CENTRO STUDI IN ECONOMIA E FINANZA

CENTRE FOR STUDIES IN ECONOMICS AND FINANCE

WORKING PAPER NO. 53

How Diagnostic Tests Affect Prevention: a Cost Benefit Analysis

Luis Eeckhoudt, Christian Gollier and Giovanni Immordino

February 2001

DIPARTIMENTO DI SCIENZE ECONOMICHE - UNIVERSITÀ DEGLI STUDI DI SALERNO
Via Ponte Don Melillo - 84084 FISCIANO (SA)
Tel. 089-96 3167/3168 - Fax 089-96 3169 – e-mail: csef@unisa.it

CSEF WORKING PAPER NO. 53

How Diagnostic Tests Affect Prevention: a Cost-Benefit Analysis

Luis Eeckhoudt*, Christian Gollier**, Giovanni Immordino***

Abstract

The purpose of this paper is to offers insight for evaluating research and development in diagnostic tests. We show that a rational policy maker perfectly informed about health risks may choose to reduce investment in prevention when efficient diagnostic tests become available. We show that prevention and diagnostic tests are substitutes rather than complements. As a result the regular improvements in diagnostic technology that are observed can justify a lower investment on prevention at any given unitary price for this activity. The analysis is a useful tool for the allocation of funding between diagnostic and preventive medicine.

JEL Classification: D81

Keywords. prevention, diagnostic tests

* Catholic Faculties of Mons and Lille

** GREMAQ and IDEI, Université de Toulouse

*** GREMAQ, Université de Toulouse, Fondazione CARISAL and CSEF, Università di Salerno

Table of contents

1. Introduction

2. The basic model

3. The optimal treatment decisions

4. Optimal preventive decisions

5. Conclusions

References

1 Introduction

The purpose of this paper is to offers insight for evaluating research and development in diagnostic tests. We show that a rational policy maker perfectly informed about health risks may choose to reduce investment in prevention when efficient diagnostic tests become available. We show that prevention and diagnostic tests are substitutes rather than complements. The analysis has important implications for the allocation of medical funding. In fact, there are welfare gains associated with diagnostic tests in terms of reduction of uncertainty and these can be estimated in resource savings on prevention.

To develop the model we consider the following plausible sequence of events and decisions. At time 0, the representative agent is healthy and he may undertake a preventive investment with the objective of reducing the probability of occurrence of a potential illness that may appear at "old age" (time 1). She is perfectly aware of the probability of occurrence and of the impact that the preventive technology has on this probability.

If illness occurs at time 1 a treatment strategy will be available. Its effects however are uncertain because if some side conditions are present the treatment will possibly have a negative impact on health. If the side conditions are not present, the treatment will have a perfectly known positive effect. At time 0, the policy maker is fully aware of the probability of side effects and of the treatment efficiency.

Now consider the following (mutually exclusive) possibilities about diagnostic technology:

a) either it is expected that between time 0 and time 1 a perfect diagnostic test will be available to ascertain the presence or absence of the side conditions;

b) or it is expected that no such test will ever be available before time 1.

We show in this paper that if case a prevails all risk averse decision makers will invest less on prevention than in case b. Therefore, if diagnostic tests are assumed to be exogenous scientific progress, because prevention and diagnostic tests are perceived as substitutes by rational well informed policy makers, the continuous improvements in diagnostic technology lowers the socially optimal level of prevention. If, instead, scientific progress is endogenous, our analysis offers insight for the optimal allocation of medical funding between ReD in diagnostic tests and primary prevention.

Our paper is organized as follows. In the next section, we are more specific about the policy maker's objectives and environment and we introduce notation. Because of the sequential nature of the problem, we have first to characterize optimal treatment decisions that are taken at the end of the decision tree. This is done in section 3 for each type of diagnostic technology. Then in section 4 we unfold the decision tree and prove the main result of the paper and we underline the relevance of the results for cost benefit analysis of research in diagnostic tests. Finally, we conclude.

2 The basic model

The representative agent lives two periods (time 0 and time 1) and his utility function in each period is additive in two arguments: wealth (W) and health (H) that is:

$U(W) + V(H)$

with $U' > 0, U" < 0$

$V' > 0, V" < 0.$

The intertemporal utility is simply a discounted sum of the utilities achieved in each period. The psychological discount factor is: ρ with $0 < \rho < 1$.

When the agent is healthy the stock of health is equal to H_2 and if illness occurs it falls to $H_0 < H_2$ so that $H_2 - H_0$ measures in a sense the severity of the disease. At time 0, the agent who is healthy knows the probability of occurrence of the disease (e.g. cancer) that is denoted Π. If the disease occurs, a treatment the quantity of which is denoted y[1] is available. The monetary cost of the treatment per unit is Θ. Its medical effects depend upon the existence of side conditions (e.g. allergy to drugs). When the side conditions are absent, the treatment has a positive impact represented by $m(y)$ so that the final health H_1 is given by:

$$H_1 = H_0 + m(y),$$

where $m(y)$ is an increasing and concave function. Since a successful treatment can never restore perfect health we have: $H_0 + m(y_m) < H_2$, where

[1] For analytical simplicity we take y as a continuous variable. It may be interpreted as the dose of a drug or the intensity of a radio-therapy treatment.

y_m is the maximum feasible level of y. When side conditions are present, the positive effects of a treatment for a sick agent are counterbalanced by negative effects denoted $d(y)$ so that:

$$\hat{H}_1 = H_0 + m(y) - d(y).$$

Function $d(y)$ is increasing and convex. The effect of the treatment on the health stock for a sick agent can then be represented as in figure 1:

$$[insert figure 1]$$

Notice that as is often the case a too extensive use of y may deteriorate the health stock of a sick agent when side conditions are present.

While treatment decisions are made at time 1 when it is known that the illness has occurred, prevention activities take place at time 0 when the agent is healthy. Self protection activities - the quantity of which is denoted x - are assumed to have a unit price equal to unity. Their impact will be to reduce Π, the probability of occurrence of the illness. We assume that:

$$\frac{d\Pi}{dx} = \Pi' < 0 and \frac{d^2\Pi}{dx^2} = \Pi" > 0$$

implying decreasing returns in the prevention technology.

In our model the level of wealth available in each period will be completely exogenous[2] and denoted respectively W_0 and W_1. The amount available for consumption in each period will be equal to the corresponding value of W minus the medical expenditure of the period (prevention at time 0 and treatment in case of illness at time 1).

It obviously results from the description of the process that we face a recursive problem. Hence we now investigate the optimal decisions at the end of the decision tree, that is the optimal treatment decisions in case of illness.

[2] In models like Dardanoni and Wegstaff (1987), Selden (1993) and Chang (1996) second period wealth is endogenous because these authors study the relationship between saving and health investment. Since we focus here our attention upon the competition between different health activities we do not treat the saving decisions.

3 The optimal treatment decisions

At time 1, two states of the world are possible: either disease (with probability $\Pi(x)$) or no disease (with probability $(1-\Pi(x))$). In case of no disease, of course no treatment is undertaken and total utility amounts to $U(W_1)+V(H_2)$.

If the disease materializes and if the presence of the side conditions cannot be diagnosed the agent must choose y under risk. He will try to maximize L where:

$$L = U(W_1 - \Theta y) + pV(H_0 + m(y) - d(y)) + (1-p)V(H_0 + m(y)), \quad (1)$$

where p is the probability that the side conditions will materialize.

The associated first-order condition for y is:

$$\frac{dL}{dy} = -\Theta U'(W_1 - \Theta y) + p\left(m' - d'\right)V'\left(\hat{H}_1\right) + (1-p)m'V'(H_1) = 0 \quad (2)$$

Since U and V are concave: $\frac{d^2L}{dy^2} < 0$.

Let us denote by y^* the value of y that solves 2 and by $L(y^*)$ the associated level of welfare when no diagnostic test is available. Although equation 1 can be used to derive many comparative statics results, we indicate only one here that will be useful for our purpose. Easy manipulations show that the sign of $\frac{dy^*}{dp}$ is given by:

$$sign\left(\frac{dy^*}{dp}\right) = \left(m' - d'\right)V'\left(\hat{H}_1\right) - m'V'(H_1).\square \quad (3)$$

When a perfect diagnostic test is available to determine if side conditions are present or not, treatment decisions will be made conditional upon the test result. If it is positive (an event of probability p[3]) the policy maker will try to maximize $M(y)$ with:

$$M(y) = U(W_1 - \Theta y) + V(H_0 + m(y) - d(y)),$$

[3] Since the test is fully sensitive and specific, its outcome is perfectly correlated with the status of the side conditions (e.g. Pauker and Kassirer (1980) or Eeckhoudt, Lebrun and Sailly (1984)).

since one is now certain that the side conditions are present.

If we denote the optimal solution by y^+ the resulting level of welfare in case of a positive test result will be:

$M(y^+) = U(W_1 - \Theta y^+) + V(H_0 + m(y^+) - d(y^+))$.

When the test result is negative, the optimal y is denoted y^- and the associated level of welfare is $R(y^-)$ with: $R(y^-) = U(W_1 - \Theta y^-) + V(H_0 + m(y^-))$.

To determinate the impact of the diagnostic technology upon preventive decisions we need to obtain the value of the perfect diagnostic test. To do so, we now express $L(y^*)$ as a function of p. Because of the envelope theorem we have:

$\frac{dL(y^*)}{dp} = V(H_0 + m(y^*) - d(y^*)) - V(H_0 + m(y^*)) < 0$, which for brevity will be denoted: $V\left(\hat{H}_1^*\right) - V(H_1^*)$.

Besides, $\frac{d^2L}{dp^2} = \frac{dy^*}{dp}\left(V'\left(\hat{H}_1^*\right)\left(m' - d'\right) - V'(H_1^*)\, m'\right)$.

From 3 is is obvious that $\frac{d^2L}{dp^2}$ is positive since it is the product of two expressions which have the same sign. Hence we can draw the following figure:

$$[insert figure 2]$$

The L function is downward sloping and convex. Besides its end points are $R(y^-)$ and $M(y^+)$. Indeed when the perfect diagnostic test is negative (positive), the probability is equal to zero (one). Then by using standard arguments (see e.g. Hirshleifer and Riley (1979)), it can be shown that the value of the diagnostic test at any given p (say p_0) is equal to the distance between the straight line ab and the convex curve $L(y^*)$ both evaluated at p_0 (that is qn in figure 2).

For the developments in the next section it is important to remember that the ordinate of q, which is the expected welfare associated to the diagnostic test and which we denote E is given by: $E = p_0 M(y^+) + (1 - p_0) R(y^-)$.

Since n corresponds to the welfare obtained in the absence of diagnostic test, the convexity of $L(y^*)$ guarantees that the test has a positive value.

4 Optimal preventive decisions

We can now characterize the optimal preventive decision that has to be made at time 0.

If a perfect test is going to be available between time 0 and time 1, the intertemporal objective function F can be written as:

$\max_x F = U(W_0 - x) + V(H_2) + \rho \left[\Pi(x) E + (1 - \Pi(x))(U(W_1) + V(H_2))\right].$

The first-order condition is:

$$\frac{dF}{dx} = -U'(W_0 - x) + \rho \Pi'(x)(E - (U(W_1) + V(H_2))) = 0, \qquad (4)$$

where $E - (U(W_1) + V(H_2))$ is necessarily negative since no medical procedure can restore full health so that E can never exceed $U(W_1) + V(H_2)$.

Notice that the second order condition for a maximum is always satisfied[4] under risk aversion. Indeed:

$\frac{d^2F}{dx^2} = -U''(W_0 - x) + \rho \Pi''(x)(E - (U(W_1) + V(H_2))) < 0.$

If no diagnostic test is to available between times 0 and 1, the objective function becomes G with:

$\max_x G = U(W_0 - x) + V(H_2) + \rho \left[\Pi(x) L(y^*) + (1 - \Pi(x))(U(W_1) + V(H_2))\right].$

The corresponding first-order condition is now:

$$\frac{dG}{dx} = -U'(W_0 - x) + \rho \Pi'(x)(L(y^*) - (U(W_1) + V(H_2))) = 0, \qquad (5)$$

and one can easily verify that under risk aversion this corresponds to a maximum.

To see the impact of the diagnostic test on optimal prevention it is enough to compare 4 and 5. Denote by x_F the value of x that satisfies 4 and then evaluate $\frac{dG}{dx}$ at x_F :

$\left.\frac{dG}{dx}\right|_{x=x_F} = -U'(W_0 - x_F) + \rho \Pi'(x_F)(L(y^*) - (U(W_1) + V(H_2))).$

Since $L(y^*)$ is smaller than E, and because Π' is negative it immediately follows that $\left.\frac{dG}{dx}\right|_{x=x_F}$ is positive so that $x_F < x_G$, where x_G is the optimal level of prevention under G.

The main features of the prevention decision are represented in figure 3.

$[insert figure 3]$

[4] This result contrasts with the one obtained in monoperiodic models of prevention (see e.g. Ehrlich and Becker (1972) or Dionne and Eeckhoudt (1985)). In these models, one cannot exclude a priori that a minimum prevails at the point where the first-order condition is satisfied.

For any x, F is always above G since the existence of a free perfect test can only be welfare improving. Besides both curves are concave. Since G is increasing in x at x_F it must be that x_G exceeds x_F. Hence a better diagnostic technology will reduce optimal prevention activities.

If, scientific progress is considered endogenous, our analysis may be useful to disintangle cost and benefit of investing in ReD in diagnostic tests. We recognize four effects: 1) a first period direct cost c due to research; 2) a first period resource saving on prevention $x_G - x_F$; 3) a second period welfare gain due to the possibility of diagnosing the presence of side conditions before the treatment when sick $\Delta\Pi\left(E - L\left(y^*\right)\right)$;4) a second period welfare loss due to a lower probability of being healthy $\left(1 - \Delta\Pi\right)\left(U\left(W_1\right) + V\left(H_2\right)\right)$. The policy maker will be ready to pay for diagnostic technologies up to a $\overline{c}$ such that:

$$F = G \Longleftrightarrow U\left(W_0 - x_F - \overline{c}\right) - U\left(W_0 - x_G\right) + \rho\left[\Pi\left(x_F\right)E - \Pi\left(x_G\right)L\left(y^*\right) + \left(\Pi\left(x_G\right) - \Pi\left(x_F\right)\right)\left(U\left(W_1\right) + V\left(H_2\right)\right)\right] = 0.$$

5 Conclusion

In the same way as insurance can be a substitute for some forms of prevention in finance models, an improved diagnostic technology is shown to be a substitute for medical prevention. As a result the regular improvements in diagnostic technology that are observed can justify a lower investment on prevention at any given unitary price for this activity. The analysis is a useful tool for the allocation of funding between diagnostic and preventive medicine.

References

[1] Chang, F.R, 1996, Uncertainty and investment in health, Journal of Health Economics 15, 369-376.

[2] Dardanoni, V. and A. Wagstaff, 1987, Uncertainty, inequalities in health and the demand for health, Journal of Health Economics 6, 283-290.

[3] Dionne, G. and L. Eeckhoudt, 1985, Self insurance, self protection and increased risk aversion, Economics Letters 17, 39-42.

[4] Eeckhoudt, L., Lebrun, Th. and J.C. Sailly, 1984, The informative content of diagnostic tests: an economic analysis, Social Science and Medicine 18, 873-880.

[5] Ehrlich, I. and G.S. Becker, 1972, Market insurance, self insurance and self protection, Journal of Political Economy 40, 623-648.

[6] Hirshleifer, J. and J.G. Riley, 1979, The analytics of uncertainty and information. An expository survey, Journal of Economic Literature 17,1375-1421.

[7] Mooney, G., 1992, Economics, Medicine and Health Care, 2nd edition Hemel Hempstead: Harvester Wheatsheaf.

[8] Pauker, S. and J. Kassirer, 1980, The threshold approach to clinical decision analysis, New England Journal of Medicine 302, 1109-1116.

[9] Selden, T., 1993, Uncertainty and health care spending by the poor: The health capital model revisited, Journal of Health Economics 12, 109-115.

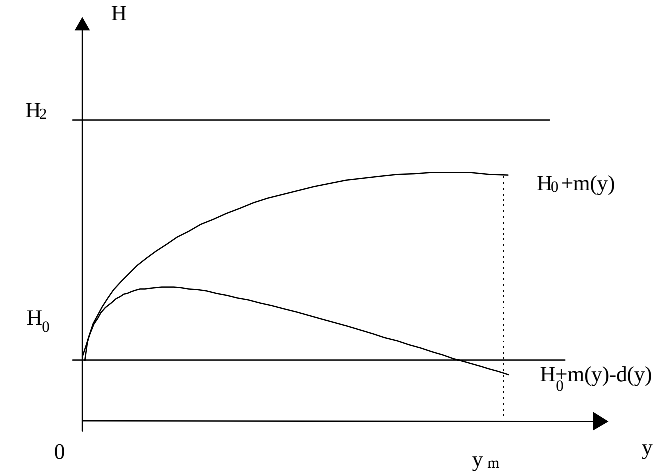

Figure 1

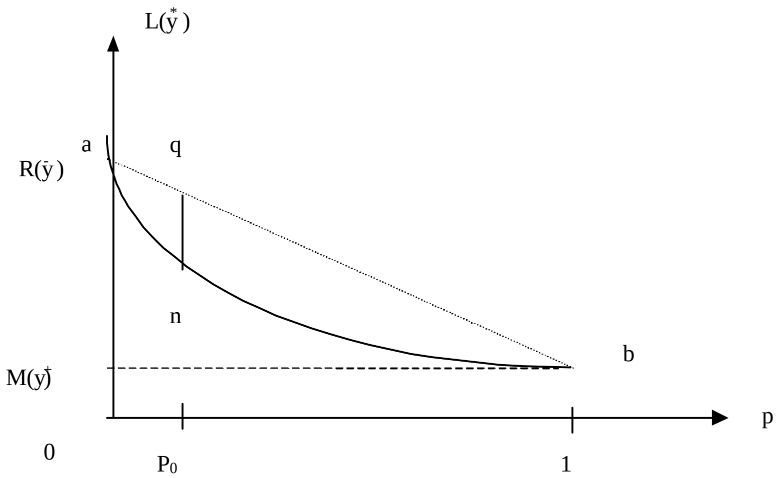

Figure 2

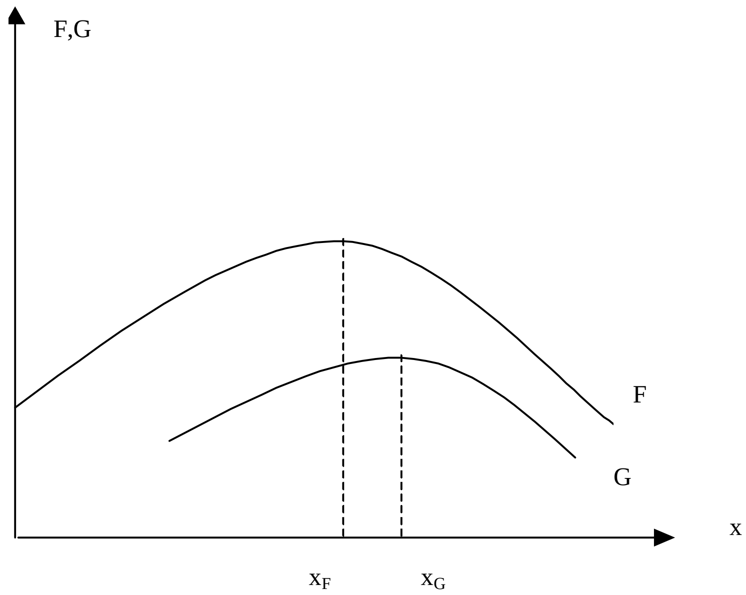

Figure 3