Can Patent Duration Hinder Medical Innovation for Neglected Diseases?

Abstract

We argue that excessive patent duration can deter investments in innovative treatments to eradicate lethal diseases in poor countries. The point is that too-long durations foster incentives to collude to delay investments in R&D for innovative treatments. We give a set of sufficient conditions for which collusion is a subgame-perfect equilibrium. We then show that reducing current duration always breaks down market discipline, and so does an increase in duration for innovative treatments.

Keywords: Neglected disease; Medical innovation
Patent duration, Collusion

1 Introduction

Many pandemics strike in developing and emerging countries, such as HIV/AIDS, malaria and tuberculosis. Despite large foreign aid, most of the burden of treating these diseases remain at local government level (UNAIDS [19]). National government in developing countries face high cost of available treatments. Much needed are therefore innovative treatments, which often take the form of therapeutic vaccines (Klausner et al. [10]).

Those innovative treatments are difficult to develop, and come at a high price and high risk of R&D failure (Leoni [14] Ch. 7-8). Private companies play a key role in developing such medical breakthroughs, and therefore, strong financial incentives are necessary to undertake the R&D process (Kremer and Glennerster [11]). The pharmaceutical industry relies on protective patents' systems to generate profits, despite some history of breaking patents for HIV/AIDS treatments in Brazil for instance. A patent gives a firm a monopolistic and strongly enforced right for commercialization for several years (this duration varies across countries, with a range of 12-20 years). Ito and Yamagata [9] strongly suggests that the patent system fosters private R&D investments for treatments for the poor.

For pandemics striking in developing countries, there is ample evidence of large investments in side treatments targeted at some particular symptoms (American Pharmaceutical Research Companies [1]). These side treatments are all under patent protection and their number is huge as documented in the following section. At the same, there is little effort to invest in R&D for medical innovations.

We argue that current patents' systems are a major deterrent for investments in much-needed innovative treatments. Our point is that the current system provides strong incentives for industry collusion, aimed at delaying R&D for such innovative treatments. Long patent duration increases the current profits and hence, reduces

the gap; i.e., the increase in profits, that the innovative treatment would produce. Henceforth, market collusion is a natural outcome that is easily enforceable in most cases. We show that reducing patents duration will increase this gap and thus, will increase the likelihood of appearance of innovative treatments by breaking down market discipline. We also show that increasing patent duration in innovative treatments (vaccines) will also increase the gap. If patent duration for current treatments (drugs) cannot be different to patent duration in innovative treatments (vaccines), due to legal constraint or wide definition of treatments, then the optimal patent duration is therefore a trade-off between rewarding innovation in current treatments, and breaking down market discipline to delay investment in R&D in innovative treatments.

We present an infinite horizon model in which firms chose their investment decisions every period. They can choose to invest in a new drug or invest in a vaccine. The former investment will yield a new drug for sure, while the former will yield a vaccine with positive (smaller than 1) probability. The vaccine R&D is not only risky, but also more expensive than drugs R&D. When a vaccine is discovered, all drugs become obsolete and yield zero profits. Under some parameter conditions, there is an equilibrium in which firms never try to develop the vaccine, even though it is profitable, because market retaliations for initiating vaccine R&D is credible. In Section 3, we give a concrete example involving US pharmaceutical companies that is consistent with our theory.

The paper is organized as follows. In Section 2, we describe the patent systems in various countries in detail. In Section 3, we describe the situation in the US pharmaceutical industry and argue why this behavior matches the predictions of our model. In Section 4, we develop the formal model. Finally, Section 5 contains some concluding remarks, and the technical proofs are left in the Appendix.

2 Patents and medical innovations

In this section, we give a broad overview of the market for treatments of Sexually Transmitted Diseases (STDs), which includes many neglected diseases[1] and HIV/AIDS, for example. We also describe the protections that patents provide for treatments of neglected diseases, and their trend in the recent years.

2.1 Market size for STDs and current treatments

In a country like the U.S., where patents are severely enforced, developing a therapeutic vaccine for a STD like HIV would be very profitable due to the large market size. In 2007, the annual direct medical cost of treating STDs was $13 billion, and HIV treatments amounted to $5 billion (American Pharmaceutical Research Companies [1]). Moreover, the market to treat the 9 million new STD infections in 2000 for the age group 15-24 amounted to $6.5 billion. Viral infections that include herpes, HIV, hepatitis B and human papillomavirus (HPV) took the biggest toll with 94% of overall infections. HIV and HPV were the costliest (and deadliest) diseases: they accounted for 90% of the overall cost (Leoni [14] Ch. 9).

A therapeutic vaccine, designed for treating infected patients and reducing HIV-transmissibility by diminishing the mean viral load in the population,would achieve this goal. The advantages of this vaccine are huge at medical level. There are also important gains at economic level, because the desired effects could be achieved at low production cost (Kremer and Glennerster [11]). However, there has been no successful attempt so far (see Klausner et al. [10], Kremer and Glennerster [11] for recent developments in HIV/AIDS therapeutic vaccine research). Few attempts to develop this vaccine have been made on a significant scale, with the noticeable exceptions of

[1]Neglected diseases are a group of tropical infections that are especially endemic in low-income populations in developing regions of Africa, Asia, and America.

Merck and the Pasteur Institute in 2005/06. Twenty other vaccines targeted at HIV infection were nonetheless developed in 2007, but those vaccines were engineered to treat specific symptoms (American Pharmaceutical Research Companies [1]) and not a general cure for the disease.

The case of HIV/AIDS is emblematic of a strategy intended at developed slightly differentiated drugs, targeted at some specific symptoms, without attempting to produce a general cure. No less than 73 new drugs against HIV/AIDS were developed in 2007 in the US only, most of them by private companies sometimes using public scientific discoveries (American Pharmaceutical Research Companies [1]). Those drugs tend to treat specific aspects of the symptoms such as immunomodulators and antivirals.

There are significant technical difficulties in developing a therapeutic vaccine, and the high risk of failure in R&D leads to potentially severe financial losses for any firm undertaking this project. The Tufts Report estimates that the R&D cost of a new vaccine is about $802 million in 2003, and Grabowski [6] argues that the cost of the clinical trial alone in 2000 was $466 million. Nevertheless, we argue that the current patent system is yet another deterrent to initiating R&D in a therapeutic vaccine of this kind; our point is that the economic environment in which firms are competing with each other provides incentives for firms to develop new patents for drugs rather than try to develop a vaccine.

2.2 Patents and R&D process

After a successful campaign, and given the high stakes involved in the process, any private company must receive sound protection during the commercialization. The standard method of protecting a medical discovery with potential commercial applications is to apply for a patent to a national authority that has the legal right to enforce it domestically. Once granted, the patent owner has the exclusive right to commer-

cialize the product for a pre-determined period of time in this country. The owner may claim financial compensations from anyone commercializing either the product itself or one of its applications during this protected period. The invention becomes public domain after this period, and unless an extension is granted it can then be freely commercialized by any other company. In the case of drugs, the production of generics after expiration is common practice nowadays.

The exact nature of the protection of a patent greatly varies across countries. The most common problem is the different time lengths of protection across regions, which for instance may vary by up to five years between the US and Europe. In the case of drugs in the US, the Food and Drugs Administration (or FDA) is in charge of regulating patent applications, setting the protection levels and enforcing patent rights. Typically, the FDA follows the regulatory recommendations of the Uruguay Round Agreement Act that was passed in June 1995. This Act stipulates that the protection period is (in general) 17 years for a patent filed before 1995, and 20 years for patents filed after this date. A patent extension may be granted at most once, for a period of no longer than 5 years, to compensate for losses incurred during the marketing and thus pre-commercialization period. The amount of financial sanctions in case of violation is to be decided in a US court of law based on the nature of the damages.

The number of HIV/AIDS related patents is considerable, and it can largely be explained by the large market profitability of this disease. In 1998, the United States Patent and Trademark Office [18] reports that the number of such existing patents exceeded 1500 in the US. Ito and Yamagata [9] also analyzes the patents application pattern for neglected diseases in Japan, which includes HIV/AIDS, for the period 1980-1998. They report 5121 applications for this period, among which roughly two-thirds of them were directly devoted to AIDS only, roughly 7% of them were targeted against TB and the remainder against various neglected diseases. The small per-

centage of patents for diseases striking in poor countries is a clear evidence that profitability is the key engine to medical innovation, since the death toll and morbidity level of TB and neglected diseases are altogether much higher than those of HIV/AIDS.

Ito and Yamagata [9] also finds that private companies in Japan are the biggest suppliers of patents both for HIV and TB, but those private companies invest proportionally much more for HIV. Among the 3507 applications for HIV/AIDS, roughly 81% of them came from private companies and 14% from universities. In sharp contrast, for the less profitable market of TB solely 64% of those applications came from private companies and 30% from universities.

This situation is typical in most developed countries. The fraction of patent applications from the public sector is roughly the same for both diseases and remains fairly low. However, the fraction of patent applications from universities more than double in the case of TB. Those figures show that most of the medical innovations for neglected diseases come from the private industry, which relies on a sound patent system for commercialization.

3 Collusive behavior

We now describe a collective collusion scheme that prevents R&D in innovative treatments for neglected diseases, and we give a past example of a related collusion in the pharmaceutical industry. We also give other empirical evidence of recent price manipulations for drugs targeted at neglected diseases. A solution to reduce the likelihood of such collusion, through the reduction of patents' duration, is also verbally described. The formal point will then be developed in the following section.

3.1 Conditions for stable collusions

At theoretical level, the possibility of collusion among oligopolists has been extensively studied (see Tirole [16] Ch. 6 or Chamberlin [5] for instance). In this literature, collusion on prices only is addressed, although a somewhat similar argument can be made for the decision of delaying R&D on an innovation that can render most current patents obsolete.

Consider a situation where many firms compete on markets that are not differentiated enough, where those firms own a large pools of patents, and where one firm may start at any time a R&D project capable of seizing the whole markets while rendering those patents obsolete. The coordination on a *status quo* situation on these markets, where no firm starts this R&D venture so as to maintain current patents in place longer, is easy to achieve. Any deviator from the status quo situation may typically face a collective punishment sufficient to deter this action, as described next. This collective punishment can be, for instance, the initiation by the other firms of the same R&D with the risk of loosing initial investments because of the race, and/or to start a war on prices on other products already commercialized by the deviator (see Bernheim and Whinston (1990)).

The threat of facing large-scale collective retaliations is typically sufficient to enforce the collusive outcome, without the need to write down contracts for delaying R&D. Basically, such contracts would be detrimental to the parties in terms of public image and hardly enforceable, whereas the collusive outcome above is tacit and its stability intuitively depends on how strong the threat of collective retaliation is. Moreover, the fact that initiating the R&D for innovative treatments renders ones' own current patents also obsolete is a self-punishment that makes the collusion even more stable.

Clearly, there must be some conditions for this scheme to work. For instance, the net benefits from unilaterally starting the R&D must not exceed the overall cost of

being punished; that is, there must be a link between the decision to initiate the R&D and some linear function of the difference between the monopolist profit less that of the status-quo situation. When at least one firm has enough incentives of this kind to take on this project, the R&D race shall start. In the formal analysis presented in the following section, we give such conditions leading to a collusive behavior or not.

Some specific industrial factors may also favor the appearance of such collusive behavior. For instance, multi-markets situations facilitate large-scale retaliations on a deviator, because the level of punishments is then large enough to act as a significant deterrent (see Matsushima [15] for instance). Bain [2] also argues that strong market concentration also favors collusion, since any deviation can be easily detected in a timely manner and treated accordingly. The point is that, for a retaliation on a deviator to be possible and effective, detection must come quickly enough to allow for a R&D race to start in time.

The pharmaceutical industry is emblematic of those collusive factors above, since few companies commercialize most of the available drugs and decisions to start a R&D venture is known to shareholders and outside investors. Therefore, one should reasonably expect to have evidence of collusive behavior in this sector. Sherer [17] p. 222 reports a large-scale collusion to maintain a high market price in the U.S. for the antibiotics tetracycline, although the group discipline broke down when the Armed Service Medical Procurement Agency placed a large order in 1956.

3.2 Other price manipulations

We now document some other strategic price manipulation by pharmaceutical companies. These discriminatory actions are independent of the collusive behavior described in the previous section; the point of presenting these evidence is to show that market manipulations are common practice in the pharmaceutical industry, and collusion is therefore a natural possibility.

Opportunistic or strategic pricing from pharmaceutical companies has long been documented in developed countries for HIV/AIDS drugs (see for instance Grabowski and Vernon [7] and Hudson [8]). Similar evidence of strategic pricing behavior can be found in developing countries with low income. Borrell [4] carries out an interesting study on the pricing pattern of the famous ARV 'cocktail therapy' for the period 1995-2004, in 34 low and middle-income countries where the therapy was under patent at the time. Borrell finds strong statistical evidence of *skimming strategy*; that is, setting high prices early and then decreasing them. Moreover, Borrell finds that the skimming period typically lasts 9 years, after which there seems to be some price stabilization. The study also shows very strong positive correlation between the domestic market price of the cocktail therapy and the GDP per capita; that is, the market price of this therapy is set so as to extract the highest surplus in some of the poorest countries.

There are also statistical evidence showing that larger drugs purchasing bodies have been capable of obtaining larger rebates from pharmaceutical companies on HIV/AIDS drugs. Leibowitz and Sood [13] carries out this study in 2007 for the AIDS Drug Assistance Program, or ADAP. This program is included in the CARE Act in the U.S., and it represents the payer of last resort for the poorest (uninsured or under-insured) infected patients. Most of the money allocated to the states is used to purchase drugs. States have full control over their drug purchase levels and eligibility requirements, a situation that leads to severe discrepancies for patients coverage (Leoni [14] Ch. 7).

This program has a large variety of purchasing methods across states: 30 states directly negotiate rebates from producers, whereas 24 states first compensate retail pharmacies in charge of drug delivery and then apply for rebates. In the later case, those states forego their bargaining power as explained earlier, since at the time they apply for rebates purchases are already made. Leibowitz and Sood find that, among states depending on retail pharmacists, those states dealing with the smallest retailing

networks have the highest purchasing costs. Moreover, among the states with direct purchase methods, they find that the higher the purchasing volume the lower the cost. Finally, they find that there is no significant difference among programs with similar organizations, showing that all of the market power from states is exploited to get the best possible prices given the relative purchasing ability.

4 The model

We now present the formal model. We first describe it, and we then establish sufficient conditions under which an investment in R&D to develop a vaccine will or will not happen in equilibrium. We finally use these conditions to show that reducing the duration of current patents increase the incentives of firms to develop a vaccine by breaking down market discipline.

4.1 Agents and payoff structure

Consider an economy with a potentially infinite number of time periods (also called years), in which two firms only are competing with each other. This assumption is made for simplicity, as our points readily extend to the case of N firms. Those two firms are in a duopoly competition for treating a particular disease. Every firm $i \in \{1, 2\}$ owns a set of patents P^i for drugs to treat this disease. To simplify matter, we assume that every patent has the same fixed duration of T years. Each patent p, owned by firm i, will produce a profit of π_p^i every year. Hence, the value of all patents for the firm is the discounted cash flow:

$$CF_p^i = \sum_{t=1}^{T} \beta^t \sum_{p=1}^{P^i} \pi_p^i = \sum_{t=1}^{T} \beta^t \Pi^i \tag{1}$$

where $\beta > 0$ is the common discount factor. We could also write $\beta = \frac{1}{1+r}$, where r is the risk premium for similar projects already used in the industry. We may let these

values depend on time without changing the qualitative nature of our results.

In every year, each firm i must take an action a_i. Each firm decides simultaneously whether to develop a new drug $a_i = d$ or to try to develop a vaccine $a_i = v$. Let $a = (a_1, a_2)$ be a vector of actions, of the stage game. If the firm decides to develop the drug, the project will be successful with probability 1 and we normalize its cost to 0. This normalization is without loss of generality as long as the development of the vaccine is more expensive than the development of a drug.

If the firm decides to develop the vaccine, the project will be successful with probability $\alpha \in (0, 1)$ and it will have a cost equal to $C > 0$. The probability of success α is independent of the actions taken by other firms and independent of the actions taken by all firms (including firm i) in the past. For simplicity in the exposition, we will assume that the knowledge obtained while (unsuccessfully) researching the vaccine can be use to develop a new drug. This assumption will simplify the proofs and is not unrealistic. This assumption will only make the developing of a vaccine even more attractive, so, if anything it strengthen our arguments.

When at least one firm successfully develops the vaccine, then all drugs become useless and they no longer produce any profits. The game is then over and the profits for the remaining firm (the firm without a patent on the vaccine) is zero forever. When all firms develop a new drug, the market structure will not vary. Each firm will lose the profits coming from an old patent that expires and will gain the profits from the new patent just developed (remember that all patents have the same duration).

The market for the vaccine will generate annual profits equal to π_v, during $\overline{T}$ years, which will be divided equally among all firms that successfully developed the vaccine. Notice that the duration of a patent on drugs T and the duration of a patent on vaccines $\overline{T}$ need not be the same. The value of the vaccine is then:

$$CF_v = \sum_{t=1}^{\overline{T}} \beta^t \pi_v, \tag{2}$$

At the beginning of the current year, the actions taken by all firms become common knowledge; i.e., perfect monitoring. Hence, actions (not outcomes) are publicly known. A strategy for firm i is an action $a_i^t \in \{d_i, v_i\}$ for every year, conditional on the information that the firm has in year t. In this case, the information that firms have when making their decisions consists on the actions taken by all firms in previous periods.

Let $h_i = ((a_i^1, a^1), (a_i^2, a^2), ..., (a_i^t, a^t))$ be a history for player i, then the corresponding public history is $\widehat{h}_i = (a^1, a^2, ..., a^t)$. A strategy σ_i for player i is a mapping between histories and actions, i.e. $\sigma_i : H_i \to A_i$. Let σ be a strategy profile. The payoff to player i is then given by:

$$U_i(\sigma) = \lim_{\tau \to \infty} \sum_{t=1}^{\tau} \beta^t u_i\left(a_i^t, a^t\right)$$

where $u_i(a_i^t, a^t)$ is the stage-game payoff of player i that depends on player i's action and on the vector of actions of all players.

A strategy σ_i is a *public strategy* if $\sigma_i(h_i)$ depends only in the public history $\widehat{h}_i$, i.e. we can write $\sigma_i(h_i) = \sigma_i\left(\widehat{h}_i\right)$.

Definition: A public strategy profile σ is a Nash Equilibrium (NE) if:

$$U_i(\sigma) \geq U_i(\widehat{\sigma}_i, \sigma_{-i})$$

for all strategies $\widehat{\sigma}_i$ *whether public or not.* A strategy profile σ is a *Perfect Public Equilibrium* (PPE) if it is a public strategy profile and it induces a Nash Equilibrium after every public history.

We next define our notion of market collusion, which involves a punishment at the first attempt to unilaterally develop a vaccine.

Definition: A Collusion Strategy $\widetilde{\sigma}_i$ for player i establishes that player i will play $a_i^0 = d$ and $a_i^t = d$ if and only if $\widehat{h}_i = (a^1, a^2, ..., a^t) = ((d,d), (d,d), ..., (d,d))$ for $t \geq 1$.

A Collusion Strategy establishes that firms will only develop drugs as long as all firms in the past had only develop drugs. If one firm tries to develop a vaccine (whether successfully or not), the other firm will also try, as a punishment, to develop a vaccine in all remaining periods until at least one firm is successful. Then, as assumed earlier, the game ends.

In the remainder of this section, we develop the sufficient conditions under which a Collusion Strategy can be sustained as a PPE. A PPE is a critical concept for our work, because it captures the idea of credible punishment. Indeed, one can easily imagine a threat to harshly punish any breach in market discipline, but once the deviation actually occurs it may prove prohibitively costly to carry out the punishment. The notion of PPE asserts that the cost of punishment is bearable by the punisher.

Notice that a Collusion Strategy imposes the most severe punishment possible after a deviation from developing drugs. Hence, if a Collusion Strategy is not sustained as a PPE, then the only PPE is one in which firms try to develop the vaccine in every period, regardless of the strategies of other firms.

Assumption (A1): We will assume that $CF_v - C > CF_p^i$ for all firms.

This assumption implies that, for all firms, it is in their individual selfish interest to try to develop the vaccine. However, as we will show, they might end up not trying to develop the vaccine.

It is worth mentioning that actions are publicly known. This assumption is more restrictive than assuming that outcomes (but not actions) are observable. In general, both assumptions are equivalent. However, in this case, since $\alpha < 1$ and a fail attempt to develop a vaccine produces a new drug, these two assumptions are different. Moreover, if actions were unobservable, even if outcomes were observable, firms will

not be able to sustain a Collusion strategy. The outcome observed in case of a failed attempt to research a vaccine is the same as the outcome in case of the research of a drug. The outcome after a successful attempt to develop a vaccine is irrelevant, become the successful firm will enjoy its monopoly and there is nothing that the others firms can do about it. Hence, with observable outcomes but unobservable actions, and because of A1, firms will have incentives to develop the vaccine 'secretly'.

This result suggests that public research or share research agendas by pharmaceutical companies will reduce their incentives to develop the vaccine. Thus, publishing research findings could decrease R&D effort while having 'secret' research projects will increase the likely of a vaccine to be discovered.

4.2 Strategic Analysis

We now analyze the duopoly presented earlier. The same analysis applies to the case when 3 or more firms are competing in the economy. As expected, the susceptibility of the equilibrium with no research in vaccine is decreasing in the number of firms. This is true here for two reasons. The first one is obvious, the greater the number of firms, the lower are the profits (per firm) from the patents on drugs. Hence, firms have greater incentives to develop the vaccine. The second reason is more subtle. Because the conditions displayed below should hold for all firms, increasing the number of firms also increase the possibility that for (at least) one of the firms the conditions do not hold.

In the duopoly case, the payoffs matrix is:

	v^2	d^2
v^1	θ^1, θ^2	$\alpha CF_v + (1-\alpha)\,\theta^1 - C, (1-\alpha)\left[\Pi_p^2 + \beta\theta^2\right]$
d^1	$(1-\alpha)\left[\Pi_p^1 + \beta\theta^1\right], \alpha CF_v + (1-\alpha)\,\theta^2 - C$	CF_p^1, CF_p^2

where $\theta^i = \frac{1}{\left[1-(1-\alpha)^2\beta\right]}\left[\frac{a(1-2\alpha)}{2}CF_v + (1-\alpha)^2\,\Pi_p^i - C\right]$ is the expected cash flow for

player i when both players are trying to develop the vaccine.

Assumption (A2): We will assume that $\alpha CF_v + (1-\alpha)\,\theta^i - C > CF_p^i$ for all firms.

Notice that A2 will hold when C is small, CF_v is big and/or α is close enough to 1. Assumption A2 means that if the other firm is not developing a vaccine, firm i will find it profitable to develop a vaccine. If A2 does not hold, then never develop a vaccine will be a trivial PPE, for any discount factor β.

Assumption (A3): We will assume that $\theta^i > (1-\alpha)\left[\Pi_p^i + \beta\theta^i\right]$ for all firms.

Notice that A3 will hold when C is small and/or α is big. Assumption A3 means that if the other firm is developing a vaccine, firm i would find it profitable to develop a vaccine. Hence, a sufficient condition for A1, A2 and A3 to hold is that α is close enough to 1. The meaning of α being close enough to one is that the vaccine is easy to develop, and therefore profitable in expected value. However, this is not sufficient: C being small or CF_v will also make the vaccine very profitable. The variable α being 'large enough' ensures that the deviation is successful. In other words, the 'deviator' is unlikely to be punished if she tries to develop the vaccine, when α is large enough.

In summary, Assumptions A1-A3 are not necessary for our results, but they are likely to happen in the real world and will allow us to focus on the important features of this market. They tells us that it will be profitable for firms to invest in R&D to develop a vaccine whether the firm is a monopolist (A1), the firm is in competition with another firm that is not developing a vaccine (A2) or the firm is in competition with another firm that is developing a vaccine (A3). These assumptions are sufficient to show that the reason why firms might not be developing a vaccine is due to the strategic dynamic interactions rather than due to technological or economic concerns.

Proposition 1 *A Collusion Strategy is a Perfect Public Equilibrium if and only if* $CF_p^i \geq (1-\beta)\left[\alpha CF_v + (1-\alpha)\,\theta^i - C\right]$ *for all firms.*

Proof: Suppose both firms play the Collusion Strategy. Then, the payoff to each is $\frac{CF_p^i}{1-\beta}$. Suppose a firm uses another strategy. This must involve researching drugs for a number of periods (maybe zero) and then researching a vaccine until the game ends. This is optimal since the other firm is playing a Collusion Strategy, hence the other firm will play v forever and, as A3 hold, the best response for firm i is to play v. Consider the game at $t = 0$ without loss of generality. If firm i plays v, it receives $\left[\alpha CF_v + (1-\alpha)\,\theta^i - C\right]$. Hence, a the Collusion Strategy is an equilibrium if and only if $\frac{CF_p^i}{1-\beta} \geq \left[\alpha CF_v + (1-\alpha)\,\theta^i - C\right]$.

Corollary 2 *There exists a patent duration on drugs* T_0 *such that, for every duration on drugs* $T > T_0$*, the Collusion Strategy is an equilibrium.*

Corollary 2 implies that the odds of discovering a vaccine decreases, as the duration on drugs increases. This is a direct consequence of CF_p^i being increasing in T. The intuition of Corollary 2 is that increasing the patent duration on drugs (temporary treatments) makes the profits of current patent holders (on drugs) greater. Greater profits implies that firms are less willing to try to develop a vaccine. It also implies that firms will lobby and pressure legislators in order to keep the current duration, or even increase it, regardless of the profitability of the new vaccine, π_v.

Corollary 3 *There exists a patent duration on vaccines* $\bar{T}_0$ *such that, for every* $\bar{T} > \bar{T}_0$*, the Collusion Strategy is not an equilibrium.*

Corollary 3 implies that the odds of discovering a vaccine increases, as the duration on vaccines increases. This is a direct consequence of CF_v being increasing in $\overline{T}$. The intuition of Corollary 3 is that increasing the patent duration on vaccines (permanent

treatments) makes the profits of a potential deviator greater. Greater profits means that firms are more willing to undertake the project, specially those firms which current patents are not that profitable.

Hence, if the legislator can modify the patent duration on drugs and vaccines independently, in order to increase incentives for developing a new vaccine for STDs the patent duration on drugs shall be 'short' and the patent duration on vaccines shall be 'large'.

Our final result links the cost of R&D and the stability of the Collusion Strategy. It is a direct consequence of Proposition 1, and our remarks about the validity of Assumptions A1-A3.

Corollary 4 *The exists $\bar{C}$ such that, for every $C < \bar{C}$, the Collusion Strategy is a PPE.*

The previous result states that, when the cost of punishing is not high, then market discipline is stable. Notice that, in general, it is not true that for C high enough, market discipline is stable because it might be overly costly to punish. Our previous analysis allows to easily calculate a range of R&D cost for which harsh market punishment is credible, in that its cost to the punisher is acceptable.

5 Conclusions

We develop the idea that the current patent system supports strong collusive behavior for delaying R&D in vaccines, because of too long durations granted to owners. We argue that under some conditions firms might not find it profitable to invest in R&D to develop a vaccine, although this vaccine is profitable. We finally show that reducing the duration in patents on drugs makes it more likely for a vaccine to be discovered. Reducing the duration in patents on vaccines, however, makes it less likely for a vaccine to be discovered.

If we impose that the duration of all patents, whether in drugs or in vaccines, have to have the same duration, the problem of finding the optimal duration is therefore critical. A fair and sound patent system must sufficiently reward innovations to provide incentives for future R&D, and at the same it must prevent market inefficiencies that leads to socially inferior outcomes. The optimal patent duration must therefore be a trade-off between those two issues.

Finally, our model suggests that public actions by firms will strengthen coordination and, thus, reduce the incentives to develop the vaccine.

Appendix: Computation of θ^i

When both firms try to develop the vaccine the payoff for firm i is:

$$\theta^i = \alpha \left[\alpha \frac{CF_v}{2} + (1-\alpha) CF_v \right] + (1-\alpha)^2 \left[\Pi_p^i + \beta \theta^i \right] - C$$

where the first term correspond to the case when firm i is successful: with probability α firm j is also successful, hence they share the profits, and with probability $(1-\alpha)$ firm j is unsuccessful, hence firm i get all the profits. The second term correspond to the case in which both firms are unsuccessful. In this case, firm i will enjoy the profits from his patents and will play the same game in the next period because the unsuccessful vaccine produces another patent on drugs. If only firm j is successful, firm i gets nothing. Whether firm i is successful or not it has to pay the cost C. Solving for θ^i gives:

$$\left[1 - (1-\alpha)^2 \beta \right] \theta^i = \frac{\alpha (1-2\alpha)}{2} CF_v + (1-\alpha)^2 \Pi_p^i - C$$

$$\theta^i = \frac{1}{\left[1 - (1-\alpha)^2 \beta \right]} \left[\frac{\alpha (1-2\alpha)}{2} CF_v + (1-\alpha)^2 \Pi_p^i - C \right]$$

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