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Helping patients and physicians reach individualized medical decisions: theory and application to prenatal diagnostic testing

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Abstract This paper presents a procedure designed to aid physicians and patients in the process of making medical decisions, and illustrates its implementation to aid pregnant women, who decided to undergo prenatal diagnostic test choose a physician to administer it. The procedure is based on a medical decision-making model of Karni (J Risk Uncertain 39: 1–16, 2009). This model accommodates the possibility that the decision maker's risk attitudes may vary with her state of health and incorporates other costs, such as pain and inconvenience, associated with alternative treatments. The medical decision problem was chosen for its relative simplicity and the transparency it affords.

Keywords Medical decision making · Prenatal diagnostic testing · CVS · Amniocentesis

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1 Introduction

Consider the following scenario: a patient diagnosed with a health problem must choose among alternative courses of action, including a treatment, a physician to administer it, and a medical facility in which the treatment is to be administered. In general, the alternatives to be considered are quite complex, involving assessment of risks and values, as well as financial and lifestyle considerations, and difficult to assess as wholes. There is an advantage, therefore, in breaking them up so that the different components may be evaluated separately, and than aggregating these evaluations to generate a decision criterion. This process necessitates inputs form both doctor and patient. Typically the doctor's input includes specifying the alternative treatments, describing the possible medical outcomes, and providing an assessment of the risks involved in each treatment at different facilities and by different physicians. The patient's input includes his/her personal valuation of the potential medical outcomes as well as his/her financial and other concerns, such as it impact on his/her lifestyle and family.[1] In principle, if there is no conflict of interests between doctor and patient, integrating these inputs should enable the patient to choose his optimal course of action. In practice, however, it is not always easy to obtain the necessary information form the doctor or to elicit the patient's preferences. Both may require some guidance on how to sort out and organizing the relevant information in a systematic manner, and identify the optimal course of action.[2]

Karni (2009) presented an axiomatic model of medical decision making in which the various ingredients of the decision-making process described above and the aggregation procedure are made explicit. The procedure requires the elicitation and integration of the patient's preferences and the physician's risk assessment.

In this study, we show how to apply this model to help doctors and patients arrive at a decision that best serves the patients' interests. More specifically, we formulated questionnaires designed to prompt patients to reveal their evaluation of the medical outcomes and financial consequences of the alternative courses of actions. We review the results to see if the responses are consistent with the basic premises of the model, and illustrate, using a few case studies, how it generates recommendations regarding which course of action should be followed.

It is important to underscore, at this point, what this study is and what it is not. This is an exercise in developing and testing the applicability of a class of questionnaires, intended to elicit information about patients' utility functions. These questionnaires are designed to prompt the patients to think systematically and to determine, in their own minds, their priorities when faced with medical decisions. As such, it is neither an experiment intended to test the validity of the expected utility model to medical decision making, nor is it a statistical analysis of patients behavior when choosing among alternative courses of actions in the face of a medical problem. Perhaps the best way to explain the nature of the exercise we embark on is to recall that Savage, when presented with the choice among lotteries designed by Allais, chose in a way

[1] For a more detailed description of the shared decision-making model in medical context, see Charles et al. (1997; 1999a; 1999b) and Lewis et al. (2005).

[2] See "Discussion" in Kremer et al. (2007); Hudak et al. (2008) and Holmes-Rovner et al. (2007).

that violated his own sure thing principle. When confronted with this "contradiction" Savage says that he would reverse his preferences, thereby correcting an error of his intuitive judgement.[3] We presume that error of judgement are possible and patients and doctors alike can benefit from a systematic reasoning, incorporating the patients' subjunctive preferences, when trying to settle on a treatment.

Our approach is normative but not paternalistic. It is normative in it's presumption that the patient would like his decision to be governed by the principles (axioms) of expected utility theory, which we take as normatively compelling. It is non-paternalistic in that the recommended course of action maximizes the patient's expected utility, but is silent on what this utility should be. The patient is the ultimate arbiter of his own well-being.

The application of the model presumes that, when properly prompted to do so, patients are able to express their preferences in a coherent manner. This study, is intended to tests this presumption. Specifically, we consider pregnant women who decided to undergo prenatal diagnostic test, which is not recommended for routine pregnancy, to determine genetic abnormalities. The test involves a risk of involuntary abortion, and has the benefit of allowing voluntary early termination of the pregnancy if genetic abnormalities are detected. The risk of involuntary abortion depends, among others, on the expertise and skill of the physician administering the test. Upon being informed of the alternative courses of action, the woman must choose the physician to administer the test.

It is not uncommon that, facing such decision, the woman will ask her gynecologist (who does not necessarily perform diagnostic tests) for recommendation. Confronted with such requests, the gynecologist may find himself in a difficult position. Presumably, his answer should depend on the assessment of the risk involved, the woman's valuation of the potential outcomes which depends on her age, family situation (how many children she has) etc. Finally, the answer must take into account financial considerations, such as the price differences among physicians and medical facilities, the women's risk attitudes which may depend, in turn, on the outcome of the diagnostic test and her wealth.

The main difficulty is the elicitation of the patient's preferences. These involves the patient's risk attitudes, which may vary according to the outcome, the alignment of her utility functions across outcomes, and the calibrations of the utility functions across courses of actions. To reduce the problem to manageable size, for the purpose of this study, we invoke a family of utility functions characterized by one parameter, which may vary according to the outcome of the medical procedure. This permits the patient's risk attitude to depend on her health-state. We develop a questionnaire that makes it possible to elicit the values of the said parameter conditional on the alternative outcomes and the alignment of the utility functions. Using this information we illustrate the application of the model to help patients and gynecologists arrive at a decision consistent with the information at their possession. We also use the responses to check whether they are consistent with basic premises of rational choice behavior.

[3] See account of this in Savage (1954), Sect. 5.6.

The decision problem we study is rather simple and transparent, namely, the choice of physician to administer a prenatal diagnostic test. The term prenatal diagnosis refers broadly to a number of different techniques and procedures that can be performed during a pregnancy to provide information about the health of a developing fetus. Prenatal diagnostic tests may also be offered to women whose pregnancies are considered high risk because of age, family history, or other factors. These tests are designed to look for specific conditions, but not all conditions can be detected and no test is completely accurate.[4] In this study, we consider the two commonly used tests described below:

Chronic villus sampling (CVS) is usually performed between 10 and 13 weeks of gestation and is designed to detect specific genetic abnormalities early in pregnancy. The greatest success occurs when the physician performing the test is experienced, CVS can be used to determine virtually all disorders that can be diagnosed by amniocentesis except the presence of neural tube defects.

Amniocentesis is usually performed between 15 and 20 weeks of gestation, to detect chromosomal abnormalities as well as other specific genetic diseases. The results from amniocentesis are highly accurate.

Amniocentesis is a relatively simple and safe procedure when performed by an experienced physician, but there is some risk of miscarriage. That risk has been quoted at being about 1 in 200. However, recent data suggests that in experienced hands, the risk may be much lower.

CVS carries a slightly higher increased risk of miscarriage (still less than one percent) than amniocentesis. In both procedures, the rate of pregnancy loss is lower when performed by experienced physician and in medical center where the procedures are performed more often. Moreover, evidence suggests that experience of the physician is relatively more important for reduce rate of miscarriage in CVS than in amniocentesis.

2 The medical decision model: a review

In this section we review the model proposed by Karni (2009), describe the parametric family of utility functions used in our study, and the procedures invoked to determine the patients' objective functions.

2.1 The analytical framework

Assume that patients' preferences are represented by action and outcome-dependent expected utility function. Formally, let A denote the set of available courses of action, or treatments, and denote by c a vector of the patient's characteristics (medical history, age, gender, race, profession, family situation, physical state, and any other personal attributes that may bear on the outcome of the medical treatments under consideration).

[4] For details regarding this point and information concerning the procedures described below, see the Genetics and Public Policy Center on the web site www.dnapolicy.org.

Let the patient's preference relation $\succcurlyeq$ on A be represented as follows:

$$(a, c) \mapsto \lambda(a) \sum_{\omega \in} [b(\omega) U(f(\omega; a, c), \omega) + d(\omega)] p(\omega \mid a, c) + v(a), \quad (1)$$

where U is the utility function; ω denotes the posttreatment health state (or outcome); is the set of all outcomes associated with a given diagnosis; $f(\omega; a, c)$ denotes the financial consequence associated with the outcome ω conditional on the patient's characteristics and the action; $p(\cdot \mid a, c)$ is the probability distribution on conditional on the action and the patient's personal characteristics; and λ and v represent the "utility cost," including pain, discomfort and inconvenience associated with different actions.[5] Note that the patient's risk attitudes, captured by the utility functions of money, $U(\cdot, \omega), \omega \in \Omega,$ are outcome dependent but not action dependent.[6]

In the context of this model, decisions are based on information from two sources: (a) medical information, provided by the doctor, specifying the possible courses of action, A, the potential outcomes, $\Omega,$ and the family, $\{p(\cdot, a, c) \mid a \in A\}$, of probabilities on conditional on the actions and patient's characteristics, and (b) personal information, provided by the patient, concerning his characteristics and preferences. Using this information, the relevant utility functions U, λ, and v are determined.

The elicitation of the subjective "parameters" (that is, the outcome-dependent utility functions and action-dependent "utility cost" coefficients) involves three distinct procedures. First, for every given outcome, it is necessary to elicit the outcome-dependent utility function on wealth (that is, for all $\omega \in \Omega,$ the functions $U(\cdot, \omega)$ must be determined). Second, the outcome-dependent utility functions need to be aligned, so that they agree on the evaluation of the monetary payoff across outcomes (that is, the coefficients $b(\omega)$ and $d(\omega), \omega \in \Omega,$ need to be determined). Third, the expected utilities of the distinct actions must be calibrated to allow comparisons among them (that is, the coefficients $\lambda(a)$ and $v(a), a \in A$ need to be determined).

In the next subsection, we review these procedures as applied to our problem. Before doing so, however, it is worth mentioning again the possible interpretations of the model. One possible interpretation is positive. According to this interpretation the patient has a preference relation representable as in (1). Upon learning the information provided by his doctor, the patient should be able to choose the course of action appropriate from him. For some patients this is the case.

Another possible interpretation is normative. According to this interpretation, some patients would have liked to choose according to the principles underlying the preference relation represented in (1), but are unable to do so intuitively. Such patients need guidance to help them clarify, in their own minds, their preferences and, following that, to aid them identify the course of action recommended by the model.

5 The fact that in general the utility cost associated with a procedure has additive and multiplicative factors is a consequence of the axiomatic structure of the underlying preference relation. It is quit possible that in application it will turn out that the estimated value of λ is one.

6 Outcomes represent states of health, and the utility functions in this model are state-dependent functions of the patient's wealth.

This study assumes the normative interpretation and our main concern is developing the means to guide patients of the second kind through their decision making process.

2.2 Elicitation of patients' risk attitudes

As a compromise between rigor and parsimony, we restrict attention to parametric families of utility functions and estimate the relevant parameters using few questions. More specifically, we employ a one-parameter expo-power utility function of the form,

$$u\left(x,\omega\right)=-e^{\frac{-x^{r(\omega)}}{r(\omega)}},\quad \text{for}\, r\left(\omega\right)=0\,\text{and}\, u\left(x,\omega\right)=-1/x\quad \text{for}\, r\left(\omega\right)=0, \tag{2}$$

where x denotes the patient's wealth and $1\geq r\left(\omega\right)\geq 0, \omega\in$.[7] For $r\left(\omega\right)\in(0,1]$, this function displays decreasing absolute and increasing relative risk aversion.[8]

To determine the risk attitudes of the women in this study, we elicit their certainty equivalents of small risks. Specifically, let x denote the subject's wealth and let $\widetilde{\varepsilon}$ be a random variable taking values in the interval $(-\varepsilon,\varepsilon)$ such that $E\left(\widetilde{\varepsilon}\right)=0$, where E denotes the expectations operator. For each x and ω let $\pi\left(x,\omega\right)$, the relative risk premium, be defined by the equation

$$u\left(x-\pi\left(x,\omega\right)x,\omega\right)=E\left[u\left(x+\widetilde{\varepsilon}x,\omega\right)\right]. \tag{3}$$

In other words, $\pi\left(\cdot,\omega\right)$ is the (maximal) proportion of her wealth a subject is willing to pay to avoid the proportional risk $\widetilde{\varepsilon}$. For small risks we have, for each ω,

$$\pi\left(x,\omega\right)=\left[-\frac{u\;\;\left(x,\omega\right)x}{u\;\left(x,\omega\right)}\right]\frac{\sigma_{\widetilde{\varepsilon}}^{2}}{2}. \tag{4}$$

In the one-parameter expo-power utility function the Arrow–Pratt measure of relative risk aversion is:

$$-\frac{u\;\;\left(x,\omega\right)x}{u\;\left(x,\omega\right)}=x^{r(\omega)}+1-r\left(\omega\right). \tag{5}$$

Hence, given $x,\widetilde{\varepsilon}$ and $\pi\left(x,\omega\right)$, we can solve for $r\left(\omega\right), \omega\in\Omega$, using the equations

$$\pi\left(x,\omega\right)=\left[x^{r(\omega)}+1-r\left(\omega\right)\right]\frac{\sigma_{\widetilde{\varepsilon}}^{2}}{2},\qquad \omega\in\Omega. \tag{6}$$

[7] The expo-power family of utility function was first proposed by Saha (1993). The one parameter variation invoked in this study was used in Abdellaoui et al. (2007). The two parameter variation

$$u\left(x\right)=\frac{1-\exp\left(-\alpha x^{1-r}\right.}{\alpha},$$

where x denotes the decision maker's wealth; $\alpha>0$ and $1\geq r\geq 0$, was used by Holt and Laury (2002).

[8] Note that $-\frac{u\;\;(x,\omega)}{u\;(x,\omega)}=x^{-(1-r(\omega))}+(1-r\left(\omega\right))x^{-1}$.

2.3 Alignment of the utility functions

Recall that, in the case under consideration, there are two outcomes, continued pregnancy without complications ω_0, and involuntary abortion, ω_1 (that is, $= \{\omega_0, \omega_1\}$).[9] Suppose that the estimated parameter values of the utility functions in (2) were obtained (that is, $r(\omega_0)$ and $r(\omega_1)$ are calculated). For every outcome, $\omega \in \{\omega_0, \omega_1\}$, the utility function elicited is unique up to a positive linear transformation. The next step requires aligning the utility functions across outcomes. This involves the following simple procedure.

First we need to normalize the outcome-dependent utility functions which in general is unique up to positive linear transformation. Fix $y > x$, and let $b(\omega_0)$ and $d(\omega_0)$ be the solution to the equations

$$b(\omega_0) \quad -e^{\frac{-y^{r(\omega_0)}}{r(\omega_0)}} \quad + d(\omega_0) = 1 \tag{7}$$

and

$$b(\omega_0) \quad -e^{\frac{-x^{r(\omega_0)}}{r(\omega_0)}} \quad + d(\omega_0) = 0. \tag{8}$$

For ω_1, let the decision maker indicate the wealth levels $x(\omega_1)$ and $y(\omega_1)$ that would leave him indifferent between the payoff-outcome pairs $(x(\omega_1), \omega_1)$ and (x, ω_0) and between the payoff-outcome pairs $(y(\omega_1), \omega_1)$ and (y, ω_0). Formally, denote by $\sim$ the indifference relation and let $x(\omega_1)$ and $y(\omega_1)$ be defined by $(x(\omega_1), \omega_1) \sim (x, \omega_0)$ and $(y(\omega_1), \omega_1) \sim (y, \omega_0)$.

Given $x(\omega_1)$ and $y(\omega_1)$, let $b(\omega_1)$ and $a(\omega_1)$ be the solution to the equations

$$b(\omega_1) \quad -e^{\frac{-y(\omega_1)^{r(\omega_1)}}{r(\omega_1)}} \quad + d(\omega_1) = 1 \tag{9}$$

and

$$b(\omega_1) \quad -e^{\frac{-x(\omega_1)^{r(\omega_1)}}{r(\omega_1)}} \quad + d(\omega_1) = 0. \tag{10}$$

Combining these results, for every x and $\omega \in \{\omega_0, \omega_1\}$, we ascribe to the patient the utility functions

$$U(x, \omega) := b(\omega)\left[-e^{\frac{-x^{r(\omega)}}{r(\omega)}}\right] + d(\omega), \quad \text{for all } \omega \in \Omega. \tag{11}$$

[9] Outcomes in these instance refer to medical conditions following the test and are not the test results.

2.4 Calibration of utility across actions

The general procedure for calibrating the utility across actions is described in Karni (2009). Considering that in the case at hand, the choice is between having the genetic test administered by expert physician, a_1, versus average physician, a_0, it is safe to assume that the "utility cost" of the actions, namely, the disutility associated with pain and other inconveniences, is the same across physicians.[10] Thus, we assume that $\lambda(a_1) = \lambda(a_0)$ and $v(a_1) = v(a_0)$.

To sum up, the patients' preferences are represented by expected utility functional of the form

$$b(\omega_0) \quad -e^{\frac{-(x-\varphi(a))^{r(\omega_0)}}{r(\omega_0)}} \quad + d(\omega_0) \quad p(\omega_0 \mid a, c)$$

$$+ \quad b(\omega_1) \quad -e^{\frac{-(x-\varphi(a))^{r(\omega_1)}}{r(\omega_1)}} \quad + d(\omega_1) \quad p(\omega_1 \mid a, c), \tag{12}$$

where $\varphi(a)$, $a \in \{a_0, a_1\}$ denotes the financial cost of the test performed by physician of type a.

3 Implementation

Consider, a pregnant woman who decided to undergo prenatal diagnostic testing, CVS or amniocentesis, and must choose between an expert physician and a average physician who is less expensive, but has a higher probability of fetus loss. In this section, we show how the model may be applied to aid such women to choose a physician to administer the test.

3.1 Risk assessment and physicians' costs

The difficulty of estimating of the physician's skill stems, in part, from missing data. Women who lost their fetus following an invasive diagnostic test have no reason to inform the physician who performed the test. Moreover, spontaneous miscarriages occur mostly during the first trimester, but also during the second and even the third trimester of pregnancy. In many cases, it is impossible to confirm whether the miscarriage was caused by the test. Despite these obvious difficulties, it has been shown that there is statistically significant learning associated with practice as measured by lower fetal losses and reduced need to perform several insertions.[11]

For the purpose of this study we use the official data of the MRM 2007—the " Israeli Medical Management Co." [12] According to these data the probabilities of con-

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[10] The term expert pertains to a physician that performs larger than average number of procedures per unit of time and, as result, has higher success rate than average physician.

[11] See Wijnberger et al. (2000).

[12] These data are most familiar to the participants in our study since they appear on the agreement document that each woman in Israel must sign before undergoing CVS or amniocentesis.

tinued pregnancy and fetus loss following CVS are 0.99 and 0.01, respectively (that is, $p_{\text{CVS}}(\omega_0) = 0.99$ and $p_{\text{CVS}}(\omega_1) = 0.01$). The corresponding figures for amniocentesis are 0.995 and 0.005 (that is, $p_{\text{A}}(\omega_0) = 0.995$ and $p_A(\omega_1) = 0.005$). We take these figures to represent the risk associated with the different tests if performed by a physician whose skill level is average. We *assume* that the corresponding probabilities if the procedures are performed by a expert physicians are twice as good as those of average physicians. Thus, for an expert physician $p_{\text{CVS}}(\omega_0) = 0.995$ and $p_{\text{CVS}}(\omega_1) = 0.005$ and $p_{\text{A}}(\omega_0) = 0.9975$ and $p_{\text{A}}(\omega_1) = 0.0025$.

The cost of performing the tests by expert and average physicians were chosen to reflect the prices in Israel in 2010. The estimated cost of CVS performed by expert physician is 4500 New Israeli Shekel (NIS) and the corresponding cost of amniocentesis is estimated at 3500 NIS. The cost of both procedures performed by average physicians in a facility of one of the HMOs is fully covered, so it taken to be zero.

3.2 Utility elicitation

For the purpose of eliciting the patients' proportional certainty equivalent, we confronted the them with the risk of winning or losing 1 % of the value of their respective assets with equal probability. Formally, use a random variable, $\widetilde{\varepsilon}$, that may take one of two possible values, namely, $+0.01$ and -0.01, with equal probability. Hence, $\sigma^2_{\widetilde{\varepsilon}} = 10^{-4}$. The relative risk premia, $\pi(x, \omega)$, were obtained by asking the subjects to state the maximal proportion of their wealth they were willing to pay to avoid the proportional risk $\widetilde{\varepsilon}$, given the test outcome, ω.

3.3 Alignment of the utility functions

To align the outcome-dependent utility functions we used the solutions $r(\omega), \omega \in$, to calculate the coefficients of the utility functions. Specifically, we confronted the subjects with the hypothetical scenario according to which they won 1,000,000 NIS and, as a result, their wealth increase from x to $y = x + 1{,}000{,}000$. We fixed $u(x, \omega_0) = 0$ and $u(y, \omega_0) = 1$ and solved for

$$b(\omega_0) = \frac{1}{-e^{\frac{-x_1(\omega_0)^{r(\omega_0)}}{r(\omega_0)}} + e^{\frac{-x_0(\omega_0)^{r(\omega_0)}}{r(\omega_0)}}} \tag{13}$$

and

$$d(\omega_0) = \frac{e^{\frac{-x_0(\omega_0)^{r(\omega_0)}}{r(x_1,\omega_0)}}}{-e^{\frac{-x_1(\omega_0)^{r(\omega_0)}}{r(\omega_0)}} + e^{\frac{-x_0(\omega_0)^{r(\omega_0)}}{r(\omega_0)}}}. \tag{14}$$

We elicited $x(\omega_1)$ and $y(\omega_1)$ by asking the subjects to indicate the sum of money they would be willing to pay to reduce the probability of miscarriage from say 1 % in the case of CVS to zero percent. Then $x(\omega_1)$ and $y(\omega_1)$ are given implicitly by the solution to the equations

$$p_j(\omega_0)\,u(y,\omega_0) + p_j(\omega_1)\,u(y,\omega_1) = u(y(\omega_1),\omega_0) \tag{15}$$

and

$$p_j(\omega_0)\,u(x,\omega_0) + p_j(\omega_1)\,u(x,\omega_1) = u(x(\omega_1),\omega_0), \tag{16}$$

where $j \in \{CVS, A\}$.

Equation (15) may be written as

$$\begin{aligned} b(\omega_1)\,u(y,\omega_1) + d(\omega_1) &= \frac{u(y(\omega_1),\omega_0)}{p_j(\omega_1)} \\ &= \frac{1}{p_j(\omega_1)} \quad b(\omega_0) \quad -e^{\frac{-y(\omega_1)^{r(\omega_0)}}{r(\omega_0)}} \quad + d(\omega_0) - p_j(\omega_0) \end{aligned} \tag{17}$$

and Eq. (16) may be written as

$$\begin{aligned} b(\omega_1)\,u(x,\omega_1) + d(\omega_1) &= \frac{u(x(\omega_1),\omega_0)}{p_j(\omega_1)} \\ = \frac{1}{p_j(\omega_1)} \quad b(\omega_0) \quad -e^{\frac{-x(\omega_1)^{r(\omega_0)}}{r(\omega_0)}} \quad + d(\omega_0) \quad . \end{aligned} \tag{18}$$

We stimate $b(\omega_1)$ and $d(\omega_1)$ by solving these equations. The solutions are:

$$b(\omega_1) = \frac{\frac{1}{p_j(\omega_1)} \quad b(\omega_0) \quad -e^{\frac{-y(\omega_1)^{r(y_1,\omega_0)}}{r(\omega_0)}} \quad - p_j(\omega_0)}{-e^{\frac{-y^{r(\omega_1)}}{r(\omega_1)}} + e^{\frac{-x^{r(\omega_1)}}{r(\omega_1)}}} \tag{19}$$

and

$$d(\omega_1) = \frac{1}{p_j(\omega_1)} \quad b(\omega_0) \quad -e^{\frac{-y(\omega_0)^{r(\omega_0)}}{r(\omega_0)}} \quad + d(\omega_0) \quad + b(\omega_1)\,e^{\frac{-x^{r(\omega_1)}}{r(\omega_1)}}. \tag{20}$$

4 Results

In this section we describe the methods used, the study population, and summarize the main general findings.

4.1 Methods and the study population

The study was conducted through " LimeService," a survey service platform for running online surveys, in Hebrew, from December 2008 to December 2009. It included two anonymous separate questionnaires, one for CVS and one for amniocentesis. Links to the CVS questionnaire in private mode (the record kept does not contain any identifying information about the survey responses) were sent, by e-mail, to doctoral and MBA students from Tel Aviv University. Links to the amniocentesis questionnaire, in private mode, were posted in four pregnancy and labor internet forums.

The online questionnaires (both for CVS and amniocentesis) included eighteen questions (see Online Appendix). The questionnaires were identical except for the descriptions of the procedures and the corresponding fetus loss probabilities. The first question was only use to encourage the participants to keep on answering questions. The next five questions were mandatory, and were design to elicit the information necessary to calculate the parameter values of the utility functions [that is, $r(\omega_0)$ and $r(\omega_1)$]. The last twelve questions were optional and intended to collect demographic and medical information to be used in the statistical analysis. The demographic questions, with minor changes, were taken from surveys of Israel's Central Bureau of Statistics.

A total of 176 women started to fill in the online questionnaire, 94 of which responded to the CVS questionnaire and 82 responded to the amniocentesis questionnaire. Seventy women (74 %) completed the mandatory questions in the CVS study and 40 women (49 %) completed the amniocentesis questionnaire.[13]

4.2 Unreasonable behavior

The first question that concerns us is to what extent the responses are consistent with the underlying tenets of the model. Responses were qualified as unreasonable given the model include (a) lower willingness to pay extra for testing that involve no risk of fetus loss when the responder is richer than when she is poorer, (b) willingness to pay to avoid financial risk equal to the largest possible loss associated with that risk. Responses of these types suggest that the respondents either were not paying attention or didn't understand the task they were asked to perform.

Examination of the responses shows that non of the participants in either study were unreasonable according to (a) and only 9 % of the respondents in the CVS study and 3 % of the participants in the amniocentesis study were qualified as unreasonable according to (b). Thus, broadly speaking, the participants in the study seem able to give useful answers.

We note that the values of the parameters $r(\omega)$ that determined the risk attitudes exhibit no systematic pattern that can be explained by demographic or medical characteristics in the subject population. We found that in the population there were patients displaying higher risk aversion in state ω_0 than in ω_1. There were patients displaying

[13] Partial responses were checked. No specific question was found in which the respondents quit the online questionnaires.

the opposite pattern of risk attitude. And there were patients whose risk attitude were outcome independent.

5 The model as a decision-making tool: case studies

The main objective of this work is to study the possibility of using the model and procedures such as the one described here to help doctors and patients make medical decision. The choice facing the women in this study is between undergoing a prenatal diagnostic test with an average physician and an expert physician. To illustrate how our method works in this context, we describe below four participants in the CVS study who display outcome-dependent risk attitudes. In each case, the graphs of two utility functions, corresponding to the two outcomes, ω_0 and ω_1, are displayed and the maximum price that a women should be ready to pay to have the procedure done by an expert physician as opposed to an average physician is calculated, based on her utility functions. This is followed by a recommended course of action, namely, a recommendation on whether to have the test administered by an expert or an average physician, given the prices charged by these physician. Throughout, we assume that the price of having the test administered by an expert is 4500 NIS. We consider two alternative costs of having the test administered by an average physician, a full subsidy which means that the patient pays nothing and partial subsidy in which the patient pays 570 NIS.

Recall that the medical risk involved if the CVS procedure is performed by an average physician was estimated at $p_{\text{CVS}}(\omega_1) = 1\,\%$.

5.1 Case 1: patient of type 1: $r(\omega_0) > r(\omega_1)$

The patient initial wealth is $x = 1{,}500{,}000$ NIS and in the study she was asked to envision gaining one million NIS so that her wealth increased to $y = 2{,}500{,}000$ NIS. This patient indicated her willingness to pay the proportional premia $\pi(\omega_0, x) = 0.5$ and $\pi(\omega_1, x) = 0.1$. to avoid the proportional risk $\widetilde{\varepsilon}$. Thus, her implied parameter values are $r(\omega_0) = 0.32$ and $r(\omega_1) = 0.21$.

The patient also indicated willingness to pay 6000 NIS at x and 10,000 NIS at y to avoid the risk of miscarriage as a result of the test altogether. Consequently, $y_0 = 1{,}494{,}000$ and $y_1 = 2{,}490{,}000$. Hence, the alignment of the outcome-dependent utility functions implies that $d(\omega_0) = 1$, $b(\omega_0) = 2.50253 \times 10^{133}$, $d(\omega_1) = 1.002$, and $b(\omega_1) = 6.87376 \times 10^{41}$ (see Fig. 1).

We simulated cost and the recommended course of action for three types of experts, namely, experts whose probabilities inducing involuntary abortion are 0.5, 0.25, and 0.1 %. The findings are summarized in the following table:

Expert physician	4,500 NIS	4,500 NIS	Recommendation
Average physician	Free	570 NIS	(In both cases)
$p_{\text{CVS}}(\omega_1) = 0.5\,\%$	3,186 NIS	3,671 NIS	Average physician
$p_{\text{CVS}}(\omega_1) = 0.25\,\%$	4,636 NIS	5,084 NIS	Expert physician
$p_{\text{CVS}}(\omega_1) = 0.1\,\%$	5,646 NIS	5,893 NIS	Expert physician

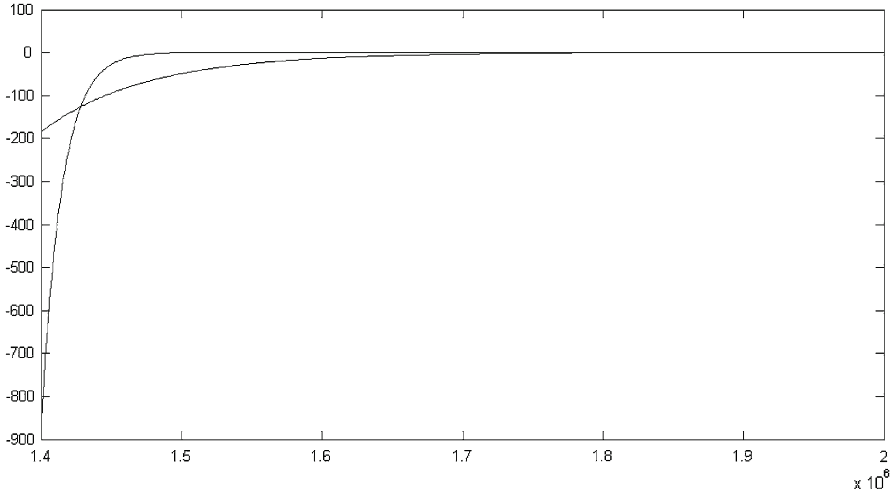

Fig. 1 State-dependent patient, Type 1 ($r_0 > r_1$) (u_{ω_1} and u_{ω_2})

5.2 Case 2: patient of type 1: $r(\omega_0) > r(\omega_1)$

The patient initial wealth is $x = 3{,}000{,}000$ NIS and in the study she was asked to envision gaining one million NIS so that her wealth increased to $y = 4{,}000{,}000$. This patient indicated her willingness to pay the proportional premia $\pi(\omega_0, x) = 0.3$ and $\pi(\omega_1, x) = 0.2$ to avoid the proportional risk $\widetilde{\varepsilon}$. Thus, her implied parameter values are $r(\omega_0) = 0.27$ and $r(\omega_1) = 0.25$.

The patient also indicated willingness to pay to avoid the risk altogether of miscarriage as a result of the test 1500 NIS at x and 1,500 NIS at y. Consequently, $y_0 = 3{,}985{,}000$ and $y_1 = 4{,}985{,}000$. Hence, the alignment of the outcome-dependent functions implies that $d(\omega_0) = 1.00$, $b(\omega_0) = 1.11516 \times 10^{94}$, $d(\omega_1) = 1.00$, and $b(\omega_1) = 7.48799 \times 10^{69}$ (see Fig. 2).

The cost and the recommended course of action for tree types of experts, namely, experts whose probabilities inducing involuntary abortion are 0.5, 0.25, and 0.1 % are summarized in the following table:

Expert physician	4,500 NIS	4,500 NIS	Recommendation
Average physician	Free	570 NIS	(In both cases)
$p_{\mathrm{CVS}}(\omega_1) = 0.5\,\%$	750 NIS	1,316 NIS	Average physician
$p_{\mathrm{CVS}}(\omega_1) = 0.25\,\%$	1,125 NIS	1,689 NIS	Average physician
$p_{\mathrm{CVS}}(\omega_1) = 0.1\,\%$	1,350 NIS	1,913 NIS	Average physician

5.3 Case 3: patient of type 2: $r(\omega_0) < r(\omega_1)$

The patient initial wealth is $x = 850{,}000$ NIS and in the study she was asked to envision gaining one million NIS so that her wealth increased to $y = 1{,}850{,}000$. This

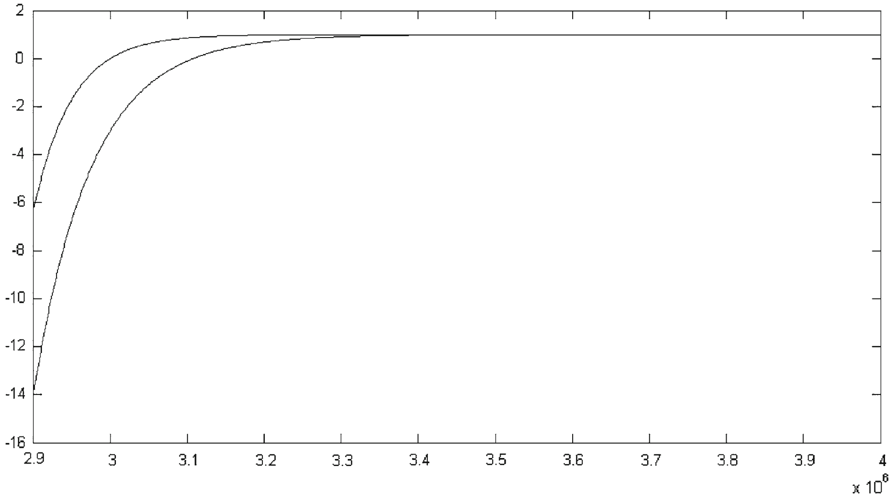

Fig. 2 State-dependent patient, Type 1 ($r_0 > r_1$) (u_{ω_1} and u_{ω_2})

patient indicated her willingness to pay the proportional premia $\pi\ (\omega_0, x) = 0.2$ and $\pi\ (\omega_1, x) = 0.9$ to avoid the proportional risk $\widetilde{\varepsilon}$. Thus, her implied parameter values are $r\ (\omega_0) = 0.27$ and $r\ (\omega_1) = 0.38$.

The patient also indicated willingness to pay to avoid the risk altogether of miscarriage as a result of the test 4,000 NIS at x and 25,000 NIS at y. Consequently, $y_0 = 846{,}000$ and $y_1 = 1{,}825{,}000$. Hence, the alignment of the outcome-dependent functions implies that $d\ (\omega_0) = 1$, $b\ (\omega_0) = 2.747044 \times 10^{63}$, $d\ (\omega_1) = 0.999$, and $b\ (\omega_1) = 1.92374 \times 10^{206}$ (see Fig. 3).

The cost and the recommended course of action for tree types of experts, namely, experts whose probabilities inducing involuntary abortion are 0.5, 0.25, and 0.1 % are summarized in the following table:

Expert physician	4,500 NIS	4,500 NIS	Recommendation
Average physician	Free	570 NIS	(In both cases)
$p_{CVS}\ (\omega_1) = 0.5\,\%$	1,381 NIS	2,034 NIS	Average physician
$p_{CVS}\ (\omega_1) = 0.25\,\%$	2,403 NIS	3,141 NIS	Average physician
$p_{CVS}\ (\omega_1) = 0.1\,\%$	3,248 NIS	4,079 NIS	Average physician

5.4 Case 4: Patient of type 2: $r\ (\omega_0) < r\ (\omega_1)$

The patient initial wealth is $x = 1{,}500{,}000$ NIS and in the study she was asked to envision gaining one million NIS so that her wealth increased to $y = 2{,}500{,}000$. This patient indicated her willingness to pay the proportional premia $\pi\ (\omega_0, x) = 0.1$ and $\pi\ (\omega_1, x) = 0.3$ to avoid the proportional risk $\widetilde{\varepsilon}$. Thus, her implied parameter values are $r\ (\omega_0) = 0.21$ and $r\ (\omega_1) = 0.29$.

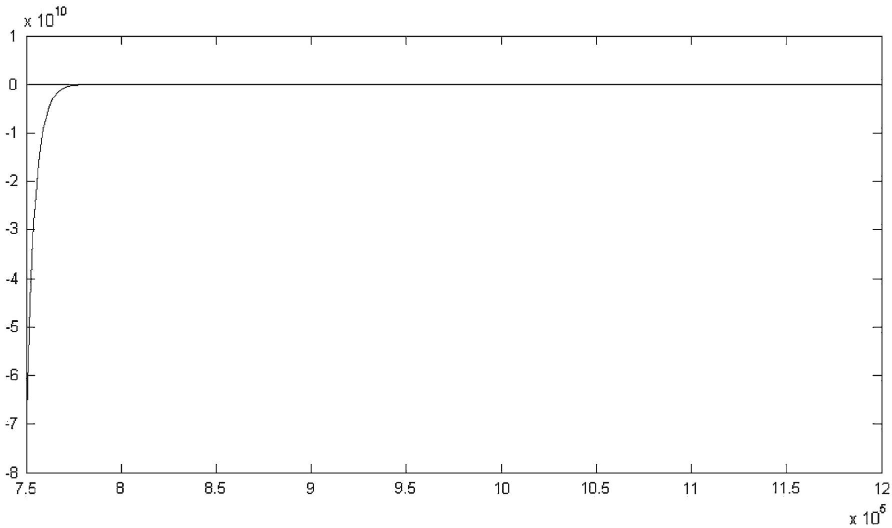

Fig. 3 State-dependent patient, Type 1 ($r_0 < r_1$) (u_{ω_1} and u_{ω_2})

The patient also indicated willingness to pay to avoid the risk altogether of miscarriage as a result of the test 2,000 NIS at x and 2,000 NIS at y. Consequently, $y_0 = 1{,}498{,}000$ and $y_1 = 2{,}498{,}000$. Hence, the alignment of the outcome-dependent functions implies that $d(\omega_0) = 1, b(\omega_0) = 1.37867 \times 10^{40}, d(\omega_1) = 0{,}999$, and $b(\omega_1) = 1.78031 \times 10^{90}$ (see Fig. 4).

The cost and the recommended course of action for tree types of experts, namely, experts whose probabilities inducing involuntary abortion are 0.5, 0.25, and 0.1 % are summarized in the following table:

Expert physician	4500 NIS	4500 NIS	Recommendation
Average physician	Free	570 NIS	
$p_{CVS}(\omega_1) = 0.5\,\%$	958 NIS	1,547 NIS	Average physician in both cases
$p_{CVS}(\omega_1) = 0.25\,\%$	1,467 NIS	4,500 NIS	Average physician if free, expert if subsidized
$p_{CVS}(\omega_1) = 0.1\,\%$	1,784 NIS	4,500 NIS	Average physician if free, expert if subsidized

6 Conclusions

The first main conclusion is that, for a large majority of the subjects participating in this study, the answers are not inconsistent with the basic premises of the decision model. This suggests that the subjects are capable to provide evaluations that can be used in the application of the model, and that, properly applied, the model is a useful instrument to help make medical decisions.

For most subjects the risk attitudes do not depend on the outcome, and for those it does, it has no particular tendency. This suggests that, since involuntary abortion does

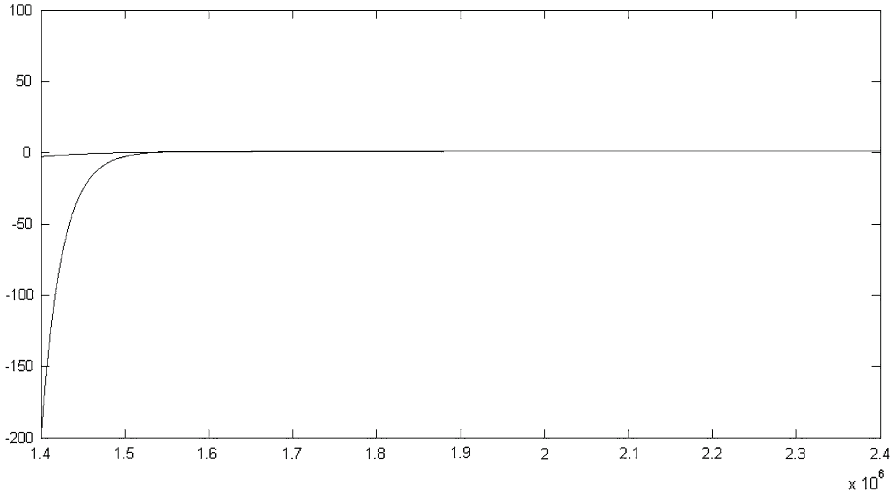

Fig. 4 State-dependent patient, Type 1 ($r_0 < r_1$) (u_{ω_1} and u_{ω_2})

not have long term physical health consequences, such as reduced earning ability, the attitudes towards risk are unaffected.[14]

Health-dependent risk attitudes may prove to be more important when the a treatment alters the health state permanently, or for a significant period of time, with consequences for the earning ability. We also note that, in the cases studied in detail, the subjects displayed decreasing absolute risk aversion and increasing relative risk aversion.[15]

For a large majority of the study population whose responses did not conflict with the underlying premises of the model, it produced recommendations about which course of action that best serves the interests of the subjects which is normatively compelling.

The generality of our conclusion is limited in two respects. First, for the sake of simplicity, we ignored the extremely rare outcome of maternal death as a result of CVS and amniocentesis. Second, the study population is rather homogenous, which may explain the fact that we found no clear distinctions in risk attitudes and between participants in CVS and amniocentesis group according to social-economic measures. In this sense, the study is not representative of the wide spectrum of pregnant women in Israel.

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[14] Rarely abortions may have long-term consequences such as loss of ability to bear children. We did not consider this possibility as an element of our set of outcomes.

[15] Note that, this characterization of risk attitude is consistent with plausible behavior. A fact that lands credence to our measurement method.

References

Abdellaoui, M., Carolina, B., & Wakker, P. P. (2007). Reconciling introspective utility with revealed preference: Experimental arguments based on prospect theory. *Journal of Econometrics*, *138*, 356–378.

Charles, C., Gafni, A., & Whelan, T. (1997). Shared decision-making in medical encounter: What does it mean? (or it takes at least two to tango). *Social Science and Medicine*, *44*, 681–692.

Charles, C., Gafni, A., & Whelan, T. (1999a). Waht do we mean by partnership in making decisions about treatment? *British Medical Journal*, *319*, 780.

Charles, C., Gafni, A., & Whelan, T. (1999b). Decision-making in physicain–patient encounter: Revisiting the shared treatment decision-making model. *Social Science and Medicine*, *49*, 651–661.

Holmes-Rovner, M., Nelson, W., Pignone, M., et al. (2007). Are patient decision aids the best way to improve clinical decision making? Report of the IPDAS symposium. *Medical Decision Making*, *27*, 599.

Holt, Charles A., & Laury, K. Susan. (2002). Risk aversion and incentive effects. *American Economic Review*, *92*, 1644–1655.

Hudak, P. L., Frankel, R. M., Braddock, C, Iii, et al. (2008). Do patients' communication behaviors provide insight into their preferences for participation in decision making? *Medical Decision Making*, *28*, 385.

Karni, Edi. (2009). A theory of medical decision making under uncertainty. *Journal of Risk and Uncertainty*, *39*, 1–16.

Kremer, H., Ironson, G., Schneiderman, N., & Hautzinger, M. (2007). "It's My Body" : Does patient involvement in decision making reduce decisional conflict? *Medical Decision Making*, *27*, 522.

Lewis, D. A., Eysenbach, G., Kukla, R., Stavri, P. Z., & Jimison, H. (Eds.). (2005). Consumer health informatics: Informing consumers and improving health care. Springer.

Saha, Atanu. (1993). Expo-power utility: A flexible form for absolute and relative risk aversion. *American Journal of Agricultural Economics*, *75*, 905–913.

Savage, Leonard J. (1954). *The foundations of statistics*. New York: Wiley.

Wijnberger, L. D. E., van der Schouw, Y. T., & Christiaens, G. (2000). Learning in medicine: Chorionic villus sampling. *Prenatal Diagnosis*, *20*, 6–241.