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Interdependent Risks, Prevention and Insurance. The case of Health Market

Samuel Berlinski
Universidad de Buenos Aires

UNIVERSIDAD DE SAN ANDRES

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Samuel G. BERLINSKI**

Universidad de Buenos Aires

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Abstract

It is usual to find in the literature on externalities references to the case of communicable diseases and vaccination. However, nor the nature and importance of the phenomena have frequently been properly addressed, neither a specific and complete proof of the public good case has been provided.

In the framework of an uncertainty model, this paper studies the phenomena of interdependent risk and prevention. It is proved that with state dependent utility functions and/or incomplete markets, the case of externality of communicable disease holds.

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1. Introduction

It is usual to find in Public Finance books and works about externalities references to the case of communicable illnesses and vaccines. However, nor the nature and importance of the phenomena have frequently been properly addressed, neither a complete and specific proof of the public good case has been provided. For example, Arrow (1963) and Preston (1975) refer to the case of communicable diseases in perfect certainty contexts. If there is no uncertainty about the likelihood of getting ill (or the effectiveness of the vaccine) when a person notices that she is going to get an illness, she faces two alternatives: to get vaccinated, or to pay those who are going to transmit her the disease to get vaccinated. This case is not very interesting because if she knows that she is going to get ill, it is not unrealistic to assume that the marginal utility of the vaccine will be greater than marginal utility of the foregone income. In this case, she gets vaccinated and she is sure of not getting ill regardless of what other people do.

As communicable diseases are a manifestation of risk interdependence the proper setup to analyze the problem is an uncertainty context. As Culyer (1989) pointed out: "There was early recognition (e.g. Weisbrod, 1961) that a direct physical externality might exist in cases of communicable diseases ... an individual in choosing or rejecting vaccination may fail to take account of the benefits accruing externally of a reduced probability of the others contracting disease" (pp. 39). Although many authors agree on the framework where the problem has to be considered they do not agree on the importance of the externality, so, look at the following examples. On the one hand, Stiglitz (1988) says: "Those who are vaccinated incur some cost (discomfort, time, risk of getting disease from a bad batch of vaccine). They receive some private benefit, in reduced likelihood of getting the disease, but a major part of the benefit is a public good, the reduced incidence of the disease in the community from which all benefit" (pp. 120). On the other hand, Cornes and Sandler (1986) assert "by immunizing oneself against an infectious disease, the individual confers a small benefit on one's fellows, by slightly reducing the probability of their becoming infected. At the same time, the benefit to oneself is particularly great" (pp. 115).

In my opinion much of this disagreement arises from the lack of a specific proof of the externality case. So, the objective of the present paper is to study, in the framework of an uncertainty model, the phenomena of interdependent risk, prevention, and its influence on the probability of getting ill. I am, particularly, interested in providing the circumstances under which the externality case of communicable diseases holds, and to have a rough assessment, at least, of the importance of the externality involved.

The sequence of the paper is as follows: First, I analyze the relationship between probability of getting ill, prevention and interdependent risk. Second, I study consumers' behavior when they get the chance to take preventive actions and/or buy market insurance. Then, I study the egalitarian Pareto optimum for each of these circumstances. Finally, some concluding remarks are made.

2. Probability of getting ill, interdependent risks and prevention

A person takes preventive actions in order to reduce the likelihood of an event[1]. The probability of getting ill of an individual depends on her genetic predisposition, on the preventive measures she takes and on the (communicable) diseases that other members of the society get or could transmit to her, which, in some cases depends on the preventive actions they have taken. Formally,

$$f_k[H/s_k; s_1, s_2, \ldots, s_n]$$

where f_k is the density function of the kth individual over the event H, health status. If we consider that there are two possible realizations of the event, *1* being ill and *0* being healthy, then the likelihood of event *1* is

$$f_k(H{=}1/s_k; s_1, s_2, \ldots, s_n) = \pi_k(s_k; s_1, s_2, \ldots s_n)$$

where π_k is the probability of getting ill of the kth individual and s_k is the quantity of prevention done by her. In the health market, when one has to face the eventuality of an illness, it is important to distinguish between communicable and noncommunicable diseases. In order to simplify the exposition (and without lost of generality) I will only refer here to preventive measures taken against communicable diseases (e.g., measles, small pox, cholera)

[1]Market insurance and self-insurance transfer income between different (random) states of nature. See Ehrlich and Becker, 1972.

and not to non communicable diseases (e.g., cancer, arterial hypertension). Furthermore, I will assume that all individuals are identical and that the number of persons is fixed. That, permits expressing this probability as a function of own care (s_k) and the average (s bar) level of care taken by the other agents.

$$\pi_k(s_k;\bar{s}) \qquad (1)$$

The average level of prevention is used here as a measure of the interdependence of risks. In other words, how the probability of illness of other people affects my probability of getting ill. Where the effect of s bar over π_k is null, the classical assumption of insurance theory, the probabilities of getting ill are independent.

In the case of certain communicable diseases, prevention may be useful in two ways. First, by directly reducing the probability of a person of getting ill. Second, less directly, by reducing the degree of interdependence of risks which influences the probability of getting ill of this person and others. Consider the following partial effects

$$\frac{\partial \pi_k}{\partial s_k} < 0 \qquad (2)$$

$$\frac{\partial \pi_k}{\partial \bar{s}} < 0 \qquad (3)$$

$$\frac{d\bar{s}}{ds_k} = \frac{1}{n} \qquad (4)$$

The marginal increase in prevention of the kth individual produces a decrease over her probability of becoming ill (2). An increase in the average level of prevention reduces the degree of interdependence of risk and so the probability of getting ill of the *k*th individual (3). In communicable diseases, the direct effect (2) of the vaccination is always greater than the indirect one (3). For example, the vaccine to prevent measles is effective in 95% of the cases. So, for any likelihood of getting measles is obvious that the direct effect of vaccination is greater than the indirect one. Finally, when n is large the agent kth increase in prevention have no effect over the average level of prevention (4). The total effect of a marginal increase in s_k on the probability of getting ill of agent k can be deduced with a total differentiation of (1) with respect to s_k

$$\frac{d\pi_k}{ds_k} = \frac{\partial \pi_k}{\partial s_k} + \frac{\partial \pi_k}{\partial \bar{s}} \frac{d\bar{s}}{ds_k} < 0 \quad (5)$$

An increase in s_k generally produces a decrease over the probability of getting ill of the kth individual. It is clear that the indirect effect of prevention (see second term of the right member) vanishes when there is a large number of consumers. In that case the total effect of the increase in s_k is equal to the partial or direct effect (first term of right member).

3. Competitive equilibrium for an exchange economy

In this section we are going to analyze which is the optimal quantity of prevention that an individual chooses with and without market insurance.

Assume an exchange economy with a great quantity of consumers in which the law of large numbers holds. In this society there exists one good and its endowments are random. There are two states of nature, i and h. A representative consumer k, risk avert, faces the event of being ill with probability π_k and the event of being healthy with probability $1-\pi_k$.

Good health, one's own life or the life of related people are very particular goods because they are essentially unique and irreplaceable. No perfect substitutes exist for these goods in any market. This implies that we cannot use the typical expected utility function where the elemental (or von Neumann and Morgenstern) utility functions are the same independently of the state of nature. Consider the following expected utility function

$$EU_k = \pi_k u_i(x) + (1-\pi_k)\, u_h(x)$$

In the case of an illness that does not imply cure expenses, or in case the individual has complete insurance over its income (x will be equal in both states of nature), the irreplaceable characteristic will be given by

$$u_i(x) < u_h(x)$$

In other words, the utility of the same income when ill is less than the utility being healthy.

The relationship among marginal utilities of income in the different state of nature is a matter of discussion. Some authors -e.g. Viscusi et al. (1987)- state that the marginal utility of income is greater when one is healthy than ill ("Bad luck: I am rich but I am sick"). Others -e.g. Ellis and McGuire (1990)- sustain that the most reasonable assumption is that the marginal utility of income is greater when ill than healthy ("Bad luck: I am sick and I do not have a nickel"). What it is clear is that the relationship depends on the cross derivate between the marginal utility of income and the state of nature. This is a fact that can only be determined empirically. Claiming "neutrality" and easiness in the exposition I will assume that

$$u_i'(x) = u_h'(x)$$

The marginal utility of the same income is equal being ill than healthy (for further reference see figure 1). However, it is to point out that second order conditions and comparative satitistics results could be affected by taking one or the other approach.

3.1 Prevention without insurance markets

A representative agent *k*th, risk avert, determines the optimal quantity of prevention through the following exercise

$$Max_{s_k} \quad EU_k = \pi_k[s_k;\bar{s}]\,u_i(W_k - L_k - s_k) + (1 - \pi_k[s_k;\bar{s}])\,u_h(W_k - s_k)$$

where W_k is the agent wealth, L_k are cure expenses and the other variables have the same meaning used so far. From here on and in order to avoid embarrassing notation the arguments of π will be omitted and partial derivates will be denoted by a prime (except in particular cases). The arguments of elemental utility functions *i* and *h* will also be avoided unless necessary. The first order condition[2] of the maximization problem is

[2]Unless I also assume that $u_h' \geq u_i'$ the agent being risk avert is not enough for the second order condition to hold . See Appendix I.

$$\frac{\partial EU_k}{\partial s_k} = \frac{\partial \pi_k}{\partial s_k}(u_i - u_h) - \pi_k u_i' - (1-\pi_k)\, u_h' = 0$$

reordering

$$\frac{\partial \pi_k}{\partial s_k}(u_i - u_h) = \pi_k u_i' + (1-\pi_k)\, u_h' \qquad (6)$$

The left term is the marginal private benefit in terms of utility which derives from the reduction in one unit of the probability of getting ill and the right term is the marginal private cost. In other words, the foregone marginal expected utility of the income spent on prevention.

3.2 Prevention with insurance markets

Now consider the following situation where consumers have the possibility of taking preventive actions and/or contracting a health insurance in the market. The agent can buy an insurance which covers Z_k of the medical expenses (L_k) which the insurer has to pay in case of getting ill. The contract for this service has two payments: one is a fixed premium, d, and the other is a variable premium, pZ_k. Where p depends on s_k and s bar in the same way I defined in (1)-(5) for π_k. The rationalization of this phenomena is the following. The insurance companies compute their premiums as if the consumers were not trying to cheat them preventing less[3]. This is due to the irreplaceable character of the good which inhibits the rational consumer from deceiving the

[3]Although there are masochists, suicidal types, etc. individuals in average are rational.

insurance company by reducing measures of self-protection. In other words, the amount of income that a consumer has to receive in order to give up one unit of good health is very large[4]. Then, no incompatibility of incentives arise between insurance companies and insurers. This does not mean that moral hazard does not exist in the health market. It exists, but in the way described by Pauly (1968) where individuals have few incentives to restrict their consumption to the levels that will prevail in case they have to face the total cost of their consumption[5].

Once we clarify these assumptions let's consider how we get the optimal consumption of Z_k and s_k. For doing this we have to

$$Max_{s_k, Z_k} \quad EU_k = \pi_k u_i (W_k - L_k + (1-p) Z_k - s_k - d) + (1-\pi_k) u_h (W_k - pZ_k - s_k - d) \qquad (7)$$

The first order conditions[6] are

$$\frac{\partial EU_k}{\partial s_k} = \frac{\partial \pi_k}{\partial s_k}(u_i - u_h) + (p' Z_k + 1)\,[-\pi_k u_i' - (1-\pi_k) u_h'] = 0 \qquad (8)$$

$$\frac{\partial EU_k}{\partial Z_k} = (1-p)\,\pi_k u_i' - p(1-\pi_k)\, u_h' = 0 \qquad (9)$$

reordering (8) and (9) we get

$$\frac{\partial \pi_k}{\partial s_k}(u_i - u_h) - (p' Z_k)\,[\pi_k u_i' + (1-\pi_k) u_h'] = \pi_k u_i' + (1-\pi_k) u_h' \qquad (8')$$

$$\pi_k u_i' = p\,[\pi_k u_i' + (1-\pi_k) u_h'] \qquad (9')$$

comparing (8') with (6) it can be seen that the introduction of

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[4]In case of death it will tend to infinity.

[5]They do not consume more because they prevent less. In other words, they move along the demand curve, they do not shift it to the east. See Berlinski, 1994.

[6]Second order conditions are analyzed in Appendix II.

market insurance affects the optimal quantity of prevention by two means. On one side, there is a marginal gain in terms of utility coming from the decrease in the price (p) of market insurance due to the marginal increase in s_k. On the other side, there is a reduction in the marginal benefit from prevention because market insurance reduces the income difference between a situation with and without good health. Finally, the marginal cost (right term) keeps being the foregone expected marginal utility of the income spent on prevention.

Consider now equation (9′), it says that the marginal benefit of buying insurance (left term) and the marginal cost (right term) must be equal in equilibrium. Moreover, assume the zero profit condition holds in the insurance market. Insurance companies provide contracts at a variable unit premium which is actuarially fair so that $p=\pi_k$. But, as risks are interdependent, part of the risk is not diversifiable so in order not to have losses, the insurance company has to collect a fixed payment d. From condition (9) when $L_k=Z_k$, the marginal rate of substitution between states h and i is equal to the marginal rate of transformation between those two states of nature. In other terms, given that

$$\frac{u_h'(\overline{x})}{u_i'(\overline{x})}=1$$

for the optimal condition to hold Z_k must be equal to L_k. Then, the agent choice is to have the mean income in both states of nature[7]. However, this is not enough to completely insure utility because good health is an irreplaceable commodity[8] (for further reference see figure 1).

As it is demonstrated in Appendix III $dZ_k/dp<0$. So it can be drawn that for an overcharge of the premium ($p>\pi_k$) the quantity of insurance acquired (Z_k) would be less than the medical expenses in case of illness (L_k). In this case, the optimal allocation implies that income is greater when you one is healthy rather than ill, so utility is greater in the healthy state even with a non state dependent utility function.

4. Egalitarian Pareto optimum

I have already determined how consumers choose their desired levels of prevention in the competitive equilibrium of an exchange economy. Now, We should see if the competitive level of prevention is equal to the socially optimum.

4.1 Prevention without insurance markets

The egalitarian Pareto optimum is obtained by

[7]It is important not to forget that the optimal allocation chosen depends on the assumption made about the marginal utility of income. In case $u_i'>u_h'$ for the optimal condition to hold $L_k<Z_k$ and if $u_i'<u_h'$ the first order condition will be fulfilled when $L_k>Z_k$.

[8]With elemental utility functions independent of the state of nature, agent insures income and utility completely when premiums are actuarially fair.

$$Max_{s_k} \sum_{k=1}^{n} EU_k = n[\pi_k(s_k;\overline{s})\, u_i(W_k - L_k - s_k) + (1-\pi_k(s_k;\overline{s}))\, u_h(W_k - s_k)]$$

The first order condition[9] of the maximization problem is

$$\frac{\partial\left(\sum_{k=1}^{n} EU_k\right)}{\partial s_k} = \left[n\frac{\partial\pi_k}{\partial s_k} + \frac{\partial\pi_k}{\partial\overline{s}}\right](u_i - u_h) - n[\pi_k u_i' + (1-\pi_k)\, u_h'] = 0$$

reordering

$$\left[n\frac{\partial\pi_k}{\partial s_k} + \frac{\partial\pi_k}{\partial\overline{s}}\right](u_i - u_h) = n[\pi_k u_i' + (1-\pi_k)\, u_h'] \qquad (10)$$

The left term is the marginal social benefit in terms of utility which derives from the reduction in one unit of the probability of getting ill and the right term is the marginal social cost.

In order to compare this solution with the competitive equilibrium lets sum over k equation (6), this equality becomes

$$n\frac{\partial\pi_k}{\partial s_k}(u_i - u_h) = n[\pi_k u_i' + (1-\pi_k)\, u_h'] \qquad (11)$$

The right term expressions in equations (10) and (11) are similar so marginal social cost and marginal private cost are equal for each level of prevention. Marginal social benefits are greater than private ones for each level of prevention. This is because income

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[9]Second order conditions are equal to those in Appendix I except that the derivates of π_k respect to s_k are total instead of partial.

in the healthy state is greater than in the ill state[10] (so $u_h>u_i$) and the indirect effect (2) of prevention is negative. Furthermore, marginal benefit is a decreasing function of total prevention and marginal cost is an increasing function[11]. Then, it can be drawn that the desired level of total prevention is greater in the egalitarian Pareto equilibrium than in the competitive one (see figure 2 for further references).

4.2 Prevention with insurance markets

The process here is similar to that presented in the other section. So, let me expose the results briefly. The first order conditions[12] (rearranged) for the egalitarian pareto optimum are

$$\left[\frac{\partial\pi_k}{\partial s_k}+\frac{\partial\pi_k}{\partial\bar{s}}\right](u_i-u_h)-n\left(\frac{dp}{ds_k}Z_k\right)[\pi_k u_i'+(1-\pi_k)u_h'] = n\left[\pi_k u_i'+(1-\pi_k)u_h'\right] \qquad (12)$$

$$n'\pi_k u_i' = np[\pi_k u_i'+(1-\pi_k)u_h'] \qquad (13)$$

the left term in equation (12) is the marginal social benefit from prevention and the right term is the marginal social cost.

To compare this solution with the competitive equilibrium is necessary to sum over k in conditions (8) and (9), resulting (with some arrangements)

[10] In this case state dependent utility functions only widen marginal benefits respect to the independent utility function case.

[11] This can be easily checked with the second order condition.

[12] Second order conditions are equal to those presented in Appendix II with the exception that the derivates of π_k and p respect to s_k are total instead of partial.

$$n\left[\frac{\partial \pi_k}{\partial s_k}(u_i-u_h)-(p'Z_k)\,[\pi_k u_i'+(1-\pi_k)\,u_h']\right]=n\left[\pi_k u_i'+(1-\pi_k)\,u_h'\right] \qquad (14)$$

$$n\pi_k u_i' = np[\pi_k u_i'+(1-\pi_k)\,u_h'] \qquad (15)$$

Again, the private and social marginal cost are equal for each level of prevention but the marginal social benefits are greater than the private ones for each level of prevention. In the latter case we have to distinguish two effects, the first depends on good health being an irreplaceable good[13] [ui(x bar)<uh(x bar)] and the indirect effect of prevention (2) being negative. The second effect comes from the extra reduction in premiums coming for each level of prevention. Again, as marginal benefits are a decreasing function of s (check this with second order conditions in Appendix II) and marginal costs are an increasing function of s the socially optimum level of prevention is greater than the resulting from the competitive equilibrium.

We have proved that if some reasonable conditions hold an increase in prevention for communicable disease will be Pareto optimum. However, we are in a typical free rider problem: everybody would like the other consumers to raise their level of prevention consumption because of the effect over the average level and consequently on the probability of getting ill. But nobody would consume above the levels drawn from (8) and (9) -or (6)- because, as I defined in (4) and (5), individual preventive actions by

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[13]When elemental utility functions are independent of the state of nature is sufficient that insurance market were incomplete so $x_i<x_h$.

risk. This is the root of the incentive to act as a free rider.

Once I deduced that an externality is very likely to arise; the question is: Are the extra benefits from immunization greater than private ones?. Being aware of the limitations that the representative agent approach means for making assessment of this kind (specially in what concerns to income distribution), the answer will be NO. Because as regarding immunization the direct effect (1) of vaccination are generally greater than the indirect one's (2).

Also, is very likely that the marginal externality could increase at an increasing rate when the proportion of immunized individuals is low and "falls quite fast as the proportion of immunized individuals rises" (Culyer, 1989, pp. 40). Then, considering that ds/dW>0 (see Appendix III) and that in developing economies information gaps (not taken into account along the paper) are very likely to arise, the marginal externality would be particularly greater in developing countries than in developed economies.

5. Concluding remarks

This paper proved that if certain conditions hold (incomplete markets and/or utility functions that depend on the state of nature in an economy with insurance markets) an increase in prevention levels, for those communicable diseases where it will be possible to reduce the degree of interdependence of risk, would be Pareto optimum. The increase in welfare could not be achieved because there are no incentives for consumers to prevent above actual levels (given the atomistic effect of their actions over the levels of mean prevention).

I also suggested that if the marginal externality increases at an increasing rate when the proportion of immunized individuals is low and falls quite fast as the proportion of immunized individuals rises then the marginal externality would be particularly greater in developing countries than in developed economies.

Appendix I

For second order condition to hold

$$\frac{\partial^2 EU_k}{\partial s_k^2} = \frac{\partial^2 \pi_k}{\partial s_k^2}[u_i - u_h] + 2\frac{\partial \pi_k}{\partial s_k}(u_h' - u_i') + \pi_k u_i'' + (1-\pi_k)\, u_h'' < 0$$

if the marginal productivity of prevention is decreasing ($\pi''>0$), health is an irreplaceable good ($u_i<u_h$) and the agents are risk avert ($u''<0$) it is a sufficient condition that

$$u_h' \geq u_i'$$

and it is a necessary condition that

$$-\frac{\partial^2 \pi_k}{\partial s_k^2}[u_i - u_h] - \pi_k u_i'' - (1-\pi_k)\, u_h'' > 2\frac{\partial \pi_k}{\partial s_k}(u_h' - u_i') .$$

Appendix II

Consider the system of equations of (8) and (9)

$$\frac{\partial \pi_k}{\partial s_k}(u_i-u_h)+(p'Z_k+1)\,[-\pi_k u_i'-(1-\pi_k)\,u_h']=0=F(s_k,\,Z_k;\,w_k,\,L_k,\,\pi_k,\,p) \quad (8'')$$

$$(1-p)\,\pi u_i'-p(1-\pi)\,u_h'=0=G(s_k,\,Z_k;\,w_k,\,L_k,\,\pi_k,\,p) \quad (9'')$$

For second order conditions to hold it is sufficient that

$$F_s<0,\quad G_z<0 \wedge F_z=G_s\leq 0$$

Taking derivates from the system of equations (8") and (9") (to avoid embarrassing notation the subindex k is omitted)

$$F_s=\pi''(u_i-u_h)+2\pi'(p'Z+1)\,(u_h'-u_i')-p''Z[\pi u_i'+(1-\pi)\,u_h']+$$
$$+(p'Z+1)^2[\pi u_i''+(1-\pi)\,u_h'']$$

$$F_z=G_s=\pi'[\,(1-p)\,u_i'+pu_h']-p'[\pi u_i'+(1-\pi)\,u_h']+$$
$$+(p'Z+1)\,[-\pi(1-p)\,u_i''+(1-\pi)\,pu_h'']$$

$$G_z=(1-p)^2\pi u_i''+p^2(1-\pi)\,u_h''$$

Taking into account that the marginal productivity of prevention is decreasing ($\pi''>0$), health is an irreplaceable good ($u_i<u_h$) and the agents are risk averts. Also consider that when $\pi=p$ then $u_i'=u_h'$ and that from equation (8) can be drawn $(p'Z+1)>0$. Then we can say that $Fs<0$. In the case where in equilibrium $p>\pi$ then $u_i'>u_h'$; so, we have to analyze the parameter values to reach a conclusion about Fs.
In addition, when $\pi=p$ the marginal utilities are equal in both states of nature and given that in the state of nature *i* the income chosen is equal to that in *h*, $u_i''=u_h''$. From all these relationships we can infer that $Gs=Gz=0$. Finally, if agents are risk avert $Gz<0$.

Appendix III

In this appendix we want to study the following comparative statistic results: *dZ/dW*, *ds/dW*, *dZ/dp* and *ds/dp*. In order to reach them, we have to replace Z^* and s^* in (8") and (9"), then take derivates (in an environment of the equilibrium points) respect to *Z*, *s*, W and *p* and finally using Cramer rule we get:

$$\frac{ds}{dw}=\frac{\begin{vmatrix}-Fw & Fz\\ -Gw & Gz\end{vmatrix}}{\begin{vmatrix}Fs & Fz\\ Gs & Gz\end{vmatrix}}=\frac{-Fw.Gz+Fz.Gw}{\Delta} \qquad \frac{dZ}{dw}=\frac{\begin{vmatrix}Fs & -Fw\\ Gs & -Gw\end{vmatrix}}{\begin{vmatrix}Fs & Fz\\ Gs & Gz\end{vmatrix}}=\frac{-Fs.Gw+Fw.Gs}{\Delta}$$

$$\frac{ds}{dp}=\frac{\begin{vmatrix}-Fp & Fz\\ -Gp & Gz\end{vmatrix}}{\begin{vmatrix}Fs & Fz\\ Gs & Gz\end{vmatrix}}=\frac{-Fp.Gz+Fz.Gp}{\Delta} \qquad \frac{dZ}{dp}=\frac{\begin{vmatrix}Fs & -Fp\\ Gs & -Gp\end{vmatrix}}{\begin{vmatrix}Fs & Fz\\ Gs & Gz\end{vmatrix}}=\frac{-Fs.Gp+Fp.Gs}{\Delta}$$

where

$$Fw=\pi'(u_i'-u_h')-(p'Z+1)\,[\pi u_i''+(1-\pi)\,u_h'']$$

$$Gw=(1-p)\,\pi u_i''-p(1-\pi)\,u_h''$$

$$Fp=\pi'Z(u_h'-u_i')-p''Z[\pi u_i'+(1-\pi)\,u_h']+Z(p'Z+1)\,[\pi u_i''+(1-\pi)\,u_h'']$$

$$Gp=-\pi u_i'-(1-\pi)\,u_h'-(1-p)\,\pi Z u_i''+p(1-\pi)\,Z u_h''$$

If we analyze the situation where $p=\pi$ and considering that in this case we have: $u'>0$, $u''<0$, $u_i'=u_h'$, $u_i''=u_h''$ and $(p'Z+1)>0$. So, it can be drawn that $Fw>0$, $Gw=0$, $Fp<0$ and $Gp<0$. Properly replacing and remembering from appendix II that the divisor is positive we get $ds/dW>0$, $dZ/dW=0$, $ds/dp<0$ and $dZ/dp<0$.

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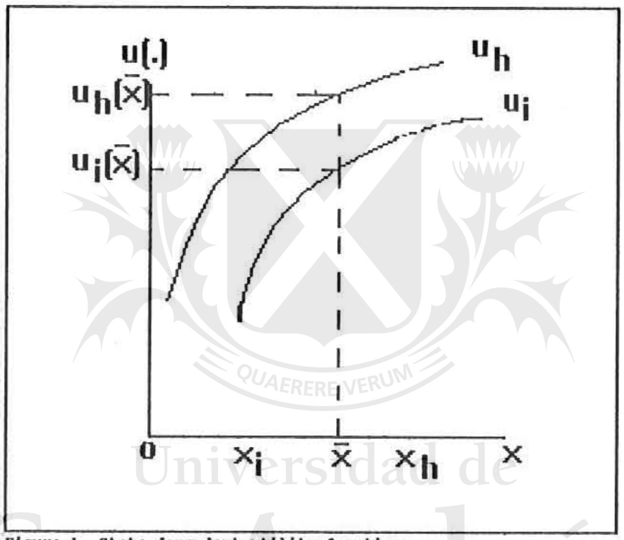

Figure 1. State dependant utility function

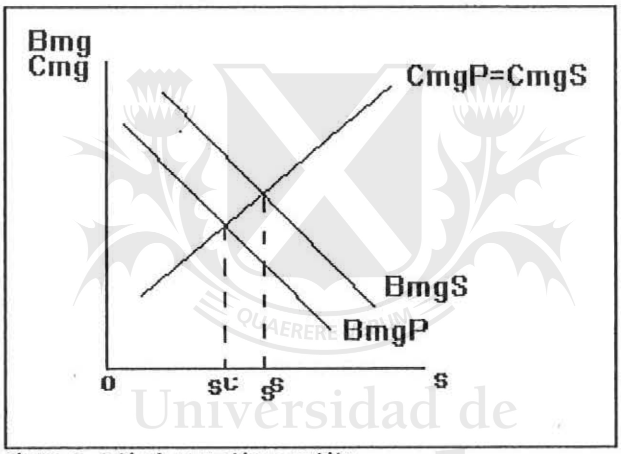

Figure 2. Optimal prevention quantity