Demand for genetic and medical testing: The role of anticipated emotions and probability distortion

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Abstract

Empirical evidence, and the emergence of direct-to-consumer markets for genetic and medical tests, indicate that there is a disconnect between the testing preferences of doctors and patients. To gain insight into this dichotomy, we contrast the testing preferences implied by a normative (expected utility) model with those implied by a behavioral (prospect theory) model that accounts for anticipated emotions (e.g., rejoicing and misery) and probability distortions. Among other findings, we isolate a "reassurance effect" whereby patients will want to test more for severe, hard-to-treat diseases that have a lower probability of occurrence. We also show that probability distortions (as conventionally captured by an inverse S-shaped transformation function) tend to decrease the discrepancy between the testing preferences of doctors and patients. Our analysis also suggests product and promotional tactics for firms operating in the direct-to-consumer testing market. For example, these firms might benefit from introducing less reliable tests (with higher probability of false negative) for severe and less treatable diseases. By highlighting the potential for such manipulative tactics, this research can support further ethical and regulatory discussions.

Keywords: genetic test, medical test, anticipated emotion, probability transformation, prospect theory, reassurance effect, direct-to-consumer marketing

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1 Introduction

In recent years a new industry was born that offers genetic and medical testing directly to consumers, without the usual requirement of a doctor's prescription. By allowing consumers to seek health information autonomously, direct-to-consumer (DTC) tests aim to empower consumers with a more proactive role in the management of their health. There has been a growing demand for DTC tests in the United States and the market for DTC tests is predicted to top $350 million per year by 2020, up from $15 million in 2010.[1][2] Even though a majority of states in the United States have formulated legislations that allow consumers to order some or all laboratory tests directly, regulators and health professionals have raised various issues regarding the reliability of tests employed, misleading marketing tactics, and the ability of consumers to act autonomously without medical counsel. Most dramatically, on November 22, 2013, the US Food and Drug Administration (FDA) banned genetic testing pioneer 23andme from offering its health-related genetic tests (Annas and Elias 2014, Vayena 2014) evoking misleading claims, the inability of consumers to accurately process health risks, and false positives. FDA revoked the ban partially in 2016 and allowed 23andme to market DTC tests for few disease categories only.

The emergence of the direct to consumer testing industry, and the debates that surround it, suggest that ordinary people may have different preferences than health professionals. Looking at the economics and medicine literature on this subject, we can tentatively identify three puzzling stylized facts that this paper will seek to explain. *First, many patients decline testing in situations where doctors normally recommend it.* Studies have found that, among high risk patients, 40% declined to test for breast and ovarian cancer (Lerman et al. 1996b), 57% declined to test for colon cancer (Lerman et al. 1999), 75% declined to test for Alzheimer (Roberts et al. 2004), and 90% declined to test for Huntington's disease (Oster et al. 2013), even though tests were highly reliable and of-

[1]See goo.gl/gaFQhF for more details.

[2]In the United States, many diagnostic companies such as Quest Diagnostics, Laboratory Corp., Direct Laboratory Services, or WellnessFX have started offering direct-to-consumer medical tests. Rising direct-to-consumers genetic testing include start-ups such as 23andme, Veritas, Ancestry, Helix, Color.

fered for free, which constitutes a decision theoretic puzzle (Wakker 1988). Surprisingly low testing rates were also observed among patients with high risk of AIDS (Matovu and Makumbi 2007) and melanoma (Richard et al. 2000).[3]

Second, patients tend to seek testing more than doctors in low risk situations. For example, studies found that 83% of low risk patients preferred to get tested for colon cancer susceptibility (Croyle and Lerman 1993, Lerman et al. 1999) when only 43% of high risk patients preferred to get tested (Lerman et al. 1996a). When asked to list reasons for testing or not testing, patients listed emotional factors such as the fear of emotional reactions (as a reason not to test) or wanting to be reassured (as a reason to test). Similarly, Caplan (1994) reports that women with breast cancer symptoms that are disappearing are more likely to test than women whose breast cancer symptoms are getting worse.

Third, while doctors are motivated by actionable information, it appears that the general public sometimes values testing for unpreventable diseases: Middleton et al. (2016) found that less than half of surveyed genetic health professionals would value testing for an unpreventable disease while 75% of the broader public would consider such testing.

The purpose of this paper is to offer a detailed analysis of the decision to undergo a medical or genetic test, our goal being to both delineate and interpret the observed differences in preferences between doctors and ordinary people summarized in the above stylized facts. To address this dichotomy of preferences, we contrast the decisions obtained under a normative expected utility model with the decisions obtained under a behavioral model formally similar to prospect theory. While the expected utility model captures a "rational" decision process focused on final health states and actionable treatments, our parsimonious behavioral model captures a "psychological" decision process that anticipates emotional states of misery or rejoicing upon the reception of test results, and accounts for some degree of probability distortion (e.g., being more particularly sensitive to changes in extremely high or low probabilities).

[3] Such information avoidance is also prevalent in other domains such as finance and is famously called the *Ostrich effect* (Loewenstein 2006, Karlsson et al. 2009).

To achieve this, we first introduce a decision tree that represents both health outcomes and anticipated emotions, as well as the structure of disease probabilities, associated with the decision to undergo a medical test for a given disease. We categorize diseases based on severity (s), treatment cost (c), and treatment efficacy (α). Then, we carry a comparative analysis between the normative preferences of a "rational" decision maker (e.g., an idealized doctor) who cares about health outcomes and costs, and acts consistently with classical expected utility theory (von Neumann and Morgenstern 1947), vs. those of a "psychological" decision maker (a consumer), whose decisions anticipate reference-dependent emotions of rejoice and misery, and whose perceptions of probabilities are distorted, as in prospect theory models (Tversky and Kahneman 1992, Wakker 2010).

Our analysis first identifies rational preference patterns whereby the decision to test is driven by the chances of efficacious treatment, reduced side effects, combined with a high prior probability of a severe disease (e.g., based on symptoms or known predispositions). Then, we look at the decision to test from the perspective of a psychological decision maker who anticipates emotions of rejoice and misery associated with health outcomes. There, we find a paradoxical inclination to test for low probability diseases that are severe and hard to treat, driven by a reassurance motive: consumers expect a negative test result that will dissipate anxieties. This theoretical effect explains the testing preference of low risk patients described in the second stylized fact. The role of reassurance as a cause of excessive testing for breast cancer (mammogram) and fetus abnormality testing (ultrasound) was also mentioned in Welch et al. (2011).

For high probability diseases, we find that the decisions of psychological decision makers obey the same logic as those of rational decision makers.[4] However, the rational and psychological demand for testing may still differ due to the relative sensitivity to anticipated emotions vis-a-vis real utility. In particular, when the decision maker is very sensitive to negative anticipated emotions (misery), consistent with the first stylized fact, she might test less for severe, hard to treat diseases due to anxiety.

[4] This is corroborated by Middleton et al. (2016) who find that 98% of respondents, whether professionals or members of the public, would want to know genetic information relating to preventable or treatable life-threatening diseases.

These basic findings are moderated by the propensity to overweight low probabilities and underweight high probabilities of gains or losses (inverse-S shaped probability weighting function - see Tversky and Kahneman 1992, Abdellaoui et al. 2011). Our analysis indicates that the inverse-S shaped weighting function reduces the above discussed dichotomy and makes a psychological decision maker's testing preferences consistent with those of a rational decision maker. In particular, the tendency of consumers to magnify low probabilities will reduce the demand for tests motivated by reassurance. On the other hand, we find that the tendency to underweight high probabilities will reduce the anxiety associated with likely diseases, and this should correct for the psychological decision maker's reluctance to test for such diseases.

In addition to these main findings, we also investigate consumer preferences for test reliability. Consistent with the empirical work of Kahn and Luce (2003) who studied information acquisition behaviors in the context of mammography testing for breast cancer we predict that patients should be remarkably wary of tests that produce false positives, and in fact would prefer a higher occurrence of false negatives for severe hard to treat diseases associated with low probability, which is another manifestation of the psychological decision maker's focus on reassurance.

Finally, we take a more instrumental perspective on our findings, and use them to identify new product policies and promotional tactics for direct-to-consumers firms on the genetic and medical testing market. We show that for low probability diseases, a DTC testing firm could benefit from introducing high false negative tests targeted at severe, hard to treat diseases. The firms may also use different promotional strategies to influence the shape of probability distortion and thereby increase DTC testing demand. Because these marketing implications may appear manipulative and pose ethical problems, the analysis can also serve as a basis for regulatory thinking.

There has been a debate as to whether genetic testing is fundamentally different from other medical testing, the so-called "genetic exceptionalism debate" (e.g., Green and Botkin 2003). Opponents to genetic exceptionalism do not see how genetic tests differ from medical tests such as pregnancy tests, blood tests, or urinalysis in terms of needs for interpretation, depth of consequence, and privacy requirements. However, based on our analysis, we can identify a fundamental difference between genetic and medical tests. Medical tests serve to diagnose the presence of a suspected disease. Their relevance is greatest when the likelihood of the condition is elevated. In contrast, genetic tests identify baseline pre-dispositions towards diseases, usually with a preventive intention, ahead of symptoms, when prior probabilities are low. This is precisely when the reassurance motive should kick in, and thus the dichotomy between rational and psychological decision makers is likely to be particularly accentuated about genetic testing, which therefore warrants exceptional attention.

Alternatives to expected utility (Kahneman and Tversky 1979, Quiggin 1982, Loomes and Sugden 1982) have often been criticized for being ad hoc, not tractable, and not applicable to the real world context (Erev et al. 2010). We address these criticisms by applying prospect theory to analyze a critical contemporary issue. This has required us to interpret prospect theory in the context of genetic and medical test acquisition. Instead of gains and losses in wealth, we have gains and losses in health (respectively, having a disease or being clear from a disease), and our reference point is the counterfactual health outcome (binary alternative to the true health outcome). Moreover, we interpret prospect theory's value function as a measure of emotions quite similar to disappointment/elation (Bell 1985, Loomes and Sugden 1986, Gul 1991, Delquié and Cillo 2006), and we enrich the analysis with an explicit contrast to non-reference-dependent evaluations as in Kőszegi and Rabin (2006). Other models based on anticipated emotions have been applied to the medical testing context, e.g., Kőszegi (2003) refers to anxiety to explain our first stylized fact. The scope of our predictions captures a more comprehensive range of stylized facts, and we hope that the rooting of our theory in well-grounded and extensively discussed prospect theory models adds to its credibility.

The paper is organized as follows. Sections 2 introduces the background notation and concepts. Section 3 and 4 discuss the decision tree and the decision models. Section 5 presents the analysis of the dichotomy between rational and psychological demands; For added realism, our theoretical propositions are graphically simulated using parameter calibrations taken from the empirical literature in decision theory. Section 6 discusses how marketers can leverage the demand in the direct-to-consumer testing market; Finally, Section 7 concludes.

2 Basic Notation and Concepts

Consider a decision maker (DM) who faces a choice whether to undertake a genetic or medical test. Such test informs the probability of having a specific disease (now or, as a future risk), and might cause the DM to seek a curative or preventative treatment. Let d and $\bar{d}$ indicate the event of having and not having a specific disease. The corresponding probabilities are denoted by $p(d)$ and $p(\bar{d})$. After taking the test and receiving a positive (+) or a negative (−) test result, the DM updates her prior probability of having that disease, consistent with Bayes rule. The posterior probabilities (after updating) of having the disease are denoted by $p(d|+)$ and $p(d|-)$. The reliability of the medical test is indicated by $p(-|\bar{d})$ and $p(+|d)$. Note that $p(+|d)$ and $p(-|\bar{d})$ are referred to as "sensitivity" and "specificity" in the medical literature. The reliability of the test can be inferred from the rates of false positive $p(+|\bar{d})$ and false negative $p(-|d)$. The focus of our study is the preference relation $\succeq$ which reflects the DM's value of testing (demand for testing) for different diseases. If the DM prefers to test for disease x than for disease y, we write $x \succeq y$.

We seek to predict dichotomies between the demands for testing of doctors and patients. To that effect, we contrast two decision models. First, an expected utility model is used to capture the behavior of a "rational" decision maker (e.g., a doctor) who focuses on objective health states and any incurred cost of treatment, and who has an unbiased perception of risks. Second, a psychological value (prospect theory) model is used to capture the behavior of a "psychological" decision maker, who is affected by anticipated emotions and probability distortion. The psychological value model, detailed in Section 4, accounts for anticipated emotions of misery or rejoice associated with counterfactual comparisons between states of disease and health. It also transforms probabilities according to the well established rules of prospect theory (Tversky and Kahneman 1992). Rational and psychological test demands are indicated by RD and PD respectively.

We describe diseases in terms of their severity $s \in \mathbb{R}^+$ and efficacy $(0 \leq \alpha \leq 1)$ of the treatment that the decision maker intents to undertake if she receives a positive test result (such treatment could be curative, preventative, palliative or take the form of a planning benefit, we make no particular assumption regarding its medicalization), so that $(1-\alpha)\,s$ represents the severity impact envisaged after treatment. A treatment cost c (which could capture either a monetary cost or a side effect) may also impact the outcome.

The severity of a disease can be experienced as a health loss outcome when the decision maker learns that she has this disease, in which case the outcome is measured negatively (e.g. $-s$), or as a health gain outcome (e.g., s) for a decision maker who learns that she does not have the disease. To capture individual evaluations of health outcomes, we consider two forms of utility functions.

1. $U_r : \mathbb{R}^- \rightarrow \mathbb{R}^-$ captures a rational response to health outcomes, such that not having a disease of severity s is processed as a status quo health outcome $s = 0$ with utility $U_r(0) = 0$. However, learning that one has a disease of severity s is processed as a negative health outcome $-s$ that will cause a *disutility* measured by $v : R^+ \rightarrow R^+$, such that $U_r(-s) = -v(s)$.

2. $U_p : \mathbb{R} \rightarrow \mathbb{R}$ captures a psychological response to health outcomes that result from counterfactual comparisons. When the DM has the disease (outcome s), she uses the healthy state (outcome $s = 0$) as reference point and experiences *misery* measured by $m : \mathbb{R}^+ \rightarrow \mathbb{R}^+$, i.e., $U_p(-s-0) = U_p(-s) = -m(s)$. However, when the DM does not have the disease (outcome $s = 0$), she uses the disease state (outcome $-s$) as reference point and experiences *rejoicing* measured by $r : \mathbb{R}^+ \rightarrow \mathbb{R}^+$, ie., $U_p(0-(-s)) = U_p(s) = r(s)$. Note that this approach is similar to the stochastic reference point approach in Kőszegi and Rabin (2006). This means that an untreated disease of severity s causes an emotion of misery $-m(s)$ but a healthy state causes rejoicing $r(s)$ as compared to the counterfactual disease state.

The main insight is that, unlike rational response, the psychological responses to "no disease" does not come with a neutral (zero) utility, but instead will cause rejoice. While the "disease" outcome will be accompanied by disutility and emotional misery for the rational and psychological DMs respectively. Functions v, m, and r are all strictly increasing and concave, and anchored at the reference point so that $v(0) = m(0) = r(0)$. Some results in the paper require m to be less steeper than the function r and v. The results that require this assumption are explicitly indicated. The assumption that m is less concave than r is a manifestation of loss aversion (Kahneman and Tversky 1979). The assumption that m is less concave than v can be justified by hedonic adaptation (Frederick and Loewenstein 1999).[5] See Figure 2.1. for a graphical representation of these functions.

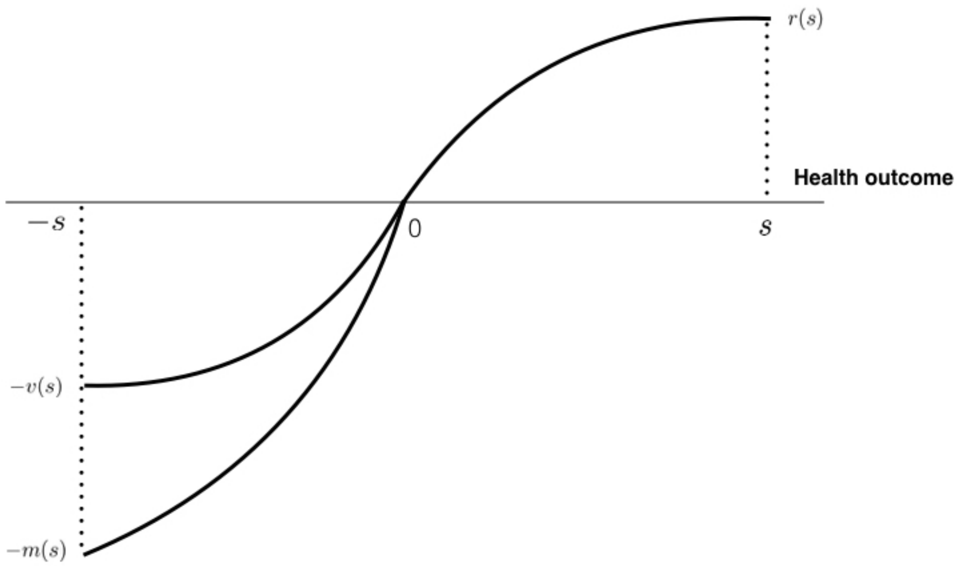

Figure 2.1: Shape of the rejoice, misery, and utility function

After a positive test result, when the decision maker undertakes an action (which we call treatment) different outcomes are possible. Suppose the decision maker has the disease of severity s (or negative health outcome of $-s$) then $-(1-\alpha)s - c$ represents the

[5]Hedonic adaptation is the tendency of humans to quickly return to a relatively stable level of happiness despite major positive or negative events or life changes (Frederick and Loewenstein 1999). For example, the Brickman et al. (1978) study observed that paraplegics, before being paralyzed, rated that they will experience greater misery, than the real utility they experienced after being paralyzed.

improvement in health after undergoing treatment with efficacy α and cost c. Suppose the decision maker does not have the disease and undergoes treatment then $-c$ is the health outcome of rational decision maker and $(1-\alpha)s-c$ is the health outcome of psychological decision maker. Figure 2.2 describes the possible outcomes and their respective evaluations.

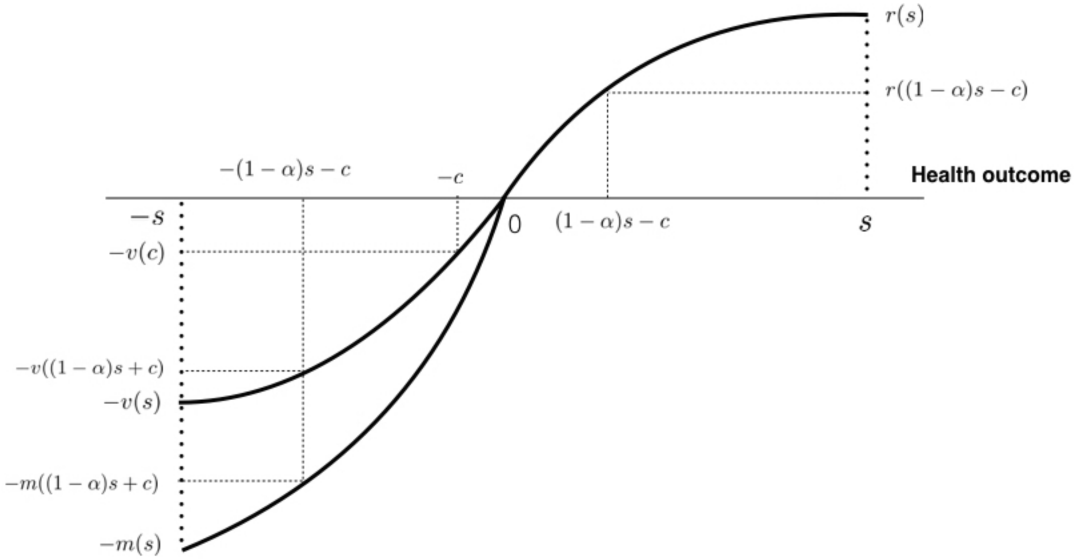

Figure 2.2: Possible outcomes and respective evaluations

3 Decision Tree

Based on the assumptions described above, we model the decision to acquire a medical test using a decision tree (depicted in the Figure 3.1). The DM can either (I) do the test or (II) not do the test. If the DM decides to do the test, she then receives either a positive or a negative result. Posterior beliefs are represented by $p(d|+)$, $p(d|-)$, $p(\bar{d}|+)$, and $p(\bar{d}|-)$. If the DM decides not do the test, the disease probabilities remain at their prior levels $p(d)$ and $p(\bar{d})$. The decision tree outcomes involve a distinction between "utility" and "anticipated emotions." The utility and anticipated emotions for each event directly follows from the Figures 2.1 and 2.2.

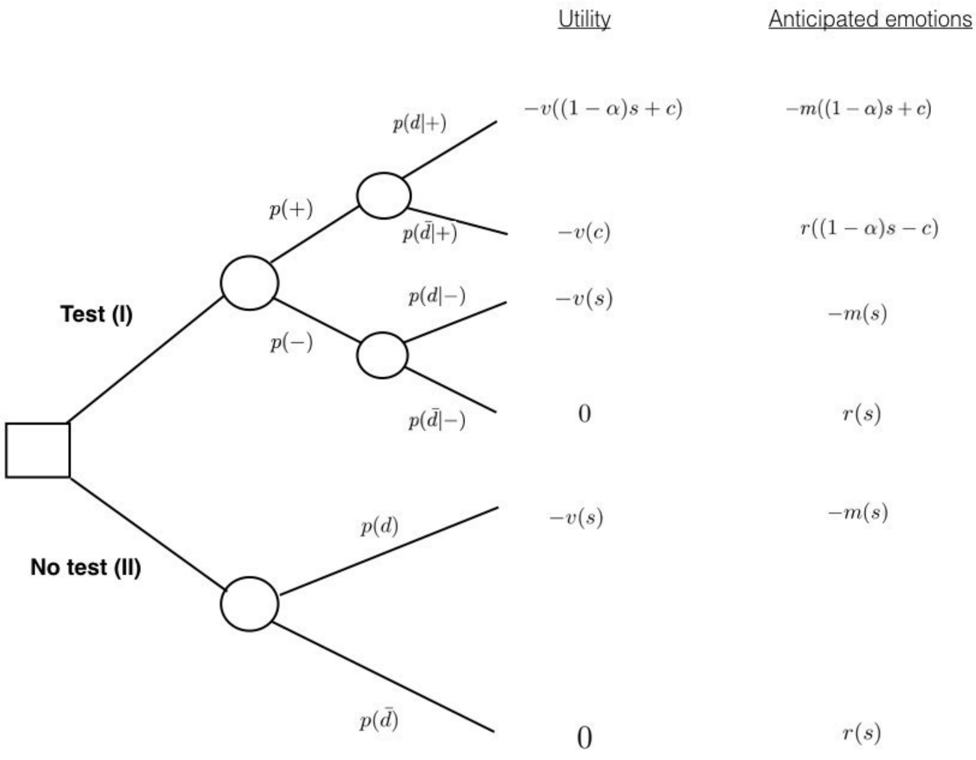

Figure 3.1: Decision Model for the Decision To Test

We now describe the outcomes of the decision tree. A choice to test leads to four possible joint events:

Event 1 (positive test, disease). Upon seeing the positive test outcome, the DM avails herself of the treatment and therefore the treatment efficacy (α) and treatment cost (c) moderate the severity level. The total disutility of a rational DM is $-v((1-\alpha)s+c)$, which is accentuated by higher disease severity (s) and cost of treatment (c), and attenuated by treatment efficacy (α closer to 1). Anticipated emotion for this event is "misery," amounting to $-m((1-\alpha)s+c)$, similarly influenced by severity (s), costs or side effects (c), and treatment efficacy (α).

Event 2 (positive test, no disease). Again, upon seeing the positive test result, the DM will unnecessarily undergo treatment and face its cost, therefore treatment efficacy (α) and treatment cost (c) moderate the severity level. As the DM does not have the disease, the total disutility is $-v(c)$, which depends only on the treatment cost. The prospect of ultimately learning that she has no disease makes the DM rejoice, and more so if the disease in question is more severe, less treatable. But the anticipated rejoice is dampened by the occurrence of treatment costs, and therefore the anticipated emotion associated with this event is $r((1-\alpha)s - c)$.

Event 3 (negative test, disease). If the test is negative, treatment is not sought and the DM experiences the full severity of the disease. In terms of utility, this is indicated by $-v(s)$. The corresponding anticipated misery is $-m(s)$.

Event 4 (negative test, no disease). When the DM tests negative and does not have the disease, the DM receives a baseline utility of 0, which is seen ex ante with the anticipated rejoice $r(s)$.

If the DM does not do the test (branch II of the decision tree), the only relevant event is whether or not she has the disease. Having the disease is associated with utility $-v(s)$ and misery $-m(s)$. Not having the disease is associated with utility zero and anticipated rejoice $r(s)$. The above possible events and outcomes now need to be integrated in a discussion of the initial decision to test or not.

4 Decision models

Because our ultimate purpose is to isolate the effects of anticipated emotions and probability distortion on the demand for testing, we plan to contrast the decisions obtained from two distinct decision models. The first is a "rational" expected utility decision model that focuses on utility consequences and omits the psychological effects of anticipated emotions. The second is a "psychological value" model that anticipates misery, rejoice, and distorts probabilities through descriptively well-established probability weighting functions (Tversky and Kahneman 1992).

4.1 Expected Utility Model

An expected utility (EU) decision maker will compare

$$EU(I) = -p(+)(p(d|+)v((1-\alpha)s + c) + p(\bar{d}|+)v(c)) - p(-)(p(d|-)v(s))$$

and

$$EU(II) = -p(d)v(s)$$

and will decide to undergo testing if and only if the rational DM's demand $RD = EU(I) - EU(II) \geq 0$, or

$$EU(I) - EU(II) = -p(+)(p(d|+)v((1-\alpha)s+c) + p(\bar{d}|+)v(c)) - p(-)(p(d|-)v(s)) + p(d)v(s) \geq 0$$

which simplifies into

$$p(d|+)(v(s) - v((1-\alpha)s + c)) \geq p(\bar{d}|+)v(c)$$

and

$$p(d|+) \geq \frac{p(\bar{d}|+)v(c)}{v(s) - v((1-\alpha)s + c)}$$

By Bayes' rule we get the following requirement in terms of test reliability:

$$p(+|d) \geq \frac{p(+|\bar{d})p(\bar{d})v(c)}{p(d)(v(s) - v((1-\alpha)s + c))}$$

The implications of this choice rule will be explored in the next section.

4.2 Psychological Value Model

We propose the following psychological value (PV) model to evaluate the anticipated outcomes along decision tree branches I and II. The model integrates probabilities and anticipated emotions in accordance with prospect theory. Consider a prospect $f = (p_1 : f_1, \ldots, p_n : f_n)$ with outcomes $f_1 \geq \ldots \geq f_k \geq 0 \geq f_{k+1} \geq \ldots \geq f_n$ and probabilities

$p_1, \ldots, p_n$. The psychological value of the prospect f is given by

$$\begin{aligned} PV(f) = \quad & \textstyle\sum_{i=1}^{k}(w^+(p_i + \ldots + p_1) - w^+(p_{i-1} + \ldots + p_1))r(f_i) \\ & - \textstyle\sum_{j=k+1}^{n}(w^-(p_j + \ldots + p_n) - w^-(p_{j+1} + \ldots + p_n))m(f_i) \end{aligned}$$

As we posited a concave misery function m, the function $-m$ is convex. Then, if $m(x) = \lambda r(x)$ with $\lambda \geq 1$ (aversion to negative outcomes), our usage of r and $-m$ is identical to employing the value function assumed in prospect theory (Kahneman and Tversky 1979) with the counterfactual outcome (disease or no disease) as a reference point that drives the anticipated emotions. Functions w^+ and w^- are probability weighting functions that capture basic behavioral regularities about the way people distort probabilities — which differs depending on whether probabilities are attached to positive vs. negative outcomes — as per prospect theory (Tversky and Kahneman 1992). The typical shape of the weighting function w observed in prospect theory measurements is inverse-S shaped (for positive and negative outcomes): There exists a fixed point $p' \in [0, 1]$ such that $w(p') = p'$, $w(p) > p$ for $p < p'$, and $w(p) < p$ for $p > p^{'}$ (see Abdellaoui et al. 2011, Gonzalez and Wu 1999). In other words, probability distortion typically involves insensitivity to probability differences in the intermediary range, strong sensitivity to increases near zero, and strong sensitivity to decreases below 1. For ease of reference, we sometimes refer to "inverse-S shaped probability weighting" as "inverse-S weighting function." For simplicity, the analysis in this paper also assumes that the weighting function for positive and negative outcomes are identical, i.e., $w^+(p) = w^-(p)$ for $\forall p \in [0, 1]$.[6]

The psychological value of not doing the test is given by

$$PV(II) = w^+(p(\bar{d}))r(s) - w^-(p(d))m(s)$$

To calculate the psychological value of doing the test $PV(I)$, we assume that the DM reduces the two-stage lottery in decision tree (branch I) into a single stage lottery, on which the probability weighting is then applied. Note that the real utility and anticipated

[6] The assumption is supported by empirical evidence in Abdellaoui et al. (2011).

emotions in decision tree are affected by treatment efficacy (α) and cost (c). Therefore, for different levels of treatment efficacy and cost, rational and psychological test demands differ. Figure 4.1 categorizes the diseases into four quadrants based on the treatment efficacy and cost. The categorization allows us to characterize and understand the testing preferences of rational and psychological DM graphically in a more intuitive way. The categorization of diseases into quadrants is also necessary for ordering the outcomes and deriving the psychological test demand.

For diseases that involve low treatment costs (e.g., minor treatment, or some precautionary behavior), both **high α - low c diseases** (Quadrant IV, e.g., typhoid, malaria, and hepatitis A) and **low α - low c diseases** (Quadrant III, e.g., alzheimer, diabetes), treatment will not hurt if the DM has the disease, and if the DM ultimately does not have the disease, having gone through treatment is not a bad health outcome. The anticipated emotions for these two categories of diseases are therefore ordered as follows $r(s) \geq r((1-\alpha)s-c) \geq 0 \geq -m((1-\alpha)s+c) \geq -m(s)$.

Another category of diseases is associated with low treatment efficacy and high treatment cost or side effects, i.e., **low α - high c** (Quadrant II, e.g., HIV-AIDS or blood cancer - chemotherapy and anti-viral drugs are physically taxing and poorly efficacious). Treatment makes you worse off, whether you have the disease or not. In that case, the anticipated emotions are ordered as follows $r(s) \geq r((1-\alpha)s-c) \geq 0 \geq -m(s) \geq -m((1-\alpha)s+c)$. The fourth category includes diseases for which the necessary treatment is highly efficacious and very costly, i.e., **high α - high c** (Quadrant I, e.g., diseases like breast cancer and ovarian cancer when risk is detected early, which can be treated through ablation). Treatment will reduce misery if the DM has the disease, but if the DM ultimately does not have the disease, having gone through treatment constitutes a bad health outcome. The anticipated emotions are ordered as follows $r(s) \geq 0 \geq r((1-\alpha)s-c) \geq -m((1-\alpha)s+c) \geq -m(s)$. The anticipated emotions ordered for the different disease categories allows deriving the psychological value of testing ($PV(I)$) and the psychological test demand (see Appendix A).

Most of the results in the paper will rely on the psychological demand (PD) under linear weighting. When the weighting function is linear, the $PD = PV(I) - PV(II)$ for the different disease categories will converge to the following:

$$PD = PV(I) - PV(II) = p(+)p(d|+)m((1-\alpha)s + c) + p(+)p(\bar{d}|+)r((1-\alpha)s - c) + p(+)p(d|+)m(s) - p(+)p(\bar{d}|+)r(s)$$

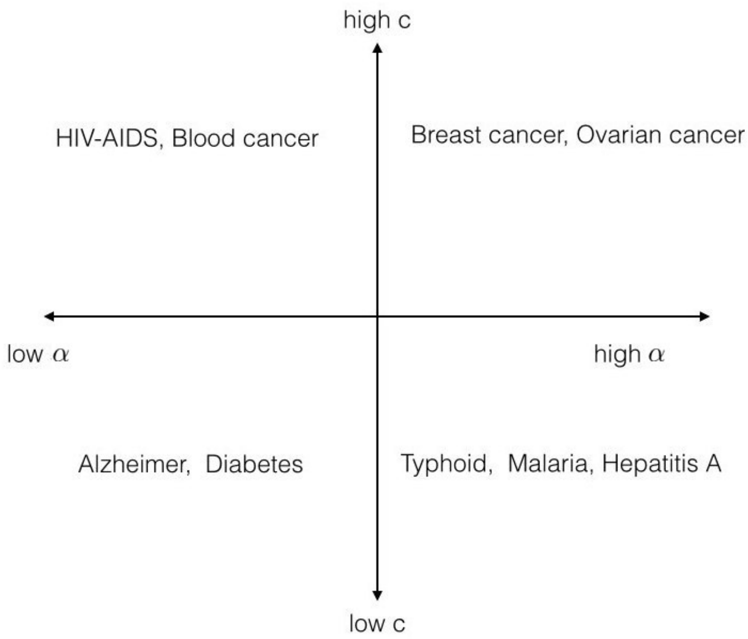

Figure 4.1: Disease classification according to treatment cost and efficacy.

5 Rational and Psychological Demand for Testing

In this section, we analyze the testing decision separately for a "rational" DM who applies the expected utility rule and for a "psychological" DM who relies on psychological value. We then focus on the dichotomy between both to fulfill our purpose of isolating the role of anticipated emotions and probability distortions on the demand for testing. The proofs of the Lemmas and Propositions are detailed in Appendix D.

5.1 Preferences of a rational decision maker

We start with elementary observations about rational preferences for testing, and progressively construct preference maps that describe the DM's testing preferences among diseases of various treatment efficacy, cost of treatment, and probability.

Lemma 1. *For any given level of severity and prior disease probability, a rational DM's demand for testing increases when treatment efficacy* (α) *increases and cost of treatment* (c) *decreases.*

Lemma 1 is intuitive and clarifies that rational DM seeks testing information when she can act upon it. However, Lemma 1 does not help us predict how the demand for testing changes in situations of trade-off (e.g., what happens to the utility of testing when we compare a disease that is less treatable but cheaper to treat vs. a disease that is more treatable at a higher cost). To address these trade-off situations analytically, we define a "treatability to cost of treatment ratio."

Definition 1. For any given level of severity, we use α_{low} , c_{low} (resp., α_{high}, c_{high}) to indicate the treatability and cost of treatment available for a low α - low c (resp., high α-high c) disease. The *treatability to cost of treatment ratio* is defined by $\alpha' = \frac{\alpha_{high}-\alpha_{low}}{c_{high}-c_{low}}$.

Comparing two diseases (otherwise equivalent in likelihood and severity) that are linked by a low treatability to cost of treatment ratio, we should expect that the demand for testing is less for the more treatable disease, which is also relatively much more expensive to treat. This role played by the α' ratio is illustrated in the next two lemmas.

Lemma 2. *Comparing two diseases of identical severity and prior probability, if* $\alpha' \leq 1/s$, *a rational DM's demand for testing is higher for the low* α*- low* c *disease than for the high* α*- high* c *disease.*

To generate a parametric illustration of Lemma 2, we simulate decision making under an empirically measured utility function, $v(x) = x^{0.8}$ (Wakker and Deneffe 1996). We assume two different values for the treatment cost i) low (20% of severity) ii) high (80% of severity) and treatment efficacy i) low ($\alpha = 25\%$) ii) high ($\alpha = 75\%$). The treatability to cost of treatment ratio $\alpha' = \frac{\alpha_{high} - \alpha_{low}}{c_{high} - c_{low}} = \frac{0.5}{0.6s} < \frac{1}{s}$. For such a specification, according to Lemma 1 and 2, a rational DM should have the following preference: high α - low c disease $\succeq$ low α - low c disease $\succeq$ high α- high c disease $\succeq$ low α- high c disease in the simulation.

The result is shown in the Figure 5.1, where x-axis indicates the prior probability of disease ($p(d)$), and the y-axis indicates the test demand. Positive values for test demand indicates the preference for doing the medical test, while the negative value indicates lack of such preferences. Consistent with Lemma 2, we observe that a rational DM's demand for testing is highest in the case of a high α - low c disease, followed by a low α - low c disease, then a high α - high c disease, and lowest for a low α - high c disease.

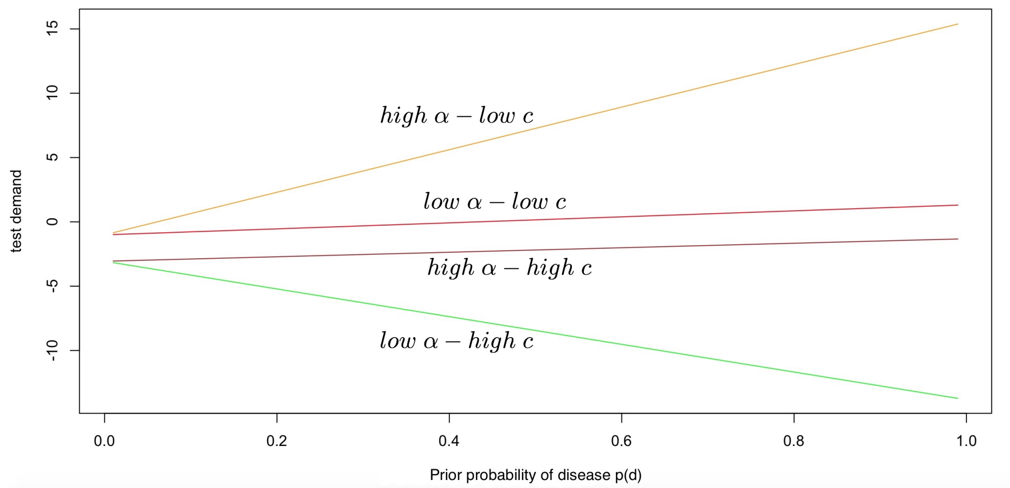

Figure 5.1: A rational DM's test demand under a low treatability to cost of treatment ratio

The Lemma 2 could also be interpreted as rational test demand for less severe diseases (as $\alpha' \leq 1/s$). For less severe diseases, the treatment efficacy is not as important as treatment cost, because even if the less severe disease is not treated, it is not a bad health outcome. However, when we look at increasingly severe diseases ($\alpha' > 1/s$) or diseases with high 'treatability to cost of treatment ratio,' a rational decision maker will be increasingly prone to test for diseases with high treatment efficacy. The intuition is that, for highly severe diseases, a small increase in treatment efficacy could make a big difference to the health outcome (life or death). This intuition is captured in Lemma 3.

Lemma 3. *Comparing diseases of identical severity, when $\alpha' > 1/s$, there exists a probability $\pi_1 \in [0, 1]$ such that a rational DM's demand for testing*

(i) is higher for a low α- low c disease than for a high α- high c disease among diseases of prior probability $p(d)$ lower than π_1,

(ii) is higher for a high α- high c disease than for a low α- low c disease among diseases of prior probability $p(d)$ higher than π_1.

As this lemma indicates, when the disease is severe ($\alpha' > 1/s$), the preferences of the rational DM depend on the prior probability $p(d)$. As expected, for severe diseases that are likely (e.g., a genetic condition that runs in the DM's family), the treatment efficacy matters more, and a rational DM prefers testing for high α - high c diseases over low α - low c diseases. However, for less likely severe diseases, the rational DM prefers to test for low α - low c diseases over high α - high c diseases (coinciding with Lemma 2). The reason for such a preference is imperfect test specificity ($p(-|d) < 1$): the rational DM does not want to test for a high α - high c disease, and undergo an unnecessary high cost treatment after a false positive result, especially when the disease is less likely.

Figure 5.2 simulates the rational DMs preference across disease categories assuming $\alpha' = \frac{0.9}{0.6s} = \frac{1.5}{s} > 1/s$ to illustrate Lemma 3. The π_1 value in Figure 5.2 is approximately 0.2. The π_1 values estimated for different α' levels and test reliability are described in the Table 7.1, in the Appendix B. Consistent with Lemma 3, we observe that π_1 increases with decreasing test reliability and decreasing severity, i.e., the psychological DM is less likely to test for high α- high c disease as chances of false positives increase and when treatment becomes less useful due to decreasing disease severity.

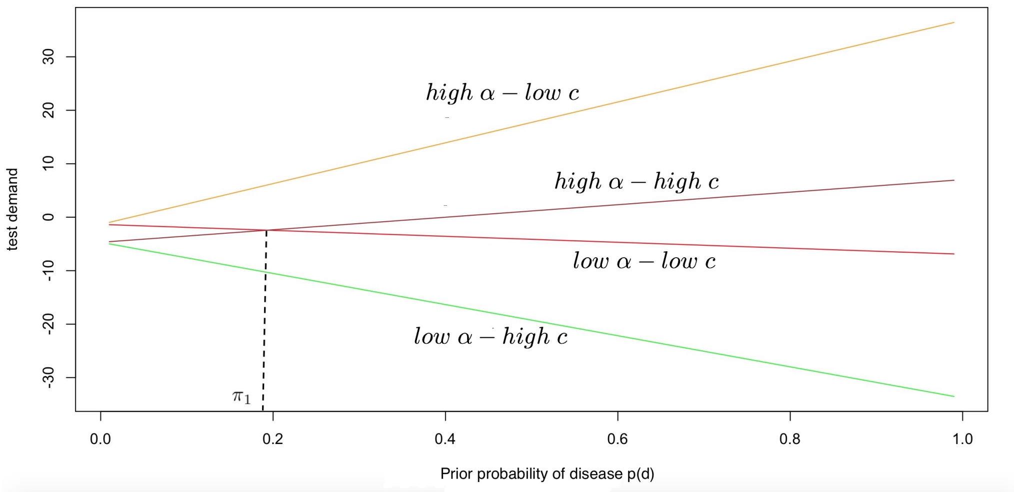

Figure 5.2: A rational DM'S test demand under a high treatability to cost of treatment ratio

Now we can use our lemmas to formulate the following proposition, which gives a generalized account of the demand for testing of a rational DM:

Proposition 1. *For any disease (α_i, c_i) chosen as reference, there exists a unique separating line such that a rational DM has a stronger incentive to test for diseases below the separating line than for diseases above that line. If disease probability $p(d) < \pi_1$, then the separating line is $c = c_i$. Otherwise when $p(d) > \pi_1'$ $(\geq \pi_1)$, the line is $c = (\alpha - \alpha_i)s + c_i$.*

The proof relies on Lemmas 2 and 3 to show that the incentive to test at reference disease (α_i, c_i) is stronger than at all points above the separator but weaker than at any point below the separator. The more general result involving a comparison between any disease below the separator and any disease above the separator follows from the transitivity of expected utility preferences.

Proposition 1 is represented in Figure 5.3 and 5.4. For every reference disease chosen, we can then define the disease categories: high α - low c, low α - low c, high α - high c, and low α - high c with respect to the reference. Note that neither s nor the α' affect the preferences of the rational DM for prior disease probabilities $p(d) < \pi_1$. The rational DM focuses on treatment cost as compared to treatment efficacy for low (prior) probability diseases. The reason for such a preference is the imperfect test specificity (as discussed before) – the rational DM does not want to incur a high (unnecessary) physical and monetary cost of treatment after a false positive test. In fact, the rational DM focus on treatment cost for low probabilities, reflects *Primum nil nocere (First, do no harm),* one of the principal precepts of the Hippocrates Oath, which the doctors follow.

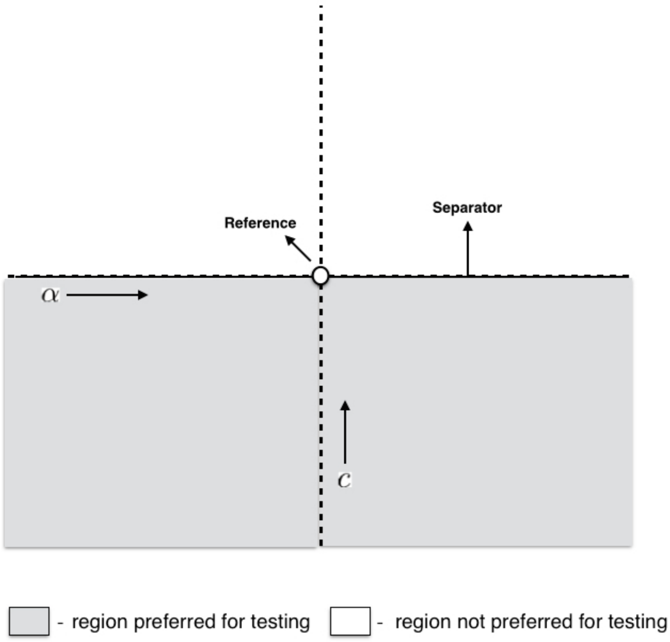

Figure 5.3: The rational DM's testing preferences for prior probability $p(d) < \pi_1$

For prior disease probabilities $p(d) > \pi_1'$, the separator line divides the quadrant with high α - high c and low α - low c into preferred and non preferred regions. From Figure 5.4, we can also observe that the rational DM prefers testing for high α - low c diseases, low α - low c diseases with $\alpha' \leq 1/s$, and high α - high c diseases with $\alpha' > 1/s$. In sum, the shaded region in the bottom right corner of Figure 5.4 reflects that, for high probabilities, the rational DM prefers testing for diseases with higher treatment efficacy and lower treatment cost. Thus rational DM (or a doctor) prefers to seek information only about diseases that can be treated effectively. .

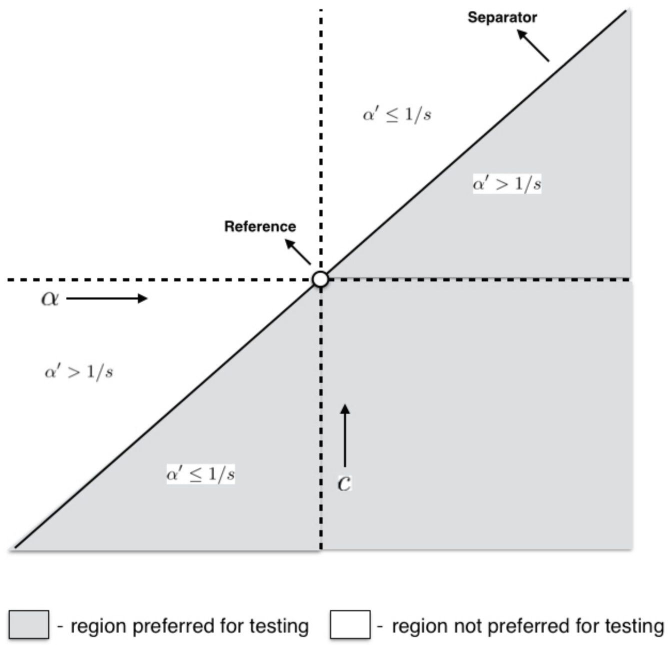

Figure 5.4: The rational DM's testing preferences for prior probability $p(d) > \pi_1'$

5.2 The Role of Anticipated Emotions

In this section, to focus solely on the role of anticipated emotions on testing preferences, we consider a psychological DM with linear weighting function. When looking at disease prospects, a psychological DM experiences mixed anticipated emotions, involving rejoice and misery. This leads to a critical structural deviation from the rational preferences outlined in Lemma 1: better treatability of a disease is not necessarily associated with a greater incentive to test for the presence of that disease. Indeed, consider a low probability disease that is difficult to treat (e.g., some form of cancer): testing in that case is expected to turn out negative (given the low prior probability) and cause a decrease in anticipated misery, which we might call a reassurance effect. This incentive to test — motivated by reassurance — diminishes if the disease becomes more treatable (and less associated with anticipated misery), which thus contradicts the intuitive prediction made in Lemma 1. For a disease with higher prior probability, however, the contradiction disappears: testing has a higher probability of turning positive, which increases anticipated misery, and more so if the disease is less treatable. In other words, psychological DMs exhibit rational demand for testing in the context of relatively likely diseases (e.g., when heredity or symptoms indicate sufficient likelihood), but they are subjected to a reassurance effect in the context of diseases that are less probable. This finding is captured in the following lemma:

Lemma 4. *For any given level of severity and prior disease probability, a psychological DM's demand for testing increases when cost of treatment (c) decreases. Moreover, there exists a probability* $\pi_2 \in [0, 1]$ *such that if* $p(d) < \pi_2$ *the psychological DM's testing demand increases when treatment efficacy* (α) *decreases, otherwise her demand for testing increases when treatment efficacy increases.*

From Lemma 4, we can observe that the psychological DM responds to treatment cost increases in the same way as the rational DM would. This is because, it is evident from Figure 2.2 that the psychological DM experiences high anticipated misery and less rejoice as treatment cost increases.

Below we generalize Lemma 4 to analyze demand for testing across different disease categories.

Lemma 5. *Comparing diseases of identical severity , for a psychological DM with linear probability weighting, there exists probabilities* $\pi_2 < \pi_2' \in [0, 1]$ *such that*

1. *For* $p(d) < \pi_2$*, testing is motivated by reassurance:*
   - (a) *When* $\alpha' > 1/s$*, demand for testing is primarily focused on less treatable diseases. Diseases can be ordered according to the implied demand for testing as follows: low* α *- low* $c \succeq$ *low* α *- high* $c \succeq$ *high* α *- low* $c \succeq$ *high* α *- high* c*.*
   - (b) *When* $\alpha' \leq 1/s$*, demand for testing is focused on less treatable diseases with low treatment costs. Diseases can be ordered according to the implied demand for testing as follows: low* α *- low* $c \succeq$ *high* α *- low* $c \succeq$ *low* α *- high* $c \succeq$ *high* α *- high* c*.*

2. For $p(d) > \pi'_2$, testing is motivated by prevention:

(a) When $\alpha' > 1/s$, demand for testing is primarily focused on more treatable diseases. Diseases can be ordered according to the implied demand for testing as follows: high α - lowc $\succeq$ high α - high c $\succeq$ low α - low c $\succeq$ low α - high c.

(b) When $\alpha' \leq 1/s$, demand for testing is focused on more treatable diseases with low treatment costs. Diseases can be ordered according to the implied demand for testing as follows: high α - lowc $\succeq$ low α - low c $\succeq$ high α - high c $\succeq$ low α - high c.

Part 2 of Lemma 5 is exactly similar to Lemma 2 and 3, and thus rational and psychological behaviors (in the absence of probability distortion) are structurally similar with respect to testing for more likely diseases. The "irrational" incentive to test for the sake of emotional reassurance occurs in the context of diseases that are both unlikely and severe ($\alpha' > 1/s$).

To visualize Lemma 5, as we did in the rational DM case, we simulate psychological demand using realistic behavioral measures from Abdellaoui et al. (2011). We assume two different values for the treatment cost i) low (20% of severity) ii) high (80% of severity) and treatment efficacy i) low ($\alpha = 25\%$) ii) high ($\alpha = 75\%$). Therefore, as $\alpha' = \frac{0.5}{0.6s} < 1/s$, the test demand in Figure 5.5 resembles preferences 1 (b) and 2 (b) of Lemma 5. The π_2 value is estimated to be approximately 0.1 and it is identical to π'_2. However, when the treatment cost is decreased and treatment efficacy is increased, such that $\alpha' = \frac{0.98}{0.4s} = \frac{2.45}{s} > 1/s$, the test demand in Figure 5.6 resemble preferences 1 (a) and 2 (a) of Lemma 5. Note that π_2 value in Figure 5.6 is just above 0.1 and the π'_2 value is approximately 0.37. The π_2 and π'_2 values estimated for different α' and reliability levels are described in Tables 7.3 and 7.2 of the Appendix B. The π_2 values increases with decreasing reliability and increasing severity (or α'). The intuition is as follows: For increasingly severe diseases, as the anticipated misery is high, the need to seek reassurance is large; therefore, the psychological DM tests more for severe diseases hoping to seek reassurance and more so when the negative test is more likely.

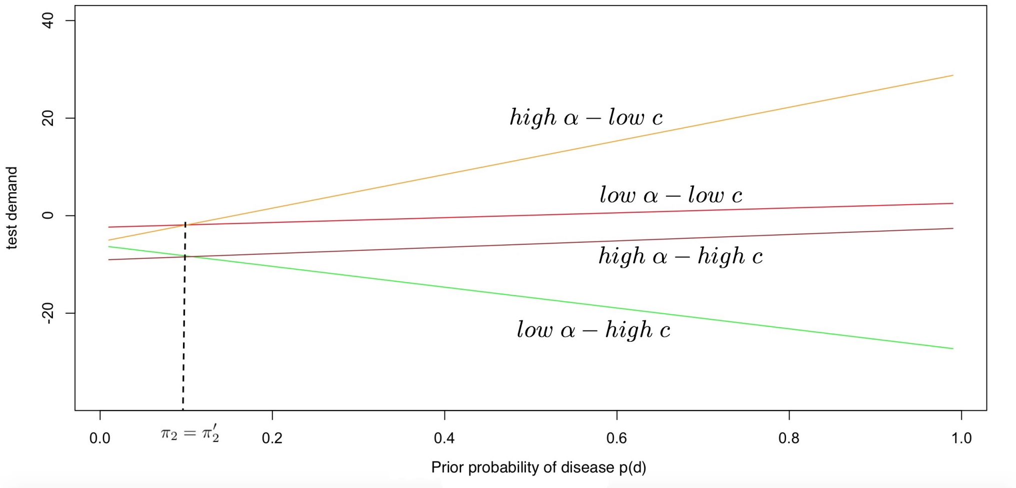

Figure 5.5: A psychological DM medical test demand when $\alpha' \leq 1/s$

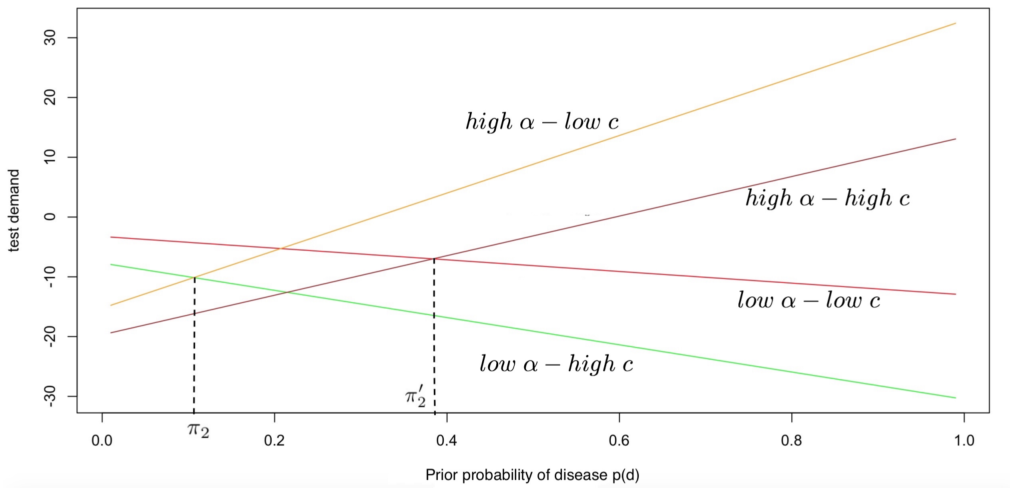

Figure 5.6: A psychological DM medical test demand when $\alpha' > 1/s$

Generalizing from Lemma 5, we can now formulate a proposition that characterizes the preferences of a psychological DM in the presence of anticipated emotions, under linear probability weighting.

Proposition 2. *For any disease* (α_i, c_i) *chosen as reference, there exists a unique separating line such that a psychological DM with linear probability weighting has a stronger incentive to test for diseases below the separating line than for diseases above that line. If* *disease probability $p(d) < \pi_2$, then the separating line is $c = (\alpha_i - \alpha)s + c_i$. Otherwise when $p(d) > \pi_2'$ the line is $c = (\alpha - \alpha_i)s + c_i$.*

As in the rational DM case, the separator varies according to the prior disease probability. Figures 5.7 and 5.8, graphically represent Proposition 2. From Figure 5.7, we can observe that the separator has a negative slope of $-s$ and crosses the low α - high c and high α - low c disease quadrants. In other words, the psychological DM prefers to test for low α - low c diseases, and some low α - high c, and high α - low c diseases, depending on the severity (or the α' ratio). The preference to test for diseases with low treatment efficacy and low cost in Figure 5.7 reflects the need to seek reassurance and avoid (unnecessary) harm.

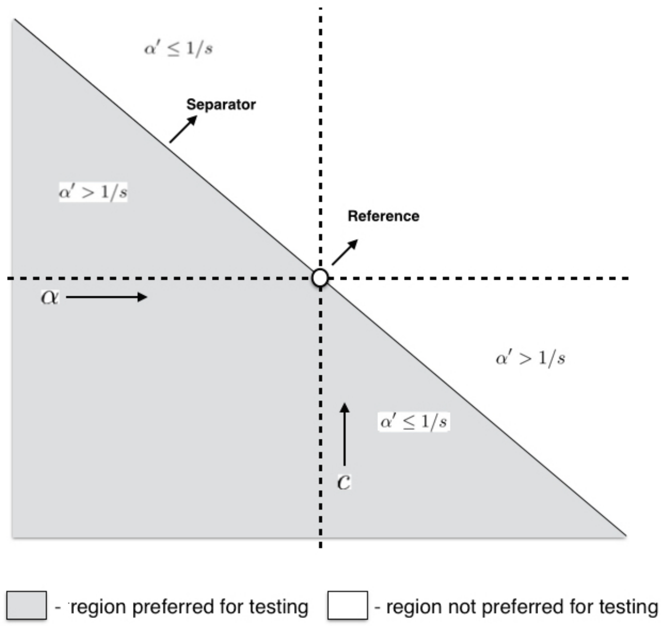

Figure 5.7: The psychological DM's testing preferences for prior probability $p(d) < \pi_2$

For prior disease probabilities $p(d) > \pi_2'$, the separator line has a positive slope. From Figure 5.8, we can see that the psychological DM with linear weighting prefers to test for high α - low c diseases and some low α - low c, high α - high c diseases depending on the severity (or the α' ratio). Such preferences mimic the rational DM's preferences for prior probabilities $p(d) > \pi'_1$ (See Figure 5.4).

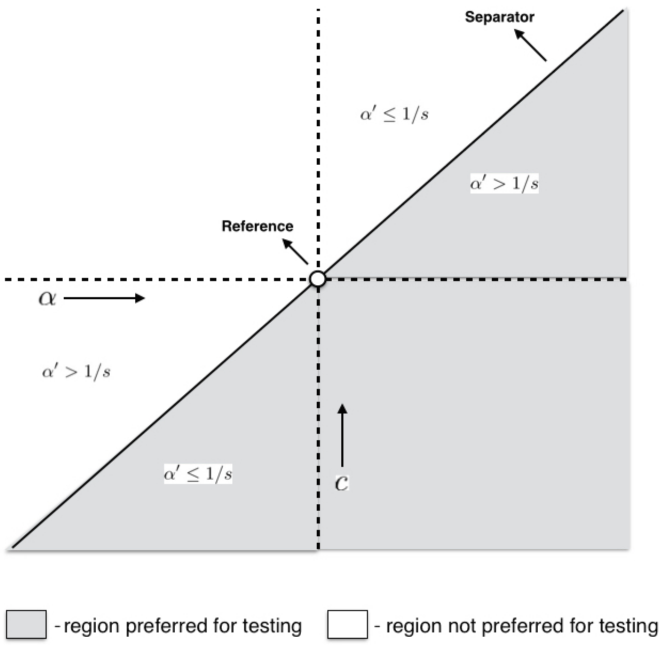

Figure 5.8: The psychological DM's testing preferences for prior probability $p(d) > \pi'_2$

5.3 Comparing Rational vs. Psychological Demand for Testing

The previous sections highlighted the reassurance effect as a structural difference: for a low probability disease, a psychological DM prefers to test more for low α than for high α, while a rational DM has the opposite preference. However this observation is not sufficient to determine whether psychological DMs typically overtest (resp., undertest) for a given low α- high c (resp., high α- low c) disease as compared to rational DMs. For example, while a rational DM would prefer to test more for a high α- low c disease than for a low α- high c disease, he still might be more motivated to test for the low α- high c disease than a psychological DM in the same situation. In this section we seek to characterize such test demand dichotomies across DM types, and across disease types.

Of special interest is the growing empirical evidence suggesting that high risk patients would undertest as compared to doctors, for probable diseases that are hard to treat (low α or high c) as per the first stylized fact mentioned in the introduction. Kőszegi (2003) already evokes anticipated emotions, e.g., anxiety, to explains such undertesting preferences. Even more puzzling is the second stylized fact, that low risk DMs — who are less likely to benefit — seek testing more for severe hard to treat diseases compared to the high risk patients and doctors. The analysis below reconciles the these empirical findings by highlighting the difference between rational and psychological demand($RD - PD$) across different disease categories (different α, c).

Proposition 3. *Consider a rational and a psychological DM who have the same demand for testing for a reference disease (α_i, c_i), then there exists a probability $\pi_3 \in [0, 1]$ such that, for the same prior disease probability $p(d) < \pi_3$, the psychological DM overtests for severe low α- high c diseases but undertests for severe high α- low c diseases, compared to the rational DM.*

The test demand dichotomy between the rational and psychological DM is depicted in the Figure 5.9. Note that this dichotomy can also be inferred by comparing Figures 5.3 and 5.7 for low prior probabilities $p(d) < min(\pi_1, \pi_2)$, where it is apparent that the psychological DM will seek more testing for low α- high c diseases of high severity ($\alpha' > 1/s$) compared to the rational evaluation. The overtesting region of the psychological DM is described in the top left quadrant of Figure 5.9. The intuition for this result is as follows: Testing for an unlikely low α- high c disease is unnecessary from the perspective of rational evaluation because even if the DM has the disease, the treatment is inefficacious and costly. However, the psychological DM wants to test for such a disease because he is scared of experiencing the extreme misery endowed by a severe untreatable disease. Therefore doing a medical test, especially for an unlikely disease where the negative test outcome is more likely, dissipates anxiety and reassures the DM.

From the bottom right corner of Figure 5.9 , it is evident that the psychological DM undertests for severe high α- low c disease ($\alpha' > 1/s$) compared to rational DM. The intuition for the result is as follows: The high α - low c diseases are effectively treatable at a low cost. Therefore the DM worries less about having such a disease, more so when the probability is low.[7] This is evident if we assume $\alpha = 1$ and $c = 0$ in the decision tree: The anticipated emotion on testing positive – $-m((1-\alpha)s+c)$ and $r((1-\alpha)s-c)$ become identical to $-m(s)$ and $r(s)$, the anticipated emotion of not testing.[8]

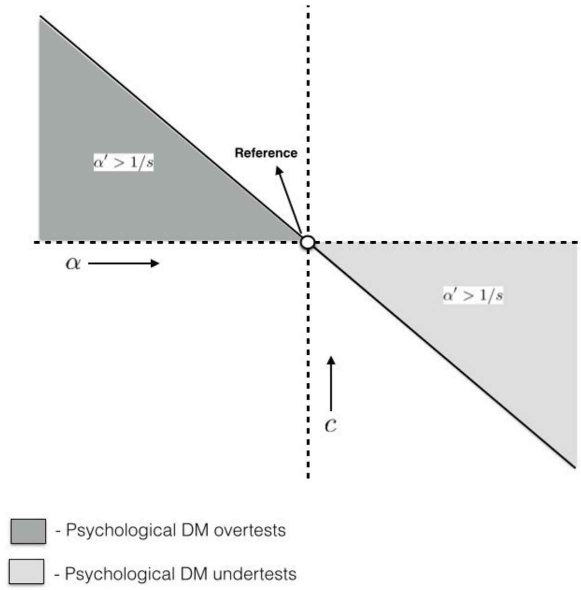

Figure 5.9: Test demand dichotomy: Regions where psychological DM under (over) test vis-a-vis rational evaluation for prior probability $p(d) < \pi_3$

For intermediate and large prior probabilities $p(d) > max(\pi_1', \pi_2')$, looking at the dichotomy in Figures 5.4 and 5.8, we can observe that the psychological DM's testing preference is identical to the rational evaluation: Both rational and psychological DM prefer to test for high α- low c diseases over low α - high c diseases (no structural difference between rational and psychological testing preferences). However as discussed previously, this does not reveal if the psychological DM overtests or undertests vis-a-vis rational DM. Proposition 4 clarifies this dichotomy.

Proposition 4. *Consider a rational and a psychological DM who have the same demand for testing for a reference disease* (α_i, c_i)*, then there exists a probability* $\pi_3 \in [0, 1]$ *such*

[7]Note that the psychological DM tests as per rational evaluation for high α- low c disease when $\alpha' \leq 1/s$. The reason is, when $\alpha' \leq 1/s$, the disease are comparatively low α, therefore the reassurance motive kicks in and leads the psychological DM to test.

[8]Proposition 3 holds also for non-severe diseases until the utility function v is not extremely concave than the rejoice function r.

that, for prior probabilities $p(d) > \pi_3$, if m is less concave than v, then the psychological DM undertests for low α- high c disease and overtests for high α- low c disease.

For more likely diseases, tests are more likely to be positive, and psychological DMs can no longer use the test as an anxiety reduction device. It is then the relative concavity of the misery and utility function (in Figure 2.1) that determines whether the psychological DM undertests vis-a-vis rational DM. When the sensitivity to negative anticipated emotions is greater than the utility (m is less concave than v) the psychological DM undertests for intermediate and high probabilities of low α- high c disease compared to the rational DM. Therefore, Proposition 3 and 4 shows that anticipated emotions might lead a high risk patient to undertest and low risk patient to overtest (compared to the doctor) for hard to treat diseases and thereby accounts for the stylized facts discussed in the introduction.

5.4 The Role of Probability Distortion

The previous section highlighted the role of anticipated emotions in affecting the psychological DM's testing preferences. In this section, we seek to understand how an inverse-S shaped weighting function affects the preferences of a psychological DM. For the discussion below, the analysis assumes that the tests are highly reliable, with low false positive and false negative rates ($p(+|\bar{d})$ and $p(-|d)$ are close to zero). Lemma 6 compares the psychological demand under inverse-S probability weighting to the psychological demand under linear weighting.

Lemma 6. *For high test reliability, there exists probability $\pi_4 \leq \pi_4' \in [0, 1]$ such that*

i) When prior disease probability $p(d) < \pi_4$, the psychological DM's demand for testing under inverse-S probability weighting is less than the psychological DM's demand for testing under linear weighting for low α - high c, high α - low c, low α - low c diseases. For high α - high c diseases, the comparison is ambiguous.

ii) When prior disease probability $p(d) > \pi_4'$, the psychological DM's demand for testing under inverse-S probability weighting is less than the psychological DM's demand for testing under linear weighting for high α - low c, low α - low c diseases, but greater *than the psychological DM's demand for testing under linear weighting for low α - high c diseases. For high α - high c diseases, the comparison is ambiguous.*

Now, using the results in Lemma 6, we formulate Proposition 5, which looks at the testing preferences of psychological DM (with inverse-S probability weighting) between different disease categories.

Proposition 5. *For high test reliability and a psychological DM with inverse-S probability weighting function, there exists a probability $\pi_4' \geq \pi_4 \in [0, 1]$ such that*

i) For $p(d) < \pi_4$, diseases can be ordered according to the implied demand for testing as follows: low α - low $c \succeq$ high α - low $c \succeq$ or $\preceq$ low α - high $c \succeq$ high α - high c.

ii) For $p(d) > \pi_4'$, diseases can be ordered according to the implied demand for testing as follows: high α - low $c \succeq$ low α - low $c \succeq$ or $\preceq$ high α - high $c \succeq$ low α - high c

Note that Lemma 5 and Proposition 5 are similar. In other words, the inverse-S weighting function plays less role in affecting the psychological DM's ordering of disease in correspondence to the incentive to test. In Figures 5.10 and 5.11, we simulate the test demand of a psychological DM with an inverse-S weighting function. We observe that inverse-S probability weighting affects the magnitude of the psychological demand. In particular, it magnifies the demand for testing across disease categories for very low and high probabilities. The π_4 and π_4' values are identical when $\alpha' \leq 1/s$,. However, when $\alpha' > 1/s$, the π_4 and π_4' values differ.

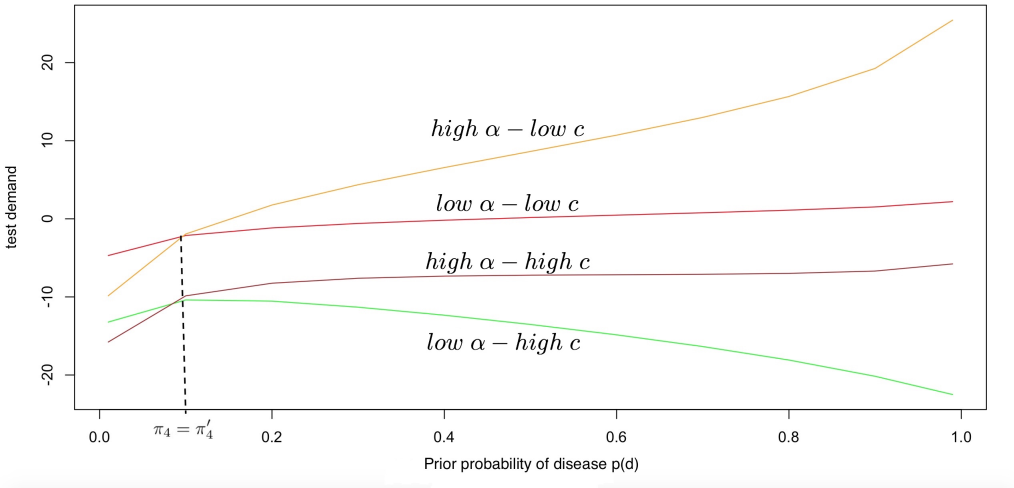

Figure 5.10: Medical test demand of a psychological DM with inverse-S shaped weighting function ($\alpha' \leq 1/s$)

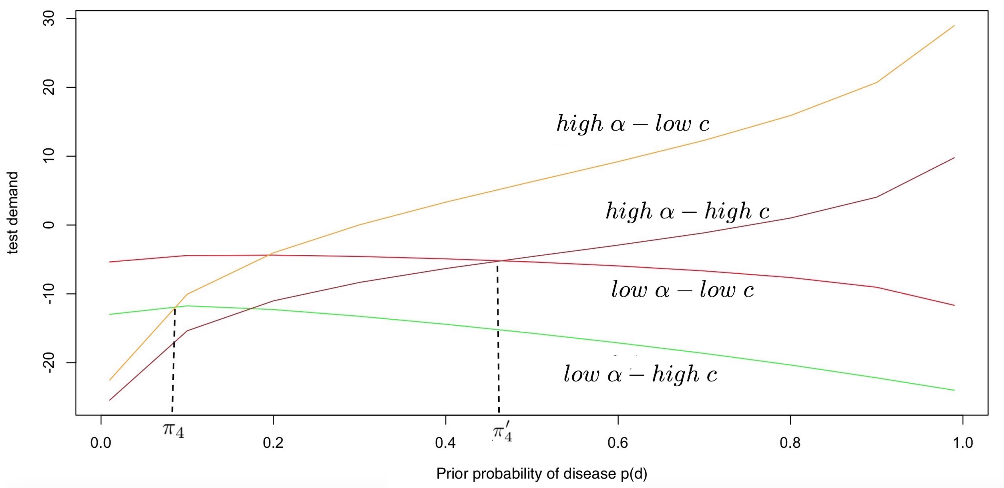

Figure 5.11: Medical test demand of a psychological DM with inverse-S shaped weighting function ($\alpha' > 1/s$)

Impact of Inverse-S probability weighting on the demand dichotomy

The shape of the inverse-S weighting function is determined by its elevation and its curvature. When the weighting function is more elevated, low probabilities are overweighted. The curvature reflects the sensitivity of DM to the probabilities. When the curvature is high, the DM is more sensitive to probabilities. In the discussion below, we analyze the impact of inverse-S probability weighting on the test demand dichotomy ($RD - PD$)

discussed in Section 5.3.

Proposition 6. *Suppose psychological test demand is identical to the rational demand for a reference disease* (α_i, c_i)*, then there exists a probability* $\hat{\pi}_3 < \pi_3 \in [0,1]$ *such that, for prior probabilities* $p(d) < \hat{\pi}_3$*, the psychological DM overtests for severe low* α*- high* c *diseases but undertests for severe high* α*- low* c *diseases, compared to the rational DM.*

Thus the inverse-S weighting function restricts the dichotomy motivated by reassurance to a lower probability range i.e., $[0, \hat{\pi}_3]$ from $[0, \pi_3]$ (in Proposition 3), where $\hat{\pi}_3 < \pi_3$. The result in Proposition 6 is driven by the following two parameters of probability weighting: the sensitivity of DM to probabilities and the elevation of the probability weighting. Suppose the DM has a more elevated probability weighting function, then the likelihood of reassurance decreases. The intuition is as follows: When the DM over-weights the (low) probability of having the disease, it makes the decision makers more pessimistic about the outcome of the test, and thereby negatively affects the likelihood of the reassurance. Similarly, when the DM is likelihood insensitive, the overweighting region increases (p' is high) and thereby the likelihood of reassurance decreases.

In addition to decreasing the size of the reassurance region, the inverse-S weighting function decreases the test demand dichotomy ($RD - PD$) induced by anticipated emotions: (i) For low probabilities, a psychological DM undertests for low probabilities of both low α- high c disease compared to a linear weighting. Therefore, the test demand dichotomy ($RD-PD$) for low probabilities of severe low α - high c diseases (highlighted in Proposition 3 and in the second stylized fact) decreases under inverse-S weighting. (ii) For intermediate and high probabilities, the inverse-S weighting function — by underweighting high probabilities — reduces anticipated misery, and thereby makes the psychological DM with inverse-S weighting overtest for low α- high c disease compared to linear weighting (See Lemma 6). Therefore, the test demand dichotomy for high probabilities of severe low α - high c diseases (highlighted in Proposition 4 and in the first stylized fact) also decreases under inverse-S weighting. Thus, the inverse-S weighting function reduces the dichotomy between the preferences of psychological and rational DMs.

6 Demand leveraging in direct-to-consumer markets

In the previous sections we analyzed rational and psychological demands for disease testing and we characterized qualitative differences between these demands depending on disease categories. In this section, we re-visit our findings from the perspective of firms who sell direct-to-consumer (DTC) testing. DTC firms might derive competitive advantages from various potential sources, such as cost structure, enriched interface, empowering consumers with controls on future data usage for research or personalized treatments. In this paper we focus on the more radical notion that DTC markets will appear to address consumer demands unfulfilled by the testing decisions that doctors make on their behalf. Doctors are highly trained and accountable professionals, focused on final health outcomes. Consistent with our model of rational decision making, they usually recommend testing only for treatable diseases, in the presence of specific symptoms or known predispositions that make these diseases likely enough. In contrast, consumers are psychological decision makers. They rely on their perceptions and are more likely to account for anticipated emotions. For example, Lerman et al. (1996a) show that consumers rated reassurance seeking and anxiety reduction as the primary motive for choosing to test for colon cancer susceptibility. Many other studies have also discussed the role of such psychological factors in consumer's decision to order a genetic or a medical test.[9] The intent of this section is to highlight theoretical opportunities — controversial as this might be — for firms who seek to leverage testing demands that are not rational. Our analysis below might inspire DTC firms, but it may also stimulate regulations of the DTC testing industry.

Product strategy 1: Genetic test vs. Medical test

From Section 5.3, we know that psychological DMs (or consumers) driven by a reassurance motive, overtest for severe, low probability, less treatable diseases. Therefore we would expect that DTC testing would supplement traditional testing for these disease

[9] See Broadstock et al. (2000), Welch et al. (2011) for a review.

categories. In particular, genetic tests are well positioned for DTC markets, because (1) they allow the identification of pre-dispositions ahead of symptomatic patterns that elevate disease probability and (2) they are usually not very diagnostic in the absence of specific environmental or behavioral factors, which corresponds to a relatively desirable situation of low test reliability in Figure 3.1.[10]

Product strategy 2: Test reliability

We compare preferences for test reliability in Appendix C, particularly Lemma 7. For treatable diseases, we expect that consumers would demand tests of even greater sensitivity than the ones normally suggested by doctors. For less treatable diseases, consumers will prefer a less sensitive test (with a higher chance of false negative) than the one demanded by their doctor, to reduce anticipated misery. The demand for false negatives in the context of severe, hard to treat disease suggests the potential for a DTC market of somewhat delusional information.

Promotional strategy

Beyond DTC product design, DTC firms could also resort to advertising campaigns, in an attempt to influence consumer perceptions, i.e., to willfully distort the probability weighting function. Indeed, the decision theory literature shows that the shape of the weighting function can be affected by context and communication. For instance Barron and Erev (2003), Abdellaoui et al. (2011) find that the weighting function becomes less elevated when beliefs are based on personal experiences. Similarly, the risk perception literature (Slovic 1987) assumes that the probability weighting function is malleable and affected by marketing communications. If this is the case, then DTC companies adjust their communication to favor demand for testing.

Based on Lemma 6 and Proposition 6, we can devise the following rules:

[10] As indicated in Table 2 of Appendix B, the reassurance region $[0,\pi_2]$ increases as test reliability decreases.

1. To increase testing for low probability diseases with low treatment efficacy (low α- high c, low α- low c): Increase the size of the reassurance region by
   (a) Triggering a pessimistic mindset (or a less elevated probability weighting function).
   (b) Making the DM sensitive to small probability change.
2. To increase testing for high probability diseases with low treatment efficacy or high cost (low α- high c, high α- high c):
   (a) Trigger an optimistic mindset (or a more elevated probability weighting function)
   (b) Make the decision maker less sensitive to negative anticipated emotion

Optimism and pessimism, as captured by the shape of probability weighting function, have been extensively studied in decision theory and psychological decision making (e.g., Wakker 2010). Triggering an optimistic mindset refers to making the consumer more sensitive to the positive outcomes of testing or making them anticipate "rejoice" more. Triggering a pessimistic mindset refers to making the consumer more sensitive to the negative effects of not testing. For instance, an optimistic promotional campaign might say something like "Test for the disease, so you can undergo treatment and lead a happy life." A pessimistic campaign, in contrast, would say something like "Test for the disease, otherwise you might die." This is obviously related to the psychological literature on regulatory focus (Higgins 1997) which would label "promotion orientation" what we call "optimistic mindset" and "prevention orientation" what we call "pessimistic mindset."

7 Conclusion

In this paper, we conducted a comprehensive analysis of the role of psychological factors (anticipated emotions of rejoice and misery, and probability distortions) in affecting a consumer's decision to order a genetic or medical test. Technically, we compared the implications of a prospect theory model (with counterfactual health outcome as the reference point) vs. an expected utility model in the context of a decision tree that accounts for test reliability, treatment efficacy and costs, disease severity, and prior disease probabilities. To complement our formal lemmas, we generated simulated results based on empirically validated parameters.

The analysis provides insights about the demand dichotomy between a rational and a psychological decision maker, which in turn helps to interpret existing empirical facts about consumer attitudes and suggest new testable hypotheses. We argue that psychological factors can yield specific demands for testing (particularly those demands motivated by "reassurance") not addressed by a system that relies on a doctor's rational prescription. Specifically, different features of our model relate to distinctive predictions: Reference dependence leads a consumer to test more for low probabilities of hard to treat diseases (to seek reassurance); Increased sensitivity to misery (compared to utility) leads the consumer to test less for high probabilities of hard to treat diseases; The inverse-S probability weighting function reduces the dichotomy induced by reference dependence and anticipated misery, and makes the consumer's testing behavior closer to the rational benchmark.

This analysis can also inspire strategies for commercial firms — and policies for regulators — in the direct-to-consumer testing market. Our findings generally support the notion of "genetic exceptionalism" to the extent that a breakdown of normative decision making occurs around diseases that are unlikely, severe, and heard to treat or prevent, which are particularly associated with genetic predispositions (usually assessed at a stage where no specific symptom raises the probability of the disease being investigated). The model and results can also be extended to other testing (and uncertainty resolution) contexts such as environment and investments, where anticipated emotions may play a role.

Appendices

Appendix A

The psychological demand for different disease categories

The psychological demand for different disease categories is described below.

For low α - low c and high α - low c disease, the psychological value of doing the test is given by,

$$\begin{aligned} PV(I) = \quad & w^{+}(p(-)p(\bar{d}|-))r(s) + (w^{+}(p(\bar{d})) - w^{+}(p(-)p(d|-)))r((1-\alpha)s+c) \\ & -w^{-}(p(-)p(d|-))m(s) - (w^{-}(p(d)) - w^{-}(p(-)p(d|-)))m((1-\alpha)s+c) \end{aligned}$$

and the psychological DM's test demand PD is

$$\begin{aligned} PD = PV(I) - PV(II) = \quad & -(w^{+}(p(\bar{d})) - w^{+}(p(-)p(\bar{d}|-)))(r(s) - r((1-\alpha)s-c)) \\ & +(w^{-}(p(d)) - w^{-}(p(-)p(d|-)))(m(s) - m((1-\alpha)s+c)) \end{aligned}$$

For low α - high c disease, the psychological value of doing the test is then given by,

$$\begin{aligned} PV(I) = \quad & w^{+}(p(-)p(\bar{d}|-))r(s) + (w^{+}(p(\bar{d})) - w^{+}(p(-)p(d|-)))r((1-\alpha)s+c) \\ & -w^{-}(p(-)p(d|-))m((1-\alpha)s+c) - (w^{-}(p(d)) - w^{-}(p(-)p(d|-)))m(s) \end{aligned}$$

and the DM's test demand PD is

$$\begin{aligned} PV(I) - PV(II) = \quad & -(w^{+}(p(\bar{d})) - w^{+}(p(-)p(\bar{d}|-)))(r(s) - r((1-\alpha)s-c)) \\ & -w^{-}(p(-)p(d|-))(m((1-\alpha)s+c) - m(s)) \geq 0 \end{aligned} \tag{7.1}$$

For high α- high c disease, the psychological test demand PD is given by

$PD = PV(I) - PV(II) = w^{+}(p(-)p(\bar{d}|-))r(s) + (w^{-}(p(d)) - w^{-}(p(-)p(d|-)))m(s) -$ $(w^{-}(p(d)) - w^{-}(p(+)p(d|+)))m((1-\alpha)s+c) + (w^{-}(p(d) + p(+)p(\bar{d}|+)) - w^{-}(p(d)))r((1-$

$\alpha)s - c)$

Appendix B

Estimated values for π_1, π_2, and π_2'

The estimated values of π_1, π_2, and π_2' for different levels of α' and reliability ($p(+|d)$ and $p(-|\bar{d})$) are tabulated below. We assume that $r = v$, and $m = 1.1 \times r$. Note that, **increasing** α' indicates **increasing** disease severity.

π_1	α'			
Reliability	2.5	2	1	0.75
0.7	0.25	0.35	–	–
0.8	0.18	0.2	–	–
0.9	0.1	0.12	–	–

Table 7.1: Estimated π_1 values

π_2	α'			
Reliability	2.5	2	1	0.75
0.7	0.2	0.15	0.3	0.35
0.8	0.1	0.09	0.2	0.22
0.9	0.05	0.04	0.1	0.15

Table 7.2: Estimated π_2 values

π_2'	α'			
Reliability	2.5	2	1	0.75
0.7	0.5	0.6	0.3	0.35
0.8	0.4	0.45	0.2	0.22
0.9	0.2	0.25	0.1	0.15

Table 7.3: Estimated π_2' values

Appendix C: Preference for Test reliability

A test's reliability is conventionally indicated by two parameters: test sensitivity $p(+|d)$ and test specificity $p(-|\bar{d})$.

With respect to test sensitivity, if treatment brings about a net benefit ($s \geq (1-\alpha)\, s + c$), all decision makers should value more highly a test with greater sensitivity, simply because it is less likely to leave diseases untreated. In addition, if anticipated emotions makes the benefit of treatment loom larger, a psychological DM will be even more motivated, giving more value than a rational DM to an improvement in test sensitivity.

With respect to test specificity, a specific test is one that does not cause false alarms. A rational DM will prefer a specific test because it reduces the monetary costs and secondary effects of unnecessary treatments caused by false positives.[11] Thus, rational preferences with respect to test specificity are tied to the level of c. For psychological DMs, the findings of Kahn and Luce (2003) highlight a very strong aversion to false positives in mammography, which suggest a heightened preference for test specificity. When a psychological decision maker looks at the event of receiving a false positive test result and engaging in treatment, she anticipates rejoice of not having that specific disease. However, that rejoice is reduced for diseases that are less severe and those that can be easily treated. The rejoice is further dampened by the monetary costs and secondary effects of unnecessary treatments caused by false positives. Thus, a psychological DM's preference for specific tests - which will not give a false positive, is not only tied to the cost of treatment, but also to the level of disease severity and treatability. In particular, for a more severe treatable disease with high cost of treatment (e.g., high α- high c diseases like breast cancer), the psychological decision maker will usually be very keen on test specificity, above and beyond what normal avoidance of unnecessary treatment costs would explain.

The lemmas below formalize these dichotomies between a rational and a psychological DM with respect to test reliability.

Lemma 7. *When $s \geq c/\alpha$,*

(i) Both rational and psychological DM prefer a test with higher sensitivity.

(ii) If m is less concave than v, then a psychological DM has a stronger preference for high sensitivity tests, as compared to a rational DM.

[11] If specificity $p(-|\bar{d})$ is high then the false positive $p(+|\bar{d})$ is low.

As discussed in Lemma 7, for diseases associated with a treatment that is either efficacious or low cost (when $s \geq c/\alpha$), all decision makers prefer a more sensitive test. However, when the diseases have costly and inefficacious treatment ($s < c/\alpha -$ low α - high c) both rational and psychological decision makers will prefer a test with low sensitivity (or high false negative). The reason for such a preference is that a positive test result for a low α - high c disease would lead the DM to undergo a costly and inefficacious treatment (and the psychological DM experiences the corresponding misery). Note also that, when m is less concave than v, the psychological demand for such low sensitive (or high false negative) tests is higher than the rational demand.

Lemma 8. *Both rational and psychological DM prefer a test with higher specificity. For severe diseases with high treatment cost or high treatment efficacy, a psychological DM has a stronger preference for test specificity as compared to a rational decision maker.*

The preference for test reliability described in Lemma 7 and 8 is also affected by prior disease probabilities: The dichotomy between the preferences of rational and psychological DM for test sensitivity (captured in Lemma 7), decreases for low probabilities, However, the dichotomy with respect to specificity (captured in Lemma 8) increases for low probabilities.

Appendix D

Proof of Lemma 1

We know that, $RD = p(+)p(d|+)(v(s)-v((1-\alpha)s+c))-p(+)p(\bar{d}|+)v(c)$. So the variation of RD with respect to treatment efficacy (α) is given by,

$$\frac{\partial(RD)}{\partial\alpha} = s \times p(+)p(d|+)(v'((1-\alpha)s+c)) \geq 0$$

Similarly the variation of RD with respect to treatment cost (c) is given by,

$$\frac{\partial(RD)}{\partial c} = -p(+)p(d|+)v'((1-\alpha)s+c) - p(+)p(\bar{d}|+)v'(c) \leq 0$$

Thus the RD is increasing with respect to treatment efficacy and decreasing with respect to the cost of treatment. Hence Lemma is proved.

Proof of Lemma 2 and 3

From lemma 1, we know that high α - low $c \succeq$ low α - low $c \succeq$ low α - high $c \preceq$ high α - high c and high α - low $c \succeq$ high α - high $c \succeq$ low α - high c. The preference of a rational DM between a low α - low c diseases and a high α - high c diseases is not yet clear. Writing down the EU under low α- low c and high α- high c we get,

$$RD_{\alpha_{low},c_{low}} = p(d)p(+|d)(v(s) - v((1-\alpha_{low})s + c_{low})) - p(+|\bar{d})p(\bar{d})v(c_{low})$$

$$RD_{\alpha_{high},c_{high}} = p(d)p(+|d)(v(s) - v((1-\alpha_{high})s + c_{high})) - p(+|\bar{d})p(\bar{d})v(c_{high})$$

$$RD_{\alpha_{high},c_{high}} - RD_{\alpha_{low},c_{low}} = $$
$$p(d)p(+|d)(v((1-\alpha_{low})s + c_{low})) - v((1-\alpha_{high})s + c_{high}))) + p(+|\bar{d})p(\bar{d})(v(c_{low}) - v(c_{high}))$$

As $c_{low} < c_{high}$ and v is strictly increasing, the second term in the expression above $(p(+|\bar{d})p(\bar{d})(v(c_{low}) - v(c_{high})))$ is always less than zero. The first term will also be less than zero if $(1-\alpha_{low})s + c_{low} < (1-\alpha_{high})s + c_{high}$. This requires $\alpha' = \frac{\alpha_{high}-\alpha_{low}}{c_{high}-c_{low}} \leq 1/s$. If both the first and second term are less than zero then high α - low $c \succeq$ low α - low c $\succeq$ high α - high $c \succeq$ low α - high c.

However if $\alpha' = \frac{\alpha_{high}-\alpha_{low}}{c_{high}-c_{low}} > 1/s$, then the first term is positive and the second term is negative. We get $EU_{\alpha_{high},c_{high}} - EU_{\alpha_{low},c_{low}} \lesseqqgtr 0$ based on the prior probability $p(d)$. For prior probability $p(d)$ greater than (resp., less than)

$$\pi_1 = \frac{p(+|\bar{d})(v(c_{high}) - v(c_{low}))}{p(+|d)(v((1-\alpha_{low})s + c_{low}) - v((1-\alpha_{high})s + c_{high})) + p(+|\bar{d})(v(c_{high}) - v(c_{low}))},$$

the $RD_{\alpha_{high},c_{high}} - RD_{\alpha_{low},c_{low}} > 0$ (resp., < 0). Therefore for $p(d) < \pi_1$, since $RD_{\alpha_{high},c_{high}} - RD_{\alpha_{low},c_{low}} < 0$ (low α - low $c \succeq$ high α - high c), we get high α - low $c \succeq$ low α - low $c \succeq$ high α - high $c \succeq$ low α - high c. Similarly for $p(d) > \pi_1$, since $RD_{\alpha_{high},c_{high}} - RD_{\alpha_{low},c_{low}} >$

0 (high α- high $c \succeq$ low α- low c), we get high α - low $c \succeq$ high α - high $c \succeq$ low α - low $c \succeq$ low α - high c. Thus Lemma 2 and 3 are proved.

Proof of Proposition 1

Consider a reference (α_i, c_i). For a reference (α_i, c_i) disease, from Lemma 1, we know that $(\alpha_k, c_i) \succeq$ (or $\preceq$)(α_i, c_i) for $\alpha_k \geq$ (or $\leq$)α_i. Similarly $(\alpha_i, c_k) \succeq$ (or $\preceq$)(α_i, c_i) for $c_k \leq$ (or $\geq$)c_i. The preference between low α - low c and high α- high c is determined by the probability π_1. Note that the probability π_1 depends on α_{high}, α_{low}, c_{high}, and c_{low}. Therefore, when we consider more than one disease in the top right and bottom left quadrant, there is more than one value for π_1. In the proof below, we refer to the minimum of those values as π_1 and max of those values as $\pi_1'(\geq \pi_1)$. We first prove the proposition for the prior disease probabilities $p(d) < \pi_1$ and then for probabilities $p(d) > \pi_1'$.

Case 1 ($p(d) < \pi_1$)

(a) Now consider the points in the bottom right quadrant of the Figure 5.3, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j < c_i$. Since the points (α_k, c_j) are high α- low c with respect to the reference (α_i, c_i) and the reference is low α- high c with respect to the points (α_k, c_j), from Lemma 2 and 3 the points in the bottom right quadrant of the Figure 5.3 are preferred to (α_i, c_i).

(b) Now consider the points in the top left quadrant of the Figure 5.3, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j > c_i$. Since the points (α_k, c_j) are now low α- high c with respect to the reference (α_i, c_i), from Lemma 2 and 3, (α_i, c_i) is preferred to the points in the top left quadrant.

(c) Now consider the points in the top right quadrant of the Figure 5.3, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j > c_i$. Since the points (α_k, c_j) are now high α- high c with respect to the reference (α_i, c_i) and the reference is low α- low c with respect to the points (α_k, c_k), from Lemma 2 and 3, (α_i, c_i) is preferred to the points in the top right quadrant.

(d) Now consider the points in the bottom left quadrant of the Figure 5.3, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j < c_i$. Since the points (α_k, c_j) are now low α- low c with respect to the reference (α_i, c_i) and the reference is high α- high c with respect to the points (α_k, c_j), from Lemma 2 and 3, the points (α_k, c_j) is preferred to the reference (α_i, c_i).

Now from (a), (b), (c), and (d) we get $(\alpha_i, c_i) \preceq (\alpha_k, c_j)$ when $c_j < c_i$ for any α_k but $(\alpha_i, c_i) \succeq (\alpha_k, c_j)$ when $c_j > c_i$ for any α_k. Thus $c = c_i$ is the unique separator, such that the points below $c = c_i$ are preferred to the reference and the reference is preferred to the points above c_i. Now from the above discussion we know that $(\alpha_k, c_j) \succeq (\alpha_i, c_i) \succeq (\alpha_{k'}, c_{j'})$ when $c_{j'} > c_i > c_j$ and for any α that are not far apart such that a positive π_1 exists. Since we use expected utility decision model, the $\succeq$ is transitive. By transitivity of the preference relation $\succeq$, we get $(\alpha_k, c_j) \succeq (\alpha_{k'}, c_{j'})$ if $c_j < c_{j'}$.

Case 2 $(p(d) > \pi_1'$)

(a) Now consider the points in the bottom right quadrant of the Figure 5.4, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j < c_i$. Since the points (α_k, c_j) are high α- low c with respect to the reference (α_i, c_i) and the reference is low α- high c with respect to the points (α_k, c_j), from Lemma 2 and 3 the points in the bottom right quadrant of the Figure 5.4 are preferred to (α_i, c_i).

(b) Now consider the points in the top left quadrant of the Figure 5.4, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j > c_i$. Since the points (α_k, c_j) are now low α- high c with respect to the reference (α_i, c_i), from Lemma 2 and 3, (α_i, c_i) is preferred to the points in the top left quadrant.

(c) Now consider the points in the top right quadrant of the Figure 5.4, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j > c_i$. Now assume $\alpha' > 1/s$, since the points (α_k, c_j) are now high α- high c with respect to the reference (α_i, c_i) and the reference is low α- low c with respect to the points (α_k, c_k), from Lemma 2 and 3, the points in the top right quadrant (α_k, c_j) is preferred to (α_i, c_i) for $\alpha' > 1/s$. However when $\alpha' \leq 1/s$, from Lemma 2 and 3, we get (α_i, c_i) is preferred to (α_k, c_j) the points in the top right quadrant.

(d) Now consider the points in the bottom left quadrant of the Figure 5.4, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j < c_i$. $c_j > c_i$. Now assume $\alpha' > 1/s$, since the points (α_k, c_j) are now low α- low c with respect to the reference (α_i, c_i) and the reference is high α- high c with respect to the points (α_k, c_k), from Lemma 2 and 3, (α_i, c_i) is preferred to the points in the bottom right quadrant (α_k, c_j). However when $\alpha' \leq 1/s$, from Lemma 2 and 3, we get (α_k, c_j) is preferred to (α_i, c_i).

Now from (a), (b), (c), and (d) we get $(\alpha_i, c_i) \succeq (\alpha_k, c_j)$ if (α_k, c_j) lies above the separator in Figure 5.4 and $(\alpha_i, c_i) \preceq (\alpha_k, c_j)$ if (α_k, c_j) lies below the separator in Figure 5.4. The slope of of the separator is s and since it passes through the point (α_i, c_i) , the equation is given by $c - c_i = s(\alpha - \alpha_i)$, we get $c = s(\alpha - \alpha_i) + c_i$. Again from the transitivity of the preference $\succeq$ we can prove that points below the separator $c - c_i = s(\alpha - \alpha_i)$ is preferred to the points above the separator.

Proof of Lemma 4

For a linear weighting, the psychological value is given by, $PD = -p(+)p(d|+)m((1 - \alpha)s + c) + p(+)p(\bar{d}|+)r((1-\alpha)s - c) + p(+)p(d|+)m(s) - p(+)p(\bar{d}|+)r(s)$. The variation of PD wrt α is given by,

$$\frac{\partial(PD)}{\partial\alpha} = s \times p(d)p(+|d)m'((1-\alpha)s + c) - s \times p(\bar{d})p(+|\bar{d})r'((1-\alpha)s - c) \geq \text{or } \leq 0$$

The expression above can be positive or negative. The expression above is positive only if $p(d) > \pi_2 = \frac{p(+|\bar{d})r'((1-\alpha)s-c)}{(p(+|d)\lambda r'((1-\alpha)s+c)+p(+|\bar{d})r'((1-\alpha)s-c)}$, otherwise the expression is negative.

Generally, for high probabilities and high test reliability, the first term in the expression above is positive and therefore the expression is positive. For low probabilities and low test reliability the expression is negative due to large $p(\bar{d})$ and $p(+|\bar{d})$. Similarly the variation of PD with respect to treatment cost (c) is given by,

$$\frac{\partial(PD)}{\partial c} = -p(+)p(d|+)m'((1-\alpha)s + c) - p(+)p(\bar{d}|+)r'((1-\alpha)s - c) \leq 0$$

The psychological DM just like the rational DM prefers treatment of lower cost. Note that the results in Lemma 4 holds irrespective of the shape of the weighting function. Because the weighting function only affects the magnitude of the psychological value and not its sign.

Proof of Lemma 5

For a linear weighting function, the $PD = -p(+)p(d|+)m((1-\alpha)s+c)+p(+)p(\bar{d}|+)r((1-\alpha)s-c)+p(+)p(d|+)m(s)-p(+)p(\bar{d}|+)r(s)$. The PD for different α, c are obtained by substituting the α and c for different disease categories. For example, the psychological demand (PD) of a low α, high c disease is given by:

$PD_{low\ \alpha,high}$ c $= -p(+)p(d|+)m((1-\alpha_{low})s+c_{high})+p(+)p(\bar{d}|+)r((1-\alpha_{low})s-c_{high})+p(+)p(d|+)m(s)-p(+)p(\bar{d}|+)r(s)$

$$\begin{aligned} PD_{\alpha_1,c_1} - PD_{\alpha_2,c_2} = \ & -p(d)p(+|d)(m((1-\alpha_1)s+c_1) - m((1-\alpha_2)s+c_2)) \\ & +p(\bar{d})p(+|\bar{d})(r((1-\alpha_1)s-c_1) - r((1-\alpha_2)s-c_2) \end{aligned}$$

The probability $d''_{(\alpha_1,c_1),(\alpha_2,c_2)} = \frac{p(+|\bar{d})(r((1-\alpha_2)s-c_2)-r((1-\alpha_1)s-c_1)}{p(+|d)(m((1-\alpha_2)s-c_2)-m((1-\alpha_1)s-c_1))+p(+|\bar{d})(r((1-\alpha_2)s-c_2)-r((1-\alpha_1)s-c_1)}$ is the probability at which $PD_{\alpha_1,c_1} - PD_{\alpha_2,c_2} = 0$. For different α_1, α_2, c_1, and c_2, d'' varies.

Now we compare the different cases ($\alpha_1 = \alpha_{low}|\alpha_{high}, c_1 = c_{low}|c_{high}$) vs ($\alpha_2 = \alpha_{low}|\alpha_{high}, c_2 = c_{low}|c_{high}$) across the probability range.

For $p(d) < d''$ (low probabilities)	For $p(d) > d''$ (high probabilities)
$PD_{\alpha_{high},c_{low}} \geq PD_{\alpha_{high},c_{high}}$	$PD_{\alpha_{high},c_{low}} \geq PD_{\alpha_{high},c_{high}}$
$PD_{\alpha_{high},c_{low}} \leq PD_{\alpha_{low},c_{low}}$	$PD_{\alpha_{high},c_{low}} \geq PD_{\alpha_{low},c_{low}}$
If $\alpha' \leq 1/s, PD_{\alpha_{high},\ c_{low}} \geq PD_{\alpha_{low},c_{high}}$ else $\alpha' > 1/s,\ PD_{\alpha_{high},c_{low}} \leq PD_{\alpha_{low},c_{high}}$	$PD_{\alpha_{high},\ c_{low}} \geq PD_{\alpha_{low},c_{high}}$
$PD_{\alpha_{low},c_{low}} \geq PD_{\alpha_{high},c_{high}}$	If $\alpha' \leq 1/s,\ PD_{\alpha_{low},c_{low}} \geq PD_{\alpha_{high},c_{high}}$ else $\alpha' > 1/s,\ PD_{\alpha_{low},c_{low}} \leq PD_{\alpha_{high},c_{high}}$
$PD_{\alpha_{high},c_{high}} \leq PD_{\alpha_{low},c_{high}}$	$PD_{\alpha_{high},c_{high}} \geq PD_{\alpha_{low},c_{high}}$
$PD_{\alpha_{low},c_{low}} \geq PD_{\alpha_{low},c_{high}}$	$PD_{\alpha_{low},c_{low}} \geq PD_{\alpha_{low},c_{high}}$

Table 7.4: Psychological value comparison for different prior probabilities $p(d)$

From Table 1, we get for low probabilities $p(d) < \pi_2 = min(d''_{(\alpha_1,c_1),(\alpha_2,c_2)})$, where $(\alpha_1 = \alpha_{low}|\alpha_{high}, c_1 = c_{low}|c_{high})$ and $(\alpha_2 = \alpha_{low}|\alpha_{high}, c_2 = c_{low}|c_{high})$.

low α*-low* $c \succeq$ *high* α*- low* $c \succeq$ or $\preceq$ *low* α*-high* $c \succeq$ *high* α*- high* c

For high probabilities $p(d) > \pi'_2 = max(d''_{(\alpha_1,c_1),(\alpha_2,c_2)})$, where $(\alpha_1 = \alpha_{low}|\alpha_{high}, c_1 = c_{low}|c_{high})$ and $(\alpha_2 = \alpha_{low}|\alpha_{high}, c_2 = c_{low}|c_{high})$

when $\alpha' \leq 1/s$: *high* α*- low* $c \succeq$ *low* α*- low* $c \succeq$ *high* α*- high* $c \succeq$ *low* α*- high* c

when $\alpha' > 1/s$: *high* α*- low* $c \succeq$ *high* α*- high* $c \succeq$ *low* α*- low* $c \succeq$ *low* α*- high* c

Proof of Proposition 2

Consider a reference (α_i, c_i). For a reference (α_i, c_i) disease, from Lemma 4, we know that $(\alpha_k, c_i) \preceq (\alpha_i, c_i)$ when $\alpha_k \geq \alpha_i$ for low probabilities $(p(d) < \pi_2)$ and $(\alpha_k, c_i) \succeq (\alpha_i, c_i)$ when $\alpha_k \geq \alpha_i$ for high probabilities $(p(d) > \pi'_2)$. Similarly $(\alpha_i, c_k) \succeq$ (or $\preceq$)(α_i, c_i) for $c_k \leq$ (or $\geq$)c_i. We first prove the proposition for the prior disease probabilities $p(d) < \pi_2$ and then for probabilities $p(d) > \pi'_2$.

Case 1 $(p(d) < \pi_2$)

(a) Now consider the points in the bottom right quadrant of the Figure 5.7, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j < c_i$. Since the points (α_k, c_j) are high α- low c with respect to the reference (α_i, c_i) and the reference is low α- high c with respect to the points (α_k, c_j), the preference between them will depend on the α' ratio. If $\alpha' \leq 1/s$, from Lemma 5 the points in the bottom right quadrant of the Figure 5.7 are preferred to (α_i, c_i), however if $\alpha' > 1/s$ then the preference is reversed.

(b) Now consider the points in the top left quadrant of the Figure 5.7, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j > c_i$. Since the points (α_k, c_j) are now low α- high c with respect to the reference (α_i, c_i), the preference between them will depend on the α' ratio. If $\alpha' > 1/s$, from Lemma 5 the points in the bottom right quadrant of the Figure 5.7 are preferred to (α_i, c_i), however if $\alpha' \leq 1/s$ then the preference is reversed.

(c) Now consider the points in the top right quadrant of the Figure 5.7, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j > c_i$. Since the points (α_k, c_j) are now high α- high c with respect to the reference (α_i, c_i) and the reference is low α- low c with respect to the points (α_k, c_k), from Lemma 5, (α_i, c_i) is preferred to the points in the top right quadrant.

(d) Now consider the points in the bottom left quadrant of the Figure 5.7, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j < c_i$. Since the points (α_k, c_j) are now low α- low c with respect to the reference (α_i, c_i) and the reference is high α- high c with respect to the points (α_k, c_j), from Lemma 5, the points (α_k, c_j) is preferred to the reference (α_i, c_i).

Now from (a), (b), (c), and (d) we get $(\alpha_i, c_i) \succeq (\alpha_k, c_j)$ if (α_k, c_j) lies above the separator in Figure 5.7 and $(\alpha_i, c_i) \preceq (\alpha_k, c_j)$ if (α_k, c_j) lies below the separator in Figure 5.7. The slope of of the separator is $-s$ and since it passes through the point (α_i, c_i) , the equation is given by $c - c_i = -s(\alpha - \alpha_i)$, we get $c = -s(\alpha - \alpha_i) + c_i$. Again from the transitivity of the preference $\succeq$ (under prospect theory) we can prove that points below the separator $c - c_i = -s(\alpha - \alpha_i)$ is preferred to the points above the separator.

Case 2 ($p(d) > \pi_2'$)

(a) Now consider the points in the bottom right quadrant of the Figure 5.8, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j < c_i$. Since the points (α_k, c_j) are high α- low c with respect to the reference (α_i, c_i) and the reference is low α- high c with respect to the points (α_k, c_j), from Lemma 5 the points in the bottom right quadrant of the Figure 5.8

are preferred to (α_i, c_i).

(b) Now consider the points in the top left quadrant of the Figure 5.8, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j > c_i$. Since the points (α_k, c_j) are now low α- high c with respect to the reference (α_i, c_i), from Lemma 5, (α_i, c_i) is preferred to the points in the top left quadrant.

(c) Now consider the points in the top right quadrant of the Figure 5.8, i.e., points (α_k, c_j) such that $\alpha_k > \alpha_i$ and $c_j > c_i$. Now assume $\alpha' > 1/s$, since the points (α_k, c_j) are now high α- high c with respect to the reference (α_i, c_i) and the reference is low α- low c with respect to the points (α_k, c_k), from Lemma 5, the points in the top right quadrant (α_k, c_j) is preferred to (α_i, c_i). However when $\alpha' \leq 1/s$, from Lemma 5, we get (α_i, c_i) is preferred to (α_k, c_j) the points in the top right quadrant.

(d) Now consider the points in the bottom left quadrant of the Figure 5.8, i.e., points (α_k, c_j) such that $\alpha_k < \alpha_i$ and $c_j < c_i$. $c_j > c_i$. Now assume $\alpha' > 1/s$, since the points (α_k, c_j) are now low α- low c with respect to the reference (α_i, c_i) and the reference is high α- high c with respect to the points (α_k, c_k), from Lemma 5, (α_i, c_i) is preferred to the points in the bottom right quadrant (α_k, c_j). However when $\alpha' \leq 1/s$, from Lemma 5, we get (α_k, c_j) is preferred to (α_i, c_i).

Now from (a), (b), (c), and (d) we get $(\alpha_i, c_i) \succeq (\alpha_k, c_j)$ if (α_k, c_j) lies above the separator in Figure 5.8 and $(\alpha_i, c_i) \preceq (\alpha_k, c_j)$ if (α_k, c_j) lies below the separator in Figure 5.8. The slope of of the separator is s and since it passes through the point (α_i, c_i) , the equation is given by $c - c_i = s(\alpha - \alpha_i)$, we get $c = s(\alpha - \alpha_i) + c_i$. Again from the transitivity of the preference $\succeq$ we can prove that points below the separator $c - c_i = s(\alpha - \alpha_i)$ is preferred to the points above the separator.

Proof of Proposition 3 and 4

The test demand dichotomy is given by $RD - PD$:

$$\begin{aligned} RD - PD = \;& p(d)p(+|d)(v(s) - m(s) + m((1-\alpha)s + c) - v((1-\alpha)s + c)) \\ & +p(\bar{d})p(+|\bar{d})(r(s) - r((1-\alpha)s - c) - v(c)) \end{aligned}$$

Now we analyze how the test dichotomy changes with respect to treatment efficacy α and treatment cost c

$$\frac{\partial(RD-PD)}{\partial\alpha} = p(d)p(+|d)(-s\cdot m'((1-\alpha)s+c)+s\cdot v'((1-\alpha)s+c))+p(\bar{d})p(+|\bar{d})(s\cdot r'((1-\alpha)s-c))$$

$$\frac{\partial(RD-PD)}{\partial c} = p(d)p(+|d)(m'((1-\alpha)s+c)-v'((1-\alpha)s+c))+p(\bar{d})p(+|\bar{d})(r'((1-\alpha)s-c)-v'(c))$$

For very low probabilities, the term that follows $p(\bar{d})p(+|\bar{d})$ influences the sign of the expressions. Therefore for such probabilities $p(d) < \pi_3 \in [0,1]$, the dichotomy is determined by the second term in the equations above. We know that $s \cdot r'((1-\alpha)s - c) > 0$ and for severe diseases $r'((1-\alpha)s - c) < v'(c)$, (due to higher relative concavity of r for high severity), therefore $\frac{\partial(RD-PD)}{\partial\alpha} > 0$ and $\frac{\partial(RD-PD)}{\partial c} < 0$. Thus, for low probabilities, the dichotomy $RD - PD$ is greatest for high α - low c disease and lowest for low α- high c disease. Therefore if there is a reference disease (α_i, c_i) for which both rational and psychological test demand are identical, for diseases which are low α- high c with respect to the reference, the psychological DM over tests and for diseases which are high α- low c with respect to the reference, the psychological DM under tests. However when $r' >> v'$ (r is extremely less concave than v). the $\frac{\partial(RD-PD)}{\partial\alpha} > 0$ and $\frac{\partial(RD-PD)}{\partial c} > 0$, therefore the psychological DM overtests for low α- low c disease and undertests for high α- high c disease. Note that π_3 decreases with increasing test reliability (or as $p(+|\bar{d})$ close to zero).

For intermediate and high probabilities $p(d) > \pi_3 \in [0,1]$, the first term that follows $p(d)p(+|d)$ becomes important. The sign of $\frac{\partial(RD-PD)}{\partial\alpha}$ and $\frac{\partial(RD-PD)}{\partial c}$ is determined by the difference between m' and v'. Suppose m is convex than v, then $m' > v'$ holds everywhere. Similarly, if v is convex than m, then $v' > m'$ holds everywhere. If $m' > v'$, then $\frac{\partial(RD-PD)}{\partial\alpha} < 0$ and $\frac{\partial(RD-PD)}{\partial c} > 0$, therefore the psychological DM under tests for low α- high c disease and over tests for high α- low c disease. When $v' > m'$, we find the opposite result – the psychological DM over tests for low α- high c disease and under tests for high α- low c disease.

Proof of Lemma 6

The inverse-S weighting function is concave for probabilities $p(d)$ less than p' and convex (or steep) for probabilities $p(d)$ greater than p'. We now analyze the psychological demand (PD) under inverse-S weighting function for different disease categories.

First, the psychological demand for low α- low c disease and high α- low c disease is given by,

$$\begin{aligned} PD = \quad & -(w(p(\bar{d})) - w(p(\bar{d})p(-|\bar{d})))(r(s) - r((1-\alpha)s + c)) \\ & +(w(p(d)) - w(p(d)p(-|d)))(m(s) - m((1-\alpha)s + c)) \end{aligned}$$

Note that the first and second term in the expression above have opposite signs. The contribution of first term (resp. second term) to the PD expression above decreases (resp., increases) with increasing (resp., decreasing) probability. Therefore for probabilities below a certain π_4, the second term affects PD less. For such probabilities, the PD is determined mainly by the first term. Considering only the first term, for low probabilities ($p(d) < \pi_4 < p'$) of high α- low c and low α- low c diseases, when $p(-|\bar{d})$ is close to 1, $w((p(\bar{d})) - w(p(\bar{d})p(-|\bar{d})) > p(\bar{d})p(+|\bar{d})$ as $w(p(\bar{d}))$ and $w(p(\bar{d})p(-|\bar{d})$ are in the steeper region of the curve (see Figure 7.1). Therefore, PD under inverse-S weighting is less than the PD under linear weighting.

For high probabilities $p(d) > \pi_4' > p'$, the first term plays less role. Considering only the second term, $w(p(d)) < p(d)$ (as $p(d)$ is in the convex region) and as $p(-|d)$ is close to zero, we get $w(p(d)p(-|d)) > p(d)p(-|d)$ (see Figure 7.1). Therefore $w(p(d)) - w(p(d)p(-|d)) < p(d)p(+|d)$. Thus, for high probabilities, PD under inverse-S weighting is less than the linear weighting. Therefore the psychological DM with inverse-S weighting undertests for high α- low c, low α- low c compared to the psychological DM with linear weighting, for both high and low probabilities.

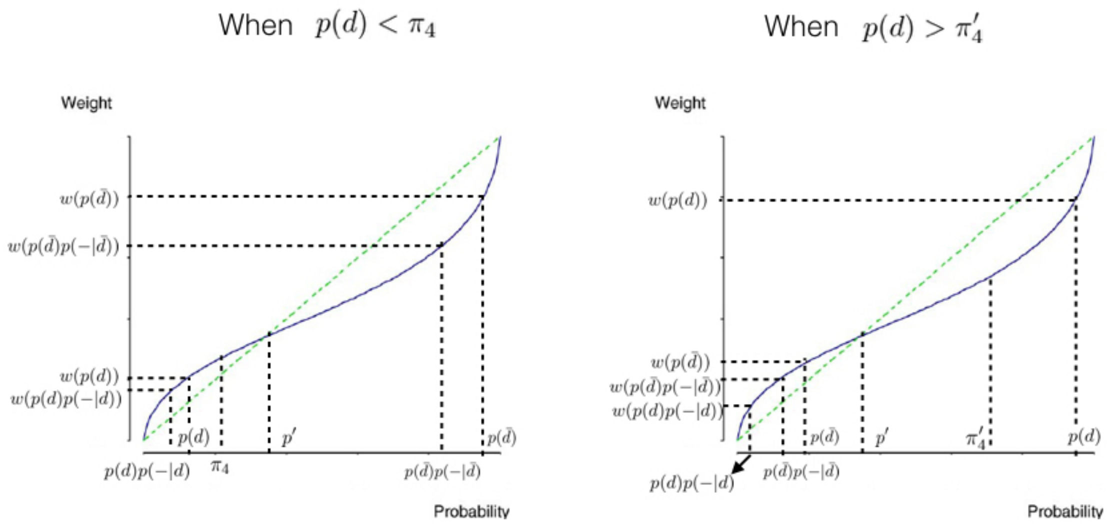

Figure 7.1: Probabilities and weights

Now the psychological demand for low α - high c disease is given by,

$$PD = -(w(p(\bar{d}))-w(p(\bar{d})p(-|\bar{d})))(r(s)-r((1-\alpha)s-c))+(w(p(d)p(+|d)))(m(s)-m((1-\alpha)s+c))$$

We analyze the demand dichotomy for low α - high c disease: For low probabilities $p(d) < \pi_4$, $w((p(\bar{d}))$ is in the convex region of inverse-S weighting and $w(p(\bar{d})p(-|\bar{d}))$ is in the concave region of the inverse-S weighting function (see Figure 7.1). Therefore, we get $w((p(\bar{d})) - w(p(\bar{d})p(-|\bar{d})) > p(\bar{d})p(+|\bar{d})$. Thus, PD under inverse-S weighting is less than the PD under linear weighting. For high probabilities $p(d) > p'$ (in the convex region of inverse-S), $w(p(d)p(+|d)) < p(d)p(+|d)$, the PD under inverse-S weighting is greater than the PD under linear weighting. Therefore the PD under inverse-S weighting is less (resp., greater) than the linear weighting for low (resp., higher) probabilities of low α - high c disease.

The psychology demand for high α- high c disease is given by,

$$\begin{aligned} PD = \; & -(w(p(\bar{d})) - w(p(-)p(\bar{d}|-)))r(s) + (w(p(d)) - w(p(-)p(d|-)))(m(s) - m((1-\alpha)s + c)) \\ & -(w(p(d) + p(+)p(\bar{d}|+)) - w(p(d))r((1-\alpha)s - c) \end{aligned}$$

.

Its not clear how the PD for high α- high c disease is affected by the shape of the weighting function.

Proof of Proposition 5

The PD expression with weighting function for high α- low c and low α- low c disease is identical. It is given by $-(w^+(p(\bar{d}))-w^+(p(-)p(\bar{d}|-)))(r(s)-r((1-\alpha)s-c))+(w^-(p(d))-w^-(p(-)p(d|-)))(m(s)-m((1-\alpha)s+c))$. Therefore the sign of $PD_{\alpha_{high}c_{low}} - PD_{\alpha_{low}c_{low}}$ under inverse-S weighting is identical to the PD under linear weighting function (see Table 7.4). Therefore, the preference between high α- low c and low α- low c (determined by the value of α and c) is identical to those under linear weighting for low and high probabilities except that probability π_2 changes..

Now we compare the PD between high α -low c and low α -high c disease for low probability $p(d) < \pi_4$. The PD for low α- high c disease is given by $-(w^+(p(\bar{d})) - w^+(p(-)p(\bar{d}|-)))(r(s)-r((1-\alpha)s-c)) - w^-(p(d)p(+|d))(m((1-\alpha)s+c)-m(s))$. Note for low $p(d) < \pi_4$, only the first term $-(w^+(p(\bar{d}))-w^+(p(-)p(\bar{d}|-)))(r(s)-r((1-\alpha)s-c))$ matters. As the term is identical to first term in the PD expression of high α- low c disease, the preference between high α- low $c$and low α- high c is identical to the preferences under linear weighting for low probabilities. For high $\alpha-$high c disease also, the first term is identical to the first term of high α- low c, low α- high c, and low α- low c diseases. Therefore for low probabilities $p(d) < \pi_4$, the preference under linear weighting is identical to the preferences under inverse-S weighting.

For probabilities $p(d) > \pi_4' \geq \pi_2'$, as the second terms are identical. Therefore, the preference under linear weighting between high α- low c and low α - low c also holds under inverse-S weighting i.e., high α - low $c \succeq$ low α- low c. Comparing the second terms of the PD expression for other diseases we get , low α- low $c \succeq$ low α- high c, high α- low c $\succeq$ high α- high c. We cannot state the preference between low α- low c and high α- high c diseases, therefore we get a preference identical to Lemma 5 (high α- low $c \succeq$ low α- low $c\succeq$ or $\preceq$ high α- high $c\succeq$ low α- high c).

Proof of Proposition 6

The psychological demand for low α - high c disease is given by,

$$PD = -(w(p(\bar{d})) - w(p(\bar{d})p(-|\bar{d}))) (r(s) - r((1-\alpha)s - c)) + (w(p(d)p(+|d)))(m(s) - m((1-\alpha)s + c))$$

For ease of computation, we replace the inverse-S weighting with a linear approximation i.e., $w(p) = a + bp$ (neo-additive weighting function, Chateauneuf et al. 2007), where a indicates the elevation of the weighting function and $a > 0$ (resp., $a < 0$) implies optimism (resp., pessimism). The parameter b indicates the likelihood insensitivity of the weighting function. Replacing, we get:

$$\begin{aligned} PD = \; & -(b - b(p(d)) - bp(-|\bar{d}) + bp(d)p(-|\bar{d}))(r(s) - r((1-\alpha)s - c)) \\ & +(a + bp(d)p(+|d))(m(s) - m((1-\alpha)s + c)) \end{aligned}$$

Differentiating PD wrt α, $\frac{\partial(PD)}{\partial\alpha} > 0$, if and only if $p(d) > \hat{\pi}_3 = \frac{r'((1-\alpha)s-c) - \frac{a}{b}m'((1-\alpha)s+c)}{(p(+|d)m'((1-\alpha)+c)+p(+|\bar{d})r'((1-\alpha)s-c))} > \pi_3 = \frac{r'((1-\alpha)s-c)}{(p(+|d)m'((1-\alpha)+c)+p(+|\bar{d})r'((1-\alpha)s-c))}$. Note that, in the above expression $\hat{\pi}_3$ increases if a decreases (more pessimistic) or b increases (more likelihood sensitive).

Proof of Lemma 7

$$RD = p(d)p(+|d)(v(s) - v((1-\alpha)s + c)) - p(\bar{d})p(+|\bar{d})v(c)$$

We differentiate the expression above with respect to $p(+|d)$, we get

$$\frac{\partial(RD)}{\partial p(+|d)} = p(d)(v(s) - v((1-\alpha)s + c))$$

For *high* α*- low* c, *high* α*- high* c, *low* α*- low* c diseases, the expression $p(d)(v(s) - v((1-\alpha)s + c)) > 0$, therefore $\frac{\partial(RD)}{\partial p(+|d)} > 0$. Thus a rational DM will prefer to do a test with low false negative. However for *low* α*- high* c diseases, the expression $p(d)(v(s) - v((1-\alpha)s + c)) < 0$. Therefore a rational DM will prefer a test with high false negative (or low sensitivity).

The psychological demand (PD) with linear weighting is given by

$$PD = -p(d)p(+|d)m((1-\alpha)s+c)+p(+)p(+\bar{d})r((1-\alpha)s-c)+p(d)p(+|d)m(s)-p(\bar{d})p(+|\bar{d})r(s)$$

Differentiating the PD expression with respect to $p(+|d)$ we get

$$\frac{\partial(PD)}{\partial p(+|d)} = p(d)(m(s) - m((1-\alpha)s + c))$$

Similar to the rational case the expression $\frac{\partial(PD)}{\partial p(+|d)}$ is less than zero only for low α- high c diseases. Otherwise the PD expression is greater than zero. Thus a psychological DM will also prefer to do a test with low false negative. However for low α- high c diseases the expression $p(d)(m(s) - m((1-\alpha)s + c)) < 0$. Therefore a psychological DM will prefer a test with high false negative (or low sensitivity).

Now characterizing the dichotomy for sensitivity, we compare $\frac{\partial(RD)}{\partial p(+|d)}$ and $\frac{\partial(PD)}{\partial p(+|d)}$, we get

$\frac{\partial(RD)}{\partial p(+|d)} - \frac{\partial(PD)}{\partial p(+|d)} = p(d)((v(s) - v((1-\alpha)s + c)) - (m(s) - m((1-\alpha)s + c)) < 0$, if v is less concave than m. Thus Lemma 7 is proved.

Proof of Lemma 8

$$RD = p(d)p(+|d)(v(s) - v((1-\alpha)s + c)) - p(\bar{d})p(+|\bar{d})v(c)$$

The expression above is always less than zero. Similarly now differentiating the RD expression with respect to $p(+|\bar{d})$, we get

$$\frac{\partial(RD)}{\partial p(+|\bar{d})} = -p(\bar{d})v(c) < 0$$

Therefore a rational DM will prefer to do a test with low false positive for all disease categories.

The psychological demand (PD) with linear weighting is given by

$$PD = -p(d)p(+|d)m((1-\alpha)s+c)+p(\bar{d})p(+|\bar{d})r((1-\alpha)s-c)+p(d)p(+|d)m(s)-p(\bar{d})p(+|\bar{d})r(s)$$

Now differentiating the PD expression with respect to $p(+|\bar{d})$ we get

$$\frac{\partial(PD)}{\partial p(+|\bar{d})} = -p(\bar{d})(r(s) - r((1-\alpha)s - c)) < 0$$

Therefore a psychological DM will prefer to do a test with low false positive for all disease categories. Note that $\frac{\partial(RD)}{\partial p(-|\bar{d})} = p(\bar{d})v(c)$ and $\frac{\partial(PD)}{\partial p(-|\bar{d})} = p(\bar{d})(r(s) - r((1-\alpha)s - c))$. Now to characterize the dichotomy we compare $\frac{\partial(RD)}{\partial p(-|\bar{d})}$ and $\frac{\partial(PD)}{\partial p(-|\bar{d})}$, we get $\frac{\partial(RD)}{\partial p(-|\bar{d})} - \frac{\partial(PD)}{\partial p(-|\bar{d})} = p(\bar{d})(v(c) - (r(s) - r((1-\alpha)s - c))) < 0$, when severity or treatment cost or treatment efficacy is high (can be inferred by substituting a large value for s, c, and α). Thus Lemma 8 is proved.

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