# Complementary and substitutability between prevention activities

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**Abstract**

This paper examines the nature of the interaction between various disease prevention activities when individuals make decisions in order to reduce the probability (primary prevention) of a first disease while public authorities implement primary or secondary prevention programs targeted on another disease. Using the multi-period prevention decision model recently introduced by Menegatti (2009), we highlight that prevention activities are substitutes. This suggests a crowding-out effect of public authorities prevention programs on individuals' prevention actions. The magnitude of this crowding-out effect is also shown to be reinforced if the correlation between diseases increases and - in case agents are downside risk averse - if individuals are in better health state at the time they make prevention efforts.

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## 1. Introduction

Disease prevention activities usually refer to two types of efforts: (1) the efforts made to reduce the probability of diseases (self-protection or primary prevention) and; (2) the efforts made to reduce the severity of diseases (self-insurance or secondary prevention). Ehrlich and Becker's (1972) classical contribution on prevention was dedicated to the interaction between three instruments - market insurance, self-protection and self-insurance – used to manage financial risks. This initiated a series of theoretical papers on this topic, going from Briys and Schlesinger (1990) who explain why more risk averse agents always invest more in self-insurance activities but not necessarily more in self-protection activities to Chiu (2005) who highlights the link between self-protection and downside risk aversion. More recently, several papers exploited the progress made in risk theory to health economics issues. For example, the substitution or complementary relationship between therapeutic and preventive medicine is investigated in Eeckhoudt, Godfroid and Marchand (2000) while Courbage and Rey (2005) examine the determinants of optimal prevention for health risks.

The increase in disease prevention programs these lasts years' raises new economic issues. We may for instance wonder whether providing the public with risk information change individuals' attitude (see for example Hsieh et *al.* (1996) about the effects of anti-smoking campaigns on smoking behaviour or Barnett et *al.*(2007) about the public response to the UK government advices about mobile phone health risks). Serror et *al.* (2009) also tackle this question focusing on multiple cause diseases in their empirical analysis of the impact of risk communication on prevention decisions. Among these economic issues related to prevention policies, the question of the complementarity or substitutability between various prevention activities has rarely been analyzed. We examine this issue through the analysis of individual disease prevention decisions using the expected utility theory. In this framework, we wonder whether the intensification of prevention actions implemented by public authorities to reduce either the probability or the severity of a given disease leads individuals to modify their efforts to reduce the probability of another disease.

We use a new approach to build the prevention decision model. First, while prevention decisions are usually examined through a single period model (assuming thus that the effort and the effect of prevention are contemporaneous) we analyze - following a recent paper of Menegatti (2009) - prevention activities using a multi-period framework. We indeed consider that prevention decisions are made currently (period 0) while the positive consequences of prevention on health are felt later (period 1 when individuals can potentially contract diseases). Secondly, we consider that the cost of prevention is expressed as a loss in the short-term quality of life while it is usually expressed as a financial loss (see for example Bleichrodt, Crainich and Eeckhoudt (2003) who evaluate the benefits of prevention as the individuals' willingness-to-pay for these activity or Ehrlich (2000) who considers that the cost of prevention is constituted by the opportunity cost of the time spent to make these efforts). Activities such as sport practice, smoking cessation, diet and abstinence from alcohol, *etc.* indeed require efforts that are mainly non-monetary but rather psychological since they reduce the current quality of life. This way to express the cost of prevention makes the multi-period framework particularly relevant to analyze disease prevention decisions since it implies that the quality of life reduction (*i.e.* the cost of the prevention effort) at period 0 precedes its effect on the probability of the disease (*i.e.* the benefit of the prevention effort) and is therefore not felt at period 1[1]. The multi-period framework moreover has another interesting property: it ensures the existence of maxima in optimization programs[2].

The paper is organized as follows. Section 2 introduces the model. The determinants of the private demand for primary prevention and the interaction of this demand with public prevention programs are analyzed at Section 3. In Section 4 we provide a comparative statics analysis of the determinants of primary prevention efforts. Section 5 concludes.

## 2. The model

The analysis is based on Menegatti's two period model where preventative decisions are made at period 0 and the state of nature (the agent is either healthy or sick) is revealed at period 1. Two diseases can be contracted. Public authorities implement disease prevention programs (either primary or secondary disease prevention actions) while individuals make primary prevention efforts in order to reduce the probability of disease 1. Prevention efforts lower the quality of life (because of the difficulty to quit smoking, to practice sport regularly, to change dietary habits,…) at period 0 but not at period 1 and have no financial impact. The programs implemented by public authorities are also costless so that utility only depends on the quality of life.

[1] This is less obvious when the cost of prevention is financial since the money spent on prevention at period 0 cannot be used at period 1. On the contrary, it is plausible to assume that efforts made at period 0 to quit smoking, make sport,…*etc.* have no impact at period 1.

[2] The second-order condition problem related to primary prevention decision - highlighted by Ehrlich and Becker (1972) - is often ignored by economists analyzing self-protection decisions.

The following notations are adopted:

- $u(H)$ stands for the utility function which depends on health ($H$). $u'(H)$ and $u''(H)$ respectively denote the first and second derivatives of the utility function;
- $H_0$ and $H_1$ denote the health states at period 0 and 1;
- $W_0$ and $W_1$ denote individuals' wealth at period 0 and 1;
- $e$ stands for the primary prevention effort made by individuals at period 0 in order to reduce the probability of disease 1 at period 1;
- $\alpha(e)$ is the cost of self-protection felt at period 0;
- $p_1(e)$ and $M_1$ are respectively the probability and the severity of the disease 1 while $p_2$ and $M_2$ are the probability and severity of disease 2. The values of $p_2$ and $M_2$ can be modified through public authorities actions;
- The effects of the two diseases are additive: $H = H_1 - M_1 - M_2$ in case both diseases are contracted.
- The interdependency coefficient between the two diseases is denoted $k$. Diseases are independent (resp. positively correlated; resp. negatively correlated) if $k = 1$ (resp. $k > 1$; resp. $k < 1$). $k$ is bounded by the fact that a probability is included between 0 and 1.

The following usual assumptions are made:

- $u'(H) > 0$ and $u''(H) < 0$ (the utility function is increasing and concave)
- $\alpha'(e) > 0$ and $\alpha''(e) > 0$ (the cost of self-protection is increasing and convex)
- $p_1'(e) < 0$ and $p_1''(e) > 0$ (self-protection lowers the probability of the disease at a decreasing rate)

## 3. The determinants of private self-protection decisions

The individual optimization program is:

$$\begin{aligned}\underset{e}{\text{Max}}\quad EU \ = \ & u(H_0 - \alpha(e)) + (1 - p_1(e) - p_2 + kp_1(e_1)p_2).u(H_1) + \\ & p_1(e)(1 - kp_2).u(H_1 - M_1) + p_2(1 - kp_1(e_1)).u(H_1 - M_2) + k.p_1(e_1).p_2.u(H_1 - M_1 - M_2)\end{aligned}$$

The first-order conditions related to this maximization program is:

$$\begin{aligned}FOC_e \equiv \frac{\partial EU}{\partial e} = 0 \Rightarrow & -\alpha'(e).u'(H_0 - \alpha(e)) \\ & - p_1^{'}(e).\left[(1 - kp_2)[u(H_1) - u(H_1 - M_1)] + kp_2[u(H_1 - M_2) - u(H_1 - M_1 - M_2)]\right] = 0\end{aligned}$$

This condition defines a maximum since:

$$SOC_e \equiv \frac{\partial^2 EU}{\partial e^2} = 0 \Rightarrow -\alpha''(e)u'(H_0-\alpha(e)) + \alpha'(e)^2 u''(H_0-\alpha(e))$$
$$-p_1''(e)\big[(1-kp_2)[u(H_1)-u(H_1-M_1)] + kp_2[u(H_1-M_2)-u(H_1-M_1-M_2)]\big] < 0$$

In order to define whether prevention activities are complements or substitutes, we first define the way the optimal level of self-protection $e$ changes as a result of variations in the probability ($p_2$) or the severity ($M_2$) of disease 2 consecutive to public authorities programs. Using $FOC_e$ and the implicit function theorem this relationship is provided by the signs of $RF_{p_2}^e$ and $RF_{M_2}^e$:

$$RF_{p_2}^e \equiv \frac{de}{dp_2} = \frac{-\partial FOC_e / \partial p_2}{\partial FOC_e / \partial e}$$
$$= \frac{kp_1'(e)[(u(H_1-M_2)-u(H_1-M_1-M_2))-(u(H_1)-u(H_1-M_1))]}{SOC_e} > 0$$

$$RF_{M_2}^e \equiv \frac{de}{dM_2} = \frac{-\partial FOC_e / \partial M_2}{\partial FOC_e / \partial e}$$
$$= \frac{kp_1'(e)p_2[u'(H_1-M_1-M_2)-u'(H_1-M_2)]}{SOC_e} > 0$$

The signs of these two reaction functions indicate that prevention activities are substitutes: public authorities' actions reducing the probability $p_2$ or the severity $M_2$ of disease 2 indeed lead to a reduction in the private efforts to reduce $p_1$.

The positive slopes of the two reaction functions can be explained in the following way. As indicated by $FOC_e$, the marginal benefit of private self-protection efforts takes three elements into account:

1. the reduction in the probability to get disease 1 ($p_1'(e)$)
2. the probability not to get disease 2 conditional to disease 1 ($1-kp_2$) and the probability to get disease 2 conditional to disease 1 ($kp_2$) that are respectively used to weight:
3. the difference between not having and having disease 1 in case disease 2 has not been contracted ($u(H_1)-u(H_1-M_1)$) and the same difference in case it has been contracted ($u(H_1-M_2)-u(H_1-M_1-M_2)$).

The concavity of the utility functions makes the first of these last two terms lower than the second ($u(H_1)-u(H_1-M_1) < u(H_1-M_2)-u(H_1-M_1-M_2)$). This implies that a public program that reduces $p_2$ gives more weight to the first term and less to the second, reducing therefore the incentives to implement private self-protection efforts. In the same way, a public program that reduces $M_2$ lowers the difference between not having and having disease 1 in case disease 2 has been contracted. This lowers the marginal benefit of $e$ and thus the incentives to make self-protection efforts. Figures 1 and 2 display the above argument[3].

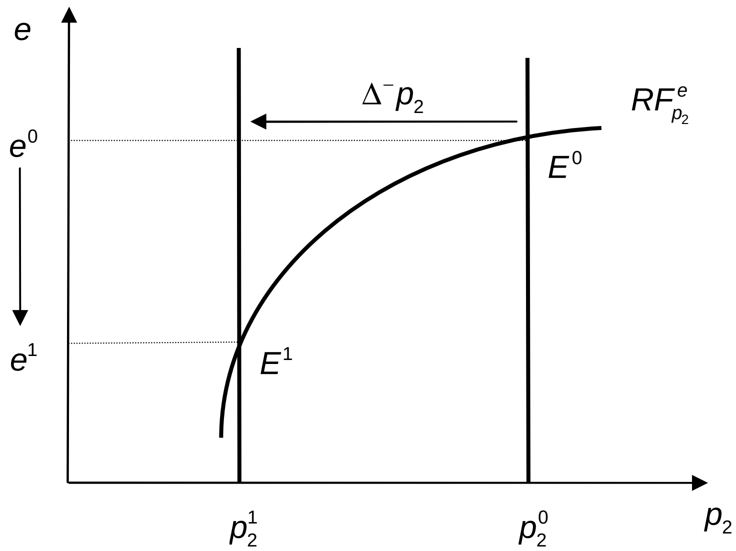


Figure 1

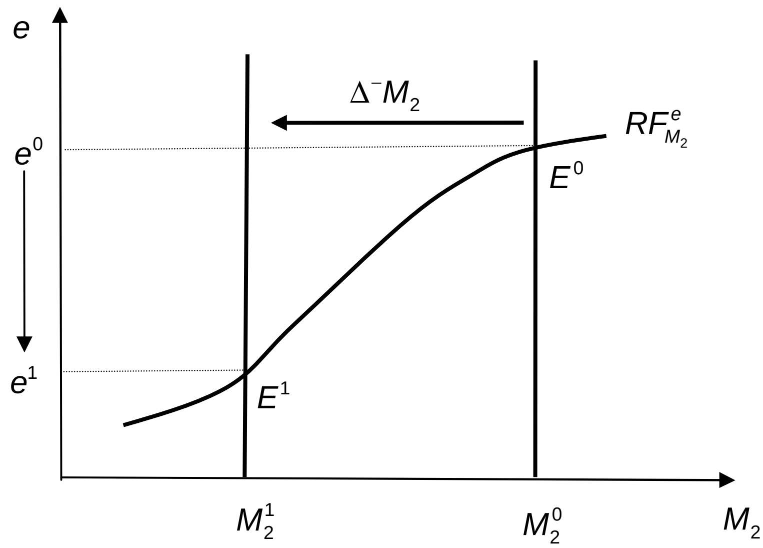


Figure 2

## 4. Comparative statics analysis

### 4.1 Change in the baseline probability to contract disease 2

We first evaluate how the substitution effect between the private demand for primary prevention and the prevention programs implemented by public authorities in order to lower the probability and the severity of disease 2 varies with the baseline probability of this last disease. After calculations, it can be shown that:

[3] The justifications of the shapes of the two reaction functions are provided later in the paper.

- The sign of $\dfrac{\partial\left({}^{de}\!/_{dp_2}\right)}{\partial p_2}$ corresponds to the sign of:
  $k^2 p_1'(e)p_1''(e)[(u(H_1-M_2)-u(H_1-M_1-M_2))-(u(H_1)-u(H_1-M_1))]<0$

- The sign of $\dfrac{\partial\left({}^{de}\!/_{dM_2}\right)}{\partial p_2}$ corresponds to the sign of:
  $-kp_1'(e)[u'(H_1-M_1-M_2)-u'(H_1-M_2)]$
  $[\alpha''(e)u'(H_0-\alpha(e))-\alpha'(e)^2u''(H_0-\alpha(e))+p_1''(e)(u(H_1)-u(H_1-M_1))]>0$

$\dfrac{\partial\left({}^{de}\!/_{dp_2}\right)}{\partial p_2}<0$ tells us that the reaction function $RF^e_{p_2}$ is concave (as indicated on figure 1), meaning that the substitution effect between primary prevention actions is mitigated when the baseline probability of disease 2 is high. On the contrary, the substitution between private primary prevention and secondary prevention programs implemented by public authorities is reinforced when the baseline probability of disease 2 is high ($\dfrac{\partial\left({}^{de}\!/_{dM_2}\right)}{\partial p_2}>0$).

### 4.2. Change in the initial severity of disease 2

Let us now have a look at the change in the substitution between prevention activities as the initial severity of disease 2 rises.

- Using Young's theorem, we know that $\dfrac{\partial\left({}^{de}\!/_{dp_2}\right)}{\partial M_2}=\dfrac{\partial\left({}^{de}\!/_{dM_2}\right)}{\partial p_2}>0$, which means that the substitution between private primary prevention and public secondary prevention rises as the initial severity of disease 2 increases.

- $\dfrac{\partial\left({}^{de}\!/_{dM_2}\right)}{\partial M_2}\underset{<}{\overset{>}{}}0$ . The reaction function $RF^e_{M_2}$ is increasing but we cannot determine, given the assumptions made, whether it is concave, linear or convex (see figure 2).

### 4.3. Change in the initial severity of disease 1

It can be shown that:

- The sign of $\dfrac{\partial\left({}^{de}\!/_{dp_2}\right)}{\partial M_1}$ corresponds to the sign of:
  $-kp_1'(e)[u'(H_1-M_1-M_2)-u'(H_1-M_1)]$
  $[\alpha''(e)u'(H_0-\alpha(e))-\alpha'(e)^2u''(H_0-\alpha(e))+p_1''(e)(u(H_1)-u(H_1-M_1))]>0$

- $\dfrac{\partial\left({}^{de}\!/\!_{dM_2}\right)}{\partial M_1} \gtrless 0$ .

The severity of disease 1 reinforces the substitution between primary prevention actions implemented by individuals and public authorities. Its impact on the substitution between public secondary prevention actions and private primary prevention efforts cannot be determined.

### 4.4. Increased correlation between diseases

To evaluate whether the correlation between the two diseases mitigates or reinforces the substitutability between public prevention programs and private self-protection actions, we have to evaluate the signs of $\dfrac{\partial\left({}^{de}\!/\!_{dp_2}\right)}{\partial k}$ and $\dfrac{\partial\left({}^{de}\!/\!_{dM_2}\right)}{\partial k}$. After calculation, it can be shown that:

- The sign of $\dfrac{\partial\left({}^{de}\!/\!_{dp_2}\right)}{\partial k}$ corresponds to the sign of:

$$-p_1'(e)[(u(H_1-M_2)-u(H_1-M_1-M_2))-(u(H_1)-u(H_1-M_1))]$$
$$[\alpha''(e)u'(H_0-\alpha(e))-\alpha'(e)^2u''(H_0-\alpha(e))+p_1''(e)(u(H_1)-u(H_1-M_1))]>0$$

- The sign of $\dfrac{\partial\left({}^{de}\!/\!_{dM_2}\right)}{\partial k}$ corresponds to the sign of:

$$-p_1'(e)p_2[u'(H_1-M_1-M_2)-u'(H_1-M_2)]$$
$$[\alpha''(e)u'(H_0-\alpha(e))-\alpha'(e)^2u''(H_0-\alpha(e))+p_1''(e)(u(H_1)-u(H_1-M_1))]>0$$

It follows that an increased correlation between the two diseases reinforces the substitutability between private and public prevention actions as represented on figures 3 and 4.

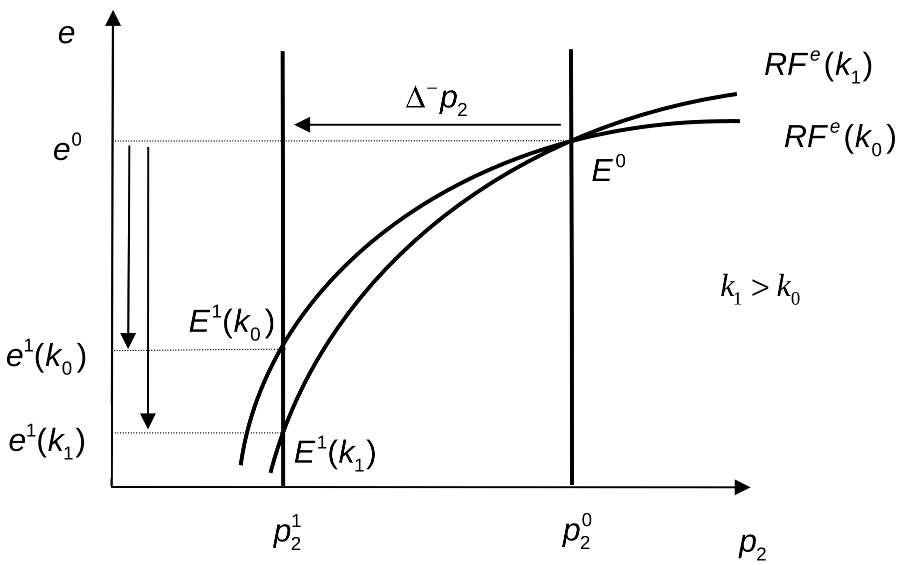


Figure 3

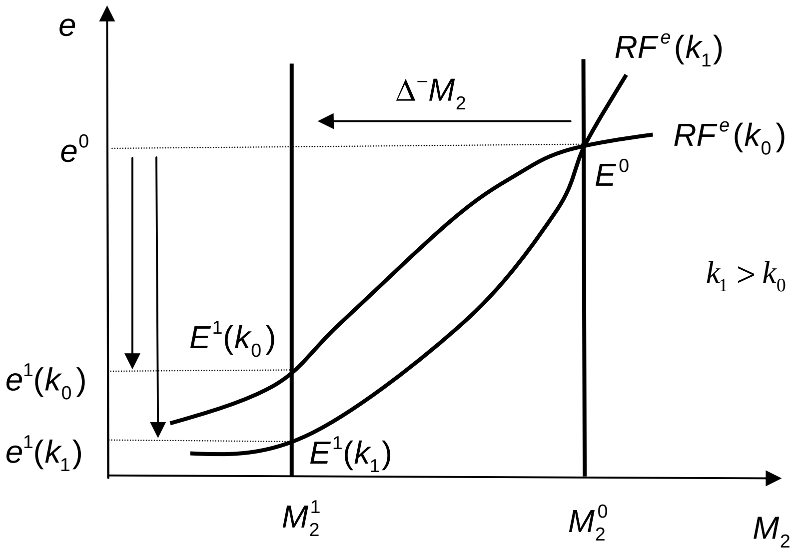


Figure 4

These two results can be explained in the following way. Any given reduction in $p_2$ consecutive to a prevention policies implemented by public authorities is reinforced by an increase in $k$. This amplifies the reduction in the probability to get both diseases and the increase in the probability not to have disease 2. The weight associated to the higher term of the marginal benefit of self-protection ($u(H_1 - M_2) - u(H_1 - M_1 - M_2)$) falls and that of the smaller term ($u(H_1) - u(H_1 - M_1)$) rises, thereby leading to a stronger reaction from the individuals who reduce even more their primary prevention efforts ($\frac{\partial\left(de/dp_2\right)}{\partial k} > 0$). In the same way, an increase in $k$ gives more weight to any reduction in $M_2$ due to public prevention programs which reduces the differences between $u(H_1 - M_2) - u(H_1 - M_1 - M_2)$ and $u(H_1) - u(H_1 - M_1)$ and thus the incentives to implement private primary prevention efforts ($\frac{\partial\left(de/dM_2\right)}{\partial k} > 0$).

## 4.5. Better current health state

We now analyze whether the current health state affect the individual response to prevention program implemented by public authorities. To do this, we evaluate how the slopes $de/dp_2$ and $de/dM_2$ of the reaction functions vary with $H_0$. It can be shown that:

- The sign of $\frac{\partial\left(de/dp_2\right)}{\partial H_0}$ corresponds to the sign of:

$$-kp_1'(e)[(u(H_1 - M_2) - u(H_1 - M_1 - M_2)) - (u(H_1) - u(H_1 - M_1))]$$
$$[-\alpha''(e)u''(H_0 - \alpha(e)) + \alpha'(e)^2 u'''(H_0 - \alpha(e))]$$

- The sign of $\frac{\partial\left(\frac{de}{dM_2}\right)}{\partial H_0}$ corresponds to the sign of:

$$-kp_1^{'}(e)p_2[u'(H_1-M_1-M_2)-u'(H_1-M_2)]$$
$$[-\alpha''(e)u''(H_0-\alpha(e))+\alpha'(e)^2u'''(H_0-\alpha(e))]$$

It follows that $u'''(H)>0$ is a sufficient condition that ensures that $\frac{\partial\left(\frac{de}{dp_2}\right)}{\partial H_0}>0$ and $\frac{\partial\left(\frac{de}{dM_2}\right)}{\partial H_0}>0$. In case individuals are downside risk-averse (prudent), the substitution effect between prevention activities is stronger if individuals are in good health when making their primary prevention efforts.

## 5. Conclusion

The paper examines the interaction between prevention actions implemented by individuals and public authorities. Using the multi-period Menegatti's framework and assuming that individuals reduce the probability of a disease through primary prevention efforts while public authorities implement programs reducing either the probability (primary prevention) or the severity (secondary prevention) of another disease, we show that the prevention activities are substitutes. This suggests that individual responses to prevention policies implemented by public authorities mitigate the effects on health of these policies and may question the efficiency of the multiplication of prevention actions implemented by public authorities.

Some limits of our analysis should be mentioned. The programs implemented by public authorities are assumed to be costless in the analysis. We should however include the fact that public programs may have a cost that can be financial (vaccination or screening programs,…) and thus require a tax increase in order to be financed or modify people quality of life (ban of smoking in public places, restriction of car use in some cities,…). The inclusion of the cost of these policies should affect individuals' decisions and thus have an impact on the interaction between disease prevention actions. This will be taken into account in futures versions of the paper.

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