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Watchfully waiting: Medical intervention as an optimal investment decision

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ABSTRACT

Watchfully waiting involves monitoring a patient's health state over time and deciding whether to undertake a medical intervention, or to postpone it and continue observing the patient. In this paper, we consider the timing of medical intervention as an optimal stopping problem. The development of the patient's health state in the absence of intervention follows a stochastic process (geometric Brownian motion). Spontaneous recovery occurs in case the absorbing state of "good health" is reached. We determine optimal threshold values for initiating the intervention, and derive comparative statics results with respect to the model parameters. In particular, an increase in the degree of uncertainty over the patient's development in most cases makes waiting more attractive. However, this may not hold if the patient's health state has a tendency to improve. The model can be extended to allow for risk aversion and for sudden, Poisson-type shocks to the patient's health state.

1. Introduction

"Watchfully waiting" involves monitoring a patient's health state over time and deciding whether or not to undertake a medical intervention – an operation, course of treatment or some other medical procedure. This process is characterized by the three essential properties of an investment decision: the existence of uncertainty, in this case concerning the development of the patient's health state and, possibly, the outcome of medical intervention; irreversibility, in the sense that the results of the intervention may be impossible or extremely costly to reverse; and flexibility of timing, implying that a key aspect of the decision is exactly when to make the intervention. At each point in time, there is the possibility of making the intervention or of postponing it and observing how the patient's health state evolves. Recent developments in the theory of investment under uncertainty, also referred to as real options approach,[2] have greatly increased our understanding of how such decisions should be taken, and this paper is concerned with the application of this theory to the watching and waiting process.

A key insight of the theory concerns the option value of waiting. A standard proposition of traditional investment decision theory is that an investment should be undertaken if (when) the present value of its benefits exceeds the present value of its costs. This however ignores the possibility that information about the inherently uncertain costs and benefits may be revealed over time, and so it may pay to postpone the investment beyond this point in order to collect more information. That is, the option to wait has a positive value, while making the investment, in the present case carrying out the medical intervention, extinguishes this option and sacrifices this value. Thus, typically, the net present value will have to be – possibly substantially – greater than zero to compensate for the loss of the option value.

In this paper we provide a formal model of the watching and waiting process and derive threshold values for initiating medical intervention. This amounts to an optimal stopping problem: the patient's health state follows a stochastic process, and medical intervention terminates this process and restores the patient's health. We also allows for the possibility of spontaneous recovery. This occurs if the patient's health state reaches the absorbing state of "good health".

In our baseline model, the patient's development is described by a geometric Brownian motion process. Here, increases in the treatment cost and in the average rate of change of the health state

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[2] See Dixit and Pindyck (1994) for an introduction.

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raise the optimal threshold value, so that waiting becomes optimal for a wider range of health states. According to the standard theory of investment under uncertainty, an increase in the variance of the stochastic process also makes waiting more attractive, because it raises the option value. This does not always apply in our model: if the patient's health state has a tendency to improve, an increase in the degree of uncertainty may work in favour of medical intervention. Intuitively, spontaneous recovery becomes less likely in this case, because uncertainty raises the probability that the patient's health state evolves against its central tendency.

The model can also be extended to allow for risk aversion on the patient's side. We also introduce a second type of uncertainty, represented by a Poisson jump process. This captures the possibility of sudden, discontinuous deterioration in the patient's health state. Depending on the degree of deterioration, a health shock may make immediate intervention optimal. Even if this is not the case, direct treatment becomes relatively more attractive compared to the baseline model, to an extent determined by the parameters of the Poisson process.

The purpose of the present paper is to explore the application of the main ideas of modern investment theory to the watchfully waiting decision at a general level. We want to clarify the kinds of insights that may be gained and the ways that intuitions may be challenged, especially by examining the comparative statics results of the models. Clearly, concrete applications to specific types of medical conditions will require far more detailed models and calibration with real data.

The paper closest to ours is Driffield and Smith (2007), who also discuss the applicability of the real options approach to watchfully waiting. Their paper is less general than ours in that they only consider a hypothetical example, and do not derive comparative statics results. The authors emphasize that more data needs to be collected to corroborate the simulation results. However, they argue that conventional approaches to medical decision making, such as decision tree models, suffer from similar or even more severe problems.

Whynes (1995) establishes a framework for identifying optimal times of transfer from a watchfully waiting program to direct intervention. Spontaneous resolution of the disease is possible, and its probability is assumed to increase over time according to specific functional forms. As a main result, increases in the probability of self-resolution and in the costs of direct treatment raise the optimal time of transfer, making watchfully waiting more attractive, whereas increases in the monitoring costs and in the probability of disease recurrence have an opposite effect.

Lasserre et al. (2006) are also concerned with the decision when to initiate medical treatment. They consider the case of HIV therapy in a two-period model. While early intervention has the downside that it causes resistance effects, waiting may result in a deterioration of the patient's health state, so that treatment may no longer be effective. An interesting result is that the magnitude of the resistance effect becomes irrelevant for the treatment decision if it is sufficiently high.[3]

In practice, watchfully waiting is often recommended for diseases which are progressing only slowly, and where the benefits of existing therapies are possibly limited. Typical examples are slowly growing cancers (e.g., lymphoma, prostate cancer), which in many cases would not cause severe problems during the patient's lifetime. Furthermore, watchfully waiting is often the preferred approach for dealing with common diseases such as children's middle ear infections, where many cases resolve spontaneously. Other examples involve inguinal hernia, abdominal aortic aneurysm and mild chronic hepatitis C. Generally, recommendations vary according to the type and severity of illness, and according to the patient's age and readiness to comply with a treatment regime that requires active monitoring.[4]

The remainder of the paper is organized as follows. The model assumptions are presented in the next section. In Section 3, the model is solved under the assumption that the patient's health state evolves according to a geometric Brownian motion. In Section 4, two extensions are discussed: the case of risk aversion, and the possibility of sudden, Poisson-type shocks to the patient's health state. Section 5 concludes.

2. The model

We consider a patient who suffers from a particular disease. Her health state at time t is denoted by $h_t \in [0, 1]$, where $h_t = 1$ represents "good health", $h_t = 0$ represents death, and time is continuous. The patient has a utility function $u(h_t)$ with the standard properties:

$$u'(h_t) > 0; \quad u''(h_t) \le 0$$

Thus, she is (weakly) risk averse with respect to lotteries over health states. We normalize $u(0) = 0$ and $u(1) = 1$. In the absence of medical intervention, the development of the patient's health state is uncertain, and a central aspect of the model is the choice of a stochastic process with which to characterize this uncertainty. Here, we consider two cases:

2.1. Geometric Brownian motion (GBM)

In this case, the development of the health state is described by a geometric Brownian motion with drift rate α and variance parameter $\sigma > 0$:

$$\frac{dh_t}{h_t} = \alpha dt + \sigma dz$$

The variable z represents a standardized Wiener process, whose increment is normally distributed with mean zero and variance dt. Thus starting from any value $h_0 \in (0, 1)$, the patient's condition may have a central tendency of improvement ($\alpha > 0$), stability ($\alpha = 0$), or deterioration ($\alpha < 0$), but its development will also be affected by a random element for the better or worse, to an extent determined by the value of σ. These random changes are uncorrelated over time, and can cumulatively cause the patient's health state to diverge significantly from its central tendency. Moreover, $h_t = 0$ and $h_t = 1$ are absorbing states. If reached by the stochastic process, the patient remains there for the rest of the time. Thus, reaching $h_t = 1$ would be "spontaneous recovery" and $h_t = 0$ "premature death".

2.2. GBM with Poisson jump process

In the second case, the patient's health state still evolves according to the GBM process defined above, but there may also be sudden, discontinuous health shocks whose arrival times follow a Poisson distribution. This process is described by the equation

$$\frac{dh_t}{h_t} = \alpha dt + \sigma dz + dq$$

[3] Further removed from the concerns of the present paper, Palmer and Smith (2000) and Pertile (2008) apply the real options approach to study the decision to adopt new health care technologies. Attema et al. (2010) consider the decision of a country to stockpile antiviral drugs to prepare for a pandemic.

[4] References for these examples are: Ardeshna et al. (2003), Bill-Axelson et al. (2005), American Academy of Pediatrics (2004), Fitzgibbons et al. (2006), Valentine et al. (1999), and Wong and Koff (2000).