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Efficient Self-Protection and Progress in Curing-Technology

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Abstract

The direct medical costs associated with obesity, smoking, and other non-healthy habits are estimated to account for more than 20% of U.S. health spending. Hence, poor health choices induce significant aggregate shift in spending away from treating competing–non preventable–medical risks and from nonmedical consumption. Such a shift in spending distorts relative incentives to innovate in different sectors, through market-size effect. As consumers fail to internalize these aggregate-level externalities, private-prevention is generally inefficient. We show that private prevention is insufficient compared with social optimum, unless technological opportunities to develop cures for preventable diseases are sufficiently superior. Furthermore, under multiple preventable-risks, prevention efforts are biased in favor of the risk with higher potential for curing advances.

Key words: *Efficient prevention, Medical Innovation.*
JEL Classification: I-18, O-31

1. Introduction

The ongoing epidemic spreading of obesity and corresponding increase in its associated medical costs, invokes calls for policy intervention that encourages better private prevention[1]. This work identifies new conditions for efficient prevention that stem from the effect of a significant increase in disease prevalence on the *relative* incentive to innovate across medical and non-medical industries.

Recent studies have documented substitution between self-protection and the effectiveness of curing technology. That is, private prevention effort decreased in light of advances in curing technology, and consequently the prevalence of medical conditions increased. For example, Lakdawalla et al. (2006) show how improvement in HIV treatment

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[1] See Philipson and Posner (2008) for an excellent compact review.

resulted in riskier sexual behavior and higher prevalence of the virus[2], and Peltzman (2011) proposes that significant improvements in treatment of cardiovascular diseases drive increasing obesity rates. These findings are in line with the more general "Peltzman Effect" (Peltzam, 1975)[3], which consider efficient prevention choice.

Nevertheless, in their recent contribution, Bhattacharya and Packalen (*The Other Ex Ante Moral Hazard*, Journal of Health Economics, 2012) explore a reversed causality that runs from private prevention to advances in curing technology: as higher prevention decreases demand for curing treatment it wanes the incentive to innovate curing technology[4]. As private self-protection choices fail to internalize the (negative) externality of *aggregate* prevention level on medical R&D, prevention is excessive compared with social optimum. In their quantitative analysis they find that current subsidies provided to obese through Medicare off set the R&D externality, and therefore conclude that no additional "fat tax" is required.

Notably, such causal relation from prevention to technological progress applies only where disease-prevalence changes slowly in response to technological advances. In this case, medical innovators take prevalence rate as given when evaluating potential demand, because by the time prevalence rate will effectively change they may lose the first mover advantage in the market (or possibly losing patent protection). This scenario seems plausible for the medical conditions associated with obesity, smoking, and alcohol, which are commonly developed over long periods of practicing unhealthy behavior (i.e. low prevention)[5]. The cost of treating these preventable diseases alone, however, accounts for a substantial fraction of national medical spending in the US.

Cawley and Meyerhoefer (2012) estimate the direct medical cost associated with obesity to account for 20% of total medical cost in the US, suggesting their improved identification strategy corrects for earlier underestimates of 9.1% by Finkelstein et al. (2009). Note

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[2] In a related study Chan et al (2012) quantify the benefits from advances in HIV treatment, accounting for gains from the implied decrease in prevention efforts.

[3] In this classic study Peltzman notes that enforcing seat-belt usage may result in riskier driving inducing an offsetting effect on overall road safety.

[4] For empirical evidence on the positive effect of market size on the medical innovation efforts see Acemoglu and Linn (2004) and Finkelstein (2004).

[5] On the other hand, HIV for example, would not fit here because viral contingent and thereby disease prevalence respond fast to self-protection measure.

however, that even for those who are not considered obese, unhealthy diet and lack of physical exercising increase the likelihood for developing hypertension, cardiovascular diseases, and strokes. For example, Palar and Sturm (2009) find that excessive consumption of sodium (i.e. salty food), which is a major cause for hypertension, is associated with annual medical costs of $18 billion. According to the National Institute of drug abuse, medical cost associated with tobacco use accounted for 5.6% of national healthcare expenditures, on average between the years 2001-2004. Bouchery et al. (2011) estimate medical costs associated with alcohol around $25 billion in 2006 (about 1% of national healthcare spending). Summing these figures together one gets that preventable medical cost may account for more than 20% of annual health spending, which are about 3.5% of Gross Domestic Product (GDP)[6].

The main argument of this study is that such a large scale of preventable medical costs induces cross sectorial effect, as they are shifted away from other medical care services and nonmedical sectors. Hence, to the extent that low prevention induces progress in the corresponding curing technologies it also hinders advances in treatments for other (competing) medical conditions, and progress in nonmedical technology. We formalize this argument by elaborating the framework studied by Bhattacharya and Packalen (2012) along two lines.

First we incorporate technological progress for non-medical products, or cures for competing (non-preventable) medical risks. Contrary to Bhattacharya and Packalen (2012), we show that private prevention efforts are insufficient unless technological opportunities for advancing cures for preventable diseases are superior. Then we discuss the policy implications of inefficient private prevention with respect to prevention and R&D subsidies, price regulation and relative patent protection in the medical sector.

Secondly, we study the efficiency of multiple private prevention efforts, like for example controlling smoking and unhealthy diet, aim to avoid different maladies: cancer and

[6] Whereas the analysis is confined to preventable medical costs, preventable diseases are also associated with productivity losses of similar scale. This potential output would be spent on nonmedical technologies by the healthy consumers.

respiratory diseases account for two thirds of smoking-attributed causes of death[7], whereas major causes of death associated with obesity are type 2 diabetes and cardiovascular diseases (Flegal et al., 2007). Here, again, we show that the deviation from optimal allocation of prevention efforts depends on the relative technological opportunity to improve curing technology for the different diseases.

Bhattacharya and Packalen (2012) overlook the potential cross-industries effects, pointing to a lower responsiveness of nonmedical R&D to decline in demand (p. 11 footnote 5): "As the share of revenue that is reward for innovation is much higher for the pharmaceutical and medical device sector than it is on average in other sectors, the impact of a prevention-induced shift from consumption of medical care goods on the reward for innovation of medical care goods dwarfs the impact on the reward for innovation of other goods". This argument, though, is not universally applicable for multiple reasons. First, National Science Foundation (NSF) data (presented in table 1) show, that the ratio of R&D to sales for some industries may be as high as in pharmaceuticals and medical devices[8].

Table 1: R&D intensity in selected industries

Industry	Share of Nonfederal R&D Funds in sales (2007)
Pharmaceuticals and medicines	12.7%
Medical equipment and supplies	3.0%
Health care services	4.5%
Semiconductor and other electronic components	12%
Communications equipment	14.7%
Internet service providers and Web search portals	13.4%
Software	19.6%
All Manufacturing industries	3.7%
All Nonmanufacturing industries	3%

Second, the cost of treating preventable conditions does not entail pharmaceuticals only: Aggregate data suggests that pharmaceuticals account only for 10% of total U.S. healthcare

[7] Source: Centers for Disease Control and Prevention. Annual Smoking-Attributable Mortality, Years of Potential Life Lost, and Productivity Losses—United States, 2000–2004.
[8] Raw data available at http://www.nsf.gov/statistics/nsf11301/pdf/tab51.pdf

spending[9]. Third, even within the medical sector, preventable medical spending is shifted away from competing medical risks.

Note that the inefficiency of private prevention in this study does not involve health insurance, which typically works by itself to reduce private prevention[10]; see for example Ehrlich and Becker (1972) and Ellis and Manning (2007). This negative effect of insurance on private prevention is known as the *Ex-ante Moral Hazard*. Bhattacharya and Packalen (2012) conclude that prevention with no insurance is excessive due to the R&D externality, referring to this type of inefficiency as *the Other Ex-ante Moral Hazard.* The empirical part of their work aims to quantify and compare the magnitude of these two opposing effects for US Medicare public health insurance. The present study, however, aims to show that even without insurance private prevention is likely to be insufficient due to cross sectorial R&D externalities.

The remainder of the paper develops as follows: section 2 introduces the model. Section 3 compares equilibrium prevention level with the socially optimal one. Section 4 discusses the main result and policy implications. Section 5 explores the case of multiple preventable risks, and section 6 concludes this study.

2. The model

To improve tractability, and without loss of generality, we modify the framework developed in Bhattacharya and Packalen (2012) for the case of homogeneous consumers. Thus, in our model changes in prevention efforts take place on the intensive margin. As in Bhattacharya and Packalen (2012), prevention takes the form of foregone leisure in the first period (when consumers are young). Then innovators set R&D efforts, and R&D outcomes and medical conditions are being realized, as to set relative demand and supply for different technologies in all sectors. The important novelty of our model is the incorporation of technological progress in other sectors, besides advances in cures for preventable diseases. Note that wherever we are explicitly considering nonmedical technologies, our analysis also applies to curing technologies for competing (non-

[9] Data available at http://www.census.gov/compendia/statab/2012/tables/12s0134.pdf
[10] Under uniform premiums not adjusted to personal prevention efforts.

preventable) medical risks, defined here as ones that may be realized if preventable diseases have not been developed.[11]

2.1 Preferences and technology

A unit mass of homogeneous consumers are endowed with a monetary income I, and l units of time. In the first period consumers derive utility from leisure only. In the second period consumers' source of utility depends on their health status: healthy consumers derive utility from consumption good, and ill consumers derive utility from medical goods. The Appendix shows that assuming ill consumers derive utility from both medical care and consumption does not change are main result. The utilization levels of consumption and medical goods, denoted C and Z respectively, depend on the consumed quantities and qualities of the products denoted c, z and q_c, q_z, respectively: $C \equiv q_z \cdot c$ and $Z \equiv q_z \cdot z$. Health status is uncertain, where π denotes the probability to become ill, and thus the probability of being healthy is $(1-\pi)$. The probability to become ill however, can be reduced through time investment h of foregone leisure:

(1) $\pi \equiv \pi(h)$, where $\pi'(h) < 0,\ \lim_{h \to 0} \pi'(h) = \infty,\ \pi''(h) > 0,\ \pi(0) < 0.5,\ \pi(l) > 0$

By assuming $\pi_0 \equiv \pi(h) < 0.5$ we define illness as the non-common state, as to ensure that positive prevention effort is chosen later on. Relying on the tractable logarithmic form, we write consumers expected utility function:

(2) $E\{U\} = \phi \ln(l-h) + \pi(h)\ln(Z) + (1-\pi(h))\ln(C)$

The parameter ϕ captures both relative preference for leisure utility compared to consumption utility, and preference for present compared to future utility. In each sector $i = \{c, z\}$ a single innovator works to improve the available quality of the product by a given factor $\lambda_i > 1$, with probability ρ_i to succeed. Hence, for a given current quality of a product

[11] Modeling mortality risks in a multiple period setup would enable us to incorporate competing risk more naturally, in the spirit of Dow et al (1999). This way or the other, our main argument applies: under higher prevention more spending are allocated to non-preventable medical needs and thereby stimulate progress in curing technologies there. That is true both for out of pocket spending, and for medical spending allocated through commercial or public health insurance.

q_i, its expected quality in the following period is $E\{q_i\} = (1-\rho_i)q_i + \rho_i q_i \lambda_i$.[12] Note that we could equivalently assumed that consumers derive utility from different consumption and medical technologies according, for example, to the Cobb-Douglas preferences: $C_t = \exp\left(\int_0^1 \ln q_{i,t} \cdot c_{i,t} di\right)$, $Z_t = \exp\left(\int_0^1 \ln q_{j,t} \cdot z_{j,t} dj\right)$. In this case, there would be a unit-mass of innovators in each sector, were each innovator works to improve the quality of one technology out of the products' continuum. Here, consumers would optimize prevention efforts in light of the (current) average and expected qualities in each sector, denoted $\bar{q}_i$. For independent probabilities of success across innovators, in each period a fraction ρ_i of the technologies would be improved in sector i, and the expected quality would be given by: $\bar{q}_{i,t} = \rho_{i,t-1}\lambda_i \bar{q}_{i,t-1} + (1-\rho_{i,t-1})\bar{q}_{i,t-1}$.

Innovator's probability to succeed in achieving quality improvement is increasing with R&D effort subject to quadratic cost function:

(3) $R(\rho_i) = \beta \frac{1}{2}\rho_i^2$

Finally, we assume that all technologies are granted with complete patent protection against imitation[13], and we normalize marginal production cost to one. The most advanced available technology – denoted q^N faces a vertical competition with the previous leading technology denoted q^o, which drives the price of the latter down to the unit marginal cost. As $q_i^N = \lambda_i q_i^o$, the limit price of the most advanced technology satisfies: $\frac{q_i^N}{p_i^N} = \frac{q_i^o}{MC} \Rightarrow \frac{q_i^0 \lambda_i}{p_i^N} = \frac{q_i^o}{1} \Rightarrow p_i^N = \lambda_i^N$. Hence, in case of successful innovation the quality to price ratio will be $\frac{q_i^N}{p_i^N} = \frac{q_i^o \lambda_i^N}{\lambda_i^N} = q_i^o$. Similarly, current available technologies would not be successfully improved, their price will be determined by their relative quality (compared with previous ones), that is $p_i^o = \lambda_i^o$. For later use, we define now relative technological

[12] For consistency and convenience we model the innovation process in line with Bhattacharya and Packalen (2012). However, our main argument does not rely on this specification.
[13] In section 4 we consider the possible implication of partial and asymmetric patent protection.

opportunity, across sectors, based on the potential size of quality improvement and its realization cost.

<u>Definition 1</u>: Under technological symmetry $\lambda_i^o = \lambda_i^N \equiv \lambda,\ \ \beta_i \equiv \beta\ \ \forall i$. Sector i has superior technological opportunity if $\beta_i < \beta_j$ and $\lambda_i^N > \lambda_j^N$.

<u>2.2 Consumer's optimization</u>

Substituting the expected qualities and prices into (2), we write consumers indirect expected utility function:

$$(4)\quad \begin{aligned} &\phi \ln(l-h) + \pi(h)\left[(1-\rho_Z)\ln\left(\frac{q_Z^o I}{\lambda_Z^o}\right) + \rho_z \ln\left(q_Z^o I\right)\right] + \\ &+\left(1-\pi(h)\right)\left[(1-\rho_C)\ln\left(\frac{q_C^o I}{\lambda_C^o}\right) + \rho_C \ln\left(q_C^o I\right)\right] \end{aligned}$$

Differentiating (4) with respect to h we obtain the first order condition for optimal private investment in prevention:

$$(5)\quad \frac{\phi}{(l-h)} = \left|\pi'(h)\right|\left[\ln\left(\frac{q_C^o \lambda_Z^o}{q_Z^o \lambda_C^o}\right) + \rho_C \ln\left(\lambda_C^o\right) - \rho_Z \ln\left(\lambda_Z^o\right)\right]$$

Under the assumed prevention technology (1), there is unique optimal level of prevention effort, given the probabilities for technological advances. Equation (5) presents the substitution between curing and self-protection: optimal prevention effort is decreasing with the relative quality of existing medical technology (compared with nonmedical technology) and with the relative likelihood that medical technology will be improved. The relative price of current medical technology determined by λ_Z^o and λ_C^o has positive effect on prevention.

<u>2.3 Innovators optimization</u>

Accounting for the cost function (3) and expected market size, price and unit marginal cost, innovators choose their R&D effort as to maximize expected profit, denoted ψ_i:

$$(6)\quad \begin{aligned} E\{\psi_Z\} &= \rho_Z \cdot z\left(p_Z^N - mc\right) - R_z\left(\rho_Z\right) = \rho_Z \frac{\pi I}{\lambda_Z^N}\left(\lambda_Z^N - 1\right) - \beta_Z \frac{1}{2}\rho_Z{}^2 \\ E\{\psi_C\} &= \rho_Z \cdot z\left(p_C^N - mc\right) - R_c\left(\rho_Z\right) = \rho_C \frac{(1-\pi) I}{\lambda_C^N}\left(\lambda_C^N - 1\right) - \beta_C \frac{1}{2}\rho_C{}^2 \end{aligned}$$

Differentiating (6) with respect to ρ_i we derive optimal probability of success for each innovator, which also defines optimal R&D effort [14]:

$$(7)\quad \rho_Z{}^* = \frac{\pi(h) I\left(1 - \frac{1}{\lambda_Z^N}\right)}{\beta_Z},\ \ \rho_C{}^* = \frac{\left[1 - \pi(h)\right] I\left(1 - \frac{1}{\lambda_C^N}\right)}{\beta_C}$$

For later use, we apply (7) calculate the expected profits for each innovator: $E\{\psi_Z\} = \beta \frac{1}{2}\rho_Z{}^2, E\{\psi_C\} = \beta \frac{1}{2}\rho_C{}^2$, and the derivatives of optimal success probabilities with respect to prevention efforts: $\rho_C{}'(h) = -\frac{\pi'(h) I}{\beta_C}\left(1 - \frac{1}{\lambda_C^N}\right),\ \ \rho_Z{}'(h) = \frac{\pi'(h) I}{\beta_Z}\left(1 - \frac{1}{\lambda_Z^N}\right)$.

3. Equilibrium Vs. Efficient prevention

3.1 Equilibrium with private prevention

Substituting innovators' optimality conditions (7) into consumers' optimality condition (5) we define the market equilibrium prevention level h^e which solves the following equation:

$$(8)\quad \frac{\phi}{\left(l - h^e\right)\left|\pi'\left(h^e\right)\right|} = \left[\ln\left(\frac{q_C^o \lambda_Z^o}{q_Z^o \lambda_C^o}\right) + \frac{\left[1 - \pi\left(h^e\right)\right] I\left(1 - \frac{1}{\lambda_C^N}\right)}{\beta_C}\ln\left(\lambda_C^o\right) - \frac{\pi\left(h^e\right) I\left(1 - \frac{1}{\lambda_Z^N}\right)}{\beta_Z}\ln\left(\lambda_Z^o\right)\right]$$

Under technological symmetry condition (8) becomes:

$$(9)\quad \frac{\phi}{\left(l - h^e\right)\left|\pi'\left(h^e\right)\right|} = \frac{I}{\beta}\left(1 - \frac{1}{\lambda}\right)\ln(\lambda)\left[1 - 2\pi\left(h^e\right)\right]$$

<u>Proposition 1</u>: *under technological symmetry there is unique equilibrium prevention-effort. Equilibrium prevention effort is increasing (decreasing) with technological opportunities in the consumption (medical) sector.*

Proof:

[14] We assume the parameters satisfy: $\rho_C{}^*, \rho_Z{}^* \in (0,1)$.

The left side of (9) is monotonically increasing with h^e from zero to infinity, whereas the right side is monotonically increasing and concave in h^e, with positive finite values. The right side of (8) shows that superior technological opportunities in the consumption (medical) technology increases (decreases) equilibrium prevention effort. *Q.E.D*

Proposition 1 implies that as technological progress affects utility under both realization – sick and healthy - it is the *relative* potential for technological progress that is crucial to the determination of prevention efforts. Note, however that previous technological progress has ambiguous effect on

3.2 Efficient prevention

The efficient prevention level is the one that maximizes total welfare which is the sum of consumers' expected utility and innovators' expected profit, given by:

$$\begin{aligned}(10)\quad & \phi\ln(l-h)+\pi(h)\left[(1-\rho_Z)\ln\left(\frac{q_Z^o I}{\lambda_Z^o}\right)+\rho_z\ln\left(q_Z^o I\right)\right]+\\ & +\left(1-\pi(h)\right)\left[(1-\rho_C)\ln\left(\frac{q_C^o I}{\lambda_C^o}\right)+\rho_C\ln\left(q_C^o I\right)\right]+\beta_Z\frac{1}{2}\rho_Z{}^2+\beta_C\frac{1}{2}\rho_C{}^2\end{aligned}$$

Differentiating (10) for h we obtain the first order condition for efficient prevention level:

$$\begin{aligned}(11)\quad \frac{\phi}{(l-h^*)\left|\pi'(h^*)\right|} &= \left[\ln\left(\frac{q_C^o\lambda_Z^o}{q_Z^o\lambda_C^o}\right)+\frac{\left[1-\pi(h^*)\right]I\left(1-\frac{1}{\lambda_C^N}\right)}{\beta_C}\ln\left(\lambda_C^o\right)-\frac{\pi(h^*)I\left(1-\frac{1}{\lambda_Z^N}\right)}{\beta_Z}\ln\left(\lambda_Z^o\right)\right]+\\ &+I\left[\frac{\left[1-\pi(h^*)\right]}{\beta_C}\left(1-\frac{1}{\lambda_C^N}\right)\left[\ln\left(\lambda_C^o\right)+I\left(1-\frac{1}{\lambda_C^N}\right)\right]-\frac{\pi(h^*)}{\beta_Z}\left(1-\frac{1}{\lambda_Z^N}\right)\left[\ln\left(\lambda_Z^o\right)+I\left(1-\frac{1}{\lambda_Z^N}\right)\right]\right]\end{aligned}$$

The right side of (11) is the social marginal benefit from prevention effort, divided by $\left|\pi'(h^*)\right|$. Note that its first addend identifies with the right side of the market equilibrium condition (9), whereas the residual term on the right side of (11) is denoted Δ:

$$(12)\quad \Delta\equiv I\left[\frac{\left[1-\pi(h^*)\right]}{\beta_C}\left(1-\frac{1}{\lambda_C^N}\right)\left[\ln\left(\lambda_C^o\right)+I\left(1-\frac{1}{\lambda_C^N}\right)\right]-\frac{\pi(h^*)}{\beta_Z}\left(1-\frac{1}{\lambda_Z^N}\right)\left[\ln\left(\lambda_Z^o\right)+I\left(1-\frac{1}{\lambda_Z^N}\right)\right]\right]$$

Note that the residual term (12) depends on the expected size of quality improvements, but

it also implicitly depends on the different in current qualities though its effect on actual prevention level and corresponding risk.

<u>Proposition 2</u>: *Unless technological opportunities are superior for the medical sector, private prevention efforts are inefficiently low and thus investment in medical R&D is excessive*.

Proof:

Under technological symmetry (12) is positive: $\frac{I}{\beta}\left(1-\frac{1}{\lambda}\right)\left[\ln(\lambda)+I\left(1-\frac{1}{\lambda}\right)\right]\left[1-2\pi(h)\right]$, and (12) is increasing with λ . *Q.E.D.*

Where technological opportunities differ across sectors private prevention is insufficient if the following inequality holds:

$$\frac{\left[1-\pi(h)\right]}{\pi(h)} > \frac{\frac{1}{\beta_Z}\left(1-\frac{1}{\lambda_Z^N}\right)\left[\ln\left(\lambda_Z^o\right)+I\left(1-\frac{1}{\lambda_Z^N}\right)\right]}{\frac{1}{\beta_C}\left(1-\frac{1}{\lambda_C^N}\right)\left[\ln\left(\lambda_C^o\right)+I\left(1-\frac{1}{\lambda_C^N}\right)\right]}$$

As (1) implies $\pi(h)<\frac{1}{2}$, the left side of the inequality above is greater than one. Under superior technological opportunity for consumption sector the right side of the inequality is smaller than one and thus, private prevention is definitely insufficient. Note however, that superior technological opportunity in the medical sector does not guarantee that private prevention efforts are excessive.

4. Discussion and policy implications

Proposition 2 reflects consumers inability to internalize the externalities induced from aggregate prevention level to R&D efforts and thereby expected technological advances. Note that if there are no technological opportunities in the nonmedical sector (i.e. $\lambda_C^N=0$) our model coincides with Bhattacharya and Packalen (2012): private prevention efforts are always excessive compared with social optimum as (12) is negative. However, if potential for technological progress is not exclusive to curing preventable diseases, the efficient prevention level depends on the relative technological opportunities across sectors.

In our model, equation (7) implies that better technological opportunities in the medical sector will be reflected in a higher R&D intensity in this sector, measured as the ratio of

R&D investment to sector size, that is $\frac{\rho_Z}{\pi \cdot I}$ compared to $\frac{\rho_C}{(1-\pi)\cdot I}$ [15]. These R&D intensities are empirically observable. However, unfortunately, the public data available to us cannot identify R&D spending aimed at improving cures for preventable diseases[16].

The inefficiency of private prevention efforts, gives room to conventional corrective policy measures. In case private prevention efforts are insufficient, prevention should be marginally subsidized as to make consumer internalize the residual marginal social gain, defined in (12). Similarly, as medical R&D is excessive in this case and nonmedical R&D is below its efficient level, marginal (flat rate) subsidy and tax on nonmedical R&D medical R&D, respectively, would be also welfare improving and will bring prevention efforts closer to efficient level; for theoretical and empirical analysis of medical R&D subsidies see Yin (2008). Finally, consider the effect of asymmetric mark ups in the model, due to price regulation or asymmetric patent protection. Lower mark-ups, in the medical sector for instance, induce contradicting effects on private prevention[17]. On one hand, under regulated priced consumers get a larger fraction of medical-innovation surplus. This works to lower private prevention. On the other hand, as the returns on innovation are decreasing optimal R&D investment is lower, along with the expected quality of medical technologies. This works to increase equilibrium prevention level. Nevertheless, price regulation on medical technologies has definite positive effects the deviation from optimal prevention, given in (12). This is because the negative externality of prevention on medical R&D is decreasing due to a weaker incentive to innovate in the medical, making prevention more beneficial from the social stand point (that account for R&D externalities).

[15] Bhattacharya and Packalen (2011) check for the efficiency of academic medical research, by matching biomedical publications with corresponding diseases prevalence and technological opportunities, evaluated based on previous - disease specific – research performance.

[16] According to NSF's aggregate R&D data for the years 2005-2007, medical R&D spending accounted for about 18% of total R&D spending in all industries, whereas health spending accounted for about 16.0% of GDP on annual average[16]. This murky comparison does not provide any instant inference for technological asymmetries between the medical and non-medical sector. Nonetheless, it overlooks spending shifts within the medical sector (towards preventable costs).

[17] Lower mark-up in the medical sector would be modeled as: $p_z = \gamma\lambda_Z$ with $\gamma \in (0,1)$.

5. Multiple risks

We turn now to consider possible distortions in the allocation of independent prevention efforts aimed to protect against independent medical risks, caused by the inability to internalize R&D externalities. The additional health risk is denoted Y. An actual example would be smoking and diet choices in accordance and there corresponding medical conditions described in section 1. For simplicity and clarity we assume identical prevention technologies for both maladies. Furthermore, we assume that when contracting both diseases consumers die, having zero normalized utility. One can alternatively assume the probability for joint medical-conditions, $\pi_Z \cdot \pi_Y$, is small enough to neglect. Consequently, the modified optimal R&D efforts become

$$(13)\quad \rho_C{}^* = \frac{\left[1-\pi(h_Z)-\pi(h_Y)\right] I\left(1-\frac{1}{\lambda_C^N}\right)}{\beta_C}, \rho_Z{}^* = \frac{\pi(h_Z) I\left(1-\frac{1}{\lambda_Z^N}\right)}{\beta_Z}, \rho_Y{}^* = \frac{\pi(h_Y) I\left(1-\frac{1}{\lambda_Y^N}\right)}{\beta_Y}$$

And the modified expected utility function (3) is given by

$$(14)\quad \begin{aligned} &\phi \ln(l-h_Z-h_Y) + \pi(h_Z)\left[(1-\rho_Z)\ln\left(\frac{q_Z^o}{\lambda_Z^o} I\right) + \rho_Z \ln\left(\lambda_Z^N I\right)\right] + \\ &+\pi(h_Y)\left[(1-\rho_Y)\ln\left(\frac{q_Y^o}{\lambda_Y^o} I\right) + \rho_Y \ln\left(\lambda_Y^N I\right)\right] + \left(1-\pi(h_Z)-\pi(h_Y)\right)\left[(1-\rho_C)\ln\left(\frac{q_C^o}{\lambda_C^o} I\right) + \rho_C \ln\left(\lambda_C^N I\right)\right] \end{aligned}$$

Optimal private prevention efforts for each medical risk should satisfy to following first order conditions:

$$(15a)\quad \frac{\phi}{l-h_Z{}^*-h_Y} = \left|\pi'(h_Z)\right|\left[\ln\left(\frac{q_C^o \lambda_C^o}{q_Z^o \lambda_Z^o}\right) + \rho_C \ln\left(\lambda_C^o\right) - \rho_Z \ln\left(\lambda_Z^o\right)\right]$$

$$(15b)\quad \frac{\phi}{l-h_Z-h_Y{}^*} = \left|\pi'(h_Y)\right|\left[\ln\left(\frac{q_C^o \lambda_Y^o}{q_Y^o \lambda_C^o}\right) + \rho_C \ln\left(\lambda_C^o\right) - \rho_Y \ln\left(\lambda_Y^o\right)\right]$$

Combining conditions (15a)-(15b), we get that optimal investment efforts should satisfy:

$$(16)\quad \frac{\left|\pi'(h_Y)\right|}{\left|\pi'(h_Z)\right|} = \frac{\ln\left(\frac{q_C^o \lambda_Z^o}{q_Z^o \lambda_C^o}\right) + \rho_C \ln\left(\lambda_C^o\right) - \rho_Z \ln\left(\lambda_Z^o\right)}{\ln\left(\frac{q_C^o \lambda_Y^o}{q_Y^o \lambda_C^o}\right) + \rho_C \ln\left(\lambda_C^o\right) - \rho_Y \ln\left(\lambda_Y^o\right)}$$

The efficient prevention efforts derived from maximizing the sum of producers' and consumers' surpluses w.r.t to prevention effort should satisfy the following conditions:

$$\text{(17a)}\quad \frac{\phi}{1-h_Z{}^*-h_Y}=\left|\pi'(h_Z)\right|\left[\ln\left(\frac{q_C^o\lambda_Z^o}{q_Z^o\lambda_C^o}\right)+\rho_C Ln\left(\lambda_C^N\right)-\rho_Z\ln\left(\lambda_Z^N\right)\right]+\pi(h_Z)\rho_Z{}'(h_Z)\ln\left(\lambda_Z^o\right)+$$
$$+\left[1-\pi(h_Z)-\pi(h_Y)\right]\rho_C{}'(h_Z)\ln\left(\lambda_Z^o\right)$$

$$\text{(17b)}\quad \frac{\phi}{1-h_Z-h_Y{}^*}=\left|\pi'(h_Y)\right|\left[\ln\left(\frac{q_C^o\lambda_Y^o}{q_Y^o\lambda_C^o}\right)+\rho_C\ln\left(\lambda_C^o\right)-\rho_Y\ln\left(\lambda_Y^o\right)\right]+\pi(h_Y)\rho_Y{}'(h_Y)\ln\left(\lambda_Y^o\right)+$$
$$+\left[1-\pi(h_Z)-\pi(h_Y)\right]\rho_C{}'(h_Y)\ln\left(\lambda_C^o\right)$$

Combining the two conditions we obtain:

$$\text{(18)}\quad \frac{\left|\pi'(h_Y)\right|}{\left|\pi'(h_Z)\right|}=$$
$$=\frac{\left[\ln\left(\frac{q_C^o\lambda_Z^o}{q_Z^o\lambda_C^o}\right)+\rho_C ln\left(\lambda_C^o\right)-\rho_Z\ln\left(\lambda_Z^o\right)\right]+\frac{1}{\left|\pi'(h_Z)\right|}\left[\pi(h_z)\rho_Z{}'(h_Z)\ln\left(\lambda_Z^o\right)+\left[1-\pi(h_Z)-\pi(h_Y)\right]\rho_C{}'(h_Z)\ln\left(\lambda_C^o\right)\right]}{\left[\ln\left(\frac{q_C^o\lambda_Y^o}{q_Y^o\lambda_C^o}\right)+\rho_C\ln\left(\lambda_C^o\right)-\rho_Y\ln\left(\lambda_Y^o\right)\right]+\frac{1}{\pi'(h_Y)}\left[\pi(h_Y)\rho_Y{}'(h_Y)\ln\left(\lambda_Y^o\right)+\left[1-\pi(h_Z)-\pi(h_Y)\right]\rho_C{}'(h_Y)\ln\left(\lambda_C^o\right)\right]}$$

<u>Proposition 3</u>: *Private prevention efforts are biased in favor of the advantaged sector.*

Proof:

Suppose $\lambda_Z^o>\lambda_Y^o$, $\lambda_Z^N>\lambda_Y^N$ or $\beta_Z<\beta_Y$ that is technological opportunities to improve cures for Z are superior. Then comparing explicit expressions for (16) with (18), one finds that the right side on (18) is *smaller* as $-\frac{\pi(h_z)}{\beta_Z}\left(1-\frac{1}{\lambda_Z^N}\right)\ln\left(\lambda_Z^o\right)<-\frac{\pi(h_Y)}{\beta_Y}\left(1-\frac{1}{\lambda_Y^N}\right)\ln\left(\lambda_Y^o\right)$. Hence, actual relative investment in preventing Z is excessive compared to social optimum. Q.E.D.

6. Conclusions

This work studies prevention externalities over R&D efforts in a multi-sector framework. It was shown that private prevention is insufficient, unless technological opportunities are superior for finding cures to preventable diseases. Insufficient prevention results in excessive preventable medical costs and excessive R&D efforts aimed to improve cures for preventable medical conditions. In this case, subsidizing prevention, regulating the price of new medical technologies, or taxing medical R&D would be welfare improving. Note

however that as we model prevention choice in terms of foregone leisure, one should be cautious with deriving immediate concrete policy from our theoretical result: Yaniv et al (2009), for example, show that even thin subsidy and fat tax, which are often considered as equivalent mitigates for obesity, have asymmetric effect on diet choices. The model provides testable measure for the relative technological opportunity, but the data available to us do not enable identification of R&D efforts aimed to improve cures for preventable diseases. Hence, the empirical test of our theoretical analysis is left for future research.

Appendix:

Here, we generalize our model to allow sick consumers derive the utility U_S from both medical technologies and nonmedical consumption, under Cob-Douglas preferences: $U_S(C,Z) = Z^{\alpha}C^{1-\alpha}$. Applying the logarithmic functional form of the Cob-Douglas preferences, we modify the expected utility function as follows:

$$\text{(A.1)} \quad \begin{aligned} E\{U\} &= \phi\ln(l-h) + \pi(h)\left[\alpha\ln(Z) + (1-\alpha)Ln(C)\right] + (1-\pi(h))\ln(C) = \\ &= \phi\ln(l-h) + \alpha\pi(h)\ln(Z) + \left[1-\alpha\pi(h)\right]\ln(C) \end{aligned}$$

Rearranging after writing the explicit expressions for we obtain the indirect expected utility function:

$$\text{(A.2)} \quad \begin{aligned} E\{U\} &= \phi\ln(l-h) + \alpha\pi(h)\left[\ln(q_Z) - (1-\rho_Z)\ln(\lambda_Z^o)\right] + \\ &+ (1-\alpha\pi(h))\left[\ln(q_c) - (1-\rho_c)\ln(\lambda_C^o)\right] + \ln I \end{aligned}$$

Optimal R&D investments are modified accordingly:

$$\text{(A.3)} \quad \rho_Z{}^* = \frac{\alpha\cdot\pi\cdot I}{\beta_Z}\left(1-\frac{1}{\lambda_Z^N}\right), \quad \rho_C{}^* = \frac{(1-\alpha\pi)I}{\beta_C}\left(1-\frac{1}{\lambda_C^N}\right)$$

The corresponding derivatives of optimal R&D with respect to prevention effort become:

$$\rho^*{}_Z{}'(h) = \frac{\alpha\cdot\pi'(h)\cdot I}{\beta_Z}\left(1-\frac{1}{\lambda_Z^N}\right), \quad \rho^*{}_C{}'(h) = -\frac{\alpha\pi'(h)I}{\beta_C}\left(1-\frac{1}{\lambda_C^N}\right)$$

Differentiating (A.2) for h we obtain the first order condition for optimal private prevention:

(A.4) $$\frac{\phi}{(l-h)} = \alpha\left|\pi'(h)\right|\left[\ln\left(\frac{q_C^o\lambda_Z^o}{q_Z^o\lambda_C^o}\right) + \rho_C\ln\left(\lambda_C^o\right) - \rho_Z\ln\left(\lambda_Z^o\right)\right]$$

Substituting (A.3) into (A.4) we obtain the equilibrium condition under technological symmetry:

(A.5)

$$\frac{\phi}{(l-h)} = \alpha\left|\pi'(h)\right|\left[\ln\left(\frac{q_C\lambda_Z}{q_Z\lambda_C}\right) + \frac{\left(1-\alpha\pi(h)\right)I}{\beta_C}\left(1-\frac{1}{\lambda_C}\right)\ln(\lambda_C) - \frac{\alpha\cdot\pi(h)\cdot I}{\beta_Z}\left(1-\frac{1}{\lambda_Z}\right)\ln(\lambda_Z)\right]$$

$$\frac{\phi}{(l-h)\left|\pi'(h)\right|} = \frac{\alpha I\left(1-\frac{1}{\lambda}\right)\ln(\lambda)}{\beta}\left[1-2\alpha\pi(h)\right]$$

Note that α has ambiguous effect on equilibrium prevention level. Positive prevention effort in equilibrium requires: $\pi_0(0) < \frac{1}{2\alpha}$.

The first order condition for the socially optimal prevention level is given by:

(A.6) $$\frac{\phi}{(l-h)} = \alpha\pi'(h)\left[\ln\left(\frac{q_Z\lambda_C}{q_C\lambda_Z}\right) + \rho_Z(h)\ln(\lambda_z) - \rho_c(h)\ln(\lambda_c)\right] +$$
$$+\alpha\pi(h)\rho_Z'(h)\ln(\lambda_z) + \left(1-\alpha\pi(h)\right)\rho_c'(h)\ln(\lambda_c)$$

After substituting the explicit expressions for $\rho_Z'(h)$ and $\rho_C'(h)$, and imposing technological symmetry, the deviation term becomes: $\frac{\alpha\cdot\pi'(h)\cdot I}{\beta}\left(1-\frac{1}{\lambda}\right)\ln(\lambda)\left[2\alpha\pi(h)-1\right]$.

Hence, according to (A.5), for positive prevention effort in equilibrium private prevention efforts are insufficient unless technological opportunities are superior for cures to preventable diseases.

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