by a function in the class $\mathbb{U}^+$, as shown on Figure 11. Indeed, the expected fraction of women who are both exempt from CVD and richer than any affluence line has increased over the period.

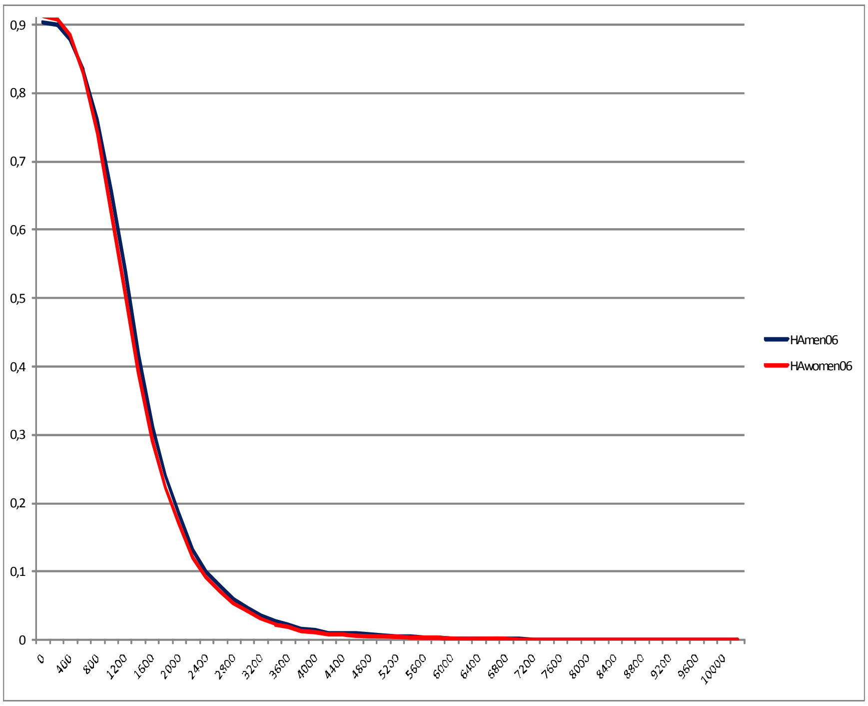

Figure 7: Expected affluence curves for healthy men and women, 2006

This improvement in women's exposure to CVD risks has *not* been observed for men, as shown on Figure 12. Indeed, as indicated on this figure, the expected fraction of the male population who is suffering from CVD and who is poor has gone down between 2006 and 2010 for poverty lines below 2000 euros or so. However the reverse conclusion holds when one considers larger poverty lines. Indeed, for sufficiently large poverty lines, the probability for a men of being both sick and having an income below the line is larger in 2010 than in 2006. This results from the fact that the average overall probability of getting a CVD has gone up for males on the period 2006-2010, so that, at a sufficiently large poverty line with respect to which all males are considered "poor", the probability of suffering from a CVD becomes indeed larger in 2010 than in 2006. It is important to notice that this absence of improvement in men' exposure to CVD result essentially from this (somewhat surprising) deterioration in men cardiovascular health that seems to have taken place over the period. Indeed, as indicated on Figure 13, the overall economic situation of French men - irrespective of their health - has increased over the period since the fraction of poor men is lower in 2010 than in 2006 for any conceivable income poverty line. Hence, and contrary to what was observed for women, the recent evolution of men' income and men' probabilities of getting a CVD have worked in opposite direction. Just like women (see Figure 10), men have seen an improvement in their economic situation on the period 2006-2010 as indicated by the non-crossing of their total headcount poverty curves shown in Figure 13. However, and contrary to women, men have, in average, seen a reduction in their protection against the probability of suffering from a CVD. Hence men have not improved over the period while women did. This conclusion would not be affected by considering the SEHA criterion that would have been subjected to the very same "veto power" of the deterioration, on the period 2006-2010, in men' cardiovascular health.

It is important to notice that both the SEHP and the SEHA criteria provided the

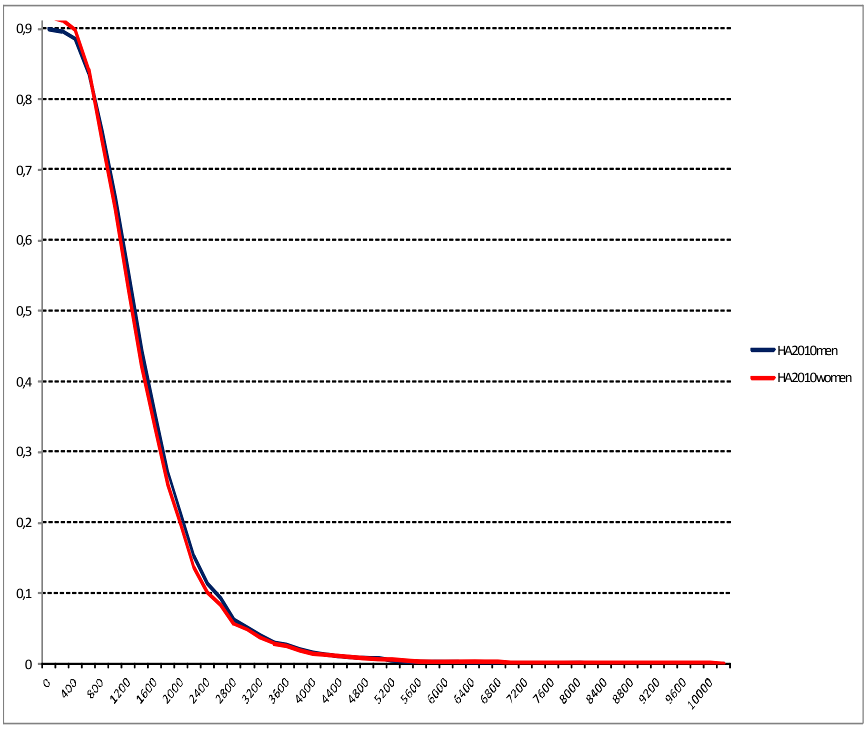

Figure 8: Expected headcount affluence curves for healthy men and women, 2010.

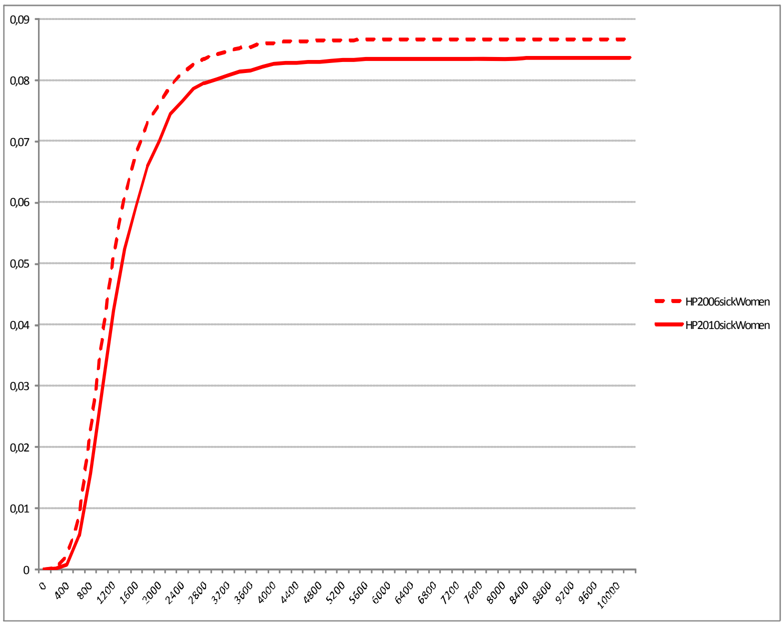

Figure 9: Expected headcount poverty curves among sick women, 2006-2010.

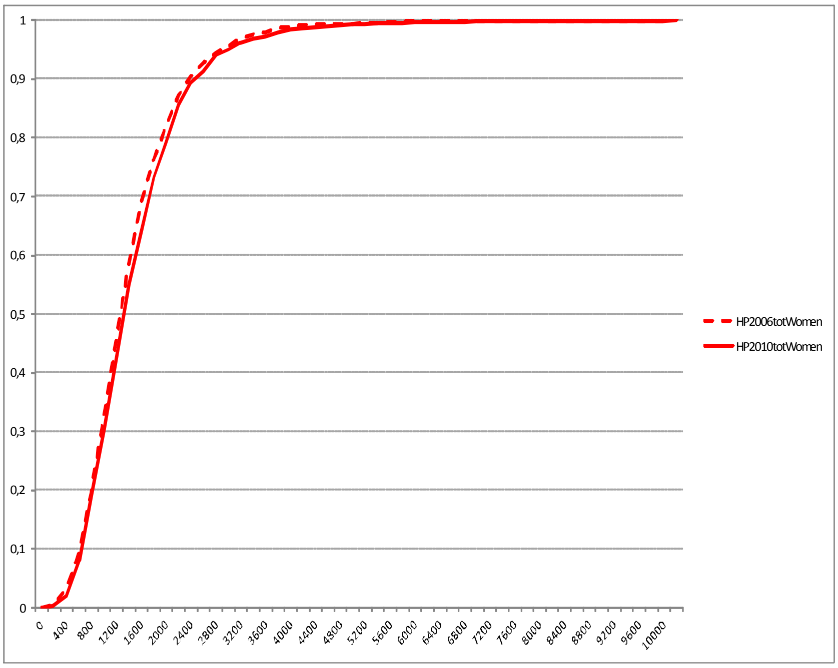

Figure 10: Expected heacount poverty curves for all women, 2006-2010.

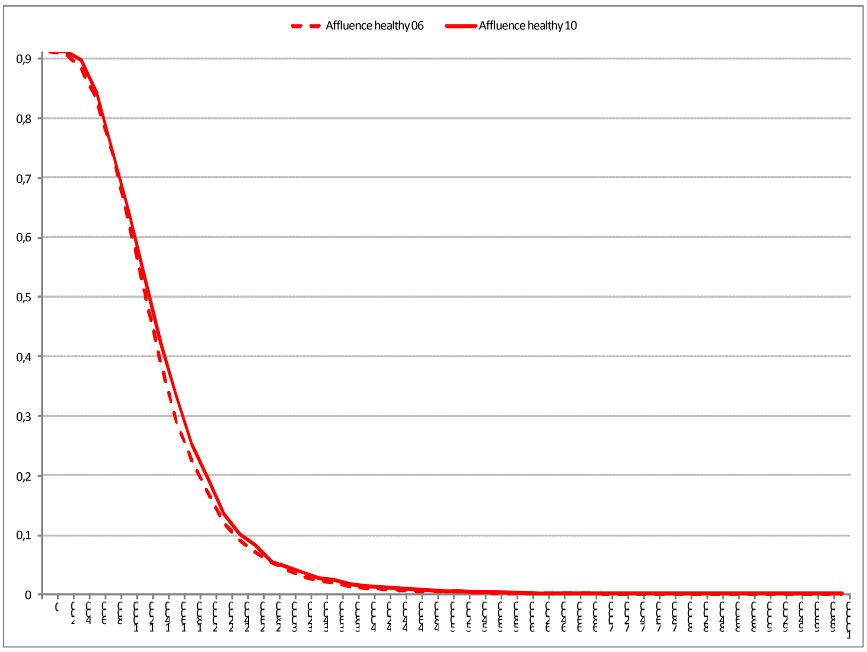

Figure 11: Expected affluence curves among healthy women, 2006-2010.

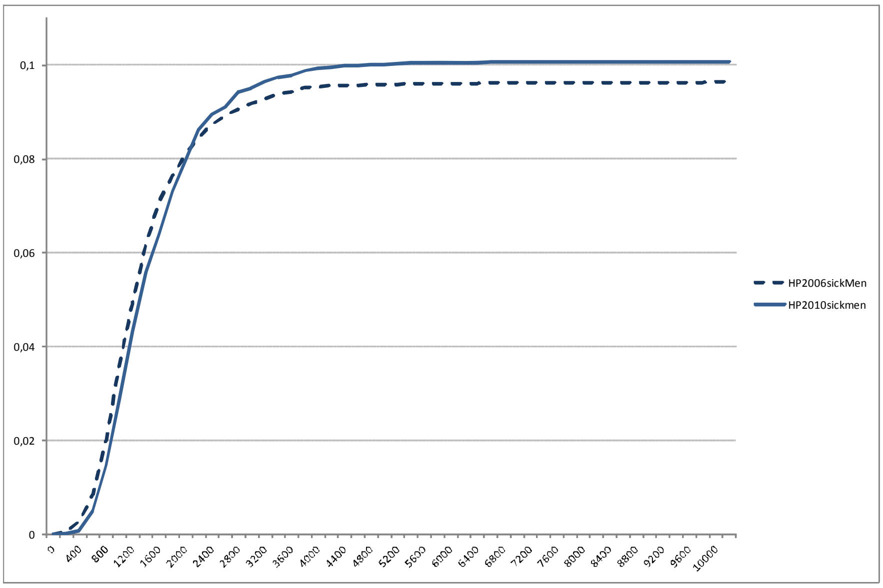

Figure 12: Expected headcount poverty curves for sick men, 2006-2010.

same clear verdict of an improvement in women protection against CVD risks. Since, as established in Theorems 1 and 2, the two criteria differ only by the assumption they make on the cross-health state variation of the marginal utility of income, we conclude that, for cardiovascular risks among women in France observed on the 2006-2010 period, this assumption does not matter. We view this as an additional indication of the robustness of the improvement of women cardiovascular health over the period.

4 Conclusion

This paper has examined the recent evolution of French men and women's exposures to CVD risks in relation to their economic situation from an explicit and robust normative point of view. It has done so by means of new dominance criteria obtained from a general approached introduced in Gravel and Tarroux (2015). In this approach, SRS - such as individuals' exposures to CVD diseases - are appraised from the view point of an ethical analyst who has VNM preferences, who treats individuals situation symmetrically, and who respects individuals' preferences for risks that are also assumed to be of VNM type and selfish (i.e. individuals only care about the consequence of the risky situations that affect them). By virtue of the famous Harsanyi (1955) aggregation theorem - and more specifically of a version of it due to Weymark (1993) - any such ethical analyst must compare these SRS on the basis of the sum of the individuals' expected VNM utility functions representing individuals' preferences that must be - thanks to the anonymity requirement - identical. This paper has proposed two operational criteria, each of which coinciding with the unanimity of such ethical analysts taken over a large class of individual VNM utility function. The first criterion, first proposed in Gravel and Tarroux (2015), coincides with the ranking of SRS that would be agreed upon by all ethical analysts who assumes that the individual's VNM utility function is increasing with respect to income and health, and prefers, at a given income level, receiving an additional income in a bad health state than a good one. This criterion, called Sequential Expected Headcount

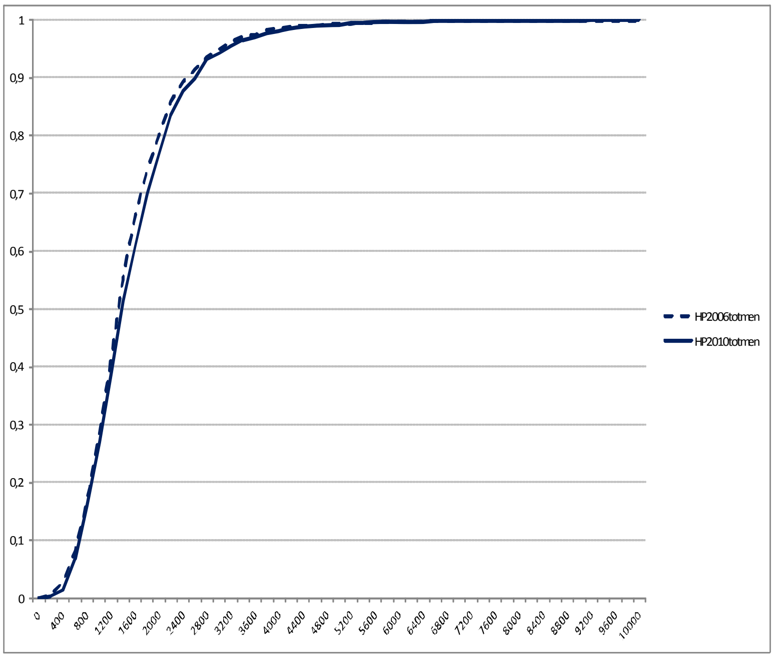

Figure 13: Headcount poverty curves in the total male population, 2006-2010.

Poverty (SEHP) dominance, requires that the expected fraction of the population that is both poorer and in a worst health state than any income poverty line and targeted health state be lower in the dominating SRS than in the dominated one. The second criterion, proposed for the first time in this paper, coincides with the unanimity of such ethical analysts who assume that individuals prefer, at a given income level, receiving the additional income when healthy than when ill. This criterion was called Sequential Expected Headcount Affluence (SEHA) in this paper. It works somewhat like the SEHP, but by focusing on affluence (e.g. having an income above some line) rather than poverty. Specifically, this criterion requires that the expected fraction of the population that is both richer and healthier than any income poverty line and health level be larger in the dominating distribution than in the dominated one.

We have put these two criteria to work by examining the exposures to CVD risks among French men and women over the period 2006-2010, based on the French EPS survey data, that provide detailed information on the health and income of a somewhat sizeable fraction of the French adult population. The first step of this exercise has been the assignment, to each individual of the sample, of a probability of getting a CVD based on his/her observable characteristics, on the basis of the estimation of a Logit model. Given this assignment, we have compared the distributions of exposures to CVD among men and among women on the period 2006-2010 by means of the two criteria.

Two main lessons have been obtained from these comparisons. The *first* is that the overall exposure to CVD risks of men and women can not be compared by any of our criteria. The reason for this lack of conclusiveness is clear enough. Women face, in average, a lower CVD risks then men while they are, at the same time, submitted to a larger poverty (or to a lower affluence). These two effects simply counteract each other, and this counteraction leads to an absence of conclusiveness of our two dominance criteria. The *second* lesson is that women exposures to CVD risks have unquestionably improved over the period 2006-2010 while no such improvement has been recorded for men. In view of the difficulty of obtaining the large unanimity of VNM individual preferences that is associated to our criteria, we interpret our conclusion for women to be somewhat strong. Indeed, any Paretian, symmetric VNM ethical analyst who assume that VNM individuals prefer more income to less (given health) and a better health to a worse (given income), and who assume that the benefit of receiving an additional euro is either decreasing (if the SEHP criterion is used) or increasing (with SEHA) with respect to health would conclude in the improvement of French women exposure to CVD risks over that period. We believe this to be good news from the view point of women's public health. Unfortunately, no such clear and robust improvement has been observed for men. because of the deterioration in men's protection against the risk of CVD observed between 2006-2010.

While we believe these empirical results, and the illustration of our ethical methodology that they provide, to be of some interest, we are aware of many limitations of the analysis,. One of them concerns the Logit estimate of the probability of obtaining a CVD, which could be improved to some extent. Another concerns the definition of the CVD that is somewhat large and, as a result, covers heterogenous forms of medical conditions (infarction, arrhythmia, stroke, etc.). This "large" definition of CVD results from our desire to have a sufficiently important fraction of the population concerned by the disease for the Logit estimation to perform well. It is obviously very difficult to estimate a Logit model if the dichotomous phenomenon that is explained concerns a too small fraction of the population. A somewhat related limitation of our analysis is its dichotomous aspect "ill-healthy". It would have been interesting to consider a more fine-grained distinction of health states (say extremely severe, severe, mildly severe, non-severe, and perfect health). But of course, doing this would have required us to enter into the details of distinguishing between the medical conditions of the individuals and to assess whether, say, having a myocardial infarction is a worse medical condition than having had stroke. Another important limitation of our analysis, as applied to CVD risks, is to neglect the death that often results from these diseases. The risks that we have covered are the risk of suffering from a CVD while remaining alive. These risks are perhaps not the most important ones. For instance, it was observed above that men's probabilities of getting a CVD has increased a bit between 2006 and 2010. Is this indicative of a deterioration of the overall men's cardiovascular health ? Perhaps not, if this increase in the probability of both being alive and suffering from a CVD is the result of a corresponding reduction in the probability of dying from a CVD. Yet our data do not provide any clue to answer this question in one way or another.

A last set of limitations concern, perhaps, the criteria themselves. For one thing, they are very incomplete, as shown by their inability to provide definite conclusion on whether or not there is a gender gap in terms of exposures to CVD risks. Can we make them "more complete" ? We certainly can, but at the cost of making additional, and more controversial, assumptions on individual's VNM preferences. Some of these assumptions, like risk aversion or, as considered in Gravel and Tarroux (2015), the assumption that risk aversion be decreasing with respect to health, may be somewhat acceptable. When combined with the assumption that the benefit of an additional income is decreasing with health, these assumptions give rise to a new dominance criterion - sequential expected poverty gap dominance - that is more discriminatory than the SEHP criterion considered in part here. Yet, applying this criterion to men-women's comparison would have not been enough to yield definite conclusion. The reason for this is the opposite directions in which the two main forces of the risks exposures of men and women are pushing to. On the one hand, men are exposed to a larger probability of suffering from CVD than women and this immediately prevents them from dominating women. On the other hand, the distribution of income among men dominates that among women at the first order of stochastic dominance, and this immediately prevents women to dominate men. Obtaining a clear cut ranking of men and women on this front would therefore require one to make very precise - and therefore inevitably controversial - assumptions on the relative importance of health and income as determinant of individuals' attitude to risk. We have chosen in this paper to avoid entering in this direction.

A Proofs

A.1 Proof of Proposition 1

By Theorem 2 in Weymark (1993), and after noticing that the condition called "independent prospects" by this author is satisfied herein if $(\succsim_1, ..., \succsim_n)$ are selfish VNM individual preferences that are not universally indifferent, one concludes in the existence of n strictly positive (thanks to the strong Pareto principle) numbers $\lambda_1, ..., \lambda_n$ such that:

$$p \succsim q \Leftrightarrow \sum_{i \in N} \lambda_i \sum_{x \in \mathbb{X}} p_x U_i(h_i^x, y_i^x) \geq \sum_{i \in N} \lambda_i \sum_{x \in \mathbb{X}} q_x U_i(h_i^x, y_i^x) \tag{11}$$

Define the function $\Phi_i : \Omega \times \mathbb{I} \to \mathbb{R}$ by $\Phi_i(h, y) = \lambda_i U_i(h, y)$ for every $(h, y) \in \Omega \times \mathbb{I}$ and write condition (11) as:

$$p \succsim q \Leftrightarrow \sum_{x \in \mathbb{X}} p_x \sum_{i \in N} \Phi_i(h_i^x, y_i^x) \geq \sum_{x \in \mathbb{X}} q_x \sum_{i \in N} \Phi_i(h_i^x, y_i^x) \tag{12}$$

By the anonymity condition, one must have, for any two (h, y) and $(h', y') \in \Omega \times \mathbb{I}$ and any two social states x and $x' \in \mathbb{X}$ for which $(h_i^x, y_i^x) = (h_j^{x'}, y_j^{x'}) = (h, y)$ and $(h_j^x, y_j^x) = (h_i^{x'}, y_i^{x'}) = (h', y')$ hold for two individuals i and $j \in N$ while $(h_g^x, y_g^x) = (h_g^{x'}, y_g^{x'})$ holds for all remaining individuals g:

$$\begin{aligned} x \quad \sim \quad & x' \Longleftrightarrow \sum_{k \in N} \Phi_k(h_k^x, y_k^x) = \sum_{k \in N} \Phi_k(h_k^{x'}, y_k^{x'}) \\ & \Longleftrightarrow \\ \Phi_i(h, y) - \Phi_i(h', y') \quad = \quad & \Phi_j(h, y) - \Phi_j(h', y') \end{aligned}$$

This equality can only be satisfied for any two (h, y) and $(h', y') \in \Omega \times \mathbb{I}$ if the functions Φ_i and Φ_j, which must also represent individuals i and j's preferences over all state-income pairs, are the same (up to a common translation). Hence, one has, for every $i \in N$ and $(h, y) \in \Omega \times \mathbb{I}$. $\Phi_i(h, y) = U(h, y)$ for some function $U : \Omega \times \mathbb{I} \to \mathbb{R}$. Since $\lambda_i U_i(h, y) = U(h, y)$, and VNM utility functions represents individual preference up to a positive affine transformation, the result follows (as λ_i is strictly positive), thanks to the definition of $\pi_i^p(h, y)$ and $\pi_i^q(h, y)$ provided by expression (2).

A.2 Proof of Theorem 1

For the first implication, assume that $p \succsim_{\mathbb{U}_1} q$. Then, the inequality:

$$\sum_{i \in N} \sum_{h \in \Omega} \sum_{y \in \mathbb{I}} \pi_i^p(h, y) U(h, y) \geq \sum_{i \in N} \sum_{h \in \Omega} \sum_{y \in \mathbb{I}} \pi_i^q(h, y) U(h, y) \tag{13}$$

holds for every function $U : \Omega \times \mathbb{I} \to \mathbb{R}$ in $\mathbb{U}_1$. Consider, for any $t \in \mathbb{I}$ and $k \in \Omega$, the function $V^{kt} : \Omega \times \mathbb{I} \to \mathbb{R}$ defined, for any $(h, y) \in \Omega \times \mathbb{I}$, by:

$$\begin{aligned} V^{kt}(h,y) &= 1 \text{ if } y \geq t \text{ and } h \geq k \\ &= 0 \text{ otherwise} \end{aligned}$$

The function V^{kt} belongs to $\mathbb{U}_1$ for any $t \in .\mathbb{I}$ and $k \in \Omega$. Indeed, V^{kt} is weakly increasing with respect to y for any given h, and is increasing with respect to h for any given y. Moreover, for given $t \in .\mathbb{I}$ and $k \in \Omega$, consider an arbitrary pair $\{h, y\} \in \Omega \backslash \{l\} \times \mathbb{I} \backslash \{m\}$. Nine cases are possible:
(i) $(k,t) \geq (h+1, y+1) \geq (h,y)$
(ii) $h+1 > k \geq h$ and $t \geq y+1 \geq y$
(iii) $y+1 > t \geq y$ and $k \geq h+1 \geq h$
(iv) $h+1 > h \geq k$ and $t \geq y+1 \geq y$
(v) $y+1 > y \geq t$ and $k \geq h+1 \geq h$
(vi) $(h+1, y+1) > (k,t) \geq (h,y)$
(vii) $h+1 > h \geq k$ and $y+1 \geq t > y$
(viii) $h+1 \geq k > h$ and $y+1 > y \geq t$
(ix) $(h+1, y+1) > (h,y) \geq (k,t)$
Consider the expression $[V^{kt}(h, y+1) - V^{kt}(h,y)] - [V^{kt}(h+1, y+1) - V^{kt}(h+1, y)]$. Depending upon each of these seven cases, this expression writes:

$$\begin{aligned} [0-0]-[0-0] &= 0 \text{ (cases (i)-(v))} \\ [0-0]-[1-0] &= -1 \text{ (case (vi))} \\ [1-0]-[1-0] &= 0 \text{ (case (vii))} \\ [0-0]-[1-1] &= 0 \text{ (case (viii))} \\ [1-1]-[1-1] &= 0 \text{ (case (ix))} \end{aligned}$$

Hence $[V^{kt}(h, y+1) - V^{kt}(h,y)] - [V^{kt}(h+1, y+1) - V^{kt}(h+1, y)] \leq 0$ and the second inequality (ii) of **P1** holds. Thus V^{kt} belong to $\mathbb{U}_1$. Because inequality (13) holds for all functions in $\mathbb{U}_1$, one has:

$$\begin{aligned} \sum_{i \in N} \sum_{h \in \Omega} \sum_{y \in \mathbb{I}} \pi_i^p(h,y) V^{kt}(h,y) &\geq \sum_{i \in N} \sum_{h \in \Omega} \sum_{y \in \mathbb{I}} \pi_i^q(h,y) V^{kt}(h,y) \\ &\Leftrightarrow \\ \sum_{i \in N} \sum_{h \geq k} \sum_{y \geq t} \pi_i^p(h,y) &\geq \sum_{i \in N} \sum_{h \geq k} \sum_{y \geq t} \pi_i^q(h,y) \end{aligned}$$

as required by (8).
For the other implication, we proceed by decomposing inequality (13) using Abel identity (see for instance (Fishburn and Vickson (1978); eq 2.49)). Doing first the decomposition with respect to the y-indexed summation operator yields:

$$\sum_{i \in N} \sum_{h \in \Omega} [\sum_{y \in \mathbb{I}} \Delta\pi_i(h,y) U(h,m) - \sum_{t=0}^{m-1} \sum_{y=0}^{t} \Delta\pi_i(h,y)(U(h,t+1) - U(h,t))] \geq 0 \quad (14)$$

where, for all $i \in N$, $h \in \Omega$ and $y \in \mathbb{I}$:

$$\Delta\pi_i(h,y) = \pi_i^p(h,y) - \pi_i^q(h,y)$$

Abel decomposing inequality (14) this time with respect to the h-indexed summation operator yields (after noticing that $\sum_{i\in N}\sum_{h\in\Omega}\sum_{y\in\mathbb{I}}\Delta\pi_i(y)=n-n=0$ thanks to (2):

$$\sum_{i\in N}[-\sum_{k=1}^{l-1}\sum_{h=1}^{k}\sum_{y\in\mathbb{I}}\Delta\pi_i(h,y)(U(k+1,m)-U(k,m))$$

$$-\sum_{k=1}^{l}\sum_{t=0}^{m-1}\sum_{y=0}^{t}\Delta\pi_i(h,y)U_l^{\Delta_t}$$

$$+\sum_{k=1}^{l-1}\sum_{h=1}^{k}\sum_{t=0}^{m-1}\sum_{y=0}^{t}\Delta\pi_i(h,y)(U_{k+1}^{\Delta_t}-U_k^{\Delta_t})]\geq 0 \tag{15}$$

where, for any $h\in\Omega$ and $t\in\{0,...,m-1\}$, the (upward) difference operator $U_l^{\Delta_t}$ is defined by:

$$U_h^{\Delta_t}=U(h,t+1)-U(h,t)$$

Notice now that, for any strictly positive integer b, and any finite sequence $\{x_n\}_{n=1}^{b}$ of b real numbers, one has:

$$x_b=\sum_{n=1}^{b-1}(x_{n+1}-x_n)+x_1 \tag{16}$$

Applying (16) to the sequences $\{U(k+1,t)-U(k,t)\}_{t=0}^{m}$ and $\{U_h^{\Delta_t}\}_{h=1}^{l}$ of inequality (15) enables one to write this inequality (after some manipulation) as:

$$\sum_{i\in N}\sum_{k=1}^{l-1}\sum_{t=0}^{m-1}[-\sum_{h=1}^{k}\sum_{y\in\mathbb{I}}\Delta\pi_i(h,y)-\sum_{h\in\Omega}\sum_{y=0}^{t}\Delta\pi_i(h,y)+\sum_{h=1}^{k}\sum_{y=0}^{t}\Delta\pi_i(h,y)](U_{k+1}^{\Delta_t}-U_k^{\Delta_t})$$

$$-\sum_{i\in N}\sum_{h\in\Omega}^{l}\sum_{t=0}^{m-1}\sum_{y=0}^{t}\Delta\pi_i(h,y)U_1^{\Delta_t}$$

$$-\sum_{i\in N}\sum_{k=1}^{l-1}\sum_{h=1}^{k}\sum_{y\in\mathbb{I}}\Delta\pi_i(h,y)(U(k+1,0)-U(k,0))\geq 0 \tag{17}$$

Observe now that, thanks to (2)

$$\begin{aligned}\sum_{i\in N}\sum_{h=1}^{k}\sum_{y\in\mathbb{I}}\Delta\pi_i(h,y) &= \sum_{i\in N}\sum_{h=1}^{k}\sum_{y\in\mathbb{I}}(\pi_i^p(h,y)-\pi_i^q(h,y))\\ &= (n-\sum_{i\in N}\sum_{h=k+1}^{l}\sum_{y\in\mathbb{I}}\pi_i^p(h,y)-(n-\sum_{i\in N}\sum_{h=k+1}^{l}\sum_{y\in\mathbb{I}}\pi_i^q(h,y))\\ &= -\sum_{i\in N}\sum_{h=k+1}^{l}\sum_{y\in\mathbb{I}}\Delta\pi_i(h,y),\end{aligned} \tag{18}$$

Similarly, one has:

$$\sum_{i\in N}\sum_{h\in\Omega}\sum_{y=0}^{t}\Delta\pi_i(y)=-\sum_{i\in N}\sum_{h\in\Omega}\sum_{y=t+1}^{m}\Delta\pi_i(y) \tag{19}$$

and:

$$\sum_{i\in N}\sum_{h=1}^{k}\sum_{y=0}^{t}\Delta\pi_i(y) = -\sum_{i\in N}\sum_{h=k+1}^{l}\sum_{y\in\mathbb{I}}\Delta\pi_i(y) - \sum_{i\in N}\sum_{h=1}^{k}\sum_{y=t+1}^{m}\Delta\pi_i(y) \tag{20}$$

Substituting (18)-(20) into (17) yields (after simplifications):

$$\sum_{i\in N}\sum_{k=1}^{l-1}\sum_{t=0}^{m-1}\sum_{h=k+1}^{l}\sum_{y=t+1}^{m}\Delta\pi_i(y)(U_{k+1}^{\Delta_t} - U_k^{\Delta_t})$$

$$+\sum_{i\in N}\sum_{h=1}^{l}\sum_{t=0}^{m-1}\sum_{y=t+1}^{m}\Delta\pi_i(y)U_1^{\Delta_t}$$

$$+\sum_{i\in N}\sum_{k=1}^{l-1}\sum_{h=k+1}^{l}\sum_{y=0}^{m}\Delta\pi_i(y)(U(k+1,0) - U(k,0)) \geq 0 \tag{21}$$

Since $U_{k+1}^{\Delta_t} - U_k^{\Delta_t} \geq 0$, $U(k+1,0) - U(k,0) \geq 0$ and $U_1^{\Delta_t} \geq 0$ holds for every function $U : \Omega \times \mathbb{I} \to \mathbb{R}$, one can see that having:

$$\sum_{i\in N}\sum_{h=k+1}^{l}\sum_{y=t+1}^{m}\Delta\pi_i(y) = \sum_{i\in N}\sum_{h\geq k}\sum_{y\geq t}\Delta\pi_i(y) \geq 0$$

for every $k \in \Omega$ and $t \in \mathbb{I}$ is sufficient for (13) to hold for any such function.

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