The CureShare mechanism, the utility from health and wealth, and optimal monopolistic pricing of breakthrough drugs

Thesis submitted for the degree of “Doctor of philosophy”

By Adi Rizansky Nir

Submitted to the senate of the Hebrew University December 2011
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ABSTRACT

This PhD work encompasses three studies.

In the first study we construct a new apparatus allowing patients to take part in the initial pharmaceutical R&D investment aimed for the development of cures for their illnesses. The mechanism we propose can, under certain conditions, lead to the development of drugs that would have otherwise not been developed and to a dramatic welfare increase. We identify the lack of such mechanism as a market failure resulting from a missing market.

At present, drug development projects for many diseases with a relatively small number of patients constitute negative NPV investments for the pharmaceutical companies, and therefore these drugs are not developed. Even if the drug is a life-saver and patients would pay everything they have for it, this may still not be enough to justify development from the company’s perspective. The suggested patient investment mechanism, which we call CureShare, has the potential to alter this occurrence without involving philanthropy or government subsidies.

We theoretically analyze the conditions under which the suggested mechanism increases overall welfare, and further assess its applicability empirically. We show that applying this mechanism can save thousands of lives annually, and can dramatically improve the quality of many others.

In the second study we investigate the utility function of health and wealth both theoretically and empirically. Tradeoffs between health and wealth are among the most important decisions individuals make, and are central to social and economic policy. Yet, surprisingly little is known about the utility of health and wealth. We approach the issue in two steps. First, we theoretically discuss the properties that a utility function from wealth and health should have. This leads us to
the general form $U(h,w)=h*U(w)$. This form is consistent with the findings of a marginal utility of wealth increasing in health (see Viscusi and Evans (1990), Sloan et. al. (1998), and Finkelstein, Luttmer and Notowidigdo (2008)). We then investigate the main utility functions $u(w)$ employed in the economics literature: the logarithmic function, the power function, the negative exponential, and the quadratic utility function. Each function has a different implication regarding the tradeoff between health and wealth, and we derive the theoretical predictions implied by each of these functions. We then employ survey data, collected from detailed personal interviews of 180 cancer patients and questionnaires filled by 132 diabetes patients, to investigate which of the alternative candidate utility functions best fits individuals’ choices. The results obtained show strong support for the utility function $U(h,w)=h\cdot\log(w)$, where $h$ denotes health and $w$ denotes wealth.

We discuss the implications of this utility function for optimal life-cycle savings and show that the empirically observed low-savings rate for retirement purposes, may be less severe of a problem than previously believed. The reason is that this function implies that the optimal consumption is proportional to health, and as health deteriorates with age on average, individuals should optimally consume less at old age.

The third study employs the utility function of health and wealth presented in the second study, in order to derive the optimal pricing of monopolistic breakthrough drugs from the pharmaceutical companies perspective.

New innovative breakthrough drugs compose a small portion of new drugs entering the market, yet they account for the greater part of the non-generic pharmaceutical industry's profit. As these drugs bear little or no competition at all, they are priced monopolistically and thus, generate a
rising public scrutiny due to rapidly increasing expenditures on drugs. We propose a new model for the prediction of the launch price of this unique group of drugs. Following model construction, we analyze 8 currently marketed breakthrough drugs and compare their actual entry prices to those obtained by the theoretical model. Empirical analysis indicates that actual drug pricing generally conforms to the theoretical predictions of the model. The suggested model provides a framework for a quantitative discussion of price cap regulations. We show that appropriate price caps can substantially increase consumer surplus and the number of patients who purchase the drug, while having only a marginal negative effect on the revenues of the pharmaceutical company.
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Introduction

This work enfolds three interrelated studies in health economics. As each work explore a different matter and was carried out independently I shall present for each study the appropriate introduction.

All three studies conducted, called for a definition of the utility function of wealth and health, either as the central purpose of research (second study) or as a fundamental element that influences the model construction and its empirical examination (first and third studies).

The form of the utility function from health and wealth is central to social and economic policies as it represents the individual’s trade-off decisions between optimal consumption and health state. Any empirical examination of this trade-off necessitates the utilization of values representing both wealth/consumption and the health state. While obtaining empirical data on wealth or consumption is relatively straightforward, estimating the health state is somewhat more complex. In all three studies we evaluate the health status of individuals suffering from different diseases, either with an empirical study we conduct (second study) or as denoted in the literature (first and third studies) via well documented methods developed for this purpose. These methods are utilized for estimating Quality Adjusted Life Years (QALYs), which is a key input for cost-effectiveness analysis.

I hereby briefly present the main idea and motivation for each of the three studies:
The CureShare mechanism

The first study deals with a particular type of market failure in the pharmaceutical industry and with ways to overcome this failure. Solving this market failure may potentially lead to a dramatic improvement in the lives of hundreds of thousands of people.

To illustrate the problem and the spirit of the solution consider the following simplified example. Suppose that a "representative patient" suffers from a terminal illness, for which there is currently no cure. If no cure is developed during this period, in the next period the patient will die. Suppose that the patient has wealth of $9 Billion (net of bare-necessity living expenses). The pharmaceutical company therefore knows that if it succeeds in developing the drug, it will be able to sell it to the patient for a maximum of $9 Billion. Assume that the investment required today to develop the drug is $1 Billion, and that the probability of success is $p=10\%$ (which is the typical success probability for drug development). Thus, the NPV for the drug company is $\text{NPV} = -1 + (0.1 \cdot 9) = -0.1$, and it will rationally decide not to pursue the development of this drug. The representative patient simply does not have enough wealth to justify the drug development, and he dies next period with certainty.

Now, suppose that the patient offers to pay the drug company $0.5 Billion today and in addition $8.5 Billion next period, if the drug development succeeds. For the drug company the NPV becomes positive: $\text{NPV} = -1 + 0.5 + (0.1 \cdot 8.5) = 0.35$ and it will develop the drug. The patient now has a $10\%$ chance of being cured in the second period. Of course, there is no miracle here- the negative NPV is borne by the patient, who pays $0.5 Billion for a $10\%

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1 In this simplified example we completely ignore the cost of capital as it is not essential to convey the basic idea. The formal model takes the time value of money and the cost of capital into consideration.
chance to get a $0.5 Billion discount on the drug price next period: $\text{NPV} = -0.5 + (0.1 \cdot 0.5) = -0.45$ (which is the difference between 0.35 and -0.1). This is a price the patient pays for the chance of being alive in the second period. Is it worth it for the patient? A formal answer requires a model of the utility of wealth and health, which is developed in chapter A. However, it is intuitively clear that most of us would be willing to give up some of our wealth today if this gives us a chance to escape death and be cured in the next period. In such situations, the suggested mechanism improves welfare, potentially in a dramatic fashion. The above example is rather extreme, describing a terminal illness and a case where the obstacle for drug development is the patient’s limited wealth. The model we develop below is general, and can be applied to various disorders with different degrees of severity, and different degrees of improvement offered by the drug. In this general case, drug development (or lack of it) depends not only on the patients’ aggregate wealth, but also on the severity of the illness, the health improvement provided by the drug, the time required for development, etc.

Arrow (1963, 1971) discusses several key differences between the health care market and competitive markets, and the resulting possible market failures. The market failure analyzed here is a specific case, resulting from a missing-market problem: at present no mechanism exists which allows patients to directly invest in the development of cures for their illnesses. To be more specific, we describe situations where the patients' total wealth is insufficient, from the perspective of the pharmaceutical company, to justify the high risk of drug development failure (or stated alternatively, the number of patients suffering from the disease is too small). Even if this is a life-saving drug, they simply cannot pay more for it. However, if a market is created where the patients (or any other entity acting on their behalf)
can bear upon themselves some of the development risk by paying a certain amount in advance, the market failure can be overcome. This patient participation in the drug development investment can be thought of as buying a share that offers a future cure, hence the name CureShare suggested for this mechanism.

The purpose of this study is to formalize this idea, and to analyze the conditions under which market failure exists and can be alleviated by the suggested CureShare mechanism. Our goal is not only to develop the theoretical concept, but to analyze the extent to which it is applicable in real life. In other words, how many diseases can be addressed with this mechanism, and how many people could potentially benefit from CureShare?

There are various existing mechanisms for public promotion of pharmaceutical R&D, and it is important to clarify at the outset the differences between these mechanisms and the suggested CureShare mechanism. A major source of public pharmaceutical R&D funding is the government. The main difference between government funding and the CureShare mechanism is that the government invests the money of all taxpayers in a wide spectrum of pharmaceutical areas. Thus, most of the healthy taxpayers subsidize a subgroup of patients. The decision whether to invest in a given R&D project, and how much, is not only a professional one, but to a large degree a social and ethical question. In contrast, in the CureShare mechanism the patients themselves invest, and they invest in development of a cure for their specific illness. Thus, no subsidies are involved. Other sources of public funding are foundations and patient associations. While a large part of these associations’ activities are focused on patient education, federal lobbying, etc., some institutions do engage
in direct R&D investments. While in these cases the funding is focused on a specific disease, it is usually targeted at basic research, which typically takes decades to turn into an applicable cure. In contrast, the CureShare mechanism involves a joint venture with a pharmaceutical company, i.e. it implies investment in the relatively advanced development stage. More importantly, while the public funding mechanism involves a severe free-rider problem, the CureShare mechanism offers a solution to this problem. Clearly, the existing public funding mechanisms play an important role in pharmaceutical development. The CureShare mechanism is not intended to replace the existing mechanisms, but rather to supplement them, facilitating direct patient investment in the effort to seek a cure for their disease in cases where the existing mechanisms fail.

The first issue we need to approach, which sets a fundamental building block for the model we construct, concerns the tradeoff people make between health and wealth. To address this matter we must specify the patient's utility function of both wealth and health and more specifically, to define the dependence of the marginal utility of wealth on the health.

The literature regarding the dependence of the marginal utility of wealth on the health status is mixed. Lillard and Weiss (1997) and Rust and Phelan (1997) find that the marginal utility of wealth decreases with health. Similar results are reported by Evans and Viscusi (1991) for minor health injuries. In contrast, Sloan et. al. (1998) and Finkelstein, Luttmer and Notowidigdo (2008) find that the marginal utility of wealth increases with health. In one of the most extensive and illuminating studies on major work-related injuries, Viscusi and Evans (1990) find that the marginal utility slightly increases with h, but it is almost constant.

2 Some examples are the Milken Institute and the Susan Komen Foundation.
Viscusi and Evans’ work (1990), motivated us to employ a utility function in which the proportion of wealth one is willing to give up for better health, is independent of wealth. We chose to utilize the formulation $U(w,h) = \log(w \cdot h)$ that serves as a useful first-order approximation for the utility of health and wealth (section a of chapter I elaborates on this choice).

In a later independent study (the second study presented below) we found strong empirical evidence for the utility function $U(w,h) = \log(w) \cdot h$ in which the marginal utility of wealth increases with health. This finding urged us to re-evaluate the CureShare model. Thus, in chapter I we present the model in two versions differing in the utility function we employ.

Following the model construction, we perform an empirical analysis of the two versions for five disorders. The empirical results suggest that applying this mechanism may save thousands of lives annually, and may dramatically improve the quality of many others.

The utility of health and wealth

The second study explores the utility of health and wealth both theoretically and empirically. Subsequently, we suggest an exact functional form for the utility of health and wealth $U(h,w) = h \cdot \log(aw)$ and discuss its implication for life cycle savings.


The proportion of total resources spent on health in the U.S. has risen dramatically and continuously over the last fifty years (Hall and Jones 2007). The 2010 U.S. health reform
bill, estimated to cost $940 Billion\(^3\), and the long and heated debate about it, is a recent manifestation of the importance of this issue. Understanding the interaction of health and wealth in the utility function may have profound implications for fundamental economic issues such as the optimal investment in health care and the optimal amount of savings.

In this study, we make use of the neo-classic welfare economics approach, by forming a new utility function from wealth and health. Nevertheless, we wish to mention another approach that has received some attention in health economics and is commonly known as ‘extra-welfarism’ (see for example Culyer, 1990; Hurley, 1998; Hurley, 2000; Brouwer and Koopmanschap, 2000; Birch and Donaldson, 2003). There are several fundamental theoretic differences between the two approaches\(^4\). The main difference between the two schools of thought relates to the delineation of the relevant evaluative space. Under welfarist economics this is, by definition, individual utility, whereas extra-welfarism broadens the evaluative space to include other relevant outcomes in addition to utility, for instance capabilities or characteristics such as health.

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\(^3\) According to the estimates of the Congressional Budget Office, see: http://www.cbo.gov/publications/collections/health.cfm.

\(^4\) The neo-classical framework is built on four key tenets (e.g. Hurley, 2000): (1) the utility principle (i.e. individuals rationally maximize their welfare by ordering options and choosing the preferred option); (2) individual sovereignty (i.e. individuals are themselves the best – some might say ‘the only’ – judges of what contributes most to their utility and how much that contribution is); (3) consequentialism (i.e. utility is derived only from the outcomes of behaviour and processes rather than the processes themselves or intentions that led to the outcomes); and (4) welfarism (i.e. ‘the proposition that the ‘goodness’ of any situation … be judged solely on the basis of the utility levels attained by individuals in that situation’ (Hurley, 1998, p.377) or, as Sen puts it (1986, p.111): ‘judging the goodness of states of affairs only by utility information’).

the extra-welfarist approach differs from the welfarist in four general ways: (1) it permits the use of outcomes other than utility; (2) it permits the use of sources of valuation other than the affected individuals, (3) it permits the weighting of outcomes (whether utility or other) according to principles that need not be preference-based and (4) it permits interpersonal comparisons of well-being in a variety of dimensions, thus enabling moving beyond Paretian economics.
There are two main reasons for which we choose not to adopt the ‘extra-welfarism’ approach in the following analysis:

The first reason- there appears to be no consensus on its definition; nor is there any consensus on a general term to describe a deviation, such as extra-welfarism appears to be, from standard welfare economics. Even the label attached to it is disputed. In addition to ‘extra-welfarism’, ‘non-welfarism’ is sometimes encountered (e.g. Kaplow and Shavell, 2001; Dolan and Olsen, 2002) so proponents of traditional welfare economics can criticize what we shall still call ‘extra-welfarism’ as not only lacking an identity but, since the ‘non’ of non-welfarism seems to put it altogether beyond the bounds of welfare theory, as lacking any sort of foundation in economic theory at all (Birch and Donaldson, 2003).

The second reason has to do with the study objectives and surrounds two issues:

(A) In the ‘extra-welfarism’ practice, health has become the central (if not exclusive) focus of evaluations, given that health care policy makers, as clients of economic analysts, are interested mainly in this aspect of human life. Health is pursued and valued by policy makers for its own sake (and possibly because of its impact on productivity) rather than because it yields utility or merely to the extent that it yields utility. Thus, under extra-welfarism, policy makers become one important potential source of value judgments; such that, the source of valuation of relevant outcomes could be an expert or a representative sample of the general public or an authoritative decision-maker.
In this research, we wish to identify a utility function capturing the trade-off between health and wealth. Hence the model we provide explores the trade from the *individual* point of view and not from the policy maker point of view.

(B) The relevant outcome in the extra-welfarism approach may include individual utility as well as extra measures and indicators of well-being. In health policy, common outcomes will include health or health gain and the distribution of health or health gain, but may include other measures like patient satisfaction or caregiver burden. The selection of relevant outcomes is an important element in extra-welfarist evaluation and is context dependent and seems not for economists to decide. In this research we address the trade-off individuals make between health and wealth, and thus found no advantage in evaluating or designing other outcomes. In addition we find the current work to be a continuation of past papers regarding the utility of health and wealth. These works too, utilized the utility function framework.

Is it reasonable to expect to find a specific utility function that provides a good description for the utility of health and wealth? At first thought, the answer would seem to be negative, because even when discussing the utility of wealth alone, the field is far from reaching a consensus about the shape of preferences. However, perhaps surprisingly, it turns out that considering the interaction and trade-off between wealth and health sheds light on the utility of wealth from a new angle, providing illuminating results. Hence, looking at the more complex two-dimensional decision-making problem provides new insight not only about the health-wealth trade-off, but also about the simpler one-dimensional problem of preferences for wealth.
Most of the empirical research on the utility of health and wealth has focused on the question of whether the marginal utility of wealth increases or decreases with the health state. Most of the evidence suggests that the marginal utility of wealth increases with health (see Viscusi and Evans (1990), Sloan et. al. (1998), and Finkelstein, Luttmer and Notowidigdo (2008)). Our results conform to these findings. The goal of this study is to extend these results and specify an exact functional form for the utility of health and wealth. We first, theoretically discuss the properties that such a utility function should have. We do so by investigating The main utility functions $u(w)$ employed in the economics literature: the logarithmic function, the power function, the negative exponential, and the quadratic utility function. Each function has a different implication regarding the tradeoff between health and wealth, allowing us to derive the theoretical predictions implied by each of these functions. We then employ survey data, collected from detailed personal interviews of 180 cancer patients and questionnaires filled by 132 diabetes patients, to investigate which of the alternative candidate utility functions best fits individuals’ choices.

The empirical study’s main question concerns the patient’s willingness to pay (WTP) for a therapy that completely cures their illness. WTP is often referred to as compensating variation, or the maximum amount of money that can be taken from an individual after having provided a good while still leaving him or her at the same level of utility as before providing the good. In the field of health economics, WTP has been extensively applied in inferring the value of a human life from what people would pay to reduce their risks of premature death. Of these studies, the best known and most influential in health research is

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5 Evans and Viscusi (1991) find that the marginal utility of wealth decreases with health for minor health injuries. Similar results are reported by Lillard and Weiss (1997) and Rust and Phelan (1997).
that of Acton’s (1973) who surveyed several groups to learn how much they would pay for the availability of mobile coronary care units.

The patient's health condition in the cancer survey is assessed based both on the patient's clinical diagnosis and on the patient's subjective responses to a standard gamble (SG) and a time trade off (TTO) question. These are two widely used methods (see, for example, Torrance (1986), Furlong et al. (1990) and Drummond et al. (1997)) which elicit the patient’s utility from health rather than an objective health state.

In both methods, the individual expresses her lack of preference for the outcome by indicating the maximum loss that she would accept to avoid the outcome. In the SG approach, the loss is expressed as a risk of specified bad outcome, often death. In the time trade off approach, the loss is expressed as a reduction in healthy life expectancy.

The accomplishment of the empirical part allows us to evaluate which of the theoretical utility function developed, best describes trade-offs between health and wealth, made by individuals.

The empirical results combined with theoretical predication strongly support the logarithmic function $U(h, w) = h \cdot \log(aw)$, which can be viewed as a generalization of the classic logarithmic utility function of wealth only. In a multi-period setting, wealth becomes consumption, $U(h, c) = h \cdot \log(ac)$.

**Monopolistic pricing of breakthrough drugs**

*The third study presents a model for the monopolistic pricing of breakthrough drugs from the pharmaceutical companies’ perspective. The model allows for the prediction of the*
entry price of breakthrough drugs. We compare the theoretical predictions with the empirical prices and further discuss the effects of price regulation on the company's revenues and on patients' welfare.

The pharmaceutical industry is under rising public scrutiny due to rapidly increasing expenditures on drugs in the United States. Drug outlay is now the fastest-growing component of health care costs, increasing at the rate of about 15 percent per year. This increase is due to both greater use of drugs and due to higher prices for individual drugs. These observable facts complement pharmaceutical industry sales growth, averaging around 12-13 percent annually over the last 15 years, along with its apparent high profitability. The rapid increase in pharmaceutical expenditures in many countries (see for example Besley and Gouvina (1994)) has generated much interest in the pricing strategy and dynamics of drugs. The pricing of pharmaceuticals is complex and controversial. Nonetheless, it is useful to distinguish between prescription drugs that are patent-protected from those whose patent protection has expired. For branded drugs, patent protection implies that the innovating firm has rights to market exclusivity for a time period commonly ranging from 12 to 15 years. Market exclusivity for a certain brand of a prescription drug, does not usually generate a pure monopoly situation, since most branded drugs face competition from other brands within a given therapeutic class. For many therapeutic classes of drugs, a number of possible alternate medications coexist, and in such cases, the market structure is more appropriately depicted by the differentiated product oligopoly framework. In the case of a prescription drug whose patent protection has expired there is no market exclusivity, hence higher level of competition and much lower market price.
In Practice, Many drugs introduced into the market represent similar alternatives or minor improvements relative to existing drugs (often called "me too" drugs). The pricing of these drugs is influenced mainly by the price of the existing competing drugs, market penetration strategies, etc., and is fairly well understood (see Brendt 2002). However, relatively little is known about the pricing of truly innovative drugs that represent breakthrough treatments. According to the International Society of Drug Bulletins only about 2% of new drug treatments approved each year in developed countries offer a real advance to patients. However, this small portion of truly innovative drugs account for a large part of the non-generic pharmaceutical industry's profit. By definition, no real competition exists for these drugs when they are introduced into the market, as they represent clinical breakthroughs, and thus they are priced essentially monopolistically. The present study offers a theoretical predictive model followed by an empirical analysis for the monopolistic pricing of such breakthrough drugs.

There have been a number of empirical studies on the pricing of new patented drugs in the U.S. market. Those prior works explored the pricing of a new drug in the context of competitive available generic and innovative drugs on the same sub-class at the point in time where market entrance took place and later on, when competition become even larger. Reekie (1978), examined the introductory prices of new chemical entities (NCEs) launched in the United States between 1958 and 1975. He found that the introductory price (relative to existing substitutes) depended on the degree of therapeutic gains. This pattern is consistent with the observation made by Dean (1969), who distinguished between two pricing strategies for new products: skimming (setting a relatively high introductory price, and then lowering the price) and penetration (lower introductory prices followed by increased prices as demand
picks up). Dean argued that skimming strategies are more often used for products offering major advantages over existing products, and that penetration strategies are used for products that offer only marginal improvements over existing products. Lu and Comanor (1998) found that the two most important factors affecting the price of new pharmaceuticals both at introductory and after 4, 6 and 8 years were the therapeutic gain and the number of branded substitutes. Weston (1979,1982) also considered factors that affect drug prices. He too found that the market success of a prescription medicine, other things being equal, is affected by its price relative to alternative products on the market.

The above mentioned prior works show that therapeutically innovative drugs are priced higher than existing substitutes, and imitating drugs. This still leaves an open question as for the optimal entry price of a new extremely innovative drug that provides a significant therapeutic advance compared to existing agents, from the pharmaceutical company perspective.

We propose a theoretical model which predicts the annual drug price for breakthrough drugs. The model constructed employs the utility function empirically estimated in chapter II6, \( U(h,c) = h \cdot \log(c) \), to derive the demand for a drug as a function of its price, the health improvement it provides, and the patient's wealth. This demand function is the basis for analyzing the optimal monopolistic price from the point of view of the pharmaceutical company, and the effects of price regulation on the company's revenues and on patients' welfare.

\[ U(h,c) = h \cdot \log(c) \]

6 We utilize the function \( U(h,c) = h \cdot \log(c) \), as we believe it adequately describes the trade off made by individuals between health and wealth. The proposed function, which was empirically obtained in chapter II, shows that the marginal utility of wealth increases with health. As such a characteristic may influence the demand function for a drug, we chose to use this specific utility function while constructing the model presented in the III chapter.
The analysis we present assumes a cash-paying patient, as opposed to a patient acquiring the drug through a health insurance provider. Drug prices for health providers are negotiated with the pharmaceutical company (sometimes by Pharmacy Benefit Managers, or BPM's), and are one of the best-kept secrets in the pharmaceutical industry (see Comanor and Schweitzer (2007)). According to Danzon and Pauly (2002) cash purchases represent about 30% of all drug sales. Developing the optimal pricing formula for health providers would be quite a difficult task, as the price to the patient is typically composed of several different elements such as copayment, coinsurance, and deductables. In addition, empirical testing of this pricing model will be next to impossible because of the secrecy of these prices. These are the reasons we are focusing on cash prices.

The remainder of this work proceeds as follows: chapter I presents the CureShare mechanism, chapter II presents study on the utility of health and wealth, and chapter III presents a model for the monopolistic pricing of breakthrough drugs and further explores the effects of price regulation on the company's revenues and on patients' welfare. Chapter IV summarizes and concludes.
Chapter I

The CureShare mechanism

In this chapter I present a novel mechanism which provides a means to overcome a currently existing market failure in the pharmaceutical industry.

The standard setup of the pharmaceutical industry is such that patients pay for a drug/cure only if its development succeeds, while the pharmaceutical company bares all the risk of development failure. In this framework, drug development projects for many diseases that constitute negative NPV investments for the pharmaceutical companies, are therefore not developed. However, if a market is created where the patients can bare upon themselves some of the risk by paying a certain amount in advance, the market failure can be overcome. We theoretically analyze these conditions.

In section A, I present the baseline utility function of wealth and health $U(w,h)=\log(w \cdot h)$ and relate this formulation to the existing literature. This utility function provides a starting point for the model formation. Section B derives the optimal mechanism design and the conditions under which the CureShare mechanism can improve welfare. In section C, I empirically review some specific disorders that may be candidates for the CureShare mechanism and present the numerical values chosen for empirical analysis. In section D, I provide a lower-bound estimate for the overall range of diseases that can be potentially addressed with CureShare. Section E extends the analysis of the CureShare model to the case of the utility function $U(w,h)=h \cdot \log(w)$, that was attained by an independent
empirical study (see chapter two). Section F concludes with a discussion of the practical implementation issues of the CureShare mechanism, and possible extensions of the model.

**A. The utility of health and wealth**

The patient's main decision is how much wealth to give up for a potential improvement in his health. To address this question we must specify the patient's utility function of both wealth and health. This is quite a formidable task – even when considering utility defined over wealth only, a situation in which one can quite easily conduct preference experiments, there is much controversy about the shape of the utility function. A benchmark case which is considered as reasonable by most economists, and which has been supported empirically and experimentally, is that of constant relative risk aversion, of which a popular choice is the logarithmic utility function, $U(w) = \log(w)$.\(^7\)

When considering a utility function that incorporates health in addition to wealth, $U(w, h)$, the problem is considerably more complicated, because it is not straightforward to experimentally or empirically estimate the utility function.\(^8\) Thus, we do not claim to provide the definite form of the utility of wealth and health. Rather, we would like to suggest a simple utility function that captures the essential elements of decision-making involving wealth and health. We suggest this form as a natural benchmark. We should stress, however,\(^7\)

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\(^7\) Latané (1959), Hakansson (1971), Markowitz (1976) and Samuelson and Merton (1975) advocate constant relative risk aversion. For empirical evidence supporting constant relative risk aversion see, for example, Friend and Blume (1975) and Chiappori and Paiella (2008). Levy (1994) finds experimental support for constant relative risk aversion.

\(^8\) Some models treat certain health impairments (typically minor) as equivalent to a cash reduction. In general, however, wealth cannot be traded for health (for example, if no cure exists), and wealth and health should be treated as separate variables. See Arrow (1974) for a discussion of this point.
that the key ideas presented in this section do not hinge on the specifics of the utility function.

Let us consider the health state \( h \) to be in the range \( 0 < h \leq 1 \), where \( h=1 \) corresponds to perfect health, and \( h=0 \) corresponds to death. Obviously, \( U(w,h) \) should be monotonically increasing in both \( w \) and in \( h \). A question which is not so obvious is whether the marginal utility of wealth increases or decreases with the health state. Suppose that you have wealth \( W \) that you have to allocate between consumption today, when you are healthy, and consumption next period, when you know that you will be ill. On the one hand, when you are ill you will not be able to enjoy your money as much as when you are healthy: traveling around the world will probably be out of the question. This is a reason to consume more today. However, on the other hand, next period when you will be ill, your utility will be lower for any given wealth than in the corresponding healthy state, which may increase the marginal utility benefit of each dollar. This is a reason to consume more next period. A marginal utility increasing in \( h \), \( \partial(U(w,h)/\partial h) > 0 \), implies that you should consume more when you are healthy. A marginal utility decreasing in \( h \) implies the opposite, consume more when ill.

The empirical and experimental evidence regarding the dependence of the marginal utility of wealth on the health status is mixed. Lillard and Weiss (1997) and Rust and Phelan (1997) find that the marginal utility of wealth decreases with health. Similar results are reported by Evans and Viscusi (1991) for minor health injuries. In contrast, Sloan et. al. (1998) find that the marginal utility of wealth increases with health. In one of the most extensive and illuminating studies on *major* work-related injuries, Viscusi and Evans (1990)
find that the marginal utility slightly increases with \( h \), but is almost constant.\(^9\) Given this evidence, it seems that the best first-order approximation is to take the marginal utility as constant in \( h \):

\[
\frac{\partial^2 U(w,h)}{\partial h \partial w} = 0. 
\]  

(1)

There are many possible formulations of \( U(w,h) \) satisfying condition (1). In order to narrow down these possibilities and to focus on the utility functions that seem most reasonable, consider the following situation: Suppose that a person suffers from some illness that corresponds to a health state \( h_{\text{low}} \). A cure is available that can increase the person's health state to \( h_{\text{high}} \). Suppose the person is asked: "what is the maximal proportion of your wealth that you are willing to give up for the cure?". We suggest that it is reasonable to expect this proportion to be roughly independent of wealth. I.e., given a certain illness, the wealthy person and the poor person will be willing to pay approximately the same proportion of their wealth to be cured. This may not precisely hold at the extremes of the very wealthy and the very poor, but it seems a reasonable benchmark for most intermediate wealth levels. Formally, if we denote the maximal proportion of wealth individuals agree to pay in order to improve their health from \( h_{\text{low}} \) to \( h_{\text{high}} \) by \( x \), we have:

\[
U(w,h_{\text{low}}) = U(w(1-x),h_{\text{high}}), 
\]  

(2)

where the \( x \) solving eq.(2) is independent of the wealth, \( w \).

---

\(^9\) Viscusi and Evans (1990) estimate the ratio between the marginal utility of wealth in the healthy state versus an injured state from survey data on major work-related injuries. They estimate this ratio with a structured model to be close to 1, in the range 1.04-1.09 (see their Table 4 on page 366).
The most straightforward formulation that captures the two basic elements given by conditions (1) and (2) is:

\[ U(w,h) = \log(w \cdot h). \]  

(3)

Condition (1) is satisfied because:

\[ \frac{\partial (\partial \log(w \cdot h)/\partial w)}{\partial h} = \frac{\partial (1/w)}{\partial h} = 0. \]  

(4)

As for the second condition, note that eq.(2) becomes in this case:

\[ \log(w \cdot h_{low}) = \log(w(1-x) \cdot h_{high}). \]  

(5)

leading to:

\[ x = 1 - \frac{h_{low}}{h_{high}}. \]  

(6)

Eq.(6) shows that the proportion x is indeed independent of the wealth, and depends only on the severity of the illness (\( h_{low} \)) and the health improvement provided by the cure (\( h_{high} \)).

We advocate that the formulation \( U(w,h) = \log(w \cdot h) \) can serve as a useful first-order approximation for the utility of wealth and health. This formulation is attractive because of its simplicity, and it greatly simplifies the analysis below. Obviously, there are many caveats: there are likely to be individual differences, this function may not provide a good description in the case of the very rich or the very poor, etc. However, we should stress that while we employ this formulation in the analysis that follows, the main ideas presented in this section and the suggested CureShare mechanism are general, and they do not hinge on this specific formulation of the utility of wealth and health. In section E, I expand the analysis of the
CureShare mechanism to the case of the utility function \(U(w,h) = h \cdot \log(w)\) discussed in chapter two

**B. The model**

We employ the most streamlined setup possible to analyze the idea of CureShare: a two-period model with a representative patient. Of course, there are many possible extensions, such as the incorporation of patient heterogeneity, multiple time periods, project abandonment options, etc. However, as these extensions are not essential for conveying the main results, we do not incorporate them in the basic framework, but rather discuss their implications in the concluding section, which considers various practical implementation issues.

The representative patient has an initial wealth \(W\). His current health status is \(h_1\). The patient suffers from a disease, and if no drug/cure is developed his health in period 2 will be \(h_{low}\) with certainty (\(h_{low} \leq h_1\)) If a cure is developed and the patient receives the cure, his period-2 health will be \(h_{high}\) (\(h_{high} > h_{low}\)). The investment required to develop the drug is \(I\), and the investment is all made in period 1. The probability that the drug development will succeed is \(p\) (i.e. there is a probability of \(1-p\) that the investment \(I\) is made but the drug fails).

The patient’s two-period additive utility is given by:

\[
U = \log(c_1h_1) + \beta \log(c_2h_2),
\]

(7)
where $c_t$ and $h_t$ ($t=1,2$) are the period-$t$ consumption and health, respectively, and $\beta$ is the inter-temporal utility discount factor.\(^{10}\) The risk-free interest at which the patient can save is denoted by $R_t (=1+r_t)$, and the pharmaceutical company’s cost of capital is $R (=1+r)$.

In the standard setting of the model (without the CureShare mechanism), the pharmaceutical company makes the initial investment $I$ in period 1, and if the development succeeds, it sells the drug in period 2 at the price which maximizes its profit.\(^{11}\) If the NPV for the pharmaceutical company is positive in this standard setting, there is no need for the CureShare mechanism – the pharmaceutical company will develop the drug without any further incentives. However, if the NPV is negative in the standard setting, the drug will not be developed. In this situation the CureShare mechanism *may* allow for the drug to be developed and for an overall welfare increase. Under the CureShare mechanism the patient pays some amount $x$ in period 1, and if the drug development succeeds, he pays an additional amount $y$ for the drug in period 2. We assume that $x$ and $y$ are determined endogenously by the patient, such that they maximize his expected utility under the condition that the NPV for the drug company is non-negative. In other words, we assume that under the CureShare mechanism all of the welfare increase goes to the patient, and the pharmaceutical company is indifferent to the drug development, because its NPV is increased only to zero. This assumption is made for simplicity – one may argue that some of the welfare increase should go to the pharmaceutical company, and it should have a strictly positive NPV under the

\(^{10}\) We ignore bequest motives. Such motives reduce the demand for the cure both with and without the CureShare mechanism.

\(^{11}\) Assuming that the pharmaceutical company has monopolistic power gives us the maximal lower bound for the applicability of the CureShare mechanism (see Theorem 1 and eq.(26) below). Thus, it is a conservative assumption. Relaxing this assumption and allowing for competition lowers this lower bound and increases the range over which CureShare is applicable.
CureShare mechanism. Assuming that the NPV must be strictly positive does not qualitatively change any of our results.\textsuperscript{12}

Below we derive the conditions under which the suggested CureShare mechanism increases overall welfare. There are two conditions that should hold: (1) Without the CureShare mechanism the NPV of the drug development for the pharmaceutical company is negative, and therefore no cure will be developed without CureShare, and (2) With the CureShare mechanism the patient is willing to pay enough to make the NPV equal to zero for the pharmaceutical company, and the drug will therefore be developed, increasing overall welfare. In deriving these two conditions in Theorems 1 and 2 below, we make use of the following lemma:

\textbf{Lemma 1:} In the absence of drug development, the patient optimally saves

\[ s^* = \frac{\beta}{1+\beta} W \text{ in period 1, and his utility is given by } U_{\text{nodrug}} = \log \left[ \frac{\beta R h_{\text{low}} W^{1+\beta}}{(1+\beta)^{1+\beta}} \right]. \]

\textbf{Proof:} Given a saving of s, the patient’s utility is given by:

\[ U_{\text{nodrug}} = \log((W-s)h_{1}) + \beta \log(sR_{1}h_{\text{low}}). \] (8)

(recall that if the drug is not developed, the patient’s health at period 2 will be \( h_{\text{low}} \) with certainty, and that the patient receives interest \( R_{1} \) on his savings). The optimal savings \( s^* \) in this case is the solution to:

\textsuperscript{12} For example, one can replace the NPV\textsubscript{>0} condition with the condition that the pharmaceutical company will undertake a project only if NPV\textsubscript{>\textalpha}I, where I is the investment required and \( \alpha \) is some positive constant. The only affect this has on the results of Theorems 1 and 2 is that in eqs.(16) and (25) I should be replaced by (1+\alpha)I.
\[
\frac{\partial U_{\text{no drug}}}{\partial s} = -1 \frac{1}{W - s^*} + \beta \frac{1}{s^*} = 0,
\]

or:
\[
s^* = \frac{\beta}{1 + \beta} W.
\]

Plugging this expression for the optimal saving into eq.(8), we find that the utility in the case of no drug development is:

\[
U_{\text{no drug}} = \log \left( \left( W - \frac{\beta}{1 + \beta} W \right) h_1 \right) + \beta \log \left( \frac{\beta}{1 + \beta} W R_{h_{low}} \right) = \log \left[ \frac{\beta^\beta R_{h_{low}} h_{low}}{(1 + \beta)^{1+\beta}} \right].
\]  

Theorem 1 below derives condition (1), the condition stating that in the standard setting (without the CureShare mechanism) the pharmaceutical company will not develop the drug.

**Theorem 1:** The NPV for the pharmaceutical company in the standard setting is negative if and only if

\[
\frac{I}{WN} > \frac{p \beta R_f}{1 + \beta} \left( 1 - \frac{h_{low}}{h_{high}} \right). \quad \text{I.e., if this condition holds the drug will not be developed without the CureShare mechanism.}
\]

**Proof:** Denote the price at which the drug will be sold (if development succeeds) by \( P \). The patient’s expected utility is:

\[
EU_{\text{standard setting}} = \log((W - s) h_1) + (1 - p) \beta \log(s R, h_{low}) + p \beta \log((s R_f - P) h_{high}),
\]

where \( p \) is the probability that the drug succeeds. The price \( P \) and the patient’s savings \( s \) are determined simultaneously. Given that the savings is \( s \), what will the price \( P \) be? The (monopolistic) company will set the price at the maximum value where the patient will be
willing to buy it, i.e. at the price where he will be indifferent between buying the drug or remaining ill:

$$\log((sR_t - P)h_{\text{high}}) = \log(sR_t h_{\text{low}})$$

or:  \( P = sR_t \left(1 - \frac{h_{\text{low}}}{h_{\text{high}}}\right). \)  \( \text{(12)} \)

Plugging this expression for \( P \) in eq.(11) we obtain:

\[
EU_{\text{standard setting}} = \log((W - s)h_1) + (1 - p)\beta \log(sR_t h_{\text{low}}) + p\beta \log\left(sR_t - sR_t \left(1 - \frac{h_{\text{low}}}{h_{\text{high}}}\right)\right)h_{\text{high}} = \\
= \log((W - s)h_1) + (1 - p)\beta \log(sR_t h_{\text{low}}) + p\beta \log(sR_t h_{\text{low}}) = \log((W - s)h_1) + \beta \log(sR_t h_{\text{low}}).
\]

\( \text{(13)} \)

Note that this is exactly the patient’s utility if no drug is developed (see eq.(8)). In other words, the price is set so that the company extracts all the benefits from developing the drug, and the patient’s utility is exactly the same as it was without the drug. Accordingly, the patient’s optimal saving is also identical to the optimal saving without the drug, \( s^* = \frac{\beta}{1 + \beta} \) \( W \).

Plugging this into eq.(12) we find that the drug price is:

\[
P^* = s'R_t \left(1 - \frac{h_{\text{low}}}{h_{\text{high}}}\right) = \frac{\beta}{1 + \beta} WR_t \left(1 - \frac{h_{\text{low}}}{h_{\text{high}}}\right).
\]

\( \text{(14)} \)

Given the prevalence characterizing a specific disease, the NPV of the drug development project from the perspective of the pharmaceutical company is:
\[ NPV = -I + \left( N \left( \frac{pP}{R} \right) \right) = -I + \left( N \frac{p\beta}{1+\beta} W \frac{R_f}{R} \left( 1 - \frac{h_{\text{low}}}{h_{\text{high}}} \right) \right), \tag{15} \]

where \( N \) denotes prevalence and \( I \), the required investment in R&D, and therefore

\[ NPV < 0 \iff \frac{p\beta}{1+\beta} \frac{R_f}{R} \left( 1 - \frac{h_{\text{low}}}{h_{\text{high}}} \right) < \frac{I}{W(N)}. \tag{16} \]

\[ \text{QED.} \]

Eq.(16) shows that if the investment required (I) is too high relative to the wealth of the patients (WN), then the pharmaceutical company will not develop the drug (or stated alternatively, if the success probability p is too low, or if \( h_{\text{high}} \) is not high enough relative to \( h_{\text{low}} \), the drug will not be developed). This is in line with the results of Acemoglu and Linn (2004) regarding the role of market size in pharmaceutical innovation (see also Acemoglu, Cutler, Finkelstein and Linn (2006) for the related analysis of the role of Medicare in innovation). Of course, condition (16) does not necessarily mean that the CureShare mechanism will work in these cases. \( I/(WN) \) may be so high that development won’t be justified even with CureShare. However, Theorem 2 below shows that the upper bound on \( I/(WN) \) may be higher with the CureShare mechanism. This implies that there is a range of \( I/(WN) \) for which the CureShare mechanism can lead to the development of drugs that would not have otherwise been developed, resulting in an overall welfare increase.

**Theorem 2:** If:
\[ \frac{I}{W(N)} < 1 - \left( \frac{R_f h_{\text{low}}^{1+\beta}}{h_{\text{high}}^{1+\beta}} \right) \left( \frac{R - pR_f}{1-p} \right) \left( \frac{1}{R} \right)^\beta \] the CureShare mechanism increases welfare relative to the case of no drug development and therefore the drug will be developed.
Proof:

In the CureShare mechanism the patient pays the pharmaceutical company an amount \( x \) in period 1, and if the drug development succeeds he buys the drug for an amount \( y \) in period 2. \( x \) and \( y \) must be high enough for the pharmaceutical company to be willing to develop the drug, yet low enough to make the patient better off relative to the case were no drug is developed. We assume that \( x \) and \( y \) are set so that the NPV for the pharmaceutical company is zero, i.e. all the welfare increase goes to the patient (see footnote 12 for a discussion of the relaxation of this assumption). I.e.,

\[
NPV = -I + \left( N \right) \left( x + \frac{py}{R} \right) = 0. \tag{17}
\]

The patient’s expected utility is:

\[
EU_{\text{withCS}} = \log((W-s-x)h_1) + \beta p \log((sR_f-y)h_{\text{high}}) + \beta (1-p) \log(sR_f h_{\text{low}}), \tag{18}
\]

where the second term corresponds to the case that the drug succeeds, and the third term corresponds to the case where the drug development fails (and \( y \) is therefore not paid). The patient optimizes \( s, x, \) and \( y \) to maximize his expected utility under the constraint (17). Let us first find the optimal values of \( x \) and \( y \) for a given saving \( s \), and then find the optimal \( s \).

Substituting \( x = \frac{I}{(N)} - \frac{py}{R} \) (from eq.(17)) in eq.(18) and deriving with respect to \( y \), we find that the optimal \( y \) is given by (see appendix):

\[
y^*(s) = \frac{sR_f(N) - \beta R(N) (W-s) + I \beta R}{(N)(1+\beta p)}. \tag{19}
\]
This implies, by the NPV=0 condition (17) that:

\[ x^*(s) = \frac{I}{N} - \frac{p}{R} \left( sR_f(N) - \beta R(N)(W-s) + I\beta R \right) \frac{(N)(1+\beta p)}{(N)(1+\beta p)}. \]  

(20)

Plugging these values into eq.(18) we obtain:

\[ EU_{withCS} = \log \left( W - s - \frac{I}{N} + \frac{p}{R} \left( sR_f(N) - \beta R(N)(W-s) + I\beta R \right) \frac{(N)(1+\beta p)}{(N)(1+\beta p)} \right) h_i \right \} + \beta(1-p) \log \left( sR_f h_{high} \right). \]  

(21)

Deriving with respect to s and equating to zero we obtain the optimal savings \( s^* \):

\[ s^* = \frac{(1-p)\beta R(I - W(N))}{(N)(pR_f - R)(1+\beta)}. \]  

(22)

Employing this value in eq.(21) we obtain the maximal expected utility in the CureShare setting (see appendix 1 for the detailed derivation of eq.(21-23)):

\[ EU_{withCS} = \log \left( \frac{h_i h_{low}^{(1-p)} h_{high}^{\beta(1-p)} R^{\beta(1-p)} R_j^{\beta(1-p)} (W(N) - I)^{1+\beta}}{(N)^{1+\beta}(1+\beta)^{1+\beta} (R - pR_f)^{\beta(1-p)}} \right). \]  

(23)

The CureShare mechanism will be employed only if it improves welfare, i.e. if and only if \( EU_{withCS} > U_{nodrug} \). Using the expressions in eq.(10) and (23) for these utilities, we see that CureShare improves welfare if:
\[
\log \left( \frac{h_i h_{low}^{\beta(1-p)} h_{high}^{\beta P} (1-p)^{\beta(1-p)} R^\beta R_f^{\beta(1-p)} (W(Pr) - I)^{1+\beta}}{(P^i)^{1+\beta} (1+\beta)^{1+\beta} (R - pR_f)^{\beta(1-p)}} \right) > \log \left[ \frac{\beta^\beta R_f^\beta h_i h_{low}^{\beta} \overline{W}^{1+\beta}}{(1+\beta)^{1+\beta}} \right]. \tag{24}
\]

or:
\[
\frac{I}{W(N)} < 1 - \left( \frac{R_f}{h_{low}} \right)^{h_{high}} \left( \frac{R - pR_f}{1 - p} \right)^\frac{\beta}{1+\beta} \left( \frac{1}{R} \right)^{1+\beta}. \tag{25}
\]

Q.E.D.

Eq. (25) shows that the CureShare mechanism works if the investment required is not too high relative to the patients overall wealth, and if the improvement offered by the drug is significant (\( \frac{h_{low}}{h_{high}} \) is small). Combining the results of Theorems 1 and 2, we see that the CureShare mechanism increases welfare by allowing for the development of drugs that would not otherwise be developed if and only if:

\[
\frac{p\beta}{1+\beta} \frac{R_f}{R} \left( 1 - \frac{h_{low}}{h_{high}} \right) < \frac{I}{W(N)} < 1 - \left[ \left( \frac{R_f}{h_{low}} \right)^{h_{high}} \left( \frac{R - pR_f}{1 - p} \right)^\frac{\beta}{1+\beta} \left( \frac{1}{R} \right)^{1+\beta} \right]. \tag{26}
\]

The inequality on the left hand side says that the drug will not be developed in the absence of CureShare (Theorem 1). The inequality on the right hand side says that the drug will be developed with CureShare (Theorem 2). On the one hand, \( I/(WN) \) must be large enough to make development unprofitable for the pharmaceutical company in the standard setting, and on the other hand, it must be lower than the critical value below which the development is welfare-increasing under the CureShare mechanism.
Disorders with parameters satisfying eq.(26) are candidates for which the CureShare mechanism offers a welfare increase. Are there any disorders and medical conditions for which eq.(26) holds? In the next section we address this question empirically.

C. Empirical considerations

a. Candidate diseases

One can very broadly divide diseases into three main categories: orphan diseases, widespread diseases, and diseases with intermediate prevalence. Orphan diseases are disease that affect fewer than 200,000 people (there are more than 5,000 such rare disorders), or diseases that are typical of developing countries (such as tuberculosis, cholera, typhoid, and malaria). In the last 20 years, western governments devoted great deal of financial (via push and pool mechanism) and legislation efforts to incentivize the pharmaceutical industry to promote R&D for orphan diseases.¹³

The second subgroup includes “famous diseases”- high prevalence diseases affecting more than 1,000,000 people, such as hyper tension, diabetes, Alzheimer’s, etc. The pharmaceutical companies aim most of their R&D efforts to these therapeutic areas hoping to

¹³The US Orphan Drug Act of 1983 offered tax incentives on clinical trials and 7 years of marketing exclusivity for drugs developed for conditions that occur only rarely in the US. Since then, more than 200 orphan drugs have been approved by the US Food and Drug Administration (FDA) and are on the market. Similar legislation has been adopted in Japan and Australia.

In the year 2000, the European Union adopted "orphan medicinal products" legislation modeled on the US law, but including tropical diseases and other disorders prevalent only in the developing world. The EU law provides for 10 years of marketing exclusivity, but no tax incentives (because there is no centralized EU taxation system).
generate “block-buster” drugs. The third subgroup is comprised of diseases that affect between 200,000 and 1,000,000 people.

In principle, the CureShare mechanism can be applied to disorders in all three categories. However, it is most likely to finds suitable candidates for CureShare in the third category, that of intermediate prevalence. The reason is that there are many ongoing efforts to develop cures for the “famous diseases” with high prevalence, i.e. drug development projects for these diseases are typically positive NPV projects even without the CureShare mechanism. On the other extreme, for orphan diseases with very few patients (or very poor patients), it is unlikely that patient participation in the investment through the CureShare mechanism will suffice to make the drug development worthwhile from the perspective of the pharmaceutical company. Thus, we focus below on disorders with intermediate prevalence.

Within this category of disorders with prevalence ranging between 200,000 and 1,000,000 patients, we looked for disorders with the following two additional characteristics: 1) the disorder is rather severe – it is not a mere inconvenience, but it is a disorder that substantially affects the patient’s quality of life. 2) There is no known effective cure for these disorders. This has led us to focus on the following five disorders: Crohn's disease, Scleroderma, Polycystic Kidney Disease (PKD), Hemochromatosis, and Ulcerative Colitis. Table 1 provides a short description of these diseases, the current therapies available, disease prevalence in the US, and the Standardized Mortality Ratio (SMR), which is the ratio of the patient mortality to the mortality in the general population. Other than the criteria described above, we applied no additional screening, i.e. we take these five disorders as typical case studies. There are probably quite a few more disorders with similar characteristics.
Here goes table 1, chapter 1
b. Parameter estimation

For each one of the five disorders we wanted to examine whether the conditions in eq.(26) hold, meaning that CureShare increases welfare. This requires us to estimate the parameters: $I, W, p, \beta, R, R_t, Pr$ and the ratio $h_{low}/h_{high}$. Below, I describe how each of these parameters is estimated.

Accurate estimation of the parameters corresponding to the drug development of specific disorders is not an easy task, mainly because a large part of the information is confidential, and is not typically disclosed by the pharmaceutical companies. Thus, for some parameters we will employ estimates available for disorder classes (rather than for the specific disorder considered), while for others we use industry-wide estimates. Obviously, many caveats apply. The purpose of this section, however, is to provide a general picture, rather than to make definitive claims about a specific disorder. We employ our best point estimates for the parameters, but we also conduct sensitivity analysis for a large range of parameter values. The empirical evidence presented below suggests that the CureShare mechanism seems relevant for quite a few disorders, affecting hundreds of thousands of people, and that this result is rather robust to the exact parameter estimates.

$I$ – the cost of drug development. We use the value of $176.5$ million estimated by DiMasi, Hansen and Grabowski (2003). This value is obtained from the average costs per development stage, summed over all clinical stages, for drugs that have obtained FDA approval. Note that this number is lower than most cost estimates reported in the literature, because the literature typically refers to the capitalized cost \textit{per approved new drug} – i.e. if a drug company invests in drugs that are abandoned at some stage of the development or fail to
meet FDA approval (prior to marketing / after phase III clinical studies), these costs are incurred in the cost per approved new drug (see DiMasi et. al. (1991) for a detailed explanation, and also DiMasi et. al. (2003) and Adams and Brantner (2006)). In the context of our model we only look at the direct costs of development for a single drug, given that it went through all the development stages. Moreover, as in our basic model all of the investment is incurred in period 1, we do not capitalize the costs.

$W$ – represents the overall wealth of individuals affected by the particular disorder. We calculate this value by multiplying the US prevalence of the disease, as reported by Table 1, by the median value of wealth per patient. The median net worth of an American household is reported by the US Census Bureau to be $58,905 (see Gottschalck (2008)). In 49% of these households there is a single adult, while in the remaining 51% there are married couples. Thus, we estimate the median wealth per adult as $39,172 (0.51 \cdot 58,905 / 2 + 0.49 \cdot 58,905 = 39,172).^{15}$

$p$ - the probability of drug development success. We employ the success rates of pharmaceutical development reported for the therapeutic category to which the disorder belongs (see Kola and Lansid (2004), and the Impact Report by the Tufts center for the study

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14 For example, suppose that a pharmaceutical company develops 10 different drugs, and invests $100 Million in each one of them. Suppose that eventually only one of these drugs succeeds and obtains FDA approval. The cost per approved drug is $1 Billion. In terms of our model, the relevant parameters in this case are $I=100$ Million and $p=0.1$.

15 As will become evident below, the results do not change much if we take the wealth per household figure instead of the wealth per adult figure.
of drug design (2006))\textsuperscript{16}. The therapeutic category and success probability for each of the five disorders are:

- Crohn’s disease - (GI/metabolism) \( p=0.11 \);
- Scleroderma - (Arthritis and pain management) - \( p=0.167 \);
- Polycystic Kidney Disease - (A general average, not according to a therapeutic category) - \( p=0.11 \);
- Hemochromatosis - (metabolic disorder) - \( p=0.137 \);
- Ulcerative Colitis - (GI/metabolism) - \( p=0.11 \).

\( R_f, R, \beta \) - we take the annual risk free rate as 4\%. We employ the annual cost of capital for drug development estimated by DiMasi et. al. (1991) and DiMasi et. al. (2003) as 11\%. The average time it takes to develop a new drug through all clinical stages is about 10 years (see Gassmann et. al. (2004)).\textsuperscript{17} Thus, we take \( R_f = 1.04^{10} = 1.48 \) and \( R = 1.11^{10} = 2.84 \). For the inter-temporal utility discount factor \( \beta \) we make the common benchmark assumption of \( \beta = 1/R_f \) which yields a value of \( \beta = 0.67 \).

\( h_{low}/h_{high} \) – this ratio reflects the health benefits provided by the new drug. Recall that

\[
1 - \frac{h_{low}}{h_{high}}
\]

is the proportion of his wealth that the patient is willing to pay for a health improvement from \( h_{low} \) to \( h_{high} \) (see eq.6). For example, suppose that a person suffers from a disease and is willing to pay 30\% of his wealth to be cured (immediately and with

\textsuperscript{16} The mentioned articles are published in the PARAXELE book, which is considered to be a very good reference benchmark by the pharmaceutical industry

\textsuperscript{17} This refers to the time for clinical studies. Preclinical studies typically require another 2-3 years. The clinical stages of development require the lion share of investment and time, and it is therefore reasonable that patients' involvement through CureShare will start at the clinical stages. However, the results reported below are not sensitive to this assumption.
certainty). This implies $h_{low}/h_{high}=0.7$. The more severe the disease (and potential improvement) the lower the ratio $h_{low}/h_{high}$. As a proxy for this ratio we employ Quality Of Life (QOL) measures. The QOL measures are the standard approach to estimating the quality (or utility) of life in different health conditions. QOL measures are typically based on direct subjective reporting of individuals in different health states on their health well-being on a scale of 0 to 1, or on indirect elicitation obtained by asking individuals to "trade-off" more years of life in their present health state for less years of life, but in perfect health. Yet another method for estimating the QOL associated with a given health state involves eliciting the indifference point of individuals in this health state to gambles offering perfect health with a certain probability $p$, and death with probability $1-p$ (see Tengs and Wallace 2000 for a comprehensive review of the QOL framework). Of course, there are differences between individuals in the same health condition category, and there is no perfect agreement in the literature about the QOL of a given health state (Brauer et al (2006)).

The QOL measures we use as a proxy for $h_{low}/h_{high}$ are as follows: Crohn’s Disease - 0.68 (Tengs and Wallace 2000); PKD – 0.70 (Sesso and Yoshihiro 1997); Hemochromatosis - 0.75 (Tengs and Wallace 2000); Ulcerative Colitis - 0.83 (Tengs and Wallace 2000). In the case of Scleroderma we did not find a QOL measure in the literature. We estimate the severity of this condition to be roughly similar to those of Chron’s Disease, Hemochromatosis and PKD, and therefore estimate the Scleroderma QOL as 0.70.

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18 A ratio $h_{low}/h_{high}=0.7$ can reflect a health improvement from state $h_{low}=0.7$ to complete health ($h_{high}=1$), or a partial improvement, for example, from a state $h_{low}=0.63$ to a better, but not perfect, health state $h_{high}=0.9$. The implications of both cases are the same in our model, as only the ratio $h_{low}/h_{high}$ appears in eq.(26).
The prevalence rates presented in table 1 exhibit the number of affected individuals but not necessarily the number of patients that will ultimately consume the drug. There are several factors that may lower the pool of potential consumers:

1. **Clinical consideration:**
   The most straightforward factors relate to the clinical indication and warnings of any new drug entering the market. These include the drug contraindication, age, sex and adverse reaction. There are quite a few articles regarding the dangerous drug-drug interactions (see for example Egger et al (2003) and Straubhaar et al (2006)) that preclude many patients from using a drug. This issue, mainly due to the high volume of new drugs entering the market each year, has become a matter of concern in the medical community, especially among the elderly. As these parameters tend to be specific for each drug, we cannot evaluate their effect on the total numbers of potential consumers.

2. **Physicians as gatekeepers to public access for prescribed drugs:**
   Public access to prescribed drugs depends on the adoption/discontinuation processes of doctors that serve as the exclusive decision makers. Attempts to explain differences in drug prescribing patterns have led to the examination of various situational, social, attitudinal and economic factors potentially influencing, or at least related to the physician in the work setting (see Christensen and Bush (1981) and Peay et al (1984)). Among the aspects that are mentioned, are the personal characteristics of physicians, data availability (commercial and non-commercial) which is mainly influenced by the information technology in the medical environment (Leshno et al (2007)), the medical community respond, the intra-group colleague contact and so on. To the best of our knowledge, there do not exist a study which compare adoption patterns for different...
therapeutical categories of drugs, yet, it appears there are differences in the adoption process of new drugs which influence the number of prescription in the after-launch following years. As the adoption pattern appears to be unique for any specific drug, we cannot assume a benchmark figure. Nonetheless, if the adoption process of the medical community for a specific drug tends to be elongated, than the actual prevalence as a measure for the potential market size (from the pharma company standpoint) is distorted. If for example physicians will prescribe a new drug only five years after it entered the market, than theoretically we should employ half of the original prevalence in the empirical examination of the model.

3. Annual consumption level, above or under median wealth/consumption:

We assume the pharma company determines the drug's price-tag according to the market size and the median consumption/wealth level of the potential market. If the drug is priced such that only half of the people, those above the median, will buy it, than effectively this means that we should use half of the prevalence figure.

4. Biological drugs aimed for small subset of patients:

The pharmaceutical industry is on the virtue of the long-awaited next revolution in medicine, commonly called “personalized medicine”. In the near future there would be a shifting of resources from traditional R&D aimed to produce blockbuster drugs to a research taking advantage of existing technology to craft individualized therapies, based on genetic information technologies. This new approach mainly involves the systematic use of genetic information and thus targets smaller patient populations that share some genetic characteristic. Hence, the prevalence figure might be lower in terms of actual market size for a specific disease.
We assume the above mentioned factors may lower the actual number of potential drug consumers, up to 20% of the known prevalence. Thus, we shall further evaluate this effect via a sensitivity analysis presented in the result section. We shall term the percent of patients for which the drug is applicable as “percent of prevalence” in the graphs presented in the result section.

Table 2 reports the estimated values of the disorder-specific parameters we utilize for each of the five disorders considered.

Recall that the CureShare mechanism increases welfare by leading to the development of drugs that would have otherwise not been developed if and only if:

\[
\frac{p\beta_R f}{1 + \beta_R} \left(1 - \frac{h_{low}}{h_{high}}\right) < \frac{I}{W(N)} < 1 - \left[\left(\frac{R_f h_{low}}{h_{high}}\right)^{\frac{1}{1 + \beta}} \left(\frac{R - pR_f}{1 - p}\right)^{\frac{1 - (p)\beta}{1 + \beta}} \left(\frac{1}{R}\right)^{\frac{1}{1 + \beta}}\right]
\]

(see eq.(26)).

Table 2: A summary of the parameters utilized

<table>
<thead>
<tr>
<th>Disorder</th>
<th>(W*full prevalence)</th>
<th>$\frac{h_{low}}{h_{high}}$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crohn's disease</td>
<td>19.59</td>
<td>0.68</td>
<td>0.110</td>
</tr>
<tr>
<td>Scleroderma</td>
<td>11.75</td>
<td>0.70</td>
<td>0.167</td>
</tr>
<tr>
<td>PKD</td>
<td>23.50</td>
<td>0.70</td>
<td>0.110</td>
</tr>
<tr>
<td>Hemochromatosis</td>
<td>39.17</td>
<td>0.75</td>
<td>0.137</td>
</tr>
<tr>
<td>Ulcerative Colitis</td>
<td>9.79</td>
<td>0.83</td>
<td>0.110</td>
</tr>
</tbody>
</table>
**D. Results**

Table 3 (panel A and B) provides the values of the three terms of the inequality (eq.26) for a full prevalence scenario. The shaded cells in the table indicate the disorders for which this inequality holds. For three of the five disorders considered the inequality holds. For these three disorders it seems that the CureShare mechanism can be applied to increase the welfare of hundreds of thousands of patients. I should again stress that there was no pre-screening of these disorders such that eq.(26) will hold. According to this result, the CureShare mechanism is most likely relevant for a large portion of the other disorders within the intermediate-prevalence category.

In panel 3A, I present the primary results which yield a negative Y (i.e.-a ten years cost of drug) for all 5 diseases. A reasonable reason for that stems from the fact that Y serves as a saving for the purpose of drug purchasing. If one chooses to put money in the bank, he gets Rf interest on his savings, but if he invest in the drug, his expected return would be R. as R>Rf, Y may be a negative number. As such a scenario in which a pharmaceutical company pays the consumer in order to sell the drug is unrealistic; we optimize the second condition while limiting Y to a non-zero number, see panel 3B. Consequently Y becomes zero and optimal X decreases. The expected utility with CureShare remains practically the same. The rest of the analysis would be based on the data presented in panel 3B.

In order to analyze the robustness of this result to variations in the parameter values, we vary the parameters of prevalence, probability of success, and h-high and numerically examine the parameter ranges for which eq.(26) holds. The first analysis explores the model sensitivity in regards to variation of h-high and prevalence. We shall assume that h-high is a
Here goes table 3 chapter 1
number between the QOL value utilized (see table 2) and 1. We take the \( p \) values as the point estimates given in table 2. The circles plotted on the graphs represent our point estimates for the five disorders: we assume an individual would choose to participate in the CureShare mechanism if he believes it would substantially improve his health status, thus all circles correspond to a h-high of 0.99. The prevalence values utilized correspond to three potential market scenarios for any new drug entering the market: 40\%, 60\% and 80\% of the full known prevalence. The results are shown in figure 1, panel A-E (see page 45 -47).

The areas with stripes represent the satisfaction of the first condition (i.e.- the R&D project from the pharma company perspective bears a negative NPV in the standard setting) and the blue areas present the satisfaction of the second condition (i.e.-the representative patient’s expected utility with the CureShare mechanism is higher than the utility gained in the standard setting). The overlapping areas represent the satisfaction of the two conditions and provide the limits of applicability. As the figure shows, for four out of five diseases the first condition is always satisfied, regardless of the prevalence or h-high values, and the limiting feature is the second condition which seems to be fulfilled at a relatively high degree of health improvement provided by the drug and a large percent of the prevalence parameter. In the case of ulcerative colitis (lowest prevalence) the second condition is unsatisfied for the entire range. For Hemochromatosis (which present the highest rate of prevalence compared to the other disease analyzed), NPV becomes negative only if the percent of prevalence goes below 63\%. Some points of estimate (plotted dots) for four out of the five disorders are located in the overlapping areas (i.e.-the satisfaction of the two conditions). Yet, we have no means to evaluate the resulting amount of people that would actually choose to participate in the CureShare mechanism. For example, the upper dot in the scleroderma graph (see graph
B), represents a dramatic health improvement, and a relatively high degree of prevalence (80%). Should the prevalence be lower, the proposed mechanism becomes irrelevant. Thus, the issue of prevalence plays an important role in the model realization, and I further discuss it in the discussion part.

Figures 2 to 6 (see page 48-57) show a similar analysis, where the probability of success and h-high are varied, and prevalence is taken as the point estimate value. As prevalence may bear a high degree of variability we provide, for each disease, a sensitivity analysis with four different prevalence rate: 80%, 50% and 20% of total prevalence, and full prevalence. The circles plotted on the graphs represent our point estimates for the five disorders: as with the former graphs, we assume an individual would choose to participate in the CureShare mechanism if he believes it would substantially improve his health status, thus all circles correspond to a h-high of 0.99. The probability of success value corresponds to a 10% chance the R&D succeeds and the drug will be marketed.

Figures 2 to 6 provide an interesting insight to the significance of prevalence in the model. The first is demonstrated in the egg-shaped blue spots. It appears the second condition is satisfied for different people who estimate the same future value of health (i.e.-h-high) with different estimation of the probability of success. A possible explanation for this occurrence may lie in the degree of health improvement from h-low to h-high rather than the final health state achieved by the drug. If for example a person assumes the drug would only provide a small health benefit, than he will choose to buy a CureShare only if the probability of R&D success is high enough, and the opposite. Second, the prevalence rate modifies the over-lapping parts of the two conditions in opposite ways. As the prevalence increases, there is a higher probability the first condition won’t be satisfied. On the other hand, a higher
prevalence increases the range in which the second condition is satisfied. The plotted circles, representing a very high $h$-high (0.99) and a 10% chance of R&D succession, narrow the model applicability as some circles are located outside the overlapping areas. It seems that for PKD, a 50% and 80% prevalence among with a full prevalence scenario, the model is applicable. For Crohn’s and Hemocromatosis there are fewer prevalence ratios for which the circles are located in the overlapping areas.

As the subjective estimation of $h$-high and the probability of success are vague to most people, it is imperative to trim down the data asymmetry between the pharma company and the potential CureShare buyers. I elaborate more on this issue in the discussion part.

In the next section we provide a second version of the model, constructed with a different utility function (presented in chapter II) of health and wealth $U(h,w)=h\log(w)$. We show quite different results, and generally, it seems the model is applicable for more diseases and scenarios.
Figure 1 – Sensitivity analysis with respect to the percent of patients for which the drug is applicable (percent of prevalence) and the health status achieved after drug treatment (h-high).

Success probabilities are taken as the corresponding empirical values: In panel A, C and E: \( p = 0.110 \). In panel B: \( p = 0.167 \). In Panel D: \( p = 0.137 \).

For figures 1-5: The areas with stripes represent the satisfaction of the first condition (i.e.- the R&D project bears a negative NPV in the standard setting) and the blue areas present the satisfaction of the second condition (i.e.-the representative patient’s expected utility with the CureShare mechanism is higher than the utility gained in the standard setting). The overlapping areas represent the satisfaction of the two conditions and provide the limits of applicability.

A. Crohn’s disease

Percent of prevalence
B. Scleroderma

Percent of prevalence

C. PKD

Percent of prevalence
D. Hemochromatosis

E. Ulcerative colitis
Figure 2 – Crohn disease.

Sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel A1 to A4 exhibit different rates of prevalence.
Figure 3 – Scleroderma.

Sensitivity analysis with respect to $h_{high}$ and the probability of success, $p$. Panel B1 to B4 exhibit different rates of prevalence.
B3. 50\% of total prevalence

Probability of success

B4. 20\% of total prevalence

Probability of success
Figure 4 – PKD.

Sensitivity analysis with respect to $h_{high}$ and the probability of success, $p$. Panel C1 to C4 exhibit different rates of prevalence.
Figure 5 – Hemochromatosis.

Sensitivity analysis with respect to \( h_{\text{high}} \) and the probability of success, \( p \). Panel D1 to D4 exhibit different rates of prevalence.

D1. Full prevalence

D2. 80% of total prevalence
D3. 50% of total prevalence

Probability of success

D4. 20% of total prevalence

Probability of success
Figure 6 – Ulcerative colitis.

Sensitivity analysis with respect to $h_{high}$ and the probability of success, $p$. Panel E1 to E4 exhibit different rates of prevalence

E1. Full prevalence

E2. 30% of total prevalence
E. Model extension-a different utility function

In a later study we performed (exhibited in chapter two and that was recently published at the journal of health economics) we investigated the utility function of wealth and health, both theoretically and empirically. We found strong support for the utility function $U(h,w) = h \cdot \log(aw)$, where $h$ denotes health, $w$ denotes wealth and $a$ is scaling parameter that can be thought of as a parameter neutralizing the effect of our choices of units for measuring $w$ ($1/a$ provides the minimal level of wealth. for more data on $a$, see part B of chapter II).

The utility function we utilize in the model construction (part B), $U(h,w) = \log(hw)$ is characterized by a marginal utility that is constant in $h$. In the utility function, $U(h,w) = h \cdot \log(aw)$, presented in chapter II, we show that the marginal utility of wealth increases with health.

As this function differs from the function $U(h,w) = \log(hw)$ we utilized in the original analysis, we were urged to re-evaluate the CureShare mechanism with this utility function. The main difference between

a. The model

The suggested CureShare mechanism increases overall welfare if two conditions are satisfied: (1) Without the CureShare mechanism the NPV of the drug development for the pharmaceutical company is negative, and (2) With the CureShare mechanism the individual’s expected utility with CureShare should be higher than its expected utility without.
As with the original model, we shall demonstrate the mathematical avenue deriving the two conditions, starting with the lemma 1:

**Lemma 1**: In the absence of drug development, the patient optimally saves

\[ s^* = \frac{w\beta h_{low}}{h_1 + \beta h_{low}} \] in period 1, and his utility is given by

\[ U_{nodrug} = \log \left[ \left( \frac{aw}{h_1 + h_{low}\beta} \right)^{h_1 + h_{low}\beta} h_1 \left( h_{low} R_f \beta \right)^{h_{low}\beta} \right]. \]

**Proof**: Given a saving of \( s \), the patient’s utility is given by:

\[ U_{nodrug} = h_1 \log(a(w-s)) + h_{low}\beta \log(asR_f) \] (27)

The optimal saving \( s^* \) is the solution to:

\[ \frac{\partial U_{nodrug}}{\partial s} = \beta h_{low} - \frac{h_1}{w-s} = 0 \]

\[ s^* = \frac{w\beta h_{low}}{h_1 + \beta h_{low}} \]

Plugging this expression for the optimal savings into equation (27), we find the utility in the case of no drug development:

\[ U_{nodrug} = \log \left[ \left( \frac{aw}{h_1 + h_{low}\beta} \right)^{h_1 + h_{low}\beta} h_1 \left( h_{low} R_f \beta \right)^{h_{low}\beta} \right] \] (28)

Theorem 1 below derives condition one, the condition stating that in the standard setting (without the CureShare mechanism) the pharmaceutical company will not develop the drug.
Theorem 1: The NPV for the pharma company in the standard setting is negative if

\[ p \left( aR_f w \beta h_{low} - h_{high} h_{low} \beta h_{low} (w a R_f )^{h_{high}} \right) \]

\[ - I + \frac{(N)}{R a (h_i + \beta h_{low})} < 0. \]

I.e., if this condition holds the drug will not be developed without the CureShare mechanism.

Proof: Denote the price at which the drug will be sold (if development succeeds) by \( P \). The patient’s expected utility is:

\[ EU_{standard} = h_i \log(a - c - s) + h_{low} \beta (1 - p) \log(a s R_f ) + h_{high} \beta p \log \left( a \left( s R_f - P \right) \right) \]  (29)

Where \( p \) is the probability that the drug succeeds. The Drug price and the patient’s savings \( s \), are determined simultaneously. Given that the savings is \( s \), what will the price \( P \) be? The (monopolistic) company will set the price at the maximum value where the patient will be willing to buy it, i.e. at the price where he will be indifferent between buying the drug or remaining ill:

\[ h_{high} \log(a \left( s R_f - P \right)) = h_{low} \log(a s R_f ) \]

or:

\[ P = s R_f - \left( \frac{(asRf)^{h_{low}}}{a} \right) \]  (30)

Plugging this expression for the drug price in eq.(29) we obtain:

\[ EU_{standard} = \]

\[ h_i \log(a - c - s) + h_{low} \beta (1 - p) \log(a s R_f ) + h_{high} \beta p \log \left( a \left( s R_f - s R_f - \left( \frac{(asRf)^{h_{low}}}{a} \right) \right) \right) \]

\[ = \log \left( \left( \frac{ac}{h_i + h_{low} \beta} \right)^{h_{low} + h_{low} \beta} \right) h_i^h \left( h_{low} R_f \right)^{h_{low} \beta} \]  (31)
Note that as with the model presented with the previous utility function of wealth and health, here too, the expected utility in the standard setting is exactly the patient’s utility if no drug is developed (see eq.(27)). Once again, the price is set so that the company extracts all the benefits from developing the drug, and the patient’s utility is exactly the same as it was without the drug. Accordingly, the patient’s optimal saving is also identical to the optimal saving without the drug, \( s^* = \frac{w\beta h_{low}}{h_i + \beta h_{low}} \). Plugging this into eq.(30) we find that the drug price is:

\[
P^* = \frac{w\beta h_{low} - Rf}{h_i + \beta h_{low}} - \frac{\left( a \frac{w\beta h_{low} - Rf}{h_i + \beta h_{low}} \right)^{h_{high}}}{a}\]

(32)

The NPV of the drug development project from the perspective of the pharmaceutical company is therefore:

\[
NPV = -I + \left( \frac{N}{R} \right) p^{(P^*)}, \text{ where } N \text{ denotes prevalence.}
\]

Plugging eq.(32), In the NPV equation and rearranging, yields:

\[
NPV = -I + \left( \frac{N}{R} \right) \left[ \frac{p \left( aR f \frac{w\beta h_{low} - (h_i + \beta h_{low})}{h_{high}} \right)^{h_{high}} \left( waR f \beta h_{low} \right)^{h_{high}}}{Ra(h_i + \beta h_{low})} \right]
\]

(33)
Equation (16) presented in the original model (section B), demonstrate a negative NPV when the investment required (I) is too high relative to the wealth of all the participating patients (W*N), which ultimately prevents the pharmaceutical company from developing the drug. However, eq. (33) unlike eq. (16), does not yield the same logical representation and therefore would not provide a lower limit, as with the former model. Rather, it would be a stand-alone condition: in case the NPV is negative,

$$-I + (N) \left\{ p \left( aR_f \left( w + bh_{low} \right) - (h_1 + bh_{low}) \right)^{h_{high}} \left( aR_f \left( w + bh_{low} \right) \right)^{h_{low}} \right\} < 0$$

the first condition is satisfied, and further examination is required to determine whether the expected utility with CureShare is higher than the expected utility without CureShare.(i.e-the second condition).

**Lemma 2:** If: 

$$h \log \left( a \left( \frac{hR(N)(w-s) - lhR - (N)hRf}{(N)h + \beta ph_{high}} \right) \right) + \beta(1-p)h_{low} \log \left( sR, a \right)$$

$$+ h_{high} \beta \log \left( a \left( \frac{Nph_{high}R(N)(w-s) - \beta ph_{high}RL}{(N)h + \beta ph_{high}} \right) \right) >$$

$$\log \left( \frac{aw}{h + h_{low}} \right)^{h + h_{low} \beta} h \left( h_{low} R_f \beta \right)^{h_{low} \beta}$$

While solved numerically with the optimal s, the CureShare mechanism increases welfare relative to the case of no drug development and therefore the drug will be developed.
In the CureShare mechanism the patient pays the pharmaceutical company an amount \( x \) in period 1, and if the drug development succeeds he buys the drug for an amount \( y \) in period 2. \( x \) and \( y \) must be high enough for the pharmaceutical company to be willing to develop the drug, yet low enough to make the patient better off relative to the case were no drug is developed. We assume, as before, that \( x \) and \( y \) are set so that the NPV for the pharmaceutical company is zero, i.e. all the welfare increase goes to the patient.

\[
NPV = -I + \left( x + \frac{py}{R} \right) N = 0
\]  

(34)

The patient’s expected utility with CureShare is:

\[
EU_{\text{with CS}} = h_l \log \left( (w-s-x)a \right) + h_{\text{high}} \beta p \log \left( (sR_f - y)a \right) + h_{\text{low}} \beta (1-p) \log \left( sR_f a \right)
\]  

(35)

where the second term corresponds to the case that the drug succeeds, and the third term corresponds to the case where the drug development fails (and \( y \) is therefore not paid). The patient optimizes \( s \), \( x \), and \( y \) to maximize his expected utility under the constraint (34). As with the model presented in the first chapter, we aim to find the optimal values of \( x \) and \( y \) for a given saving \( s \), and then find the optimal \( s \). Substituting \( x = \frac{I}{pr} - \frac{py}{R} \) (from eq.(34)) in eq.(35) yields:

\[
EU_{\text{with CS}} = h_l \log \left( \frac{w-s - \frac{I}{N} + \frac{py}{R}} {N} a \right) + h_{\text{high}} \beta p \log \left( (sR_f - y)a \right) + h_{\text{low}} \beta (1-p) \log \left( sR_f a \right)
\]  

(36)

Deriving this expression with respect to \( y \), we find that the optimal \( y \) is:
\[
\frac{\partial EU_{withCS}}{\partial y} = \frac{h_t p}{R\left(c-s-\frac{I}{pr}+py\right)} - \frac{p\beta h_{high} h_t}{(sR_f-y)} = 0
\]

\[
y^*(s) = \frac{h_t sR_f - \beta h_{high} R\left(c-s-\frac{I}{pr}\right)}{h_t + \beta h_{high} p}
\]

(37)

This implies, by the NPV=0 condition (33) that:

\[
x^*(s) = \frac{I}{N} - \frac{p}{R}\left(\frac{h_t sR_f - \beta h_{high} R\left(w-s-\frac{I}{N}\right)}{h_t + \beta h_{high} p}\right)
\]

\[
= \frac{I h_t R - p(N)h_t sR_f + \beta h_{high} p R(N)(w-s)}{R(h_t + \beta h_{high} p)(N)}
\]

(38)

Plugging (37) and (38) into eq.(36) and rearranging, we obtain (39):

\[
EU_{careshare} = h_t \log\left(a\left(\frac{h_t R(N)(w-s) - I h_t R - (N)h_t pR_f s}{(N)R(h_t + \beta p h_{high})}\right)\right) + \\
+ h_{high} \beta p \log\left(a\left(\frac{(N)p sR_f R_{high} + \beta h_{high} R(N)(w-s) - \beta h_{high} R I}{(N)(h_t + \beta p h_{high})}\right)\right) + \\
+ \beta (1-p) h_{low} \log(sR_f a)
\]

(39)
Eq. 34-39 replicates the steps provided by eq. (17-21). In the original CureShare model, we exhibited the optimal saving $s^*$ (see equation (22)), and utilized it to obtain the maximal expected utility in the CureShare setting. However, we were unable to present optimal $s$, as the derivation of eq. (39) in respect to $s$, such an attempt results in a somewhat complex quadratic equation. Alternatively, we shall exhibit a numerical analysis for each of the five diseases analyzed in the first chapter, and provide the numeric optimal saving which maximize the expected utility with the CureShare. After doing so, one can determine whether the second condition, $EU_{\text{withCS}} > U_{\text{no drug}}$, is satisfied:

$$h_1 \log \left( \frac{a \left( h_1 R(N)(w-s) - Ih_1 R - (N)h_1 pR_f s \right)}{(N)R(h_1 + \beta ph_{\text{high}})} \right) + \beta(1-p)h_{\text{low}} \log (sR_f a)$$

$$+ h_{\text{high}} \beta p \log \left( a \left( \frac{(N)psR_f \beta h_{\text{high}} + \beta h_{\text{high}} R(N)(w-s) - \beta h_{\text{high}} RI}{(N)(h_1 + \beta ph_{\text{high}})} \right) > \log \left( \frac{ac}{h_1 + h_{\text{low}} \beta} \right)^{h_1 h_{\text{low}} R_f \beta} \right)^{h_{\text{low}} \beta \beta}$$

(40)

**b. Parameter estimation**

For each one of the five disorders, we examined whether the two conditions are satisfied, which required us to estimate the following parameters:

$I, w, p, R, R_f, \beta, h_1, h_{\text{low}}, h_{\text{high}}, a$. 
In the current analysis, as with the original CureShare study, we assume the R&D period is ten years and that there are additional 10 years in which the people that purchased the CureShare, will consume the new drug. We were motivated to presume a ten years consumption given the two following reason: 1. the disease chosen for analysis are considered chronic, hence we assume the therapy would be a prolonged one, and 2. the patent protection period should expire at about 10 years after launch. During the first ten after-launch years the pharmaceutical company sets the drug price as to maximize its revenue. Following this period, a generic substitute is usually available and the price of drug declines dramatically, sometimes even to less than 50% of the original price.

We made use of the values used in the original CureShare model for \(I, p, R, R_f, \beta, h_{\text{low}}, w\) and estimated \(h_1, h_{\text{low}}, h_{\text{high}}, a\), which were absent from the conditions obtained in the original analysis (see table 4, next page):

- \(h_1\): The representative patient suffers from a disease, and we denote his current health status as \(h_1\). If no drug/cure is developed his health in period 2 will be \(h_{\text{low}}\) with certainty. If a cure is developed and the patient receives the cure, his period-2 health will be \(h_{\text{high}}\) (\(h_{\text{high}} > h_{\text{low}}\)). Thus, \(h_1\) may have a numerical value which is either \(h_{\text{low}}\) or higher: \(h_{\text{low}} \leq h_1 < 1\). We shall commence the analysis with \(h_1 = h_{\text{low}}\), as we assume the current health state is worse enough to justify a CureShare purchasing.
In the original numerical analysis we were in need to utilize the ratio \( \frac{h_{\text{low}}}{h_{\text{high}}} \).

For simplicity, we assumed that \( h_{\text{high}} \) is equal to one and that \( h_{\text{low}} \) is the QOL measurement. We shall follow the same assumption in the following analysis.

\[ \alpha \] can be thought of as a scaling parameter neutralizing the effect of our choices of units for measuring wealth (see chapter II, section B), denoting the minimal wealth level. A recently published report by the Pew Research Center, regarding the wealth gaps between Whites Blacks and Hispanics, reveals the median net worth of household. In 2009, the median net worth of white households—$113,149—was the highest of all groups. In sharp contrast, Hispanic and black households had median net worth of $6,325 and $5,677 respectively\(^{19}\). Following this report, we utilize a minimal wealth level of 6000$. Thus \( \alpha \) corresponds to \( 1/6000 \).

### Table 4- summary of numerical values

<table>
<thead>
<tr>
<th>Disorder</th>
<th>prevalence</th>
<th>( p )</th>
<th>( W )</th>
<th>Investment (millions)</th>
<th>( h_{\text{low}} = h_1 )</th>
<th>( h_{\text{high}} )</th>
<th>( R_f )</th>
<th>( R )</th>
<th>( \beta )</th>
<th>( \alpha )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crohn's</td>
<td>500,000</td>
<td>0.110</td>
<td>39,000</td>
<td>176.5</td>
<td>0.68</td>
<td>1</td>
<td>1.48</td>
<td>2.8</td>
<td>0.67</td>
<td>1/6,000</td>
</tr>
<tr>
<td>Scleroderma</td>
<td>300,000</td>
<td>0.167</td>
<td></td>
<td></td>
<td>0.7</td>
<td>0.7</td>
<td>2.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PKD</td>
<td>600,000</td>
<td>0.110</td>
<td></td>
<td></td>
<td>0.7</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemochromatosis</td>
<td>1,000,000</td>
<td>0.137</td>
<td></td>
<td></td>
<td>0.75</td>
<td>0.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulcerative Colitis</td>
<td>250,000</td>
<td>0.110</td>
<td></td>
<td></td>
<td>0.83</td>
<td>0.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

c. Results

Applying the above mentioned parameters (table 4) yields a negative NPV for three diseases, without the CureShare mechanism. In other words, the pharmaceutical industry’s incentive to promote R&D, in the standard setting, for Crohn’s, Scleroderma and Ulcerative Colitis assuming a full prevalence and perfect health (h-high=1) scenario, do not exist. Thus, in the standard setting no drug would be developed for these diseases. See table 5

Table 5

<table>
<thead>
<tr>
<th>Disorder</th>
<th>NPV of R&amp;D Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crohn's</td>
<td>(19,131,928)</td>
</tr>
<tr>
<td>Scleroderma</td>
<td>(40,411,888)</td>
</tr>
<tr>
<td>PKD</td>
<td>2,777,753</td>
</tr>
<tr>
<td>Hemochromatosis</td>
<td>143,595,492</td>
</tr>
<tr>
<td>Ulcerative Colitis</td>
<td>(130,500,355)</td>
</tr>
</tbody>
</table>

The analysis of the second condition, $EU_{withCS} > U_{nodrug}$, was made in two steps. First, we optimized the expected utility with CureShare allowing s (the saving parameter) to vary in order to obtain the optimal $s^*$ numerically (table 6 panel A and B, next page). The result (panel A) yields a negative $Y$. Hence, we repeat the optimization of $EU_{withCS}$ while limiting $Y$ to a non-negative number (panel B). Table 6 shows the second condition is always satisfied for a setup of full prevalence and h-high=1, and $Y$ equals zero for all diseases. We next repeat the analysis conducted in chapter D in order to analyze the robustness of these results to variations in the parameter values. In Panel A-E of figure 7, we vary prevalence,
and \textit{h-high} for the two conditions. As in the original analysis, we shall assume that h-high is a number between the ignore do not delete

\textbf{Table 6 goes here}
and $h$-high for the two conditions. As in the original analysis, we shall assume that $h$-high is a number between the QOL value utilized and 1, and we take the $p$ values as the point estimates given in Table 4.

The circles plotted on the graphs represent our point estimates for the five disorders: again, we assume an individual would choose to participate in the CureShare mechanism if he believes it would substantially improve his health status, thus all circles correspond to a $h$-high of 0.99. The prevalence values utilized correspond to three potential market scenarios for any new drug entering the market: 40%, 60% and 80% of the full known prevalence. The results of figure 7 shows that the first and second conditions are almost always satisfied, there appears to be a variable range of both the health improvement and actual prevalence which allows for model applicability. Most of the point estimates are located in the overlapping areas (i.e. the satisfaction of the two conditions).

Figure 8 to 12 provides a sensitivity analysis, where the probability of success and $h$-high are varied, and prevalence is taken as four constant values: 80%, 50% and 20% of total prevalence, and full prevalence. The plotted circles represent our point estimates, which correspond to a very high $h$-high (0.99) and a 10% chance of R&D succession.

Results show that the second condition (EU with CS $> U$ standard setting) is always satisfied regardless of prevalence. On the other hand, prevalence rate plays an important role in the first condition (the R&D project bears a negative NPV in the standard setting). As prevalence decline, the overlapping parts (denoting the model applicability) increase. Results show that our points of estimates are usually placed in the overlapping areas. There is an opposite relationship between actual prevalence and the probability of success: as the probability of
success increase, only lower prevalence rates would maintain the point of estimated on the overlapping areas.
Figure 7– Sensitivity analysis with respect to the percent of patients for which the drug is applicable (percent of prevalence) and the health status achieved after drug treatment ($h_{high}$). Success probabilities are taken as the corresponding empirical values: In panel A, C and E: $p=0.110$. In panel B: $p=0.167$. In Panel D: $p=0.137$

For figures 7-12: the area with stripes represents the satisfaction of the first condition and the blue areas present the satisfaction of the second condition. The overlapping parts signify the satisfaction of the two conditions and provide the limits of applicability.
B. Scleroderma

Percent of prevalence

C. PKD

Percent of prevalence
D. Hemochromatosis

E. Ulcerative colitis
Figure 8 – Crohn disease.

Sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel A1 to A4 exhibit different rates of prevalence.

**A1. Full prevalence**

![Graph showing sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel A1 to A4 exhibit different rates of prevalence.]

**A2. 80% of total prevalence**

![Graph showing sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel A1 to A4 exhibit different rates of prevalence.]

Figure 9 – Scleroderma.

Sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel B1 to B4 exhibit different rates of prevalence.

**B1. Full prevalence**

![Full prevalence graph](image)

**B2. 80% of total prevalence**

![80% prevalence graph](image)
B3. 50% of total prevalence

Probability of success

B4. 20% of total prevalence

Probability of success
Figure 10 – PKD.

Sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel C1 to C4 exhibit different rates of prevalence

- C1. Full prevalence
- C2. 50% of total prevalence
C3. 50% of total prevalence

Probability of success

C4. 20% of total prevalence

Probability of success
Figure 11 – Hemochromatosis.

Sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel D1 to D4 exhibit different rates of prevalence.

D1. Full prevalence

Probability of success:

D2. 30% of total prevalence

Probability of success:

- Satisfaction of the first condition
- Satisfaction of the second condition
- Satisfaction of the two conditions
D3. 50% of total prevalence

Probability of success

D4. 20% of total prevalence

Probability of success
Figure 12 – Ulcerative colitis.

Sensitivity analysis with respect to $h_{\text{high}}$ and the probability of success, $p$. Panel E1 to E4 exhibit different rates of prevalence

E1. Full prevalence

Probability of success

E2. 80% of total prevalence

Probability of success
**E.3. 50% of total prevalence**

Probability of success

**E.4. 20% of total prevalence**

Probability of success
F. Discussion

At present, there is no efficient mechanism that allows patients to directly invest in the development of a cure for the disease from which they are suffering. This paper suggests such a mechanism, which we call “CureShare”. We show that the CureShare mechanism can lead to the development of drugs that would have otherwise not been developed, increasing overall welfare. This mechanism does not involve any philanthropy, government financial support, or subsidies.

We exhibit one model in two versions, differing in the utility function form of health and wealth. The two versions share an equivalent rational and mathematical pattern. In the first version exhibited (section B), we presume that the utility function from health and wealth is \( U(w,h) = \log(w \cdot h) \). In a following independent study presented in chapter B, We found strong support for the utility function \( U(w,h) = h \cdot \log(w \cdot \alpha) \). Thus, we chose to also exhibit the model with this utility function (section E).

For the two versions, we derive the conditions under which the CureShare mechanism increases welfare and show that these conditions tends to hold for disorders of intermediate prevalence, with between 200,000 and 1,000,000 patients (but it is not restricted to this category).

An empirical analysis of five typical intermediate prevalence case-study disorders provide different results for each model. Yet in both models the CureShare mechanism can potentially improve the lives of hundreds of thousands of people suffering from such disorders. Beyond the direct welfare increase to patients, the economic benefits of such
health improvements can be tremendous (see Murphy and Topel (2006)). Note that we are discussing here disorders with severe and often disabling health effects, as opposed to minor health effects analyzed in French (2005)). The two models make the simplifying assumption that all of the welfare increase generated by the CureShare mechanism goes to the patients. In any practical application the welfare increase will be divided between the patients and the pharmaceutical companies, i.e. the NPV of the new development projects will be strictly positive from the pharmaceutical companies’ perspective. The positive NPV requirement is straightforward to both models (see footnote 12), and it ensures that the pharmaceutical companies will also have a strong incentive to adopt the CureShare mechanism.

In order to present the main idea clearly and transparently, in this chapter we employ the simplest model that captures the essence of the CureShare mechanism. We have consciously abstracted away several realistic elements. Below we discuss some of these elements, and various possible extensions of the model.

Our models encompass two-periods: the investment is made in period 1, and in period 2 the drug development either succeeds or fails. Obviously, reality is quite a bit more complex. Drug development is typically composed of different clinical stages (phase I, II, and III) with distinct characteristics. The investment for each stage is different, and the ending of each stage is typically a junction where a decision is made about the continuation of the project, based on the clinical results and market information up to that point. The abandonment option may be quite valuable (see, for example, Hsu and Schwartz (2008)). Thus, one possible extension of the models would be to introduce intermediate stages with abandonment options. In this framework the patients’ involvement in the investment may also be made at several different stages corresponding to different success probability of
R&D. In principle, at every stage of the development, if the NPV becomes negative from the perspective of the pharmaceutical company, the CureShare mechanism can potentially be evoked. Of course, such situations involve complex asymmetric information and contractibility issues, and would require professional representation of the patients in the process, via patient associations, government agencies, or new specially designed entities.

In our models, the patients and the pharmaceutical companies interact directly. We have not modeled the role of various health care providers (such as HMO’s), that act as intermediaries between the patients and the drug companies. The main role that health insurance provides is facilitating risk-sharing among individuals who do not know who will become ill in the future. This is very different than the situation discussed here, where individuals know if they are ill or not. However, health care providers may play an important role in the CureShare mechanism by facilitating coordination between patients and by representing various patient groups. Of course, this is not a simple interaction as the interests of the health care providers are not necessarily aligned with those of the patients. While it has been shown that health insurance may lead to excess innovation under certain conditions (Garber, Jones and Romer (2006)), the fact that the number of new drugs developed has been decreasing over the last several decades suggests that this effect does not suffice to overcome the market failure discussed in this chapter.

Another assumption of the presented models is that of a “representative patient”. This assumption circumvents a potentially serious problem that can arise in practical applications – the free-rider problem. Most patients would like for the drug to be developed, but they would rather other patients make the initial investment instead of themselves. To overcome this problem, the patients’ incentives must be such that they would choose to participate in
the investment, rather than wait for other patients to do so. An extreme way to achieve this is to allow only patients who participated in the investment to get the drug if and when development succeeds. This extreme solution may involve ethical problems, for example, what about patients who became ill only after the investment stage? A more moderate way to achieve participation would be to set the price of the drug for non-participants at a very high level. Incentive for participation may also be provided by giving participants priority in participation as subjects in the clinical studies.

Participation need not necessarily be a binary choice. It’s reasonable to assume that Patients who suffer from the disorder will likely buy a large number of shares, while others who only have a genetic tendency towards the disorder, but are not ill yet, may buy only a smaller number of shares or no shares at all. This is in the spirit of Cameron et.al.(1998), where the level of insurance is related to the expectations regarding future health. Of course, the medical condition of the patients may change over time. Allowing for CureShares to be traded in the free market (after the initial investment is made) can facilitate efficient allocation of the shares among patients.

In this chapter we model the development of a single drug for a given disorder. However, it may be optimal for patients to invest in two, or even more, independent efforts to develop a cure for their illness.

In a multi-period setting, investment can be made in several independent efforts in the first stage, while continuing investment only in the most promising direction at later stages. Another possible extension of the model is to the development of vaccines. In this case, the entire population constitutes potential participants in the development. Clearly, many
extensions and variations of the basic CureShare mechanism are possible, and perhaps
different variations would be best suited for different disorders.

It is our hope and belief that the implementation of the CureShare mechanism will
save thousands of lives, and dramatically improve the quality of many others.
Chapter II

The utility of health and wealth

This chapter investigates the utility of health and wealth both theoretically and empirically. Following a theoretical discussion on the main utility functions $u(w)$ employed in the economics literature and their implication regarding the tradeoff between health and wealth, we perform detailed personal interviews with 180 cancer patients, and obtain questionnaires from 132 diabetes patients. We find strong support for the utility function $U(h,w)=h \cdot \log(w)$, where $h$ denotes health and $w$ denotes wealth. The implications of this utility function for optimal life-cycle savings are discussed.

The structure of this chapter is as follows. In the next section we discuss the shape of the utility of health and wealth from a theoretical standpoint. Theoretical considerations lead us to conclude that the utility function should be linear in health\(^20\). Section B suggests several functions as candidates for the utility of health and wealth that can be viewed as generalizations of the standard utility-of-wealth functions employed in the literature. We analyze the health-wealth tradeoff implications of each of these functions. In Section C we describe our surveys, and in Section D we compare the empirical results with the predictions of the various candidate utility functions. We find strong support for the function $U(h,w) = h \cdot \log(aw)$, where $h$ denotes health, $w$ denotes wealth (or consumption) and $a$ is a scaling parameter. Section E explores some of the economic implications of this utility function.

\(^{20}\) Health is elicited by the TTO and SG approaches, yielding the utility of health
A. Theoretical considerations

Consider a general utility function of health and wealth, $U(h,w)$, where $w$ denotes wealth (or alternatively, in a multi-period setting, consumption), and $h$ denotes health. Obviously, $U$ should be increasing (or at least non-decreasing) both in $w$ and in $h$. Viscusi and Evans (1990), Sloan et. al. (1998), and Finkelstein, Luttmer and Notowidigdo (2008) empirically find that the marginal utility of wealth increases with health, i.e.

$$\frac{\partial}{\partial h} \frac{\partial U(h,w)}{\partial w} > 0.$$ 

Can we determine additional properties of the utility function from theoretical considerations?

First, note that the formulation of the utility function depends on how one defines the "level of health", $h$. There are three main alternatives for defining and measuring the health level of a given individual at a given time. In all three approaches $h$ can be defined on a scale of 0 to 1, with 0 representing death and 1 representing perfect health. The first and most common approach is the "Standard Gamble" (SG) approach. In this approach a person who is not perfectly healthy is asked the following question:

"suppose that you are offered a treatment that will cure you and bring you to perfect health with probability $p$, but will cause death with probability $1-p$. What is the minimal $p$ for which you would accept this treatment?"

The health level $h$ is defined as the answer to this question, i.e. in this approach $0 \leq h \leq 1$ is equivalent to the minimal probability at which the above gamble is accepted. Obviously, a perfectly healthy person would not accept this treatment for any $p<1$, i.e. he has $h=1$. The more the person is ill, the lower the probability at which he would be willing to
accept the treatment, i.e. the lower his \( h \) (see, for example, Bleichordt and Johannesson 1997).

The second approach for quantitatively evaluating health is the Time Trade-Off (TTO) approach. In this approach the person is asked how many years of his life he is willing to give up in order to live the years remaining in perfect health. If we denote the expected number of years left by \( T \) and the number of years the person is willing to give up by \( \tau \), \( h \) is typically defined by \( h = 1 - \frac{\tau}{T} \). A perfectly healthy person will not be willing to give up any life years, i.e. for him we have \( \tau = 0 \) and \( h = 1 \). The more ill the person, the higher \( \frac{\tau}{T} \), and the lower \( h \). Again, \( h \) is on the scale of 0 to 1.

The third approach is purely subjective. In this approach the person is typically asked to subjectively assess his health on a scale of 0 to 1\(^{21}\).

For some medical conditions, all three approaches yield similar results (see Torrance 1976, 1986, Krabbe et. al. 1997, Patrick et. al. 1973, Kaplan et. al. 1979, Read et. al. 1984, Bass et. al. 1994, Dolan et. al. 1996, Badia et. al. 1999, Martin et. al. 2000, and Salomon and Murray 2004). Yet other health states have wide ranges of health utilities reported. This may result from differences in the health state descriptions or the populations from which the utilities were elicited (see for example Brauer et al (2006)).

\(^{21}\) Some studies use other scales. For example, the National Health Interview Survey discussed in Section V employs a scale of 1 to 5.
All three approaches are employed to obtain Quality Adjusted Life Year (QALY) estimates that provide an important measure for estimating the welfare increase generated by different treatments.

The first point that I would like to make is that the Standard Gamble approach for defining \( h \) implies that the utility function must be linear in \( h \). This is also true of the Time Trade-Off approach, up to a first-order approximation. This linearity greatly simplifies the theoretical analysis of the possible forms of \( U(h,w) \).

Consider an individual faced with the following "gamble": a treatment that yields health \( h_1 \) with probability \( p_1 \) and health \( h_2 \) with probability \( p_2 \) \((=1−p_1)\). What is the certain level of health \( h^* \) that makes the individual indifferent between it and the uncertain treatment? Notice that in the Standard Gamble approach the health state \( h_1 \) is by definition equivalent to a gamble yielding perfect health with probability \( h_1 \) or death with probability \( 1−h_1 \). Similarly, the health state \( h_2 \) is equivalent to a gamble yielding perfect health with probability \( h_2 \) or death with probability \( 1−h_2 \). Thus, the uncertain treatment is a composite lottery which is equivalent to a gamble yielding perfect health with probability \( p_1 h_1 + p_2 h_2 \) or death with probability \( 1−(p_1 h_1 + p_2 h_2) \). Such a gamble is, again by definition, equivalent to the health state \( p_1 h_1 + p_2 h_2 \). Thus, the uncertain treatment is equivalent to a health level \( h^* = p_1 h_1 + p_2 h_2 \), and the individual is indifferent between the health gamble \( \{p_1 h_1; p_2 h_2\} \) and its expected value \( p_1 h_1 + p_2 h_2 \). Formally, we have:

\[
p_1 U(h_1,w) + p_2 U(h_2,w) = U(p_1 h_1 + p_2 h_2,w), \tag{41}
\]

which implies that \( U \) is linear in \( h \).
While the above analysis is formulated in the one-period setting, it can be extended to the multi-period setting in a straightforward manner. The Time Trade-Off concept by nature involves multiple periods; thus, it must be formulated in the multi-period setting. In this setting we assume a time-separable additive utility function with an inter-temporal discount factor $\rho$ of future utility. In the multi-period context $w$ denotes consumption, rather than terminal wealth. I show below that the Time Trade-Off approach for evaluating $h$ also implies that $U$ is linear in $h$, up to a first order approximation in $\rho$.

Consider an individual with health $h$ and expected $T$ years to live. Let us first assume that health and consumption are constant over time (we later relax the assumption of constant consumption). The total utility of this individual is given by:

$$
\frac{U(h, w)}{1 + \rho} + \frac{U(h, w)}{(1 + \rho)^2} + \ldots + \frac{U(h, w)}{(1 + \rho)^T} = \frac{U(h, w)}{\rho} \left[ 1 - \frac{1}{(1 + \rho)^T} \right].
$$

(42)

In the Time Trade-Off approach $h$ is defined as $1 - \frac{\tau}{T}$, where $\tau$ is the number of years that the individual is willing to give up in order to live his remaining years in perfect health. In this case the individual has $T - \tau$ years to live in perfect health and his utility is:

$$
\frac{U(1, w)}{1 + \rho} + \frac{U(1, w)}{(1 + \rho)^2} + \ldots + \frac{U(1, w)}{(1 + \rho)^{T-\tau}} = \frac{U(1, w)}{\rho} \left[ 1 - \frac{1}{(1 + \rho)^{T-\tau}} \right].
$$

(43)

The individual’s indifference between the two states implies the equality of the utility in (42) and (43), i.e.:
\[
\frac{U(h,w)}{\rho} \left[1 - \frac{1}{(1+\rho)^\theta} \right] = \frac{U(1,w)}{\rho} \left[1 - \frac{1}{(1+\rho)^{\theta-\tau}} \right],
\]

(44)

or:
\[
U(h,w) = U(1,w) \left[1 - \frac{1}{(1+\rho)^\theta} \right] = U(1,w) \left[\frac{(1+\rho)^\theta - (1+\rho)^{\theta-\tau}}{(1+\rho)^\theta - 1} \right].
\]

(45)

Expanding the expression in the square brackets of (45) up to the first order in \( \rho \) we obtain:
\[
U(h,w) \cong U(1,w) \left[1 + \rho^\theta - 1 - \rho\tau \right] = U(1,w) \left[1 - \frac{\tau}{T} \right].
\]

(46)

As \( h \) is defined as \( 1 - \frac{\tau}{T} \), we finally have:
\[
U(h,w) = U(1,w) \cdot h.
\]

(47)

Thus, we again obtain that the utility is linear in \( h \).\(^{23}\) Furthermore, if we denote the utility of consumption (or wealth) when in perfect health by \( u(w) \equiv U(1,w) \) we see that the utility function can be written as follows:

\[\text{(46)}\]

\(^{22}\) The approximation in eq.(46) is good if \( \rho^\theta \) small. For typical values of \( \rho = 0.01, T = 20, \) and \( \tau = 5 \), the exact expression for \( U(h,w) \) as given by eq.(45) yields
\[
U(h,w) = U(1,w) \left[\frac{(1.01)^{20} - (1.01)^5}{(1.01)^{20} - 1} \right] = 0.768 \cdot U(1,w).
\]

The approximation in eq.(46) yields:
\[
U(h,w) = U(1,w) \left[1 - \frac{5}{20} \right] = 0.75 \cdot U(1,w), \text{ i.e. the approximation error is only 2.3%}.
\]

\(^{23}\) This result is generalized to the case of stochastic consumption in a straightforward way. In this case, the expected utility in health state \( h \) is given by:
\[
\frac{EU(h,\tilde{w})}{1+\rho} + \frac{EU(h,\tilde{w})}{(1+\rho)^\theta} + \ldots + \frac{EU(h,\tilde{w})}{(1+\rho)^{(\theta-\tau)}} = \frac{EU(h,\tilde{w})}{\rho} \left[1 - \frac{1}{(1+\rho)^\theta} \right],
\]

and the expected utility in perfect health but \( \tau \) less life years is:

\[\text{\ldots}\]

95
\[ U(h, w) = u(w) \cdot h, \quad (48) \]

where \( u(w) \) is a standard utility of wealth function.

Note that this form conforms with the empirical findings of Viscusi and Evans (1990), Sloan et. al. (1998), and Finkelstein, Luttmer and Notowidigdo (2008), who find that the marginal utility of wealth increases with health, because:

\[ \frac{\partial}{\partial h} \left( \frac{\partial U(h, w)}{\partial w} \right) \geq 0, \quad (49) \]

The formulation in eq.(48) is a special case of the formulation \( U(h, w) = u(w) \cdot q(h) \) in Bleichrodt and Quiggin (1999). Bleichrodt and Quiggin show that this form is implied by the requirement of consistency of utility maximization with the QALY framework, and they develop an axiomatic foundation for this utility function under expected utility and under rank-dependent utility theory. The above analysis shows that in order for \( h \) to be consistent with the standard methods for evaluating health, we must have \( q(h) = h \). The formulation in eq.(48) is also consistent with the model of Hall and Jones (2007, eq.1), where health is measured as the inverse of the mortality rate.

The formulation \( U(h, w) = u(w) \cdot h \) implies that an individual with, say, \( h=0.8 \), enjoys the consumption of a given amount only 0.8 as much as a perfectly healthy individual with \( h=1 \). What is the intuition for this result? Why does an apple yield only 0.8 the utility to an

\[
\frac{EU(1, \tilde{w})}{1+\rho} + \frac{EU(1, \tilde{w})}{(1+\rho)^2} + \ldots + \frac{EU(1, \tilde{w})}{(1+\rho)^{T-\tau}} = \frac{EU(1, \tilde{w})}{\rho} \left[ 1 - \frac{1}{(1+\rho)^{T-\tau}} \right].
\]

The equality between these two expected utilities yields: \( EU(h, \tilde{w}) \approx EU(1, \tilde{w}) \left[ 1 - \frac{\tau}{T} \right] \).
individual with $h=0.8$ than the utility of the same apple to the healthy individual? The TTO approach offers the following intuition. Suppose that consumption is constant at "an apple every period". Consider an individual with $h=0.8$ and 20 years to live. This individual is by definition indifferent between living 20 years with $h=0.8$, or living 16 years with $h=1$. I.e., he is indifferent between eating 20 apples when in state $h=0.8$ and eating only 16 apples in health state $h=1$. Thus, each apple in the $h=0.8$ state yields only 0.8 the utility that the same apple yields in the healthy state.

The utility function of wealth, $u(w)$, is typically investigated by eliciting preferences between different wealth gambles. With the utility of health and wealth given by eq. (48) we can learn about the function $u(w)$ from indifference trade-offs between health and wealth. Thus, the empirical analysis described in Sections C and D reveals not only preferences among health-and-wealth combinations, but it also sheds light from a new perspective on the analysis of the utility function of wealth, $u(w)$. In the next section we examine various specific alternatives for the general function $U(h, w) = u(w) \cdot h$, and analyze their implications for economic behavior.
B. Various Utility Functions and Their Implications

The main utility functions $u(w)$ employed in the economics literature are the logarithmic function, the power function, the negative exponential, and the quadratic utility function. Each of these functions has a different implication regarding the tradeoff between health and wealth. Below we derive the theoretical predictions implied by each of these functions, and in the next section we compare these predictions with the empirical results.

In the empirical study we interview cancer patients about their health state, and about their income and consumption. One of the main questions that the patients are asked is the following: “Suppose that there was a pill that would completely cure you of your illness if taken daily, with no side effects. What proportion of your monthly consumption would you be willing to pay for this treatment?” Each utility function has a different prediction about the answer to this question, as discussed below. Throughout the analysis below $w$ represents wealth in the single-period setting; in the more general multi-period setting $w$ should be interpreted as consumption.

A. Logarithmic Preference

Consider the utility function $u(w) = \log(aw)$ implying the utility of health and consumption.

---

24 Prospect Theory offers an important alternative approach to the expected utility maximization framework, based on changes in wealth. In the context of decisions about health and wealth the expected utility approach seems more appropriate, because it corresponds to “global” decisions about the total wealth, rather than transitory changes in wealth. However, it may be possible to extend the current analysis to the Prospect Theory framework. Maybe to put in discussion.

25 Karni (2009) develops an axiomatic model of medical decision-making, where the utility function parameters depend on the state, and in particular on the health state. Our framework can be viewed as a simplified special case, where the health state is captured by a single parameter - h.
\[ U(h,w) = h \cdot \log(aw) , \quad (50) \]

where \( a \) is a scaling parameter (more on \( a \) below). In the economically relevant range we must have \( aw \geq 1 \), otherwise \( \log(aw) < 0 \), which implies \( \frac{\partial U}{\partial h} < 0 \). Consider an individual with health \( h \). If we denote the maximal proportion of consumption that the person is willing to give up in order to be cured by \( x \), we have:

\[ h \cdot \log(aw) = 1 \cdot \log(aw(1-x)) , \]

where the left hand side is the utility without the treatment, and the right hand side is the utility with the treatment – perfect health but only \( w(1-x) \) to consume. From this equality we obtain:

\[ (aw)^h = aw(1-x) , \quad \text{or:} \]

\[ x = 1 - \frac{1}{(aw)^{1-h}} . \quad (51) \]

First, note that, as one would expect, \( x \) is decreasing in \( h \), i.e. the healthier the individual the lower the proportion \( x \) he is willing to give up for perfect health (and if \( h=1 \), then \( x=0 \)). Furthermore, the proportion \( x \) is increasing in \( w \), i.e. by this utility function the higher the consumption the higher the proportion of it that the individual is willing to give up for perfect health.

The scaling parameter \( a \) plays an interesting part in the analysis. Economists are accustomed to the idea that the utility function is invariant to a positive linear transformation. Thus, in the context of preferences over stochastic monetary alternatives there is no
difference whatsoever between the utility functions $\log(w)$ and $\log(aw)$ for any $a > 0$. In other words, it does not matter if we measure consumption in dollars or in cents. However, in the context of utility over both health and wealth $a$ clearly makes a difference, as eq.(51) reveals. $a$ can be thought of as a scaling parameter neutralizing the effect of our choices of units for measuring $w$. Thus, if we decide to measure $w$ in cents instead of in dollars, $w$ will be multiplied by 100. If we choose $a$ appropriately (i.e. divide its original value by 100), the economic behavior remains invariant to the change in the units of $w$. As discussed above, $aw \geq 1$, otherwise the utility decreases with health. Thus, we have $w \geq \frac{1}{a}$, and $\frac{1}{a}$ can be interpreted as the minimum consumption required for existence. Hence, if we measure $w$ in units of the minimum consumption level, we have $U(h, w) = h \cdot \log(w)$.

B. Power Preference

Consider the generalized power utility function $u(w) = \frac{(w+A)^\gamma}{\gamma}$ with $\gamma < 1$. This function reduces to the well-known Constant Relative Risk Aversion (CRRA) case $u(w) = \frac{w^\gamma}{\gamma}$ for $A = 0$ (see, for example, Kroll, Levy and Markowitz (1984) for this generalization). In the case of a generalized power utility, the utility of health and consumption is given by:

$$U(h, w) = h \cdot \frac{(w+A)^\gamma}{\gamma}.$$  \hspace{1cm} (52)

This function is defined for $w > -A$, i.e. $-A$ can be interpreted as the minimal consumption level required for existence. This function for the utility of health and consumption (with
A=0) has been employed by Kotlikoff (1989), Palumbo (1999), Murphy and Topel (2003) and Domeij and Johannesson (2006). The proportion of consumption, \( x \), that an individual with health \( h \) and consumption \( w \) is willing to give up for perfect health is given by the solution to:

\[
\frac{h \cdot (w+A)^\gamma}{\gamma} = 1 \cdot \frac{(w(1-x)+A)^\gamma}{\gamma},
\]

which yields:

\[
x = \left(1 + \frac{A}{w}\right) \left(1 - h^\gamma\right).
\]

First, note that \( x \) decreases in \( h \), and for perfect health (\( h = 1 \)) we have \( x = 0 \), as expected. Next, note that for the special CRRA case with \( A = 0 \), \( x \) is independent of the consumption, i.e. a rich person and a poor person with the same health state \( h \) are willing to give up the same proportion of their consumption (or wealth) in order to be cured. For \( A < 0 \) the proportion \( x \) increases with consumption, and \( u(w) \) implies Decreasing Relative Risk Aversion (DRRA).\(^{26} \) In contrast, \( A > 0 \) implies that \( x \) decreases with consumption, and \( u(w) \) implies Increasing RRA. As \( -A \) can be interpreted as the minimal consumption level required for existence, we would expect \( A \) to be negative. In the context of utility functions of consumption only, the logarithmic function is equivalent to the generalized CRRA function

\[
u(w) = \frac{(w+A)^\gamma}{\gamma}
\]

when \( A = 0 \) and \( \gamma \to 0 \). In contrast, when the utility is a function of both

\[u'(w) = (w+A)^{\gamma-1}, \quad u''(w) = (\gamma-1)(w+A)^{\gamma-2}, \quad RRA = -u''w/u' = (1-\gamma) \frac{w}{w+A} \frac{\partial RRA}{\partial w} = (1-\gamma) \frac{A}{(w+A)^\gamma}.\]
health and consumption, this equivalence no longer holds. If we take $A=0$ and $\gamma \to 0$ in eq.(54) we obtain $x=1$, in contrast with the logarithmic case that implies $x = 1 - \frac{1}{(aw)^{1-h}}$ (see eq.51). The reason that the equivalence does not hold is that the utility of health and consumption is not invariant to a positive linear transformation of $u(w)$, as discussed above.

C. Negative Exponential Preference

The negative exponential utility function $u(w) = -e^{-bw}$ is very popular because of its analytic tractability properties. As we require $u(w) \geq 0$, (otherwise $U$ decreases with $h$), we must add a positive constant to this function. Thus, we analyze the case where $u(w) = B - e^{-bw}$, with $B>0$, and the relevant range of $w$ is the range over which $u(w) \geq 0$ (i.e. $w \geq -\log(B)/b$). With this utility function the proportion $x$ is given as the solution to:

$$h \cdot (B - e^{-bw}) = 1 \cdot (B - e^{-bw(x-1)})$$

This implies:

$$x = \frac{1}{bw} \log\left( B(1-h)e^{bw} + h \right).$$

In the relevant range $B > e^{-bw}$ $x$ is decreasing in $h$, as expected, and for $h=1$ we have $x=0$.

D. Quadratic Preferences

The quadratic preference is often used as a justification for mean-variance analysis, and as a local approximation for general risk-averse utility functions (see Levy and Markowitz 1979). This function is given by $u(w) = w - bw^2$, and the relevant range where the
function is positive and non-decreasing is \(0 \leq w \leq 1/2b\). The quadratic preference implies that \(x\) is given by:

\[
h \cdot \left(w - bw^2\right) = 1 \cdot \left(w(1-x) - bw^2(1-x)^2\right),
\]

which simplifies to\(^{27}\):

\[
x = 1 - \frac{1 - \sqrt{1 - 4bw(1-bw)}}{2bw}.
\]

As we have seen in this section, each of the commonly employed utility functions \(u(w)\) yields different implications regarding the health-consumption tradeoff. In the result section we compare the theoretical predictions of the different utility functions regarding \(x(w)\) with the results obtained in our surveys.

\(^{27}\) Eq. (17) can be written as \(bwz^2 - z + h(1-bw) = 0\) where \(z \equiv 1-x\). Solving for \(z\) and the requirement that \(x = 0\) for \(h=1\) yields eq.(18).
C. The Surveys

We conducted two independent patient surveys\(^{28}\). The first survey involved personal interviews with cancer patients. The second survey was carried via an internet questionnaire for diabetes patients promoted by the diabetes association. There is no doubt that the personal interview methodology is superior because it allows the interviewer to make sure that the interviewee understands the questions asked, and is consistent in his/her answers. (see Thompson 1986). Indeed, most of our analysis is based on the personal interviews with cancer patients. The diabetes survey allows us to examine the results for a very different medical condition, typically much less severe than that of the cancer patients.

Cancer Survey

The personal interviews were conducted by me and by a specially trained interviewer. The interviews were based on a written questionnaire, provided in the appendix (see appendix 2). 180 cancer patients from two sub-groups were interviewed: 102 breast cancer patients, and 78 colon cancer patients. These are among the two most prevalent cancer types.

The interviews took place in day-care oncology units of HADASSAH and RAMBAM hospitals under the authorization of the two hospital’s Helsinki comities. The two day care units are characterized by patients arriving for a series of chemotherapy treatment, usually, every couple of weeks. During and between the treatments they are not hospitalized, and the majority of interviewed patients, under the age of 63, claim to work in between treatments.

\(^{28}\) For the purpose of survey construction, we consulted several medical experts in the field of oncology and endocrinology.
Each interview typically lasted between 30 to 40 minutes. The interviews were conducted on a voluntary basis, and the response rate was rather high: about 50% of the patients approached agreed to be interviewed while waiting for their medical treatment.

The questionnaire is made up of four main parts: i) general background questions (e.g. age, sex, education, etc.), ii) income, consumption, and health expenditures, iii) medical condition, and iv) questions about Willingness to Pay (WTP) for a cure. Parts iii and iv are central to our analysis, and we expand on them below.

The patient's medical condition is assessed based both on the patient's clinical diagnosis and on the patient's subjective responses. The clinical diagnosis specifies the type of cancer and the cancer phase. The cancer phase is given on a scale of 1-3 indicating the severity of the medical condition. We utilized the Tumor Nodes Metastasis (TNM) staging system for solid tumors\(^{29}\) that classify the following disease phases: Phase I correspond to cancer tumor which is localized to one part of the body (i.e. colon or breast). In Phase II the tumor is locally advanced- there exists regional lymph nodes that are involved. Phase III describes distant metastasis- the spread of cancer from one body part to another.

In addition, the patient is asked two subjective questions that elicit his medical condition. These are the Standard Gamble (SG) and Time Trade-Off (TTO)\(^{30}\), which are extensively used in Quality Adjusted Life Years assessments (see Tammy et. al. 2000). The SG question

\(^{29}\) TNM is developed and maintained by the International union against cancer (UICC) to achieve consensus on one globally recognized standard for classifying the extent of spread of cancer. The TNM classification is also used by the American joint committee of cancer (AJCC) and the International Federation of Gynecology and Obstetrics.

\(^{30}\) In order to utilize the SG and TTO approaches, one must specify that the interviewed individual prefers living with a disease rather than not living at all. To address this issue we asked patients, who chose the last possible answer to question 11 or 12 (appendix 2), if they rather die or continue living in their current health state. In the case of a positive answer, we excluded the interview data from the analysis.
we ask is: "Suppose that there was a new drug that would either cure you completely and bring you to perfect health, or would cause your death. What is the maximal probability of death for which you would accept this drug?"\(^{31}\)

The TTO question we ask is:

"Suppose that there was a new drug that would allow you to live in perfect health, but for a shorter period. How many years of life would you be willing to give up to live the remaining years in perfect health?"

These two questions allow us to estimate the patient's subjective health state, \(h\).

In the fourth part of the questionnaire we ask the patient the central questions to this study, which are about the willingness to pay for a cure:

"Suppose that there was a new drug that would cure you completely and bring you to perfect health. The treatment involves taking a daily pill, with no side effects. What part of your monthly non-medical consumption would you be willing to pay for this drug?"\(^{32}\)

While the above question refers to the patient's actual consumption level, we also ask the same question in a different form. We ask the patient to answer the above question, but assuming he had a different hypothetical monthly consumption. We ask the question for five

\(^{31}\) Before asking this question, we begin with a series of easier questions, e.g.: “Suppose that the probability of death involved by taking the drug is 20%. Would you accept the drug?”. We repeat this question with different probabilities, and only then ask the question where we elicit the indifference probability. This iterative approach allows us to examine the consistency of the subjects' answers. See Thompson (1986) for the advantages of this iterative approach. As the SG question may be misunderstood due to its complexity, we intentionally excluded it from the self reported diabetes survey, and incorporated it only in the interviews with cancer patients.

\(^{32}\) We check for the consistency of the answer in the following way. As the patient reports his income in part ii) of the questionnaire, we ask: "Now, that would mean that you would have … left for you to live on. Could you manage to live on this sum? Would you like to modify your answer?"
hypothetical consumption levels, representing about 25%, 50%, 100%, 200%, and 500% of the average income in the market. Throughout the paper we discuss the non-medical consumption. For the individuals surveyed, the difference between total consumption and non-medical consumption is typically small, as practically all of them have close to full insurance. These questions allow us to estimate the form of $x(w)$ and to compare the survey results with the theoretical predictions of the different utility functions discussed in section B. Note that the above questions are framed in the multi-period setting: the treatment is ongoing, and the percentage of consumption given up for it is out of the monthly consumption.

**Diabetes Survey**

The diabetes patient survey (see appendix 3) is very similar to the cancer patient survey with the following main differences. First, it was conducted by a self reported online questionnaire, rather than by a personal interview. There is no doubt that the personal interview format has many advantages. The main advantage of the self-reported questionnaire format is that it allows us to obtain results in a much more time-efficient way. The second difference is that the willingness-to-pay questions were framed in terms of a one-time payment as a fraction of the total wealth (rather than as a constant monthly payment as a fraction of the monthly consumption, as framed in the cancer patient survey). A recent working paper by Karni et al (2011) presents a procedure designed to aid physicians and patients in the process of making medical decisions based on a model designed by Karni (2009). They too utilize a questionnaire that includes a WTP question in the context of total wealth rather than the patient’s monthly income.
We used the WTP as criteria for survey exclusion—we treated two types of answers as implausible: any response of zero per cent or 100 percent (in one of five hypothetical presented wealth levels) was ignored for further analysis.

The third difference is that we excluded the SG and TTO question since we assumed there are a bit complex, when un-explained in a person–person interface, and thus may be misunderstood. Finally, diabetes is typically a much less severe medical condition than cancer. Hence, the diabetes survey allows us to examine the robustness of the results along these dimensions. The diabetes patient survey appeared on a Diabetes Association website and was endorsed by the association. We have obtained 232 filled surveys and excluded 100 from further analysis.
D. Results

The main purpose of the survey response analysis was to examine which (if any) of the theoretically motivated utility functions reviewed in Section B best describes individuals' health-wealth trade-off choices. Our main survey is the cancer patient survey, and we begin by describing the results obtained in this survey.

Panel A and B of table 7 display results for the two WTP questions in regards to actual and hypothetical income. The two panels show that the percent of income people are willing to pay (WTP-PI) increase as income rises. In order to test the statistical validity of this result we conduct several t-test analyses (panel C and D) while comparing the data collected for the WTP-PI question for different income groups, both actual and hypothetical. Panel C and D correspond to panel A and B respectively. A comparison between different income groups of the hypothetical question (panel D) demonstrates P-value<0.05. A comparison of the different actual income groups (panel C) shows a P-value<0.05 only when comparing the first and fifth quintile. We believe the reason for that has to do with the fact that this data is noisier, given the large standard deviation observed in panel A for all income groups.

Figure 13 (page 112) shows the average percentage of consumption that patients were willing to give up for perfect health as a function of their consumption, i.e. the $x(w)$ in the notation of Section B. The figure reports the answers to the questions referring to hypothetical monthly consumption levels presented to the patients (3,000, 5,000, 10,000, 20,000, and 50,000 NIS; the exchange rate during the time of the survey was about 3.7NIS per $US, and the average household net income was about 11,000 NIS).
Table 7- WTP as proportion of income (WTP-PI).

Panel A report results of the first WTP question. Exhibited are 5 (monthly) income groups in ascending order. Panel B report results of the second WTP question, in which, all subjects reported WTP as percent of income (WPT-PI) to each of five presented hypothetical monthly income level. Numbers in parentheses present standard deviation.

Panel C and D provide results for several T-tests, comparing WTP-PI for different income level groups .panel C compares WTP-PI for actual income, and D compares WTP-PI for hypothetical income .

### Panel A:

<table>
<thead>
<tr>
<th>Number of subjects</th>
<th>Average monthly income (NIS)</th>
<th>WTP-PI</th>
<th>Number of subjects</th>
<th>hypothetical monthly income (NIS)</th>
<th>WTP-PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>4,665 (1232)</td>
<td>26.46 (23)</td>
<td>180</td>
<td>3,000</td>
<td>17.85 (20.59)</td>
</tr>
<tr>
<td>35</td>
<td>7,863 (918)</td>
<td>27.02 (26.28)</td>
<td>180</td>
<td>5,000</td>
<td>24.5 (20.75)</td>
</tr>
<tr>
<td>36</td>
<td>11,198 (1310)</td>
<td>33.36 (23.68)</td>
<td>180</td>
<td>10,000</td>
<td>31.10 (21.22)</td>
</tr>
<tr>
<td>36</td>
<td>16,548 (1506)</td>
<td>37.34 (21.73)</td>
<td>180</td>
<td>20,000</td>
<td>38.9 (22.85)</td>
</tr>
<tr>
<td>35</td>
<td>24,764 (7408)</td>
<td>50.88 (22.20)</td>
<td>180</td>
<td>50,000</td>
<td>48.55 (23.38)</td>
</tr>
</tbody>
</table>

### Panel B:

<table>
<thead>
<tr>
<th>Number of subjects</th>
<th>Average monthly income (NIS)</th>
<th>WTP-PI</th>
<th>Number of subjects</th>
<th>hypothetical monthly income (NIS)</th>
<th>WTP-PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>4,665 (1232)</td>
<td>26.46 (23)</td>
<td>180</td>
<td>3,000</td>
<td>17.85 (20.59)</td>
</tr>
<tr>
<td>35</td>
<td>7,863 (918)</td>
<td>27.02 (26.28)</td>
<td>180</td>
<td>5,000</td>
<td>24.5 (20.75)</td>
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<tr>
<td>36</td>
<td>11,198 (1310)</td>
<td>33.36 (23.68)</td>
<td>180</td>
<td>10,000</td>
<td>31.10 (21.22)</td>
</tr>
<tr>
<td>36</td>
<td>16,548 (1506)</td>
<td>37.34 (21.73)</td>
<td>180</td>
<td>20,000</td>
<td>38.9 (22.85)</td>
</tr>
<tr>
<td>35</td>
<td>24,764 (7408)</td>
<td>50.88 (22.20)</td>
<td>180</td>
<td>50,000</td>
<td>48.55 (23.38)</td>
</tr>
</tbody>
</table>

### Panel C:

<table>
<thead>
<tr>
<th>WTP-PI, Average monthly income</th>
<th>P-value</th>
<th>WTP-PI, hypothetical monthly income</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Vs second quintile</td>
<td>0.971638927</td>
<td>3,000 Vs 5,000</td>
<td>0.002377119</td>
</tr>
<tr>
<td>second Vs third quintile</td>
<td>0.063365641</td>
<td>5,000 Vs 10,000</td>
<td>0.00297859</td>
</tr>
<tr>
<td>Third Vs fourth quintile</td>
<td>0.512734207</td>
<td>10,000 Vs 20,000</td>
<td>0.000859436</td>
</tr>
<tr>
<td>fourth Vs fifth quintile</td>
<td>0.116546149</td>
<td>20,000 Vs 50,000</td>
<td>8.5625E-05</td>
</tr>
<tr>
<td>First Vs fifth quintile</td>
<td>3.32401E-06</td>
<td>3,000 Vs 50,000</td>
<td>7.60592E-33</td>
</tr>
</tbody>
</table>
The circles denote the average x for each of the consumption levels, and they are the
same in all four panels of Figure 13. Each panel depicts the best fit of a different theoretical
utility function to the survey data.

The answers obtained for the actual consumption levels are very similar to the results
obtained with the hypothetical consumption levels. Figure 14 (page 113) shows the
comparison of the actual and hypothetical consumption results. However, as each individual
has only one actual consumption, but all patients answer all five questions about the
hypothetical consumption levels, the actual consumption results are more noisy. Another
advantage of the hypothetical consumption results is that they span a larger range of
consumption levels, and allow us to test the theoretical predictions over a larger domain. This
advantage is particularly important, as we had no patients with an income of 50,000 ILS or
more.

Of course, each individual has a different health condition and possibly different
preferences. By aggregating across individuals we aim to obtain initial insights into the
"typical" preference best describing behavior. In the next step we present results where
individuals are sorted on their health condition.

The average proportion of consumption that individuals are willing to pay for a cure
increases with the consumption level. This result is in accordance with a prior WTP study
conducted by Thompson (1986) with subjects suffering from rheumatoid arthritis.
Figure 13: Cancer Survey Results and Theoretical Predictions

The average proportion of consumption that patients were willing to pay for a complete cure, $x$, is shown by the circles. The solid lines show the best fit for the survey data by the theoretical prediction implied by the various utility functions analyzed: A: logarithmic – eq.(51); $R^2=0.996$. B: generalized power – eq. (54); $R^2=0.882$. C: negative exponential – eq.(56); $R^2=0.992$. D: quadratic – eq. (58).
Figure 14: Hypothetical versus Actual Consumption

The circles represent the answers given when the willingness to pay questions are asked for various hypothetical consumption levels, as in Figure 13. The triangles represent the answers when the question is asked for the patient’s actual consumption level (for each income level, $x$ is averaged over the 20 patients with actual consumption closest to this level). While the actual consumption results are more noisy and span a smaller income range, they are generally similar to the hypothetical consumption results.
Panel A of Figure 13 shows the best-fit of the predictions of the logarithmic utility function (see eq.(51)) to the empirical data. Panel B compares the empirical data with the prediction of the generalized power function (eq.(54)), and panels C and D do the same for the negative exponential function (eq.(56)) and the quadratic function (eq.(58)). The figure reveals that the power function and the quadratic functions yield predictions that deviate systematically and significantly from the survey results. The negative exponential yields a good fit, and the logarithmic utility function \( U(h,w) = h \cdot \log(aw) \) provides an exceptionally good fit over the entire range.

A formal comparison of the goodness-of-fit of the various utility models can be obtained by employing the Akaike Information Criterion (AIC), which takes into account both the deviations of the model's predictions from the empirical data, and the number of parameters in the model. Table 8 (next page) shows this comparison for the four alternative utility functions of health and wealth. The table reveals that the logarithmic function provides the best fit, followed by the negative exponential function in second place. Thus, of the four utility functions, the logarithmic function provides the best fit, but the negative exponential function also provides a good fit. The main problem with the negative exponential is that it implies Constant Absolute Risk Aversion for decisions involving only wealth, and this property is very unrealistic (see, for example, Markowitz, Reid, and Tew 1994). Thus, if we require a utility function of health and wealth that provides a good description of both the health-wealth tradeoff and decisions involving only wealth, we are left with the utility function \( U(h,w) = h \cdot \log(aw) \) as the only good candidate.

---

33 The parameters in eqs.(11), (14), (16) and (18) are fitted to minimize the square distance between the theoretical predictions and the survey results.
Table 8

The table shows the goodness of fit of the four utility models to the empirical data. The second column provides the number of free parameters for each utility function: 1 for the logarithmic (a), 2 for the generalized power function (A, γ), 2 for the negative exponential (B,b), and 1 for the quadratic (b). The third column reports the residual sum of squares for each function, and the fourth column provides the Akaike Information Criterion, given by $2k + n \cdot \ln(RSS)$, where $k$ is the number of free parameters, $n$ is the number of observations, and $RSS$ is the residual sum of squares (Akaike 1974). The lower the AIC, the better the model. The fifth column provides the ranking of the utility functions according to their goodness of fit as measured by the AIC.

<table>
<thead>
<tr>
<th>Utility function</th>
<th># of parameters</th>
<th>Residual sum of squares</th>
<th>AIC</th>
<th>Rank of utility model</th>
</tr>
</thead>
<tbody>
<tr>
<td>logarithmic</td>
<td>1</td>
<td>2.28$\cdot$10^{-4}</td>
<td>-39.9</td>
<td>1</td>
</tr>
<tr>
<td>generalized power</td>
<td>2</td>
<td>6.84$\cdot$10^{-3}</td>
<td>-20.9</td>
<td>3</td>
</tr>
<tr>
<td>negative exponential</td>
<td>2</td>
<td>2.67$\cdot$10^{-4}</td>
<td>-37.1</td>
<td>2</td>
</tr>
<tr>
<td>quadratic</td>
<td>1</td>
<td>0.174</td>
<td>-6.7</td>
<td>4</td>
</tr>
</tbody>
</table>
Eq. (51), which is implied by the logarithmic function, can also be written as:

\[ \log(1-x) = (h-1) \log(aw). \]

Regressing \( \log(1-x) \) on the logarithm of consumption yields an \( R^2 \) of 0.996 and the estimates \( \hat{h} = 0.83 \) and \( \hat{a} = 0.001 \). The value of \( h=0.83 \) is consistent with TTO and SG values reported in several studies exploring health utilities of breast and colon cancer patients. These health estimates range from \( h=0.80 \) to \( h=0.88 \) (see Grann et. al. 1998, Carter et. al. 1998, Gerard et. al. 1993, Launois et. al. 1996, Jansen et. al. 1998 and Smith et. al. 1993). Recall that \( 1/a \) is the minimal consumption level required for existence. The estimated value of \( \hat{a} = 0.001 \) obtained implies that a minimal existence level of 1,000 NIS per month, which seems reasonable.

Figure 13 shows the results aggregated across all patients. While all individuals are cancer patients with either breast or colon cancer, no two patients are alike, and each one has a different clinical condition. In order to examine the effects of the health condition in more detail, we divide the patients into three groups according to their medical condition, i.e. their clinical cancer phase, as described in Section C (phase 3 being the most severe condition). Figure 15 (page 118) shows \( x \) as a function of consumption for the three cancer phase groups.

The figure reveals that the logarithmic function of health and wealth provides an excellent fit to the individuals' choices not only in the aggregate (Figure 13), but also for each subgroup separately. The value of \( h \) estimated for the phase 3 group is 0.82. As expected, this is lower than the \( h \) values obtained for the phase 1 and 2 groups, which are 0.84 and 0.85 respectively (and the difference between these two groups is not statistically significant).

We also regress \( \log(1-x) \) on \( \log(\text{consumption}) \) for each individual separately. I.e. we obtain estimates \( \hat{h}_i \) and \( \hat{a}_i \) for each individual \( i \). We obtain a median value similar to the
values obtained with the aggregate data. Thus, the function $h \cdot \log(aw)$ provides a good description of choices not only at the aggregate level, but at the individual level as well.

The above analysis shows that the logarithmic utility function of health and wealth given by eq.(50) provides an excellent description of the indifference trade-off decisions of cancer patients. We next examine the predictions of this function in the context of the generally less severe medical condition of diabetes, and for decisions framed in terms of total wealth rather than monthly consumption.

Figure 16 shows the proportion of total wealth diabetes patients are willing to pay for a one-time treatment that will completely cure them from their diabetes. The circles represent the average answers for different hypothetical wealth levels, and the solid lines represent the best fit of the predictions implied by the various utility functions. Again, the logarithmic function provides the best fit. Regressing $\log(1-x)$ on the logarithm of wealth yields an $R^2$ of 0.87. The value of $\hat{h}$ obtained is 0.97. This is higher than the $h$ value obtained for the cancer patients, as expected. It is encouraging that we find consistent results for the two very different medical conditions, and for both the multi-period and the single-period frameworks.
Figure 15: Cancer Survey Results by Clinical Phase

The three cancer phases are as described in Section III, phase 3 being the most severe. The demand implied by the logarithmic function (eq.11) fits each of the three groups very well. The best fit value of $h$ obtained for the phase 3 group is 0.82 which is lower than the $h$ values obtained for the phase 1 and 2 groups, 0.84 and 0.85, respectively.
Figure 16: Diabetes Survey Results and Theoretical Predictions

The average proportion of total wealth that diabetes patients were willing to pay for a complete cure, \( x \), is shown by the circles. The solid lines show the best fit for the prediction of the various utility functions, as in Figure 13. As in the cancer patient survey results, the logarithmic function and the exponential function provide the best fit to the survey data. The best fit value of \( h \) for the logarithmic function is 0.97, much higher than the value obtained for cancer patients (0.83), which is as expected, as cancer is typically a much more severe medical condition.
The logarithmic function \( U(h, w) = h \cdot \log(aw) \) can be viewed as a generalization of the classic logarithmic utility function of wealth. For perfect health, or for any situation where the health is constant, the function reduces to the classic Bernoulli function \( U(w) = \log(w) \). This is encouraging, as the logarithmic function is one of the most popular choices for modeling decisions involving wealth (see, for example, Latané 1959, Friend and Blume 1975, Rubinstein 1976, Markowitz 1976, and Sinn 2003). For choices involving both wealth and health, we suggest that the function \( U(h, w) = h \cdot \log(aw) \) is a very good first-order approximation for individual choice.

The survey results show that the logarithmic function of health and wealth provides a very good description of the health-wealth tradeoff for two very different medical conditions, and both in the consumption and in the total wealth contexts. In the next section we analyze some of the economic implications of this utility function.
E. Discussion – life cycle savings

An issue of central concern in recent years is that individuals may not be saving enough for their retirement. This problem has become much more pronounced with the switch from defined-benefit to defined-contribution plans by many firms, placing the burden of savings responsibility on the shoulders of employees (see Thaler and Benartzi 2004). Our findings regarding the utility of health and wealth suggest that while this problem may indeed be very serious, it is probably less severe than previously believed. The reason is that health declines with age on average. As the marginal utility of consumption decreases as health declines (as also been observed by Viscusi and Evans (1990), Sloan et. al. (1998) and, Finkelstein, Luttmer and Notowidigdo (2008)), this implies that individuals should optimally consume less at older age. A reduction in consumption at older age was observed in several studies. Börsch-Supan and Stahl (1991) extend the life cycle model by introducing a constraint on the physical consumption opportunities of the elderly which, if binding, imposes a consumption trajectory declining in age. Their theory explains much of the received evidence on the elderly's consumption and savings behavior, particularly the declining (increasing) of consumption (savings and wealth) with increasing age. A following paper by Börsch-Supan (1992) provides an empirical analysis of saving and consumption choices of the elderly in Germany, based on the German income and expenditure surveys 1978 and 1983. The expenditure data collected in the empirical analysis, suggest the following explanation: due to the generous German pension system and the almost complete coverage of health expenses by the mandatory health insurance in Germany, the declining consumption in very old age cannot exhaust the annuity income of the elderly such that wealth is being accumulated in old age. Hurd (1992) reviews some evidence on how wealth
changes as the elderly age. He shows the elderly do dissave as required by the life-cycle hypothesis. Next, he presents some findings based on consumption data in the Retirement History Survey (RHS). As measured in the RHS, consumption declines as household’s age, which is in accordance with the lifecycle hypothesis.

Our empirically estimated logarithmic utility of health and consumption allows us to quantify the magnitude of this effect, and we find it to be quite substantial. Domeij and Johannesson (2006) conduct a similar analysis with a power utility of consumption, and a much more elaborate model, capturing the effects of morbidity risk, limited borrowing, age-dependent income, and bequest motives. They calibrate their model to Swedish health and income data, and solve for the optimal consumption path numerically. As we wish to isolate only the effects of age-dependent health on the optimal consumption, below we adopt a very simplified model, abstracting from many of the above mentioned features.

Consider an individual with a time-separable additive lifelong utility function of the form:

$$U = \sum_{t=0}^{T} \frac{1}{(1+\rho)^t} U(h_t, c_t),$$

(59)

where $c_t$ and $h_t$ are the period $t$ consumption and health, respectively, and $\rho$ is the discount rate for future utility. Denoting the individual's current wealth plus the present value of the lifelong future income stream by $W$, we have the constraint that the present value of lifelong consumption cannot exceed $W$:

$$\sum_{t=0}^{T} \frac{c_t}{(1+r)^t} \leq W,$$

(60)
where $r$ is the rate of return on savings. Utility maximization yields the first order condition:

$$\frac{\partial U(h,t,c)}{\partial c_t} = \lambda \left( \frac{1+r}{1+\rho} \right)^t$$

for all $t$, \hspace{1cm} (61)

where $\lambda$ is a constant determined by the constraint (60). Plugging the empirically estimated function $U(h,c) = h \cdot \log(ac)$ we obtain:

$$\frac{h_t}{c_t} = \lambda \left( \frac{1+r}{1+\rho} \right)^t, \text{ or: } c_t = \frac{h_t}{\lambda} \left( \frac{1+r}{1+\rho} \right)^t.$$ \hspace{1cm} (62)

Note that in this analysis we are assuming that the health state is exogenous – i.e. we are implicitly assuming full health insurance coverage – one cannot pay to substantially improve the exogenously given health. This assumption is clearly unrealistic for individuals in several countries, especially in the lower socio-economic groups. However, it seems a reasonable approximation for the median and high-income classes. In addition, there are countries in which the older population is considered to have complete coverage of health expenses, Germany for example (for more info see the empirical analysis provided by Börsch-Supan (1992)).

Allowing individuals to trade consumption for health significantly complicates the analysis, because in this case one would have to specify the health-technology available (or the “health production function”), and this depends on many factors such as the clinical health condition, age, etc.

---

34 We do not model bequest explicitly. Bequest can be expressed through $W$, i.e. one can replace $W$ by $W^* = W - b/(1+r)^T$, where $b$ is the bequest.
Consider the baseline case of $\rho = r$, where (62) simplifies to:

$$c_t = \frac{h_t}{\lambda}.$$  \hfill (63)

In the case where health is constant, $h_t = h$, we have constant consumption, consistent with the permanent-income hypothesis of Friedman (1957). However, as health typically deteriorates with age, the optimal consumption is not constant but given by eq.(63) with $h_t$ decreasing with $t$. This implies optimal consumption that decreases with age.

In order to quantify this effect one has to specify the dependence of health on age. Obviously, this is not a simple task, as the estimation of health is quite complicated (see, for example, Torrance 1976, 1986, Krabbe et. al. 1997, Patrick et. al. 1973, Kaplan et. al. 1979, Read et. al. 1984, Bass et. al. 1994, Dolan et. al. 1996, Badia et. al. 1999, Martin et. al. 2000, and Baker, Stabile, and Deri 2004). Still, a rough approximation of health can be obtained from self-reported health status measures, reported by the National Health Interview Survey (NHIS). The NHIS measures health on a scale of 1 to 5, where 1 represents "excellent health", and 5 represents "poor health". In order to employ this measure, we first need to translate the NHIS health scale to the 0-1 health scale used here. If we take the NHIS score of 1 (excellent health) to correspond to $h=1$, and the NHIS score of 5 (poor health) to correspond to $h=h_{Low}$, we have the following relationship between the two scales:

$$h = 1 - \left( \frac{\text{NHIS score} - 1}{4} \right) (1 - h_{Low}).$$  \hfill (64)

Note that this implies that $\text{NHIS score} = 1 \iff h = 1$, and $\text{NHIS score} = 5 \iff h = h_{Low}$. The appropriate value of $h_{Low}$ corresponding to the NHIS score of 5 for “poor health” is not
obvious. Thus, below we employ the two alternative possible values of $h_{Low}=0.7$ and $h_{Low}=0.5$, to provide an idea about the effect of health on life-cycle consumption.

Panel A of Figure 17 reports the average NHIS health score as a function of the age, as documented by the NHIS\textsuperscript{35}. The average health decreases almost monotonically from age 20 to age 85. It is interesting to note that the decline in health revealed by the NHIS data occurs approximately at a constant rate, whereas Domeij and Johannesson (2006) find that for the Swedish data health deteriorates very slowly up to the age of about 60, after which it deteriorates at a much faster rate. For more detail about the NHIS results, including the breakdown of the results by gender, see Case and Deaton (2005).

Panel B of Figure 17 shows the optimal consumption implied by this health deterioration, as given by eq.(63), for the two possible values of $h_{Low}$. As health deteriorates with age, so does the optimal consumption. For $h_{Low}=0.7$ optimal consumption at age 85 is less by approximately 10% than the optimal consumption at age 20. For $h_{Low}=0.5$ optimal consumption at age 85 is less by approximately 18% than the optimal consumption at age 20. Of course, one has to take into account that the NHIS average health score for a given age is conditional on being alive at this age.

Thus, the above analysis is very conservative in this respect, and the actual health effects could be considerably stronger. While the estimation of health is admittedly far from being straightforward, the model is very simplistic, and many caveats apply, the analysis

\textsuperscript{35} Self-assessed health status estimates prior to 1997, was obtained from the Vital and Health Statistics, Series 10 Reports named “Current Estimates from the National Health Interview Survey, United States. As of 1997, we collected data from, “Summary Health Statistics for the U.S. Population: National Health Interview Survey, Series 10 Reports.
suggests that the under-savings problem is considerably less severe than it seems when the health state is not taken into account.
Figure 17: Health and Life Cycle Savings

Panel A shows the average self-reported health on a scale of 1-5 (1=perfect health, 5=poor health), as documented by the NHIS. The dotted lines depict the 95% confidence interval, which grows at very old age because of the smaller number of respondents. Panel B shows the implications of this health deterioration to optimal life-cycle savings, as given by eq. (63). The parameter $W$ is chosen so that consumption=1 in the baseline case of constant health. The optimal consumption is calculated for two possible values of $h_{low}$ corresponding to “poor health” (see eq.(64)). $h_{low}=0.5$ implies that optimal consumption at age 80 should be about 18% lower than at age 20.
Chapter III

Optimal drug pricing of breakthrough drugs

This chapter studies the entry price of new innovative breakthrough drugs. These drugs compose a small portion of new drugs entering the market, yet they account for the greater part of the non-generic pharmaceutical industry's profit. As they provide a substantial health improvement relative to existing therapies, they are priced monopolistically. We propose a new model for the launch price of these monopolistic drugs. We analyze 8 currently marketed breakthrough drugs and compare their actual entry prices to those obtained by the model in a setup of individuals having no health insurance. Empirical analysis indicates that actual drug pricing generally conforms to the theoretical predictions of the model. The suggested model provides a framework for a quantitative discussion of drug price regulation. We show that appropriate price caps substantially increase consumer surplus and the number of patients who purchase the drug, while having only a marginal effect on the revenues of the pharmaceutical company.

The chapter is organized as follows. In section A we derive theoretical model regarding optimal monopolistic pricing. Section B provides a methodology overview of the various sources and considerations used for the empirical examination of the model. In section C we describes the annual drug cost as predicted by the model for 8 available breakthrough drugs, and compare these to the actual annual costs. In Section D we discuss the implications of our results to the debate over drug price regulation.
A. Model

Consider a new breakthrough drug that offers a health improvement from $h_{\text{Low}}$ to $h_{\text{High}}$, where $h$ denotes the health level on a scale of 0 to 1 (death=0 $< h_{\text{Low}} < h_{\text{High}} \leq 1$=perfect health). The drug is patent protected and offers a substantial improvement relative to existing therapies. Thus, it is assumed to be priced monopolistically. The individual's utility of health and consumption is taken as the function empirically estimated, that we present in chapter B:

$$U(h,c) = h \cdot \log(c),$$

where $h$ denotes health, and $c$ denotes consumption measured in units of the minimum consumption required for existence\(^{36}\). If we denote the maximal proportion of consumption that the person is willing to give up in order to obtain the drug by $x$, we have:

$$h_{\text{Low}} \cdot \log(c) = h_{\text{High}} \cdot \log(c(1-x)),$$

where the left hand side is the utility without the drug, and the right hand side is the utility with the drug – better health but only $c(1-x)$ to consume. From this equality we obtain:

$$x = 1 - (c)^{\frac{h_{\text{Low}}}{h_{\text{High}}}} = 1 - (c)^{\frac{1}{h}}$$

where $h \equiv \frac{h_{\text{Low}}}{h_{\text{High}}}$ denotes the relative health with and without the drug\(^{37}\).

\(^{36}\) Thus, $c=2$ means consumption twice that of the minimum consumption level. This formulation neutralizes the effect of the unit of consumption chosen (e.g. dollars or cents), and is equivalent to the formulation in terms of the normalization constant $a$ (chapter B).
The pharmaceutical company chooses the drug price $P$ so as to maximize its profit. We make the simplifying, and typically fairly realistic, assumption that the pharmaceutical company's main cost is the development cost, which is a sunk cost at the time the drug is introduced, and that the production and marketing costs of the drug are insignificant for the determination of the cost of drug\textsuperscript{38}.

Given a price $P$, only patients with consumption exceeding some threshold income $c_{T}(P)$ will buy the drug. $c_{T}(P)$ is given by:

$$\frac{P}{c_{T}(P)} = x = 1 - (c_{T}(P))^{h-1}.$$  \hfill (68)

\textsuperscript{37} The above analysis is framed in the simplified one-period setup. However, the extension to a multi-period framework is straightforward. In the multi-period setting the time-separable additive utility is given by:

$$U = \sum_{t=0}^{T} \frac{1}{(1+\rho)^t} h_t \log(c_t),$$

where $c_t$ and $h_t$ are the period $t$ consumption and health, respectively, and $\rho$ is the discount rate for future utility. Denoting the individual's current wealth plus the present value of the lifelong future income stream by $W$, we have the constraint that the present value of lifelong consumption cannot exceed $W$: \textsuperscript{38}

$$\sum_{t=0}^{T} \frac{c_t}{(1+r)^t} \leq W,$$

where $r$ is the rate of return on savings. Utility maximization yields the first order condition: $c_t = \frac{h_t}{\lambda} \left(1 + \frac{r}{1+\rho}\right)^t$, where $\lambda$ is a constant determined by the lifelong income constraint. Under the standard simplifying assumption of $\rho = r$, this simplifies to: $c_t = \frac{h_t}{\lambda}$. Thus, for constant health consumption is also constant as in Friedman's (1957) permanent-income hypothesis. We are comparing the choice between two alternatives: living without the drug, i.e. health $h_{Low}$ and consumption $c$, or with the drug, i.e. health $h_{High}$ and a consumption of $(1-x)c$. As health, and therefore consumption, is assumed constant across time in each of these two alternatives, the multi-period problem reduces to eq.(66).

\textsuperscript{38} For some drugs, marketing costs may actually be very large (see, for example, Angell 2004). However, this is primarily more so for "me too" drugs than for breakthrough drugs that typically receive a great deal of attention even with little marketing efforts. This assumption may be inappropriate for some "biological" drugs, that have relatively high variable production costs.
For patients with $c < c_T(P)$ the fraction of their consumption that they would be required to pay for the drug, $P/c$, is too high relative to the alternative of living without the drug. Eq. (68) can be rewritten as:

$$P = c_T - c_T^h. \quad (69)$$

The revenue of the pharmaceutical company is therefore:

$$R = N P \int_{c_T(P)}^{\infty} f(c) dc \quad (70)$$

where $f(c)$, is the probability density function of the patient consumption distribution and $N$ is the total number of patients. While eq. (70) is general, in order to obtain more concrete results we should assume a specific form for the consumption distribution. The most natural form to consider is the Pareto distribution of income, which has been widely documented for over a century, and is given by:

$$f(c) = A c^{-(1+\alpha)} \quad \text{for } c > c_0, \quad (71)$$

where $A$ is a constant, and $\alpha$ is the Pareto exponent. (Empirical estimates of $\alpha$ in Western countries range from 1.5 to 4, depending on the country and the year; see, for example, Clementi and Gallegati (2005)). Employing the Pareto distribution (71) in (70) yields:

$$R = PA \int_{c_T(P)}^{\infty} c^{-(1+\alpha)} dc = - \frac{PA c^{-\alpha}}{\alpha} \bigg|_{c_T}^{\infty} = \frac{PA}{\alpha} c_T^{-\alpha}. \quad (72)$$

---

39 See Pareto (1897). It is now believed that the Pareto distribution fits well the upper part of the income distribution, while other forms may better fit the lower part (Atkinson and Bourguignon (2000)). The analysis here involves the upper part of the distribution, where the Pareto distribution provides a good fit to the empirical income distribution.
Substituting \( c_T - c_T^h \) for \( P \) (see eq. 69), we can write the pharmaceutical company’s revenue as a function of \( c_T \):

\[
R = \frac{A}{\alpha} \left( c_T - c_T^h \right) c_T^{-\alpha} = \frac{A}{\alpha} \left( c_T^{1-\alpha} - c_T^{h-\alpha} \right). \tag{73}
\]

Deriving this expression with respect to \( c_T \) and equating to zero, we find the revenue maximizing value of \( c_T \), \( c_T^* \):

\[
c_T^* = \left( \frac{\alpha - h}{\alpha - 1} \right)^{\frac{1}{1-h}}. \tag{74}
\]

Plugging this value in eq.(69) we obtain the equilibrium drug price,

\[
P^* = \left[ \left( \frac{\alpha - h}{\alpha - 1} \right)^{\frac{1}{1-h}} - \left( \frac{\alpha - h}{\alpha - 1} \right)^{\frac{h}{1-h}} \right]. \tag{75}
\]

The equilibrium values in equations (74) and (75) yield several interesting implications. First, note that \( c_T^* \) is monotonically increasing in \( h \).\(^{40}\) This means that the more

\(^{40}\) \( c_T^* \) can be written as \( c_T^* = f(h)^{g(h)} \), where \( f(h) = \frac{\alpha - h}{\alpha - 1} \) and \( g(h) = \frac{1}{1-h} \). Recall that

\[
\frac{\partial}{\partial h} \left[ f(h)^{g(h)} \right] = f(h)^{g(h)} \left[ g'(h) \ln(f(h)) + \frac{g(h)}{f(h)} f'(h) \right].
\]

With \( f(h) \) and \( g(h) \) as defined above we have

\[
f'(h) = \frac{1}{1-\alpha} \quad \text{and} \quad g'(h) = \frac{1}{(1-h)^2},
\]

and therefore:

\[
\frac{\partial c_T^*}{\partial h} = c_T^* \left[ \frac{1}{1-h} \right] \left[ \frac{1}{1-h} \ln \left( \frac{\alpha - h}{\alpha - 1} \right) - \frac{1}{\alpha - h} \right].
\]

To see that the expression in the preceding square brackets is positive, note that the natural logarithm can be expressed as:

\[
\ln(z) = \sum_{n=0}^{\infty} \frac{1}{(2n+1)} \left( \frac{z-1}{z+1} \right)^{2n+1}.
\]

Here we have \( z = \frac{\alpha - h}{\alpha - 1} \), and \( \frac{z-1}{z+1} = \frac{1-h}{2\alpha - h - 1} \), which is positive because \( \alpha > 1 > h \). This implies that
substantial the health improvement provided by the drug, (i.e. the lower $h$), the lower $c^*_T$, i.e. the drug will be priced such that it will be purchased by a larger part of the population. In contrast, $P^*$ may increase or decrease in $h$, though for typical parameter values $P^*$ decreases with $h$, as one would intuitively expect.

Note that the above analysis assumes a cash-paying patient, as opposed to a patient acquiring the drug through a health insurance provider. This is consistent with the empirically observable prices, as reported prices are prices for cash purchases.

Drug prices for health providers are negotiated with the pharmaceutical company (sometimes by Pharmacy Benefit Managers, or BPM's), and are one of the best-kept secrets in the pharmaceutical industry (see Comanor and Schweitzer (2007)). According to Danzon and Pauly (2002) cash purchases represent about 30% of all drug sales. Developing the optimal pricing formula for health providers would be quite a difficult task, as the price to the patient is typically composed of several different elements such as copayment, coinsurance, and deductables. In addition empirical testing of this pricing model will be next to impossible because of the secrecy of these prices\textsuperscript{41}.

\[ \ln \left( \frac{\alpha - h}{\alpha - 1} \right) > 2 \left( \frac{1 - h}{2 \alpha - h - 1} \right), \] because the right hand side takes only the term $n=0$ of the expansion, and ignores all the other terms with $n>1$, which are all positive. Thus, we have:

\[ \frac{\partial c^*_T}{\partial h} > c^*_T \left[ \frac{1}{1 - h} \left( \frac{1}{1 - h} \left( \frac{1 - h}{2 \alpha - h - 1} \right) - \frac{1}{\alpha - h} \right) \right] = c^*_T \left( \frac{1}{2 \alpha - h - 1} \right) > 0, \] which proves that $c^*_T$ increases with $h$.

\textsuperscript{41} In many countries there is no connection between the insurer cost of drug, and the actual price paid by the insured individual. The reason for that has to do with laws and regulations, which are country specific, regarding the maximum prices allowed and the co-payment/co-insurance costumed to each drug by a governmental health authority. For example, in Israel, the department of health sets the maximal limit of drugs prices and provides with insurer a rather rigid list of permitted co-payments. So, even if the drug prices paid by insurers are known, this still does not shed light on the prices paid by consumers.
even if the health providers drug prices were available, we could not assume these prices are paid by the majority of breakthrough drug consumers, as we could not presume the fraction of these patients from the largest part of US population (about 70%) that own health insurance. There are two main reasons which may hamper the opportunity of this group of patient from owning a health insurance. The first concerns adverse selection (Enthoven, 1993) which is a major problem with the health insurance /managed care health care policy. Generally, plans may take actions to discourage or encourage potential enrollees. For example, they may refuse some applicants. The second is that plans may distort the mix of the quality of health care they offer to discourage high-cost persons from joining the plan. This feature is more troublesome as decisions about what care is medically necessary are fundamentally outside the scope of direct regulation (Miller and Luft, 1997; Newhouse, 1996) leaving open the opportunity for plans to manipulate the quality they offer in an effort to achieve a profitable mix of enrollees. Glazer and McGuire (2002) show how risk adjustment of premiums paid by governments to health plans can address the individual access problem and the quality problem.

In addition, in the case health providers drug prices were available, we could not assume these prices are paid by drug consumers given a new trend named Value-based insurance design (VBID) that has emerged as an important tool for tamping down health care spending by lowering consumer cost-sharing for everything from preventive care services to prescription drugs. under the new growing trend employer health plans are designed to ensure the best clinical outcome for employees, or get more health out of every health care dollar- the alignment of financial incentives for patients and providers encourages the use of “high-value” care, while discouraging the use of low-value or unproven services. An
example of high-value care under VBID would be eliminating or lowering the co-payment for medicines used to treat a chronic condition, such as diabetes or asthma.

As there is no organised available data source regarding the different insureres VBID programs, we could not assume a certain co-payment for a certain drug

**B. Empirical consideration**

**a. Identification of breakthrough drugs**

Seventy two innovative medicines that represent major therapeutic advances over existing therapies were identified using definitions used by the US Food and Drug Administration (FDA) and the Canadian Patented Medicines Prices Review Board (PMPRB). The PMPRB designates all newly registered pharmaceutical products as either innovative, line extensions, or similar to existing therapies marketed in Canada. An innovative product is defined as “the first drug product to treat effectively a particular illness or to provide a substantial improvement over existing drug products”. We identified all products designated as innovative in the 2000-2008 PMPRB annual reports. The FDA provides fast-track review of new drugs or biologics that are intended to treat serious or life-threatening conditions and that demonstrate the potential to address unmet medical needs. Filling an "unmet medical need" is defined as providing a therapy where none exists, or providing a therapy which may be potentially superior to existing therapy. Thus, a fast track drug must show advantage over available treatment, such as: superior effectiveness, avoiding serious

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side effects of an available treatment, and decreasing a clinically significant toxicity of an
accepted treatment\textsuperscript{43}. Our analysis requires empirical estimates of the drug price and the
health improvement it provides. We were able to find this data for eight out of 72
breakthrough drugs. See Table 9.

\textsuperscript{43} Food and Drug Administration. Fast Track approvals. Available from:
# Table 9 – Summary Data on Breakthrough Drugs

<table>
<thead>
<tr>
<th>Brand Name</th>
<th>Generic Name</th>
<th>Data source</th>
<th>Year of FDA approval (first indication)</th>
<th>Main Indications</th>
</tr>
</thead>
</table>
| Enbrel     | Etanercept   | PMPRB       | 1998                                    | 1. Rheumatoid Arthritis  
2. Polyarticular juvenile idiopathic arthritis (JIA) in patients ages 2 and older.  
3. Psoriatic Arthritis  
4. Ankylosing Spondylitis  
5. plaque psoriasis |
| Gleevec    | Imatinib Mesylate | PMPRB       | 2001                                    | 1. Chronic Myeloid Leukemia (CML)  
2. Malignant gastrointestinal stromal tumors (GIST). |
| Relistor   | Methylaltrexone Bromide | PMPRB      | 2008                                    | For the treatment of opioid-induced constipation in patients with advanced illness who are receiving palliative care, when response to laxative therapy has not been sufficient. |
| Revlimid   | Lenalidomide | PMPRB       | 2005                                    | 1. patients with transfusion-dependent anemia due to Low- or Intermediate-1-risk myelodysplastic syndromes (MDS)  
2. multiple myeloma patients who have received at least one prior therapy. |
| Macugen    | Pegaptanib   | PMPRB       | 2004                                    | Neovascular (wet) age-related macular degeneration (AMD). |
| Exjade     | Deferasirox  | FDA         | 2005                                    | Chronic iron overload due to blood transfusions(transfusional hemosiderosis) |
| Arimidex   | Anastrozole  | FDA         | 2005                                    | Breast cancer |
| Remicade   | Infliximab   | FDA         | 1998                                    | 1. Crohn's Disease  
2. Ulcerative Colitis  
3. Rheumatoid Arthritis  
4. Ankylosing Spondylitis  
5. Psoriatic Arthritis  
6. Plaque Psoriasis |
b. Parameters estimation

Testing the drug pricing formula (eq (75)) requires the estimation of the following parameters: the health improvement provided by the drug \( h \equiv \frac{h_{\text{Low}}}{h_{\text{High}}} \), the drug price \( \), the required average daily dosage and the income distribution Pareto exponent \( \alpha \). We must stress at the outset that the precise estimation of these parameters, especially the defined daily dose and \( h \), is quite difficult, as explained below. This caveat should be kept in mind when evaluating eq.(75) empirically. Below we describe the estimation procedure and the data sources for each of the parameters.

**Health Improvement**

In order to assess the average health improvement provided by the drug, i.e. \( h_{\text{High}} \) and \( h_{\text{Low}} \), we employ data from the Tufts Medical Center Cost-Effectiveness Analysis (CEA) registry. The CEA registry is a comprehensive database of cost-utility analyses on a wide variety of diseases and treatments. A key input for cost-effectiveness analysis and for estimating Quality Adjusted Life Years (QALYs) is the health improvement provided by each treatment. We employ the CEA estimated health state which is defined on the 0 to 1 scale. Methods for health assessment broadly fall into two categories - direct and indirect. The two widely used direct approaches are the standard gamble (SG)\(^{44}\), and time trade off

\(^{44}\) In the Standard Gamble approach a person who is not perfectly healthy is asked the following type of question: "suppose that you are offered a treatment that will cure you and bring you to perfect health with probability \( p \), but will cause death with probability \( 1-p \). What is the minimal \( p \) for which you would accept this treatment?" The health level \( h \) is defined as the answer to this question, i.e. in this approach \( 0 \leq h \leq 1 \) is equivalent to the minimal probability at which the above gamble is accepted. Obviously, a perfectly healthy person would not accept this treatment for any \( p<1 \), i.e. he has \( h=1 \). The more the person is ill, the lower the
(TTO)\textsuperscript{45} approaches. These methods directly produce a health state estimate on the 0 to 1 scale. Indirect methods involve a two-step procedure and make use of health status instruments such as the Quality of Well-Being (QWB) Scale, Health Utilities Index (HUI), or EuroQol EQ-5D. Respondents are asked to indicate the level of a particular health state with regard to several attributes (e.g., mobility and pain). These attributes levels are then “mapped” to the 0 to 1 scale using weights estimated by the instrument developers.

Out of the 72 breakthrough drugs obtained via the FDA and PMPBR publications, we were able to attain the $h_{\text{High}}$ and $h_{\text{Low}}$ values for 15 drugs, from which seven drugs represented treatments which are not administered for chronic condition. In order to be consistent with the theoretical model, we chose to employ in our analysis drugs that are administered for chronically diseases/conditions or that require continually drug uptake. This is the typical setting for most drugs. The pricing of a drug which is taken as a one-time treatment and affects health in all subsequent periods can be derived in the multi-period setting (see footnote 36). Thus out of the 15 drugs, seven were excluded from further analysis. The following empirical examination focuses on 8 breakthrough drugs for which most of the health values where attained with either the EQ5D or with TTO (Table 10, page 140 to 141).

\textsuperscript{45} In the TTO approach the person is asked how many years of his life he is willing to give up in order to live the years remaining in perfect health. If we denote the expected number of years left by $T$ and the number of years the person is willing to give up by $\tau$, $h$ is typically defined by $h=1-\frac{\tau}{T}$. A perfectly healthy person will not be willing to give up any life years, i.e. for him we have $\tau=0$ and $h=1$. The more ill the person, the higher $\frac{\tau}{T}$, and the lower $h$. Again, $h$ is on the scale of 0 to 1.
Here goes table 2 chapter 3 page 1=table 10
Here goes table 2 chapter 3 page 2={table 10}
A paper by Brauer et al (2006) presents trends and changes in methods used for utility weight elicitation. They demonstrate that many of the health states have wide ranges of utilities reported which may result from differences in the health state descriptions or the populations from which the utilities were elicited. For example, published myocardial infarction (MI) utilities are estimated at 0.58 and 0.88 in separate studies. The lower utility (0.58) was elicited using the EQ-5D in patients after peripheral vascular surgery, a subset of which had a postoperative MI. In contrast, the higher utility (0.88) was elicited using time trade-off, in patients with a recent MI and a mildly depressed ejection fraction but no clinical symptoms of heart failure. Subtle differences in the descriptions of seemingly similar health states may also have led to the wide variations found in the published utilities for health states.

For three out of eight breakthrough drugs analyzed in my work, there were several $h_{\text{High}}$ and $h_{\text{Low}}$ values (see table 10). In these cases we employed the average $h$ values. The differences across health estimates for the same medical condition, as also discussed in the above mentioned paper, provide an indication of the rather large estimation errors involved in estimating the health state and should be kept in mind while analyzing the results.

**Drug Price**

For the purpose of a comparison of the annual cost of drug and the model prediction, we needed to attain the actual annual costs of the eight drugs. In reality, the American market is characterized by a great deal of heterogeneity in the prices of drugs, both from the up-
stream purchaser and the end-consumer stand point. The data regarding the varied prices of a single drug is naturally confidential; hence, the presented actual annual cost embodies uniform/consistent pricing data from non-confidential/available resources.

We calculated a drug’s actual annual average cost per patient, by using the following data resources: the world’s health organization (WHO) daily defined dose (DDD), Maccabi (the second largest healthcare service organization in Israel) health care DDD values, and Red Books pharmacy’s fundamental references which provide the average whole sale price (AWP), for the different dosages available in the US market. In order to attain analysis accuracy, we utilize AWP data for each drug as close as possible to the year at which the drug was FDA approved. For most of the drugs we were able to attain the AWP from the Red Book edition published one year after launch, and we assume the prices of these drugs have not changed in a substantial manner.

All drugs analyzed demonstrate a “flat price” phenomenon- the price per tablet/capsule/vial is essentially invariant over different amount of the active pharmaceutical ingredient embodied within it, hence the calculation of the annual drug cost was invariant to different dosages available for marketing. For the detailed data and calculation, see table 11 (page 145).

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46 Within the United States there is a pattern of differential pricing, for example, the lowest prescription drug prices are typically negotiated by the department of veteran affairs and the Department of Defense. Next lowest are prices to hospitals for inpatient use. Prices charged from institutions such as health maintenance organizations (who reimburse pharmacies that dispense to their insurees) are typically discounted even less, and prices charged retail pharmacies for their cash-paying customers are discounted off “list” price the least.
As we choose to employ the Red Book AWP figures as a price measurement, that in fact, do not represent the expenditure of the end-consumer or the pharma company income from selling the drug, we feel that a short clarification of AWP is required.

The price at which brand manufacturers sell to wholesalers and chain warehouses is generally the Wholesale Acquisition Cost (WAC), a published list price, minus a few percents discount for prompt payment and other incentives. In turn, wholesalers sell branded small molecules to retail and mail order pharmacies, usually at a few percent above their WAC, and at a 15-20% or larger discount off of what is known as the Average Wholesale Price\textsuperscript{47}. A recent working paper by Brendt and Newhouse (2010) on the pharmaceutical pricing and reimbursement in the U.S, provides an illuminative perspective on the often-used AWP data. According to their work, In the 1970s and 1980s (and in many cases continuing on to this day), AWP tends to be 20% or 25% greater than WAC, implying that WAC is usually 16.7% or 20% smaller than AWP.

There is ample evidence that since the 1980s these wholesaler markups have declined substantially, with pharmacies acquiring branded drugs at discounts that approach 20% off of AWP, consistent with WAC plus a few percents. Thus principally, the AWP is closer in value to the pharmaceutical earnings from selling a drug rather than the actual price paid by consumers.

\textsuperscript{47} In contrast, many biologics are administered via injection or infusion by health care providers (i.e., physicians and nurses), rather than being patient self-administered oral tablets or capsules purchased from retail or mail order hospitals and physician offices rather than to the wholesalers to which the branded small molecule manufacturers usually sell. Firms known as “specialty pharmaceuticals,” however, often provide wholesaler-type intermediary services between biologic manufacturers and providers. Although the practice is not as firmly ingrained as it is with branded small molecules, biologic manufacturers generally sell products to the specialty pharmaceutical firms at a slightly discounted WAC, and often at slightly higher prices to the providers who are buying directly (Brendt and Newhouse, working paper, 2010).
here goes table 3 chapter 3 = table 11
A DDD is the assumed average maintenance dose per day for a drug used for its main indication in adults. Hence, DDD data should be regarded as a rough estimate of consumption and not an exact picture of actual use. We found the WHO DDD values for six breakthrough drugs: Enbrel, Relistor, Revlimid, Arimidex and Remicade. For the rest, No DDDs have been established because of highly individualized use and wide dosage ranges. For Gleevec, and Exjade, we attained DDD values that were established by Maccabi Healthcare Services-one of Israel’s leading healthcare service organization. We could not attain the DDD value of the drug Macugen, for which we used annual drug cost from the literature. In addition, for most of the drug having a DDD value, we derived the annual cost of drugs from articles as an additional/alternative reference for the comparison of the actual annual cost of drug (as depicted mostly in clinical trials) and the model forecast. Those articles do not necessarily provide annual cost figures for the first year those drugs were introduced to market, and are based on different methodologies and calculations. There appears to be a great deal of discrepancy between the calculated annual drug cost (via DDD and AWP) and the annual cost depicted by literature (table 11). A possible reason for the observed variance may stem from the fact that the defined daily dose is a unit of

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48 When a new DDD is assigned, various sources are used to get the best overview of the actual or expected use of a substance (DDDs are not assigned before marketing is approved in at least one country). The assigned DDD is based on the main two following principles:1. The average adult dose used for the main indication as reflected by the Anatomical, Therapeutic and Chemical (ATC) code. When the recommended dose refers to body weight, an adult is considered to be a person of 70 kg. 2. The maintenance dose (long term therapeutic dose) is usually preferred when establishing the DDD. The initial dose may differ but this is not reflected in the DDD. If the approved dose recommendation provides limited information about maintenance dose, the DDD will usually be the average of the maintenance dose range.

49 Maccabi Healthcare Services usually calculate DDD’s for drugs with no WHO DDD. This usually takes place at least one year after a drug is approved for marketing in the USA/Europe, following a marketing approval from the Israeli ministry of health. Hence, one important advantage of using those DDD’s, comes from the fact that they are calculated relatively late (a year or two after a drug is launched in the US) and sometime reflect more studies published on these drugs since they were first approved.
measurement and does not necessarily reflect the recommended or prescribed daily dose. Doses for individual patients and patient groups often differ from the DDD and will necessarily have to be based on individual characteristics (e.g. age and weight) and pharmacokinetic considerations.

**Income Distribution**

The Pareto income distribution has been widely documented in the long time that has passed since Pareto’s (1897) original work. Empirical estimates of $\alpha$ in Western countries range from 1.5 to 4, depending on the country and the year (see, for example, Clementi and Gallegati (2005)). In the U.S., which is the focus of our empirical study, the average value is close to 2 (see Nirei 2009), and this is the value we employ in our analysis.

Note that the utility of health and consumption (eq. 65) is defined such that consumption is formulated in terms of the minimal consumption level. Otherwise, if $c<1$ we have a paradoxical result where the utility formulation ensures that the health-wealth choice is invariant to the measurement units of consumption, e.g. dollars or cents, (for more detail see chapter B). Thus, the income and the optimal drug price in eq.(75) are expressed in terms of units of minimal consumption. We empirically estimate this minimal value as the poverty threshold value reported by the U.S. Census Bureau in 2009, which is close to $11,000.51

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50 The Pareto distribution fits well the central and upper parts of the income distribution, while other forms may better fit the lower part of the distribution (Atkinson and Bourguignon (2000)). The analysis here involves the upper part of the distribution, where the Pareto distribution provides a good fit to the empirical income distribution.

\textit{C. Results}

\textbf{a. Optimal drug pricing}

Figure 18 and Panel A of table 12 (next page) compare the prices theoretically predicted by eq.(75) with the actual prices. Panel B of table 12 provides a summery of three regressions conducted for the purpose of the evaluation of our underlying assumption that prices tend to decrease with $h$. In each regression we denote the dependent variable as the annual cost of drug and the independent variable as the H-low to H-high ratio.

While the estimation errors of h are large (see table 10), and some drug prices are very different than the theoretical prediction (e.g. Revlimid), the general empirical price pattern, according to the literature figures, does seem to conform with a key feature of the theoretical prediction- prices tend to decrease with $h$, i.e. the greater the health improvement provided by the drug (lower $h$), the higher the price tends to be. This is as one would intuitively expect, and is consistent with previous empirical findings (see Reekie (1978), Weston (1979,1982) and Comanor and Lu (1998)).

In the case of the third regression, in which the dependent variable is achived via a calculation of the AWP (average wholesale price) and DDD (daily defined dose), the regression result is insignificant (T-stat=0.46). This is not very surprising, due to two reasons which add lots of noise to the calculation: (1) the AWP, as explaines earlier, is not the end price paid by consumers and is merely an approximation, and (2) DDD valus may change dramatically between different patients and thus entail a very general and non-specific recommendation.
Table 12

Panel A - a summary of the annual cost of drugs

*Annual cost of drug according to literature was divided to two groups since we obtained different figures for some drugs. List I and II, provide the lower and upper annual costs of drug respectively (see table 11).

<table>
<thead>
<tr>
<th>Brand name</th>
<th>H-low / H-high</th>
<th>Annual cost (US$)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>model prediction</td>
<td>DDD+AWP</td>
<td>Literature*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Gleevec</td>
<td>0.15</td>
<td>10,419</td>
<td>27,732</td>
<td>32,000</td>
</tr>
<tr>
<td>Enbrel</td>
<td>0.43</td>
<td>8,806</td>
<td>14,410</td>
<td>14,715</td>
</tr>
<tr>
<td>Revlimid</td>
<td>0.55</td>
<td>7,801</td>
<td>97,200</td>
<td>52,596</td>
</tr>
<tr>
<td>Remicade</td>
<td>0.571</td>
<td>7,585</td>
<td>8,007</td>
<td>9,619</td>
</tr>
<tr>
<td>Relistor</td>
<td>0.67</td>
<td>6,450</td>
<td>8,760</td>
<td>152</td>
</tr>
<tr>
<td>Exjade</td>
<td>0.73</td>
<td>5,694</td>
<td>22,538</td>
<td>24,400</td>
</tr>
<tr>
<td>Arimidex</td>
<td>0.851</td>
<td>3,613</td>
<td>7,873</td>
<td>2,164</td>
</tr>
<tr>
<td>Macugen</td>
<td>0.93</td>
<td>1,996</td>
<td>NA</td>
<td>9,950</td>
</tr>
</tbody>
</table>

Panel B - regression analysis results.

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>R</th>
<th>coefficient</th>
<th>T-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature I</td>
<td>-0.469956</td>
<td>-15883.1</td>
<td>-2.06203</td>
</tr>
<tr>
<td>Literature II</td>
<td>-0.522007</td>
<td>-29354.3</td>
<td>-2.3703</td>
</tr>
<tr>
<td>DDD+AWP</td>
<td>-0.128519</td>
<td>-6528.98</td>
<td>-0.46726</td>
</tr>
</tbody>
</table>
Figure 18-Annual cost of drugs Vs H-low to H-high ratio

The annual cost of drug according to literature, is the average cost according to all literature figures (see panel A of table 12)
b. Implication for price cap regulation

Regulation of drug prices, which is applied in most countries excluding the U.S., obviously decreases the pharmaceutical company’s revenues, but benefits patients. The heated debate about price regulation is thus a debate about the relative weight of these two opposing effects of regulation. Clearly, both sides of this debate seem to have a point. In order to reach a conclusion regarding the question of drug price regulation, one must estimate its effects in a quantitative fashion. Namely, the main questions to be addressed are: what are the effects of drug price regulation on the revenues of the pharmaceutical company? What is the effect on the number of patients who will purchase the drug, and on the consumer surplus? In order to answer these questions one should estimate the demand function for the drug, which in turn, depends on the utility of health and wealth.

The framework developed in section A allows us to measure these effects in order to facilitate a quantitative discussion of the issue at hand.

It is important to note that price regulation is not a zero-sum setup, because a $1 decrease in revenue for the pharmaceutical company does not generally mean a $1 increase in consumer surplus. The consumer surplus can be much more (or less) than $1, depending on the exact shape of the demand function.

Consider a monopolistic drug which provides a health improvement $h$ and is priced at price $P$, which is not necessarily the optimal monopolistic price. The pharmaceutical company’s revenue is given by:

$$R(P) = \frac{A}{\alpha} \left( c_T^{1-\alpha} - c_T^{h-\alpha} \right)$$
where $c_T(P)$ is the threshold consumption given the price $P$, and is the solution to $P = c_T - c_T^h$ (see equations 69 and 73). Only patients with consumption exceeding this threshold will purchase the drug. This revenue is by definition lower than the maximal revenue at the optimal price $P^*$ given by eq.(75), which is:

$$R(P^*) = \frac{A}{\alpha} \left( c_T^{1-\alpha} - c_T^{h-\alpha} \right),$$

where $c_T^*$ is given by eq.(74). The loss of revenue to the pharmaceutical company caused by regulating the price at $P$ is thus:

$$\Delta R = R(P^*) - R(P).$$

(76)

Regulating the price at $P < P^*$ increases both the consumer surplus and the number of patients using the drug. A patient with consumption level $c$ is willing to pay for the drug up to a proportion $x = 1 - c^{h-1}$ of his consumption, i.e. an amount of $cx = c - c^h$ (see eq.(67)).

Given a price $P$, patients with consumption above the threshold $c_T(P)$ will purchase the drug, and the aggregate consumer surplus is given by:

$$CS(P) = \int_{c_T}^{\infty} f(c)dc \left[ (c - c^h) - P \right].$$

Substituting the Pareto distribution (71) for $f(c)$, we obtain:

$$CS(P) = A \int_{c_T}^{\infty} c^{-(1+\alpha)}dc \left[ (c - c^h) - P \right] = \frac{A}{\alpha} \left( \frac{1}{1-\alpha} c_T^{1-\alpha}(P) - \frac{h}{\alpha-h} c_T^{h-\alpha}(P) \right),$$

(77)
The extra consumer surplus relative to the unregulated situation with the monopolistic price \( P^* \) is given by:

\[
\Delta CS \equiv CS(P) - CS(P^*) .
\]  

(78)

Figure 19 shows \( \Delta R \) and \( \Delta CS \) as a function of the price \( P \) for a typical drug with \( h=0.5 \). With this value of \( h \), and with a Pareto exponent of \( \alpha = 2 \), the optimal monopolistic price implied by eq.(75) is 0.75. Panel A shows the loss of revenue to the pharmaceutical company relative to the monopolistic price setup as a function of the price \( P \). Note that by definition this function has a minimum at \( P^* \), where the revenue is maximal (and thus the loss of revenue is minimal). Hence, moderate changes in \( P \) around \( P^* \) have only a second-order effect on the revenues. In contrast, the effect on consumer surplus is first-order, see Panel B. While both \( \Delta R \) and \( \Delta CS \) shown in Figure 19 are in units of the minimal consumption times the Pareto constant \( A \) (which depends on the number of patients, see eq.(71)), they are both in the same units. This implies that imposing a price of, for example, \( P=0.6 \), leads to a consumer surplus which is roughly 10 times as large as the decrease in revenues.

Given a certain price \( P \), the number of patients using the drug is:

\[
N(P) = A \int_{c_T(P)}^{\bar{c}} c^{-(1+\alpha)} dc = -A c^{-\alpha} \bigg|_{c_T}^{\bar{c}} = \frac{A}{\alpha} c_T^{-\alpha} .
\]  

(79)

where the lower threshold \( c_T \) is the solution to \( P = c_T - c_T^h \). In the unregulated monopolistic case, the number of patients using the drug is \( N^* = \frac{A}{\alpha} c_T^{*-\alpha} \). Panel C of Figure 19 shows the relative change, in percent, of the number of patients using the drug as a function of the price.
\[ P: \Delta N(P) \equiv \frac{N(P) - N^*}{N^*} \]. The figure shows that imposing a price cap of 0.6 increases the number of patients using the drug by about 25%, relative to the unregulated situation.

Figure 19 implies that a "small" change in price relative to the monopolistic price has a first-order effect on consumer surplus and the number of patients using the drug, but only a second-order effect on revenues. From this perspective it is clear that some amount of price regulation is socially desirable. Of course, the practical question is how much regulation is not too much? If a price cap is set too low, this may have a drastic influence on revenues, stifling all R&D incentives for the pharmaceutical companies. Tables 13 and 14 present some quantitative results regarding this issue. Table 13 reports the effects of imposing a price cap which is 20% lower than the monopolistic price \((P \leq 0.8P^*)\), for various different drugs (different values of \(h\)). This amount of regulation leads to a decrease in revenues of only about 1%, but to an increase in surplus of about 10%. The magnitude of \(\Delta CS\) is about 25 times the magnitude of \(\Delta R\). The regulation leads to an increase of about 23% in the number of patients using the drug.

Table 14 reports the same analysis, but this time for the case of a price cap that is 40% lower than the monopolistic price \((P \leq 0.6P^*)\). In this case the loss in revenues of the pharmaceutical company is significant, and can reach 6%. While the consumer surplus also increases, the ratio \(\Delta CS/\Delta R\) is lower than in the case shown in Table 13, and is now only about 10. Thus, it seems that this type of price cap is "going too far", in the sense that the costs to the pharmaceutical companies may be too severe. In any case, the optimal monopolistic price provides a useful benchmark as a basis for price regulation.
Figure 19
The effects of price regulation in the form $P \leq 0.8P^*$, i.e. the price is set 20% lower than the optimal monopolistic price. This price constraint lowers revenues by only 0.69%-1.18% relative to the monopolistic revenues, depending on $h$, the benefit provided by the drug (4). The consumer surplus is increased by 7.9%-10.8% relative to the unregulated case (6). The increase in consumer surplus is about twenty-fold or thirty-fold the decrease in revenues (7), and the number of patients using the drug increases by about 23% relative to the unregulated case.

<table>
<thead>
<tr>
<th>$h$</th>
<th>$P^*$</th>
<th>$\Delta R$</th>
<th>$\frac{\Delta R}{R}$ (%)</th>
<th>$\Delta CS$</th>
<th>$\frac{\Delta CS}{CS^*}$ (%)</th>
<th>$\frac{\Delta CS}{\Delta R}$</th>
<th>$\Delta n$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.97</td>
<td>0.0014</td>
<td>1.18</td>
<td>0.0258</td>
<td>10.83</td>
<td>18.90</td>
<td>23.53</td>
</tr>
<tr>
<td>0.20</td>
<td>0.93</td>
<td>0.0012</td>
<td>1.12</td>
<td>0.0237</td>
<td>10.53</td>
<td>19.91</td>
<td>23.61</td>
</tr>
<tr>
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<td>0.0165</td>
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<td>0.0107</td>
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<td>0.0075</td>
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<tr>
<td>0.90</td>
<td>0.24</td>
<td>0.0001</td>
<td>0.69</td>
<td>0.0039</td>
<td>7.90</td>
<td>32.11</td>
<td>24.13</td>
</tr>
</tbody>
</table>

Table 13
The effects of price regulation in the form $P \leq 0.6P^*$, i.e. the price is set 40% lower than the optimal monopolistic price. In this case the decrease in revenues is much more substantial, at 3%-6% (4). While the increase in consumer surplus is also larger (6), the ratio between consumer surplus increase and revenue decrease is lower than the case of $P \leq 0.8P^*$ (compare column (7) with column (7) in Table 13).

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h$</td>
<td>$P^*$</td>
<td>$\Delta R$</td>
<td>$\frac{\Delta R}{R^*}$ (%)</td>
<td>$\Delta CS$</td>
<td>$\frac{\Delta CS}{CS^*}$ (%)</td>
<td>$\frac{\Delta CS}{\Delta R}$</td>
<td>$\Delta n$ (%)</td>
</tr>
<tr>
<td>0.10</td>
<td>0.97</td>
<td>0.0069</td>
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<td>9.25</td>
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<tr>
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<td>5.13</td>
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</tr>
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<td>0.0088</td>
<td>17.91</td>
<td>13.83</td>
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D. Discussion

Pharmaceutical sales have grown rather dramatically over the last decade, from $365 billion in 2000, to $837 billion in 2009, and they are expected to exceed $1.1 trillion by 2015. The price of new drugs has also been rising over time (see for example Besley and Gouvina, (1994)) and this trend is expected to continue. A central reason for the predicted future increase of drug prices is the realization of the long-awaited revolution in medicine, commonly called “personalized medicine”. In the near future there would be a shifting of resources from traditional R&D aimed to produce blockbuster drugs to a research taking advantage of existing technology to craft individualized therapies, based on genetic information technologies. This new approach mainly involves the systematic use of genetic information and thus targets smaller patient populations that share some genetic characteristic. From the pharmaceutical industry stand point, the hope is that increased safety and quality assurance and the possibility of moving drugs up into earlier phases of treatment—could bolster sales and help make up for narrower markets for each drug. Yet, there's no certainty, as the markets for specific drugs shrink, that drug companies will be able to make up for the size of their lost blockbusters by developing enough new personalized products to treat the same population their drugs previously treated. It would be reasonable to assume that a large quantity of the future breakthrough drugs would treat small groups of patient and be highly expensive.

The main purpose of this work was to provide a model for the optimal drug pricing of breakthrough drug which offer a substantial improvement over existing drugs for the same indications. We show that the greater the health improvement provided by the drug (lower h),
the higher the price tends to be (which is in one line with past research done on the subject of drug prices and health improvement). We further, appreciated the model ability to predict the optimal cost of drug by comparing the results obtained via the model to the actual cost of drugs. For some drugs, the prices obtained by the model were very much alike to some of the actual market prices (table 12). On the other hand, for others, there is quite a difference. We think that one major reason for this deviation stems from the H-low to H-high ratio utilized in the model.

The first difficulty in that regard was the limited amount of available H-low and H-high data (8 drugs altogether). Second, some health states have wide ranges of utilities which may result from differences in the health state descriptions or the populations from which the utilities were elicited (Brauer et al (2006)). That was the case of Gleevec, Exjade, Macugen and arimidex. In the analysis of these drugs we show the average H-low to H-high ratio as we have no means to determine which article (presented in the tufts website) best describes the health improvement provided by the drug.

In reality, when a pharmaceutical company accomplishes phase III clinical study and gets the desired regulatory approval for marketing, it has quite a clear understanding as for the relevant market (i.e-sub group of patients and specific clinical indications) and the available therapeutics existing in it. Thus, a pharmaceutical company claiming to provide a new breakthrough therapeutic entity, would probably be able to define the health improvement provided by the drug (i.e- H-low to H-high ratio). Hence, the presented model may become a tool for the pricing of breakthrough drugs from the pharmaceutical standpoint.
Following the construction of the optimal drug pricing model, we wanted to address the issue of the new generation’s (i.e.- personalized therapeutics) breakthrough drug prices from the point of view of a policy maker.

The ongoing trend generates a debate about drug price regulation. Critics of the pharmaceutical industry claim that pharmaceutical companies, that benefit from public investment in basic research, later on price drugs essentially monopolistically, protected by patent rights, leading to prices that are "too high", especially in the U.S.. While most countries regulate drug prices, either directly (e.g. France and Italy), or indirectly (e.g. U.K., Germany and Japan), the U.S. does not (see Comanor and Schweitzer 2007). Indeed, drug prices are on average higher in the U.S. than in the rest of the World (United States Congress General Accounting Office, 1992, 1994). Thus, it is also argued that U.S. patients subsidize patients in the rest of the world. On the other hand, proponents of the pharmaceutical industry argue that drug prices reflect the very high R&D costs in the pharmaceutical industry, estimated at over $800 million per drug (DiMasi et. al. 2003), and that any price regulation will stifle innovation.

In order to reach a conclusion regarding the question of drug price regulation, we estimate its effects in a quantitative fashion. We find that appropriate price caps can substantially increase consumer surplus and the number of patients using the drug, while having only a second-order effect of the revenues of the pharmaceutical companies. Thus, our results show that drug price regulation does not stifle the pharmaceutical industry and the important economic incentive for drug innovation.
Chapter IV

Summary and Conclusions

The chapters presented in this work correspond to the actual chronological research done in this PhD. The first study explored a market failure in the pharmaceutical industry and proposes a model to overcome it. In a second independent study presented in chapter II, we investigated the utility form of health and wealth. The result of this study provided a new look and a better understanding of this utility function, and thus allowed us to re-evaluate the first work. Next, we make use of this utility function in chapter III as an underlying basis for the investigation of the optimal monopolistic drug pricing and price cap regulations.

The second work, therefore, provided a gate for most of the research presented in this PhD work. It is my hope and belief that the utility function from health and wealth presented in the second chapter would offer a ground for more studies in the field of health economics.

I hereby present a summary for each study.

The CureShare mechanism

Most of the people who suffer from a disease that influence their life quality/expectancy would be willing to give up some wealth today if this gives them a chance to escape a severe illness or death and be cured in the future. However, none of them can invest in a specific pharmaceutical R&D project aimed to cure the disease from which they suffer. One can only purchase a drug if R&D is successfully completed and FDA approved.
In case the NPV of an R&D project would be considered unsatisfying from the pharmaceutical’s company perspective, it would abolish the project, even if unhealthy people would be willing to give up everything they own for the purpose of drug development. We show that such situations may constitute market failure. The market failure analyzed here results from a missing-market problem: at present no mechanism exists which allows patients to directly invest in the development of cures for their illnesses. We suggest a novel mechanism to overcome this failure in which patients can bear upon themselves some of the development risk by paying a certain amount in advance, and thus allowing the R&D project to take place. The solutions we propose designate two conditions under which the new mechanism may be applicable and provide an increase of overall welfare. The first condition, states that without the CureShare mechanism the NPV of the drug development for the pharmaceutical company is negative, and therefore no cure will be developed. The second condition states that with the CureShare mechanism the individual’s expected utility should be higher than his expected utility without it, and thus the patient is willing to pay enough to make the NPV equal to zero for the pharmaceutical company, and the drug will therefore be developed, increasing overall welfare.

We empirically analyze the two conditions for five disorders that are considered to have poor medical treatment and a “medium” prevalence rate (200,000-1,000,000 people). We conduct two distinct analyses which differ in the utility function from health and wealth we utilize. In the first analysis we show that the NPV condition is usually satisfied (i.e.- without the CureShare mechanism the NPV of the drug development is negative, and therefore no cure will be develop) while the second condition tends to limit the applicability of the model. In the second analysis we utilize a different utility function (empirically
investigated in chapter II) and show different results-the first and second conditions are usually satisfied allowing for model applicability in a wide range of h-high (i.e. health improvement provided by the drug) and prevalence values. Both models show that applying this mechanism may save thousands of lives annually, and may dramatically improve the quality of many others.

We discuss some practical implementation issues. There are quite a few barriers that have the potential to impede the implementation of the CureShare mechanism. Among them are: the free rider problem, the information asymmetry characterizing a direct interaction between the patients and a pharmaceutical company, and ethical considerations concerning the price of drug for people who did not buy a CureShare. We discuss these issues and propose possible solutions

**The utility of health and wealth**

The most fundamental decisions we make throughout life have to do with health and wealth. In Chapter II we examine the utility of health and wealth both theoretically and empirically. Theoretical considerations and the standard measures of health lead to the utility being linear in health, in the form \( U(h, w) = h \cdot u(w) \), where \( h \) denotes health, \( w \) denotes wealth (or consumption, in a multi-period setting), and \( u(w) \) is the standard utility of wealth.

We consider the most commonly employed forms for the function \( u(w) \), and show that each function implies different health-wealth tradeoff characteristics. Analysis of the health-wealth tradeoff choices of 180 cancer patients and 132 diabetes patients, via personal
interviews and questionnaires, reveals that the utility function $U(h, w) = h \cdot \log(aw)$ provides excellent agreement with the patients' choices, where $a$ is a constant presenting the minimal consumption level. This function implies the classic logarithmic utility of wealth for a constant level of health. Thus, for any choices not involving a change of the health status, $h$ is constant, and the utility function is equivalent to the classic Bernoulli function. This function also implies that the marginal utility of wealth increases with health, consistent with the findings of Viscusi and Evans (1990), Sloan et al. (1998), and Finkelstein, Luttmer, and Notowidigdo (2008).

We examine the economic implications of this utility function of health and wealth and show that this function suggests that the low-savings rate problem may be less severe than previously believed. The reason is that this function implies that the optimal consumption is proportional to health, and as health deteriorates with age on average, individuals should optimally consume less at old age.

The economic tradeoff between health and wealth is a central issue in modern economics and politics. We hope that the analysis in this chapter constitutes a step towards a better understanding of this important issue.

**Optimal drug pricing of breakthrough drugs**

Healthcare expenditures in the U.S. are projected to reach $2.8 trillion in 2011, representing 17% of GDP (see Heffler et al (2002)). The percentage of health expenditures as a fraction of GDP is increasing over time, not only in the U.S., but worldwide (Anell and Willis (2000)). It is thus not surprising that economic discussion of healthcare has become a
central issue for policy and academic discussion. In chapter III we employ the empirical findings about the utility of health and wealth presented in chapter II along with the distribution of income in society, in order to formulate a model for the optimal monopolistic pricing of breakthrough drugs.

While empirical testing of this model is rather difficult, because of the large estimation error involved in assessing the health improvement provided by a drug, the empirical evidence is generally consistent with the key pricing features of the theoretical model. We show that the optimal drug price is typically higher the more substantial the health improvement provided by the drug, but this need not always be the case.

We next focus on the debate about drug price regulation. While critics of the pharmaceutical industry argue that pharmaceutical companies exploit monopolistic power granted by patent protection to make “unreasonable” profits at the expense of patients, proponents of this industry claim that high drug prices are required to sustain the very large R&D expenditures in pharmaceuticals. An in-depth discussion of this important issue requires a quantitative framework of analysis. The discussion of chapter III suggests such a framework.

We find that appropriate price caps can substantially increase consumer surplus and the number of patients using the drug, while having only a second-order effect of the revenues of the pharmaceutical companies. Thus, there seems to be a “golden path” of regulation that on the one hand greatly improves patient welfare, and on the other hand does not stifle the pharmaceutical industry and the important economic incentive for drug innovation.
Appendices

Appendix 1

Derivation of eq.(19):

Substituting $x = \frac{I}{(Pr)} - \frac{Py}{R}$ in eq.(18) we obtain:

$$EU_{with \ CS} = \log \left( \left( W - s - \frac{I}{(Pr)} + \frac{Py}{R} \right) h_t \right) + \beta p \log \left( (sR_f - y) h_{high} \right) + \beta (1 - p) \log \left( sR_f h_{low} \right).$$

(A1)

Deriving (A1) with respect to $y$ and equating to zero yields the optimal $y^*$ for a given level of savings $s$:

$$\frac{\partial EU(y)}{\partial y} = 0 \Rightarrow \frac{h_p}{R} - \frac{h_{high} \beta p}{h_{high} (sR_f - y^*)} = 0,$$

or:

$$(sR_f - y^*) = \beta R \left( W - s - \frac{I}{(Pr)} \right) + \beta py^*,$$

finally leading to:

$$y^*(s) = \frac{sR_f (Pr) - \beta R (Pr) (W - s) + I \beta R}{(Pr)(1 + \beta p)}.$$

By the NPV=0 condition $x = \frac{I}{(Pr)} - \frac{Py}{R}$, this implies that the optimal $x^*$ given $s$ is:

$$x^*(s) = \frac{I}{(Pr)} - \frac{p}{R} \left( \frac{sR_f (Pr) - \beta R (Pr) (W - s) + I \beta R}{(Pr)(1 + \beta p)} \right).$$

Derivation of eq.(22):

Plugging the above values of $x^*(s)$ and $y^*(s)$ into eq.(18) gives us the maximal expected utility for a given savings $s$: 
\[
EU_{withCS} = \log \left( W - s - \frac{I}{Pr} + \frac{p}{R} \left( sR_j(Pr) - \beta R(Pr)(W - s) + I\beta R \right) \right) h_i \\
+ \beta p \log \left( sR_j(Pr) - \beta R(Pr)(W - s) + I\beta R \right) h_{high} + \beta (1 - p) \log(sR_j h_{low})
\]  

(A2)

Deriving this expression with respect to \( s \) and equating to zero yields the optimal savings \( s^* \):

\[
\frac{\partial EU(s)}{\partial s} = 0 \Rightarrow \\
\frac{h_i \left( \frac{pR_j(Pr) + R\beta p(Pr)}{R(Pr)(\beta p + 1)} \right)}{h_i \left( W - s - \frac{I}{Pr} + \frac{p}{R} \left( sR_j(Pr) - \beta R(Pr)(W - s) + I\beta R \right) \right)} + ,
\]

or:

\[
\frac{\beta p h_{high} \left( R_f - \frac{R\beta(Pr) - R_j(Pr)}{Pr(\beta p + 1)} \right)}{h_{high} \left( sR_j(Pr) - \beta R(Pr)(W - s) + I\beta R \right)} + \frac{\beta (1 - p)}{s} = 0
\]

Multiplication by the denominators leads to:

\[
spR(Pr) - sR(Pr) + s\beta p^2 R_j(Pr) - s\beta p R(Pr) + \beta p R_j s(Pr) - s\beta p^2 R_j(Pr) + (Pr)R\beta(1 - p)(W - s)
\]

\[- \beta IR + \beta p IR = 0
\]

Rearranging we obtain:
\[ s^*(pR_f - R(Pr) + \beta pR_f (Pr) - R\beta(Pr)) = \beta IR(1-p) - R\beta W(Pr)(1-p), \]

and finally:

\[ s^* = \frac{(1-p)\beta R(I-W(Pr))}{(R-pR_f)(Pr)(1+\beta)}. \]

**Derivation of eq.(23)**

Plugging the values of the optimal \( s^* \), \( x^* \), and \( y^* \) in eq.(18) yields the maximal expected utility under the CureShare mechanism:

\[
\text{EU}_{\text{with CS}} = \log((W-s^*-x^*)h_{1}) + \beta p \log((s^{*}R_{f} - y^{*})h_{\text{high}}) + \beta (1-p) \log(s^{*}R_{f} h_{\text{low}}).
\]

Plugging the values for \( s^* \) and \( x^* \) from eq.(20) and (22) into the expression for the period-1 consumption yields, after some algebraic manipulation:

\[
W - s^* - x^* = \frac{W(Pr) - I}{(1+\beta)(Pr)}.
\] (A3)

Employing the value of \( y^* \) from eq.(19) in the expression for the period-2 consumption in the case that the drug is successful yields:

\[
s^*R_{f} - y^* = \frac{(W(Pr) - I)\beta R}{(1+\beta)(Pr)}.
\] (A4)

The period-2 consumption in the case that the development is unsuccessful, and \( y^* \) is not paid is:

\[
s^*R_{f} = \frac{(1-p)\beta R(I-W(Pr))R_{f}}{(R-pR_{f})(Pr)(1+\beta)}.
\] (A5)

Thus the expected utility can be written as:

\[
\log((W - s^* - x^*)h_{1}) + \beta p \log((s^{*}R_{f} - y^{*})h_{\text{high}}) + \beta (1-p) \log(s^{*}R_{f} h_{\text{low}}).
\]
\[ EU_{with\, CS} = \log \left( \frac{W(Pr) - I}{(1 + \beta)(Pr)} h_l \right) + \beta p \log \left( \frac{(W(Pr) - I) \beta R}{(1 + \beta)(Pr)} h_{\text{high}} \right) + \beta (1 - p) \log \left( \frac{(1 - p) \beta R (I - W(Pr)) R_j}{(R - p R_j)(Pr)(1 + \beta)} h_{low} \right) \]

Finally, collecting all terms we have:

\[ EU_{with\, CS} = \log \left( \frac{h_l h_{low}^{\beta(1-p)} h_{\text{high}}^{\beta p} (1 - p)^{\beta(1-p)} R^\beta R_j^{\beta(1-p)} (W(Pr) - I)^{1+\beta}}{(Pr)^{\beta+\beta}(1 + \beta)^{\beta+\beta}(R - p R_j)^{\beta(1-p)}} \right) \]
Appendix 2

Interview with breast and colon cancer patient

The personal interviews were based on the written questionnaire below, which was filled out by the interviewer:

Date: ______________  Hospital: ______________  Serial number: ______________

This anonymous questionnaire is performed for research purposes in the field of health economics. The questionnaire contains four major categories of questions: general information, current health state, economic status and health expenditures, and willingness to pay for a hypothetical cure.

Part A- General Information

1. Male ☐  Female ☐

2. Age______

3. Years of education______

4. Marital status______

5. Number of persons in household_______
6. Degree of optimism: I am …

☐ Highly pessimistic
☐ Usually pessimistic
☐ Neither pessimistic nor optimistic
☐ Usually optimistic
☐ Highly optimistic

**Part B- Health State**

7. I suffer from:

Breast cancer ☐
Colon cancer ☐

8. The disease was diagnosed ________ months/years ago

9a. Breast cancer phase

☐ I was diagnosed with a benign tumor
☐ I was diagnosed with a malignant tumor.

☐ The tumor has not metastasized.

☐ The tumor has metastasized to areas close to the breast (i.e. arm pit lymph nodes, ribs and breast muscles).

☐ The tumor has metastasized to remote organs (i.e. brain, liver and/or bones)
☐ The disease has reappeared after some cancer-free period. The tumor is currently localized in the breast/other organs.

9b. Colon cancer phase

☐ I was diagnosed with a benign tumor
I was diagnosed with a malignant tumor.

☐ The tumor has not metastasized.

☐ The tumor has metastasized to areas in the vicinity of the colon (i.e. near lymph nodes).

☐ The tumor has metastasized to remote organs (i.e. brain, liver and/or bones)

☐ The disease had reappeared after some cancer-free period. The tumor is currently localized in the colon/other organs.

10. Surgical intervention

☐ I underwent tumor excision

☐ I may be operated for tumor excision in the future

☐ I will not need to undergo tumor excision

11. The impact of the disease and the treatment on my life:

☐ Does not affect me whatsoever

☐ Minor nuisance. No change in daily activities

☐ Major burden, but no change in daily activities

☐ Have altered considerably my daily activities.

12. What, in your opinion, will be the impact of your disease on your life a year from today?

☐ I will be cured

☐ I will be healthier

☐ My health state will remain the same

☐ I will be sicker

☐ My life might be in danger

13. Any co-morbidities?
14. Is your partner generally in good health?

☐ Yes
☐ No, please specify:
☐ Hypertension ☐ Diabetes ☐ Stoke ☐ Atherosclerosis ☐ Other chronic Disease
☐ Other

15. Was your income reduced due to your illness?

☐ Yes ☐ No

16. What is your monthly household budget?

☐ Under 2000 ☐ 10000-9000 ☐ 30000-25000
☐ 3000-2000 ☐ 12000-10000 ☐ 40000-30000
☐ 4000-3000 ☐ 14000-12000 ☐ Above 40,000
☐ 5000-4000 ☐ 16000-14000
☐ 6000-5000 ☐ 18000-16000

Part C - Economic Status and Health Expenditures

(All monetary values are specified in NIS. $1 US ≡ 3.7 NIS).
17. Of the above mentioned monthly budget:

A. What is your household monthly expenditure for health purposes (i.e. drugs, health insurance, medical treatments and so on)? _________

B. What are your household monthly non-health expenditures? ______

C. What is your household monthly savings? _________

18. Consider the following two alternatives: participating in a lottery or receiving a fixed sum of money for sure. The lottery provides you with a 50% chance of winning 20,000 NIS and a 50% chance of winning nothing at all. What is the minimal sure sum that you would prefer over participating in the lottery? (i.e.- for a smaller sure sum I would rather participate the lottery)__________

Part D- Willingness to Pay for a Cure

In the following Part we wish to quantify the subjective burden of your disease. We will ask what part of your household monthly income you will be willing to pay in order to be disease-free. We wish to stress that these are hypothetical questions that do not relate to drugs currently in the market.

19. Suppose that there was a new drug that would completely cure your disease, instantaneously and without any side-effects. You will take one pill per day, eliminating the need for any drugs you currently take for this specific disease.

How much will you be willing to pay for this drug on a monthly basis from now on? Please denote the maximal monthly sum that you would be willing to pay for the drug, assuming there is no other means of receiving the drug (i.e. HMO, Insurance etc) __________
20. Now, that would mean that________ percent of your monthly income would remain for you to live on. Please think about whether you and your family could manage to live on this amount of money. Do you wish to revise your previous answer to question 19? No/Yes: __________

21. While the above question (Q 19) refers to your actual income level, we now wish to ask you an equivalent question, but this time, assuming you had a different hypothetical monthly income:

A. What part of your monthly income would you be willing to pay for the drug, assuming your monthly budget was 3000 NIS? ________. I would rather be healthy and manage with a monthly income of __________, than living with a monthly budget of 3000 NIS, in my current health state.

B. What part of your monthly income would you be willing to pay for the drug, assuming your monthly budget was 5000 NIS? ________. I would rather be healthy and manage with a monthly income of __________, than living with a monthly budget of 5000 NIS, in my current health state.

C. What part of your monthly income would you be willing to pay for the drug, assuming your monthly budget was 10,000 NIS? ________. I would rather be healthy and manage with a monthly income of __________, than living with a monthly budget of 10,000 NIS, in my current health state.

D. What part of your monthly income would you be willing to pay for the drug, assuming your monthly budget was 20,000 NIS? ________. I would rather be healthy and manage with a monthly income of __________, than living with a monthly budget of 20,000 NIS, in my current health state.

E. What part of your monthly income would you be willing to pay for the drug, assuming your monthly budget was 50,000 NIS? ________. I would rather be healthy and manage with a monthly income of __________, than living with a monthly budget of 50,000 NIS, in my current health state.

22. Suppose that there was a new drug (One pill per day with no side-effects) that reduces mortality rate by 30%. How much would you be willing to pay for this drug on a monthly
basis? Please denote the maximal monthly sum that you would be willing to pay for the drug, assuming there is no other means of receiving the drug (i.e. HMO, Insurance etc)

23. Suppose that there was a new drug (One pill per day with no side-effects) that reduces the current anti-cancer treatment side effects (i.e. weakness, hair loss, vomiting etc) by 50%. How much would you be willing to pay for this drug on a monthly basis? Please denote the maximal monthly sum that you would pay for the drug, assuming there is no other means of receiving the drug (i.e. HMO, Insurance etc)

24. Suppose that there was a new drug (One pill per day with no side-effects) that reduces the current anti-cancer treatment side effects by 80%. How much will you be willing to pay for this drug on a monthly basis? Please denote the maximal monthly sum that you would pay for the drug, assuming there is no other means of receiving the drug (i.e. HMO, Insurance etc)

25. Now I'd like you to imagine that there was a new drug that would either cure you completely and bring you to perfect health, or would cause your death.

A. Suppose that 20 per cent of the people who take the new medication are cured and 80 percent die. Would you risk taking the new medication? 
B. Suppose that 50 per cent of the people who take the new medication are cured and 50 per cent die. Would you risk taking the new medication? 
C. Suppose that 80 per cent of the people who take the new medication are cured and 20 percent die. Would you risk taking the new medication? 
D. What is the maximal probability of death for which you would accept this drug?

26. Suppose that there was a new drug that would allow you to live in perfect health, but for a shorter period. How many years of life would you be willing to give up to live the remaining years in perfect health?
Appendix 3

**Self reported survey of diabetes patients**

This anonymous questionnaire is performed for research purposes in the field of health economics. The questionnaire contains four major categories of questions: general information, current health state, economic status and health expenditures, and willingness to pay for a hypothetical cure.

**Part A- General Information**

1. Male ☐ Female ☐
2. Age_______
3. Years of education_______
4. Marital status_______
5. Number of persons in household_________
6. Degree of optimism: I am …
   ☐Highly pessimistic
   ☐Usually pessimistic
   ☐Neither pessimistic nor optimistic
   ☐Usually optimistic
   ☐Highly optimistic

**Part B- Health State**

7. I have:
   ☐Type I diabetes
   ☐Type II diabetes
The disease was diagnosed ________ months/years ago
8. Disease phase/Degree of severity:

☐ I’m treated by diet and work out regime

☐ I’m treated by drugs (pills or insulin injection/pump)

☐ I’m experiencing a deterioration of sight as an outcome of the diabetes

☐ I’m experiencing deterioration in my kidney function as an outcome of the diabetes

☐ I was hospitalized due to kidney problem/hypo/heart attack/diabetic leg

9. The impact of the disease and the treatment on my life:

☐ Does not affect me whatsoever

☐ Minor nuisance. No change in daily activities

☐ Major burden, but no change in daily activities

☐ Have altered considerably my daily activities.

10. What, in your opinion, will be the impact of your disease on your life five year from today?

☐ I will be cured

☐ I will be healthier

☐ My health state will remain the same

☐ I will be sicker

☐ My life might be in danger

11. Any co-morbidities?

☐ No

☐ Yes, please specify:
12. Is your partner generally in good health?

☐ Yes

☐ No, please specify:

☐ Hypertension  ☐ Diabetes  ☐ Stoke  ☐ Atherosclerosis  ☐ Other chronic Disease____

☐ Other_______

Part C - Economic Status

13. What is your economic status?

☐ Wealthy

☐ Upper middle class

☐ Lower middle class

☐ Poor

Part D - Willingness to Pay for a Cure

In the following Part we wish to quantify the subjective burden of your disease. We will ask what part of your household monthly income you will be willing to pay as percent of your total wealth in order to be disease-free. We wish to stress that these are hypothetical questions that do not relate to drugs currently in the market.
14. Suppose that there was a new drug that would completely cure your disease, instantaneously and without any side-effects. You will take one pill per day from now on, eliminating the need for any drugs you currently take for this specific disease.

What percent of your total wealth will you be willing to pay for this drug on a monthly basis from now on? Please denote the maximal percent of your total wealth that you would be willing to pay for the drug, assuming there is no other means of receiving the drug (i.e. HMO, Insurance etc) ___________

More than 35% 30%-35% 20%-25% 25%-30% 15%-20% 15%-10% 10%-5% 2%-5% 1%-2% less than 1%

Please write the precise percent from the range you chose______

15. Suppose that there was a new drug that completely cure 50% of diabetic patient, instantaneously and without any side-effects, taking one pill per day from now on, and eliminating the need for any drugs you currently take for this specific disease. You cannot know in advance whether the drug cures you and you will need to take the drug to find out. What percent of your total wealth will you be willing to pay for this drug on a monthly basis from now on? Please denote the maximal percent of your total wealth that you would be willing to pay for the drug, assuming there is no other means of receiving the drug (i.e. HMO, Insurance etc) ___________

More than 35% 30%-35% 20%-25% 25%-30% 15%-20% 15%-10% 10%-5% 2%-5% 1%-2% less than 1%

Please write the precise percent from the range you chose______

16. How would your answer to question 14 change in case the drug cures only 10% percent of patient:
17. While the above question (Q 14-16) refers to your actual wealth, we now wish to ask you an equivalent question, but this time, assuming you had a different hypothetical level of wealth.

A. What percent of your wealth would you be willing to pay for the drug, assuming your wealth is 50,000 NIS? ______

B. What percent of your wealth would you be willing to pay for the drug, assuming your wealth is 50,000 NIS? ______

C. What percent of your wealth would you be willing to pay for the drug, assuming your wealth is 100,000 NIS? ______

D. What percent of your wealth would you be willing to pay for the drug, assuming your wealth is 500,000 NIS? ______

E. What percent of your wealth would you be willing to pay for the drug, assuming your wealth is 1,000,000 NIS? ______

F. What percent of your wealth would you be willing to pay for the drug, assuming your wealth is 5,000,000 NIS? ______
References


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Pareto V. (1897), Cours d'Economie Politique, tome 2, Pichon, Paris.


In this doctoral work, I present three research studies that deal with different issues in the field of the economics of health. Therefore, in this summary, I present the summary of the things for each research in a separate manner.

I wish to note that the common factor among the three studies is the use of the utility function of the individual's health and wealth.

In the first and third studies, we use this function in the models we propose. In the second study, we conduct an empirical research to define and describe the utility function of health and wealth, and after that, we use its results in all the other research studies presented in this doctoral work. Therefore, the second study has a significant impact on all the results and conclusions presented in this work.

Study One

Introduction and Goals

In the first study, we develop a new mechanism that allows the public to invest in research and development that is being carried out by the pharmaceutical companies, for specific diseases that they suffer from.

The motivation for developing a mechanism of this type stems from the rejection of many research and development projects in the pharmaceutical industry due to a low economic return that is manifested in the calculations of these projects. There are many diseases that are suffered by a small number of people, and therefore, development of new drugs is not performed for them. If a drug can save lives, which is suffering from such diseases, and the public is willing to pay for it, there is no justification for the research from the company's perspective.

For the public, there is no possibility of participating in the funding of these projects, and therefore, they are not implemented in many cases.

We identify the absence of the possibility of the investors' public taking part in the funding of research and development for their disease as a market failure, and we propose a mechanism to solve it.

The proposed mechanism does not include government involvement or donations, and it creates an overall profit.

The new mechanism, allows patients to share the risk with the pharmaceutical company in the advanced stages and we demonstrate that this participation, in certain conditions, may change the economic incentive of the company to develop.
The treatment. And currently, the most prominent among them is the method of applying a treatment that helps to solve problems and treat various diseases.

Moreover, the treatment aims to improve the health of the patient by investing in the treatment process. Now, we have several tools that allow the public to promote health through partnerships with pharmaceutical companies. We will briefly describe them and highlight the differences between this method and the method of health insurance:

The public funding is the largest in the world, primarily in the United States, through the NIH. The government invests in a wide range of health projects, which is funded by taxpayers' money.

The first difference will be the type of investment involved: governments have interests in the general health of the population. In the method of health insurance, the possibility is given to patients with the same disease to invest in the treatment of their disease and not in research aimed at developing a drug for another disease.

Public funding also comes from patient associations which are usually based on donations. In this case, it is the investment in the development of very specific drugs, usually not developed in the companies but in universities and research centers. The importance of basic research is significant, but it is usually at an early stage and it may take years to bring a drug to the market.

The second difference is the timeline of the project. The project we propose is not a substitute for public funding methods, but rather a supplement that allows the patient's community to invest directly in the development of a drug for their disease, where this is not happening today.

In summary, we present a theoretical model, which defines two conditions that must be met in order for the method to work in reality.

The first condition is negative for the company's perception of the project. In this case, the company will not develop the drug unless we have the method of health insurance.

The second condition is based on the utility of the individual in terms of money and health. To the extent that the individual suffers from any disease, he improves his chances of being healthy in the future (or in the future), in exchange, his investment decreases his ability to spend in the future.

Finally, we present a theoretical model, which defines two conditions that must be met in order for the method to work in reality.
A decision to acquire health insurance is influenced by the insured's health status and their ability to save. The insured's health status remains unchanged or deteriorates. Their benefit is greater than their current benefit when they choose to acquire health insurance. Only when both conditions are met, the model is applied. The second condition requires that we define the utility function of wealth and health, especially the utility of health decreased when the insured's health status is decreased.

The preference of health outcomes in the literature is not clear. There are articles indicating that the utility of health increases when health deteriorates (Lillard and Weiss (1997), Evans and Viscusi (1991), Rust and Phelan (1997), Lillard and Weiss (1997)). On the other hand, there are studies showing that the utility of health decreases when health deteriorates (Sloan et al. (1998), Finkelstein, Luttmer and Notowidigdo (2008)). In sample surveys, the utility of health remains constant (Aigner et al.(2000)).

We choose to adopt this research and use the utility function $U(w,h)=\log(w)h$. In this study, we conduct a laboratory experiment to determine the utility function $U(w,h)=\log(w)h$. This shows a decrease in the utility of health when the insured's health status decreases. We present the model of health equity in two forms, in each form, we examine the validity of both conditions but use a different utility function.

In the empirical research, we conduct five studies for five diseases, both have two common factors:

- The first factor is that it is a chronic disease, for which there is no treatment, and therefore the quality of life of the patient is low.
- The second factor is the number of patients.

We examine the model for diseases with a prevalence of 0.222 - 0.222 patients. We estimate that the model can be applied to diseases with higher or lower prevalence, but we chose the prevalence to be higher for two reasons: we estimate that in higher prevalence, the development of a new drug is likely to be positive. In diseases with prevalence lower than 0.222, it is possible that obtaining all patients' health equity is not sufficient from the perspective of the drug company.
אנון, ובנוסף, נשות נpaRepository בשפות שונות. אנו מתאימים את עולמות פיתוח הת horrופה, ואת סכום הצלחת הפיתוח ואת הנתונים המגנים לסטטוסיםバリוזיווי של "החולות המייג" לכל אופן מתאימים המשולב.

נתונים מת쁘יזים

הגרסא הראשונה של המודל, אשר לכלול את פניקיוון הת görülויות יותר ומباشرות - הדגימה כי התנייה הארשון ("שלillow בערב הת Hornets") תומך מתכרים ל İz לה בוא אדם (כלכל השכיחות) רוח מהבין הריבוע וברחית השפיים הרבות שמייצג הזמן. התאני השתי, להעמת את מתכרים כי נער מית השפיים הרבות שמייצג התרופה והchrift רכש מיני ההבריאת בזוכה. בהכרח הנגשימם בשימוחו ובזימית נועפים שהритори השתי.

U(w,h)=\log(w\cdot h)

הגראס השניה של המודל, אשר לכלול את פניקיוון הת慝ouplesות יותר ומباشرות יותר - הדגימה כי התנייה הארשון ("שלillow בערב הת Hornets") תומך מתכרים ל İz לה בוא אדם (כלכל השכיחות) רוח מהבין הריבוע וברחית השפיים הרבות שמייצג הזמן. התאני השתי, להעמת את מתכרים כי נער מית השפיים הרבות שמייצג התרופה והchrift רכש מיני ההבריאת בזוכה. בהכרח הנגשימם בשימוחו ובזימית נועפים שהרתי השתי.

U(w,h)= h \cdot \log(w)

הגרסא השנייה של המודל, אשר כלל את פניקיוון הת慝ouplesות יותר ומקסימליות - הדגימה כי התנייה הארשון ("שלillow בערב הת Hornets") תומך מתכרים ל İz לה בוא אדם (כלכל השכיחות) רוח מהבין הריבוע וברחית השפיים הרבות שמייצג הזמן. התאני השתי, להעמת את מתכרים כי נער מית השפיים הרבות שמייצג התרופה והchrift רכש מיני ההבריאת בזוכה. בהכרח הנגשימם בשימוחו ובזימית נועפים שהרתי השתי.

תמצית דיון

חלק הדיון של פרק זה עוסק בבית נוספים אופטימיות חסרות בברכה במגשים. קיים מספר הספירה חלק זה של פארק זה ע iphone אופטימיות בביאור המגשים. קיים מספר הספירה ובה ע""ת"" למגשים"", סיסטוריה איקופרמציה המגשים המקומית של iphone situéית על iphone או iphone אתה הנגשות בברך התרופה העבר יוצר iphone. אם כי משות בריאת. בין מספרים צויצא אל iphone ע""ת"" במגשים לתחתיו.
מחקר שני

פונקציות התועלות מהון ומבריאות

תמצית מהובא ומפורטות

במחקרים שונים זוהי בניה בחשיבותו והمبחרות בין פרספקטים שונים של🧩 ישראליים והבריאות בסביבה גורב של משאבי הון לǹכשו של פתרון, ייצוגי בירוח, מחירים הוראות ומרכבים ייחודים ותפקידים משאבי בושק הנבאות, והם. על כן נמצאים מחקרים בנייני זה היא מעכבת דילית. רוז המחקר הקים

בנוסף זה עוקב בשאלות התועלות שלו מון ביבס למבראות. תקצוב מברואות על תועלות שולית

הבריאות ורוא

(Viscusi and Evans (1990), Sloan et al. (1998), and Finkelstein, Luttmer and Notowidigdo (2008)).

המצאות שאנו מצפים בעבברוד וזחמים בבר. לאורר הגזרה פורמלגי של פונקציות התועלות מון ומבריאות, אשר לקיימים של פונקציות התועלות הקדידיות לשאלות העדפות של פריטים המעורבות והבריאות. לאחר秣ו אנパイ ביצוע מחקר אפירי

ועשה בריאות

לע מת לאיצוף! nạn ההצהרה של פונקציות התועלות מון ומבריאות והמקים של תיאורית בוגוע

לתונניות של ארבע פונקציות התועלות מון שהשק锂电池 עב בpaypal כתוביל: פונקציית

הלוגריתמית, פונקצית החזקה, פונקצית האקספוננציאלית של פונקציה הביא את. הביא 17\\אמשייט

שחיתות מסופת מלבד לתועלות השלישית מון בין בריאות.

עדבר כו פונקציה אם אנכיים למסוף את פונקציות התועלות מון ומבריאות והמקים של תיאורית בוגוע

אנשים שאינם בירוחי או/ואים לבריאות,エステרים והשמאים את השאלות הצבע: מהי החזקה

המכמיות של התוכנות использова נהין לירוך לירוח ישר לירוח אנכי או/ואם קבוצ

ומאשרת את פונקציה של נהיה? בר פונקציה מתכלי ביו מתחתי, שאנה לפורפוזיציה, ווליפר

גב השלכות שלון בוגוע לתוכלות של פונקציות התועלות.

מחקר אפירי

בצורת שי מחקרים בולטים, הראשו הصدرת של שאלונים אינטגרליים, לימי ענבי בבר והם, הקבילים בריאות השתבות עשים חולי סרטוט ש jp ועוצרת העוין במחילתואנוקוגויצית שלטויפה, אם והש

In hospitals Hadassah and Rambam.

We conducted an analysis of 2100 questionnaires filled out by patients with diabetes and 1082 interviews conducted among cancer patients.

We attach great importance to the results of the interviews conducted among cancer patients, since they allowed us to recognize the understanding of the questions of the research sources.

We therefore found a high degree of importance in bringing the results of the two trials, since diabetes is a disease that has a less clinical severity and its impact on life expectancy is lower compared to cancer.

In the cancer questionnaire, the central research question is the question that was discussed in the theoretical discussion. In the bill of rights, we asked the participants a similar question about the proportion of what they are willing to pay, which is hypothetical for various levels of income. This question was also asked in the diabetes questionnaires, but we asked about the maximum proportion that the patients are willing to pay, out of their income, in order to acquire the medication. This is the major difference between the two trials.

The questions of this type are called in the literature (WTP) willingness to pay and they are recorded in a large number of empirical studies that examine the preferences of individuals throughout the interview and questions WTP took place after Thompson's article (1986) that examines the willingness of individuals to pay for the treatment of chronic diseases.

In order to estimate the health status of the individuals, we asked two types of questions. The first type included questions related to the severity of the disease in the clinic and the response of which is objective, so we received an expert opinion from professionals in the relevant fields. The second type enabled us to receive a subjective assessment of all participants on a scale of 0 (a state of death) to 1 (perfect health). To receive the subjective assessment of each participant regarding his health, we used two questions: time trade off (TTO) and - SG Standard Gamble (Quality Adjusted) QALY. This method was developed by (Drummond et al. 1997), et al. (1990). SG- SF-12 questionnaire or SF-36 which evaluates health status in 36 dimensions, Life Years. Shaul etc-SG- SF-12 then examined a random sample of 500 patients with diabetes and 500 cancer patients and found no statistically significant difference between the two groups in any of the dimensions.

A summary of the findings in the two trials, the proportion of income/income that the patients are willing to pay in order to remove their disease increases as the proportion of income/income increases. This result is consistent with Thompson (1986).

The interviews...
Best fit analysis of the empirical results to the theoretical functions discussed in the theoretical section. It is found that there is a significant deviation between the empirical results and the quadratic and power functions. On the other hand, the exponential function and the logarithmic function show good fit within the entire range. The main drawback with the exponential function is that it is characterized by CARA (Constant Absolute Risk Aversion) in U(w), which is unrealistic (Markowitz, Reid, and Tew 1994). Therefore, we propose the logarithmic function, which describes the changes between income and health (U(w,h)) = h \cdot \log(w).

The results of this study concerning the utility of income, health, and decisions related only to income (U(w)) indicate that the observed savings are not necessarily as severe. The reason for this is that the health level decreases with age and the utility function we propose, the income/health utility decreases as the health状况 worsens. Thus, the optimal consumption in people over 50 is likely to be lower.

In the discussion section, we use the logarithmic function to measure this effect.
In the third research chapter, we present a theoretical model of monopolistic competition for breakthrough drugs.

The model uses the logarithmic utility function \( U(h, w) = h \cdot \log(c) \), and describes the demand function of the drug as a function of price, the level of health improvement it creates, and the patient's consumption. This demand function forms the basis for examining the monopolistic price of breakthrough drugs, from the perspective of the drug company for patients without health insurance and who bear the full cost of the drug.

In the continuation of the work, we use this function to study the impact of regulation on drug prices and profits, and examine its impact on the drug company's profits and the patient's profits.

Healthcare spending worldwide is increasing at a rate of 0.1% per year and is a central component of the financial resources allocated by countries for healthcare. This fact is a result of increased drug use and rising drug prices.

It is possible to divide the range of drugs available in the market into two main groups. The first group includes innovative drugs that are patented for several years after their initial entry into the market, and therefore are produced and marketed by a unique drug company. The drugs in this group are often in competition with drugs that are already on the market, and therefore their price is often affected by the existing pharmacological alternatives, and by the entry strategy of the manufacturers (Brendt 2002).

The second group consists of generic drugs, which are perfect substitutes for drugs that were once innovative, and whose patent expired. In these drugs, there is often strong competition as they are marketed by several drug companies and therefore their price is significantly lower than that of the original innovative drugs.

This research is focused on a brief summary from the first group, which consists of innovative drugs that have a significant breakthrough and therefore provide a significant pharmacological response compared to the existing alternatives. For this reason, the price of these drugs is monopolistic and in practice constitutes the main source of profit in the pharmaceutical industry.


הוא רווי סיכוני המﲢלים את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק את התחרות בשוק את התחרות בשוק את התחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתחרות בשוק אתהתאלה.
עבודדה זו נעשתה בהדרכתו של פרופ' משה לוי.
מנגנון מניעת הבריאה, התערבותה מחודד ומביריאות והמתחר

מונופוליסטי של תרופות פורצות דרך

תורם לשם קבלת דוקטור לפילוסופיה

מאת

עדי רידנשטיין ייר

הוגן לפנים האוניברסיטה העברית בירושלים

דצמבר 2011
מנגנון מatriות הבירהות, התערלת מחנה ומברירת המחדשים
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zählמבר 2011