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A model of patent-complements:

Incentivizing drug development for neglected diseases

by

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Contents

1 Introduction

Although pharmaceutical companies pour billions of dollars each year into developing new drugs, drug development for neglected diseases is insufficient. Neglected diseases are estimated to affect 1.4 billion people annually. And yet, from 1980 to 2005, only 1% of new medicines developed were intended for tropical or neglected diseases [1]. This poses a serious problem: despite the millions of people in third world countries affected by neglected diseases, little research and development is dedicated to their plight.

One commonly proposed solution to the neglected disease problem is to use incentive mechanisms to induce firms to develop drugs for neglected diseases. On paper, incentive mechanisms like patent-complements are promising solutions. However, many of these mechanisms have not passed their design or proposal stages. Why is this? Practical implementation of these mechanisms is very costly, as most require donors such as governments and large private funds to subsidize pharmaceutical firms in the billions. This makes it difficult to evaluate whether or not such mechanisms will be effective until implementation. It is understandably difficult to realize a mechanism that will affect millions of people without even theoretical grounding to support basic functionality of the mechanism. I believe it is therefore important to first use a theoretical framework to assess the effects of these mechanisms before discussing implementation.

The main contribution of this paper is the development of a simple method that can assess the potential of certain incentive mechanisms in the most cost-efficient manner possible: this paper introduces a mechanism model for patent-complements, a certain type of incentive mechanism. Although simple, the model is somewhat novel; to my knowledge, no other model for patent-complements exists the literature. For any incentive mechanism that can be classified as a patent-complement, the model can be used to determine the quantity of the neglected disease drug that would be produced under the model, the funding amount required to support the patent-complement, and the deadweight loss result-

ing from the patent-complement implementation. Thus, this model serves an important purpose: applying the model to proposed patent-complement designs can aid potential patent-complement donors and supporters in gauging the implications and effectiveness of the mechanism without undergoing costly, uncertain implementation.

Broadly speaking, a patent-complement is an incentive mechanism that rewards pharmaceutical firms for developing neglected disease treatments and distributing their drugs in developing countries, where the reward is typically in the form of a subsidy. Given this definition, there are many possible variations of patent-complements that can be explored. In this paper, I will focus on two existing proposed patent-complements: Advance Market Commitments (AMC), and the Health Impact Fund (HIF). I will then use the model to explore economic questions concerning the AMC and HIF designs. In particular, how do incentive mechanism designs under the AMC and the HIF lead to different behaviour? Exploring such questions even in the framework of two specific designs may be an important first step in understanding which patent-complement properties are effective.

My analysis concludes that, for a single monopolistic firm, the design of the AMC is a Pareto improvement upon the design of the HIF. The distinguishing feature that causes the AMC and HIF incentives to lead to different behaviour is the patent-complement's restriction of the total number of units that will be subsidized; that is, failure to restrict the quantity of drugs that can be subsidized results in inefficient behaviour for the manufacturing firm. Note that the model was able to pinpoint a specific component of the mechanism design that was effective. Expansion of the model could potentially lead to broader and more comprehensive conclusions.

The rest of the paper is structured as follows. Sections 2 and 3 provide an in depth foundation justifying the need for incentive mechanisms such as patent-complements. Section 4 details the mechanism model using a timeline framework. Finally, Section 5 applies the model to the AMC and the HIF and explores the implications of both mechanisms.

2 The Neglected Disease Problem

In 2013, approximately 600,000 people died from malaria [2]. Diseases like malaria and tuberculosis are examples of neglected diseases. The World Health Organization (WHO) defines neglected diseases as diseases that affect the poorest populations in the world and tend to persist under poverty, affecting an estimated 1.4 billion people annually.

Neglected diseases are named after the alarmingly low level of drug development dedicated to treating those affected. Only four percent of new drugs developed between 2000 and 2011 were for neglected diseases [3]. This is the neglected disease problem: in the current state of the pharmaceutical market, firms tend not to develop drugs for neglected diseases.

In general, the far reaching effects of neglected diseases are not a result of treatment development being impossible. In fact, diseases like malaria are easily preventable but simply go untreated in developing countries. There is no legal barrier preventing biotechnology companies, which conduct the basic research necessary for drug development, from researching neglected diseases treatments. In some cases, there even already exist chemical compositions developed for first world country drugs that could be re-purposed for third world country use [4].

Thus, the neglected disease problem is not unsolvable – and yet it persists. Why exactly is this a problem? The primary first reason is that the underprovision of neglected disease treatments deters economic development in poorer populations [5]. This underprovision can be explained through thinking of neglected disease drugs as public goods. Consider the Ebola outbreak in 2014, where there was serious concern that the disease would make its way into developed countries like the US. In such cases, drugs can be considered global public goods: if person A is vaccinated or treated for a certain disease, person B is less likely to be infected by person A and is therefore better off. Of course, underprovision directly affects the quality of life in developing countries, but it indirectly

creates inefficiences in developed countries, too. This leads to the second problem. The existence of first world NGOs like UNICEF suggests that first world consumers experience a positive caring externality due to third world consumers receiving treatment they would have otherwise not received without external support. Failure to internalize this externality results in market inefficiency. The caring externality will be an important proponent in my model later on.

Before investigating solutions, it is important to first understand the causes of the problem, which are perpetuated by both the developing country consumers and the pharmaceutical firms. From a demand perspective, or the consumers' point of view, consumers in developing countries experience barriers to access in drug markets. These consumers typically have low incomes and cannot afford high patented drug prices, meaning they do not receive treatment. Even if a treatment existed, many of these people would either not be able to immediately afford treatment, or would not be able to save enough of their future income at once to afford the treatment without forgoing other necessities like food and water.

On the other hand, there is also the supply perspective, or the firms' point of view. In the drug development process, small biotechnology firms conduct initial development for treatments. Consider these firms to be operating in a perfectly competitive market of innovation. Biotech companies then sell their basic research to big pharmaceutical firms. These firms have access to resources that permit them to run clinical trials, manufacture on a large scale and heavily market their products, resulting in large barriers to entry to the oligopolistic development world. Without these firms' investments, drugs typically cannot be fully developed. From this point onwards, "firm" will refer to a big pharmaceutical firm as opposed to a small biotechnology firm. For one of these firms, the average market for one drug in a country like the US would provide revenues of $3 billion. In contrast, the total market size for vaccines in developing countries is a mere $500 million. Given the extreme research and development (R&D) costs associated with drug development which

can easily surpass $1 billion each, it is clear that firms avoid investing in drugs for poorer populations in the interest of profit maximization.

Thus, the neglected disease problem can be pared down to there being insufficient incentives for firms to develop drugs for neglected diseases. How can this problem be solved?

Several solutions to the neglected disease problem have been proposed in the literature: PRVs, patent buyouts, prizes, and virtual pharmaceuticals, to name a few. These solutions all take the form of incentive mechanisms that reward firms for developing drugs for certain diseases. The focus of this paper will be on one such solution which I call the "patent-complement".

3 Patent-complements

A patent-complement is an incentive mechanism that funds pharmaceutical firms developing neglected disease treatments to distribute in developing countries. The name "patent-complement" succinctly describes this particular mechanism design, under which pharmaceutical firms are free to either produce drugs under patent-complement contract, or produce drugs for developed country markets under the existing patent system. In other words, patent-complements are designed to *complement* – not replace – the patent system.

3.1 Are Patents Not Good Enough?

Patent-complements provide additional incentives for pharmaceutical firms to develop drugs beyond the incentives of the patent system. It should be noted here that patents are crucial for encouraging innovation and development of products in a wide range of markets, including pharmaceutical markets, and that patents are still in effect under patent-complements. However, pharmaceutical markets have certain features that limit the scope of what pharmaceutical patents can incentivize.

A primary reason why further incentives are required to encourage neglected disease drug development in particular is because pharmaceutical drugs are products that are consumed for health purposes, not for leisure. This alters the basic demand curve interpretation underlying demand and supply in typical markets. For a typical normal good, consumers' willingness to pay for the good can be ordered and thus arranged to create a demand curve. The first unit of the good produced goes to the consumer with the highest willingness to pay; the second unit goes to the second highest willingness to pay, and so on. Those who are not willing to pay the market price do not buy the good. This is an adequate method for describing demand for non-essential goods, such as movie tickets or jewellery. But this method becomes less convincing in describing "demand" for essential goods, such

as medicine, in developing countries. Many consumers in these regions have low incomes, which constrains their ability to pay for goods. In this context, "willingness to pay" is composed of two factors: the consumer's true need for the drug, and the consumer's ability to pay for the drug. Because willingness to pay is therefore restricted by the consumer's ability to pay, their overall willingness to pay will be lower than that of a consumer in a developed country with a comparable need for treatment. Thus, in poorer populations, willingness to pay becomes a more of a normative than positive economic concept, and is less clear cut in nature.

This breakdown of the usual demand measurement affects supply. Suppose there is one drug that both a first and a third world country demand, but the market only has enough firms to supply one country. Suppose too that the demand curves for first and third world countries are taken to be willingness to pay, so that the third world country demand is substantially less than the first world country simply because they are restricted by their ability to pay. Recall that the reason additional incentives are necessary to spur drug development for neglected diseases is because firms are profit-maximizing. Given that the firm only has the resources to supply one country, the lacking monetary market size in the third world country will deter the firm from investing in the poorer populations, and the firm will opt to produce in the larger first world market. This paragraph explains theoretically why we observe the $3 billion first world drug markets versus the $500 million third world markets referenced in the previous section.

Finally, a typical patent in the US grants pharmaceutical firms exclusive rights for their drug for twenty years [8]. Of course the purpose of this is to allow firms to earn back the vast amounts they spent on researching and developing the product, and for some leisure consumption products twenty years' time is sufficient for this. But for pharmaceutical firms, twenty years is often not enough. Firms must claim patents on their developed product before running clinical trials, and clinical trials can take up to ten years or more. This reduces their effective time over which the patent delivers on its purpose to help the firm

earn back R&D costs by half. This also creates an incentive for firms to develop drugs that will require the least amount of clinical trial time, hence increasing the amount of time that good profits are earned. As a result, firms tend to upgrade or slightly change drugs that are already available in first world countries, simply to renew their patent although adding little additional health benefits, because doing so is the most profitable option.

These points highlight how patents tend to only reward development based on how much people are willing to pay [6]: the lower the willingness to pay, the weaker the incentives that patents attempt to provide. In summary, patents are insufficient in incentivizing firms to develop drugs for poorer populations, justifying the need for solutions such as patent-complements.

3.2 Implementation

A high level explanation of patent-complement mechanisms is as follows. At the start of a period (say a year), consider the behaviour of a single firm in a world where a patent-complement exists. At the start of the period, the firm will decide what drug they will develop next. Even if there are hundreds of drugs that the firm can produce, it essentially would have two distinct options. Option one is for the firm to enter a contract under the patent-complement, which will provide the firm with funds typically in the form of subsidies to produce a neglected disease drug. Option two is for the firm to produce a drug for first world countries, like an improved or updated aspirin, and operate under the regular patent system. As was pointed out earlier, in this sense the patent-complement offers the additional "option" of producing drugs in a way that complements and does not substitute for the patent system, because the patent-complement merely provides additional incentives on top of the existing patent incentives.

Under option one, the firm will develop neglected disease drugs, and are incentivized to distribute their drugs to developing country populations. The incentives provided usually

involve the firm having receiving increments of their subsidy that would be most beneficial to the firm if they distributed to third world markets before serving first world markets. The total amount of potential earnings each firm can receive under patent-complements is designed to be approximately the same as in a first world drug market, at around $3 billion. This creates a market that firms would be interested in entering, as opposed to the substantially smaller third world market size without the subsidy.

The firms are required under contract to sell their drugs at low prices below the usual high prices used under patent in developed countries.The only sense in which patent-complements impede upon the flexibility of patents is in the stage after patent expiration. Typically, once a patent expires, if the firm is able to modify their product to secure a patent renewal, the firm can essentially hold similar patent rights for over twenty years. However, patent-complement contracts usually require firms to either continue selling their product at the low price specified over the patent-complement time specified on the contract, or they must sell or give up their licenses to generic firms to produce their drugs. This takes down the barriers to access that developing country consumers usually face when it comes to buying pharmaceutical drugs.

Therefore patent-complements have the potential to be very effective solutions. They alleviate the neglected disease problem by ensuring access for neglected disease treatments in the short and long run, and by creating markets for neglected disease treatments that are comparable to average drug markets in developed countries.

But some patent-complements are in still in proposal stage. An example of such a patent-complement is the Health Impact Fund (HIF). Few have been launched and properly implemented: for example, recently a pneumococcal pilot Advance Market Commitment was launched in 2006. So if patent-complements are such effective solutions, why haven't more been implemented?

An obvious reason is that implementation would be difficult. Developing such a mech-

anism, approving the mechanism through government, hiring and training the necessary staff for drug distribution among other administrative duties would be cost both time and money. Finding backing supporters will also require considerable effort. To generate a market of $3 billion for, say, two drugs a year would require support from many world governments, in which case politics would undoubtedly get involved.

A more comprehensive reason that is related to the above is that the implications of implementing patent-complements are currently unclear. Proposed designs such as the HIF outlining what the patent-complement will strive to do are appealing. However, it is not always clear what the welfare implications of implementing such mechanisms would be. The primary contribution of this paper is the development of a patent-complement model that can explore these welfare implications. Although simple, the model is somewhat novel as no other model for patent-complements exists the literature. As was discussed previously, I believe there may be major benefits to analyzing the patent-complement framework from a theoretical perspective. Models allow analysis of variations upon designs to see what works and what doesn't and to identify the comparative advantages between different designs. This would provide a standardized, cost effective method with which to rank designs without undergoing the trouble of actual implementation.

4 The Model

The optimal mechanism design of patent-complements can be determined through a model of a timeline of decisions. The model specifies how two players, the patent-complement and the manufacturing firm, make decisions along the timeline. Each player has objective functions it wishes to optimize: the firm chooses quantities that will maximize its profit, and the patent-complement will have its own objective welfare function to maximize. Solving each player's problem and using backwards induction techniques will ultimately yield the following outcomes under each patent complement:

1. The quantity of neglected disease drug that will be produced,
2. The total amount of funding required, and
3. The deadweight loss resulting from the outcome, if any.

These proposed outcomes will be revisited at the end of this section. Obtaining these outcomes under different patent-complement will allow for simple comparisons between designs, which will be done in the next section for the HIF and the AMC.

This model only describes a world in which one patent-complement exists. Because the economic question of interest concerns the comparative advantages between single patent-complements, modelling one patent-complement is sufficient in this context. Further work can be done to expand the model to explore firm behaviour under two or more patent-complements.

Note too that the model will only be presented in the single firm case. Modelling two or more registered firms under each patent complement would require modelling firm competition as well, which can be done using a classic Cournot framework assuming simultaneous decision making between firms. Simultaneity may be viewed as an unrealistic assumption because real firms do not necessarily ever act at the same time. However, in

order to prevent any one firm from exhibiting dominant behaviour, the simplest possible assumption to make would be to assume simultaneity. Further work can be done to explore how the model fares under Cournot duopoly firms.

That being said, the focus of this paper is to explore how incentives under different patent-complements lead to different behaviour, which can be sufficiently demonstrated using one firm. A single monopolistic firm assumption is not necessarily unrealistic either: when a new drug is developed for a disease that has never been treated before, the initiating manufacturer may well be the only firm licensed to produce the drug for a certain period of time. This would allow the firm to make its production decision as a monopolist.

4.1 Assumptions

Four sets of assumptions are required for the model framework. These assumptions are on the feasibility of the patent-complement, the firm, the consumers, and the patent-complement itself.

4.1.1 Assumptions for feasibility

The model assumes feasibility of the patent-complement in question; that is, assume

(A1) There exist sufficient donor funds to sustain patent-complement operations, and

(A2) There exist technological means for firms to produce drugs for neglected diseases.

These assumptions are necessary to avoid the trivial scenario in which patent-complements are infeasible and non-existent, in which case the model would fruitlessly describe non-existent behaviour. Fortunately, both assumptions are also reasonable in light of the later discussion outlining the AMC: the AMC is currently functioning thanks to existing donor support and existing sufficient technology. The latter point emphasizes the idea that firms

currently do not produce neglected disease treatments not because they lack the technology to do so, but because they lack the financial incentives to do so [1].

4.1.2 Assumptions on the firm

The firm in the model is a "big pharma" firm responsible for full drug development. Assume only two drugs can be developed at the start of the timeline, and that:

(F1) Small biotechnology firms have developed the basic research required for the full development of two drugs: drug 1, for the developing world, and drug 2, for the developed world.

(F2) The "big pharma" firm is licensed to produce both drug 1 and drug 2, but

(F3) The "big pharma" firm has the same sunk fixed costs for both drugs; specifically, it has enough resources to realize the development of *one* of drug 1 or drug 2.

(F4) Marginal costs are constant for each drug: for drug 1, MC_1; for drug 2, MC_2.

Given (F1) and (F2), the firm need only choose which drug it would like to pursue in developing. Because the firm has access to the resources needed to fully develop drugs, the firm will need to invest some fixed costs in running clinical trials and mass producing drugs for both developing and developed world drugs. (F3) simply states that these sunk costs are large enough in magnitude such that firms may only develop one of drug 1 or drug 2, and assuming equality, it is not necessary to include fixed costs in the calculations of firm profits.

The true difference in cost of producing one drug over the other will depend on the marginal cost incurred for each drug, which will include the marginal cost of production, marketing and clinical trials. Let these costs represent both marginal private and social costs of supplying the developing world markets. (F4) is assumed for simplicity.

Then marginal social cost (MSC) is independent of the quantity of the drug produced, and can be defined as follows:

Definition 4.1 *The marginal social cost of a drug is simply the marginal cost MC of developing the drug; that is,*

$$MSC = MPC = MC$$

4.1.3 Assumptions on consumers

Consumers do not make explicit decisions in the model framework. However, the consumers' demand functions are key factors in both the firm's and the patent-complement's decisions, and thus their demand functions must be clearly defined.

Recall that patent-complements exist because developing country drug markets are too small to attract firms' supply when firms have more profitable alternative markets in developed countries. Out of altruism, consumers in developed countries who are likely to be unaffected by neglected diseases still believe it is important that consumers in developing countries receive treatments for neglected diseases. The altruism of developed country consumers can be modelled using a positive "caring" externality [10].

Definition 4.2 *A caring externality is a positive externality experienced by developed country consumers due to caring about developing country consumers increasing health.*

The following example illustrates how the caring externality can be used to distinguish between the demand of consumers in developing and developed countries.

Example 4.1 *Consider a consumer in a developed country, C_1, and a consumer in a developing country who is suffering from a neglected disease, C_2. C_2 may be in desperate need of treatment, but his/her demand for treatment is restricted by his/her ability to pay:*

that is, a limited budget may only allow C_2 demand one unit of treatment at price p, if such a treatment exists.

C_1 observes the suffering of C_2. Although C_1 is not directly affected by C_2's ailment, C_1 would be happier or better off out of altruism if C_2 were to receive treatment. Thus, C_1 wants there to be affordable treatment for C_2, and would be better off if such treatment were provided. In other words, C_1's demand can be thought of as the affordable price p plus some positive externality E that C_1 experiences due to C_2 receiving treatment.

In this example, E is the caring externality present.

It is now natural to think of the demand of the consumers in developing countries as marginal private benefit (MPB). Consider demand of consumers in developed countries to be marginal social benefit (MSB). Then the following familiar expression can be achieved:

$$MSB = MPB + E$$

where E is the positive caring externality. For simplicity, assume that

(C1) The caring externality E is constant at all quantities of the drug produced.

Definition 4.3 *Marginal private benefit is the demand of developing country consumers. Marginal social benefit is the demand of developed country consumers. Under (C1), for $a, b, c > 0$,*

$$\begin{aligned} MPB(Q) &= a - bQ \\ MSB(Q) &= (a + E) - cQ \end{aligned}$$

where $E > 0$ is the constant positive caring externality experienced by developed country consumers due to developing country consumers receiving treatment.

For simplicity, let $b = c = 1$.

4.1.4 Assumptions on the patent-complement

Firms have clear objectives: they are always profit maximizing entities. But what is the objective of the patent-complement?

(P1) The patent-complement's choice variables are:

- Amount of subsidy per unit, S_{unit}, or total amount of funding available, F
- p_l, the low price at which firms must sell under contract

(P2) The patent-complement's optimization problem is

$$\begin{aligned} (\text{PC}) \quad \max_{Q_1} \quad & PC(Q_1) = W(Q_1) - \lambda \cdot S_{unit} \cdot Q_1 && (1) \\ \text{s.t.} \quad & f_1(Q_1, MC_1, S_{unit}) = f_2(Q_2, MC_2), && (2) \\ & MSB(Q_1) = MSC(Q_1) && (3) \end{aligned}$$

where

- $W(Q)$ is a welfare function defined as the total benefits to both first and third world consumers of distributing Q drugs, i.e.

$$\begin{aligned} W(Q) &= \int_0^Q MSB(q)dq \\ &= \int_0^Q [(a+E) - q]dq \\ &= (a+E)Q - Q^2/2 \end{aligned}$$

- $\lambda < 1$ is the shadow price representing the opportunity cost of forgoing similar investments in similar drugs,

- S_{unit} is the subsidy per unit provided by the patent-complement,
- $Q_i = Q_i(S_{unit}, F, MC_i, p_l)$ is the quantity of drug i produced, and
- f_i is the profit for a single firm under production of drug i

The patent-complement will be able to use its power over choice variables under (P1) to attempt to achieve (P2) since Q_1 is implicitly a function of S_{unit}, F and the subsidy amount chosen. Equation (1) is the patent-complement's primary objective function, under which the patent-complement seeks to maximize welfare penalized by the opportunity cost of using the funds for drug versus other investment alternatives, such as similar drugs. Presuming that developing drug 1 will generate a sizeable health impact and that alternative drugs to fund are either similar in size or smaller justifies setting $\lambda < 1$.

Equation (2) is a profit constraint. If the incentives provided by the patent-complement are too strong, causing $f_1 > f_2$, all firms would enter the market for drug 1 given their profit-maximizing behaviour. On the other hand, market 1 will not be served at all if $f_1 < f_2$. Thus it is important that the patent-complement is able to strike a balance such that $f_1 = f_2$ and that firms are able to randomly choose which market to serve.

Finally, in the case that the firm does choose to produce drug 1, Equation (3) imposes the optimal social planner outcome. Because the objective function (1) is not equal to (3), it is inaccurate to call the patent-complement a social planner. However, ideally the patent-complement would also like to satisfy the social planner's problem given in (3). It will be shown later on that this constraint may be impossible to satisfy in some instances; in these situations, this constraint will be dropped from the optimization problem.

4.2 Single Firm Case

The timeline spans a year, and begins at the start of the year where firms must decide whether to allocate their resources to produce a drug for developing country consumers or for developed country consumers. From a high level perspective, the decisions being made can be viewed as follows:

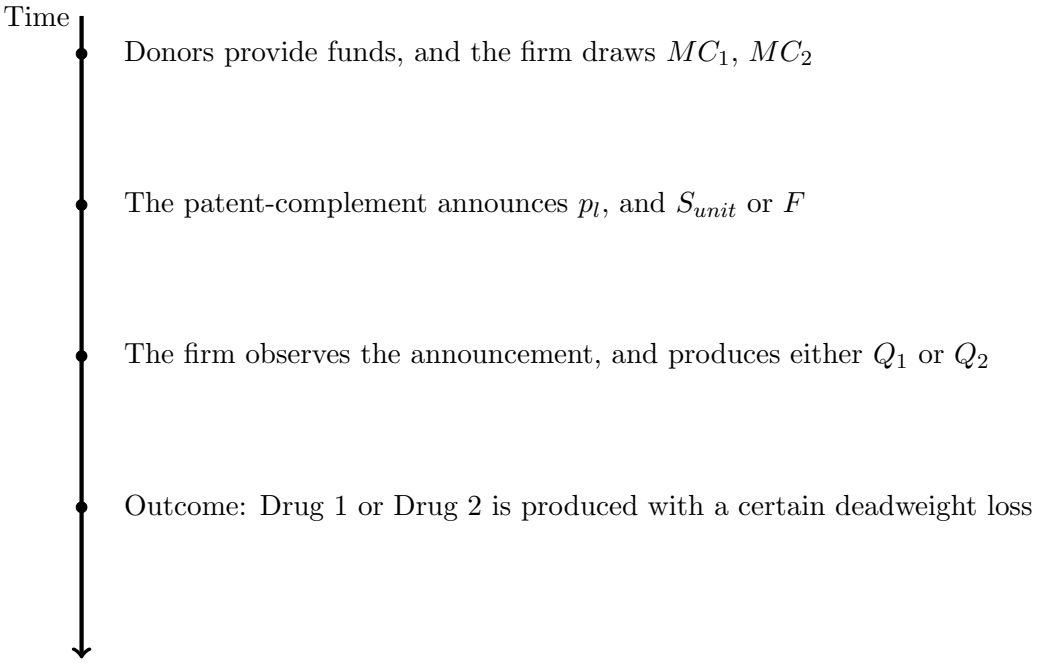


Figure 1: High level timeline of decisions under patent-complement design

But the high level timeline does not show how the patent-complement and firm determine the choice variables p_l, S_{unit} or F and the quantities of drugs produced. Recall that the patent-complement's optimization problem (PC) with objective function (1) and constraints (2) and (3), and that firms are profit-maximizing. Assume complete information such that the patent-complement knows the firm's marginal costs. Then the following timeline outlines the players' decisions in detail.

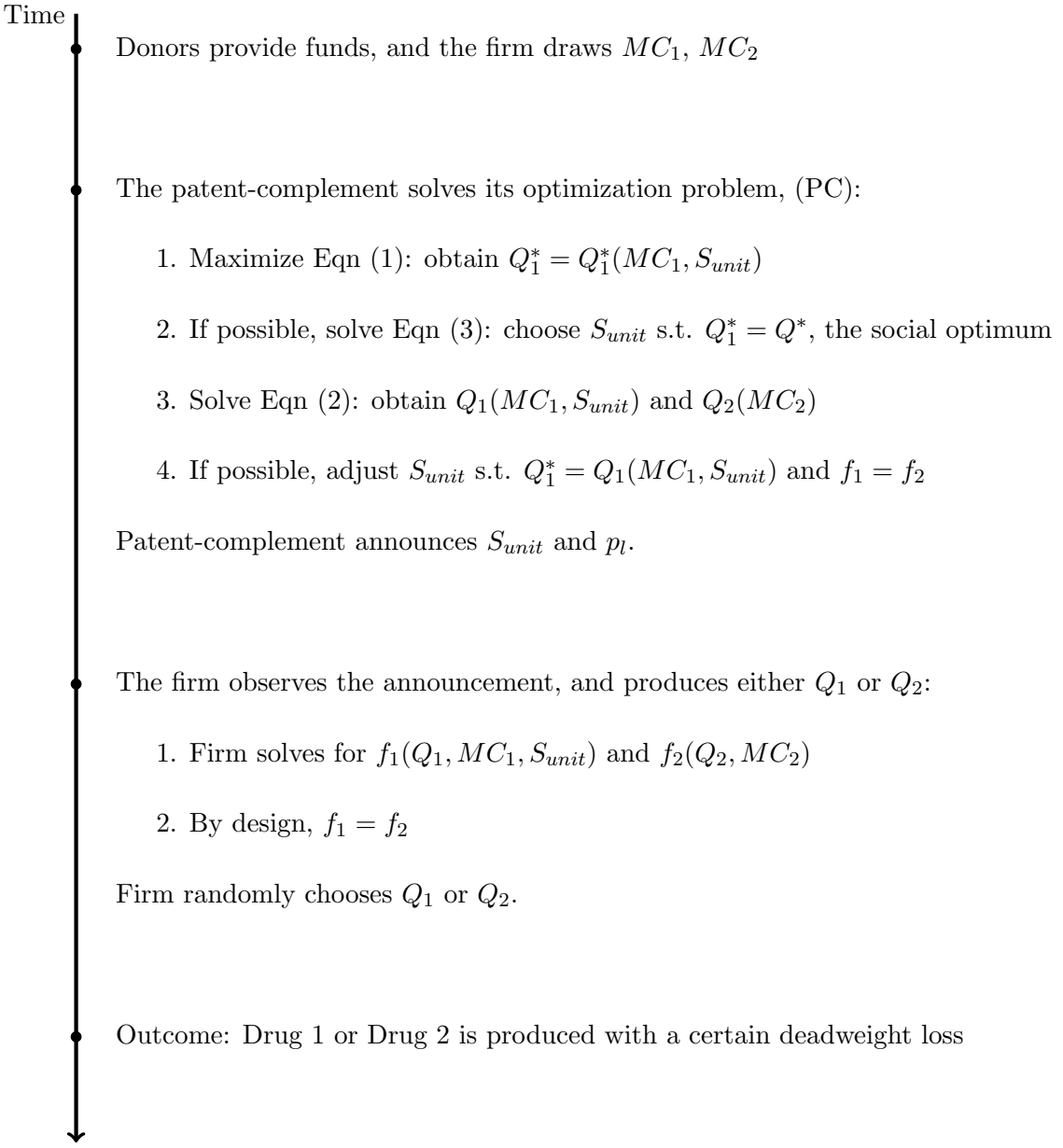


Figure 2: Detailed timeline of decisions under patent-complement design

Replacing S_{unit} with F in the above timeline will produce equivalent results, as the terms can be used interchangeably. The choice of whether to use S_{unit} or F depends on the context within the design of the patent-complement in question: for example, as will be seen shortly, the Health Impact Fund defines its funding as a pool F, whereas an Advance Market Commitment prefers to define its funding as a subsidy per unit of the drug sold.

The proposed outcomes at the start of the section can now be revisited as a theorem.

Theorem 4.1 *For a given patent-complement, applying the modelled detailed timeline steps will determine:*

1. *The quantity of neglected disease drug that will be produced,* Q_1
2. *The total amount of funding required,* $S_{unit} \cdot Q_1$*, and*
3. *The deadweight loss resulting from producing drug 1, if any.*

The reader may refer to Appendix A for the graphical method of determining deadweight loss used in finding 3. from Theorem 4.1.

5 Applications

To fully demonstrate how the model can be used to assess patent-complement mechanisms, I will model two existing examples of patent-complements: Advance Market Commitments, and the Health Impact Fund. The founders of the HIF describe the HIF as a "comprehensive AMC", in the sense that the HIF possesses a similar patent-complement framework to the AMC, but also carries essential differences.

5.1 Advance Market Commitments

5.1.1 Mechanism Overview

AMCs were initially proposed by Michael Kremer (Harvard), and exclusively target development of vaccines. Each AMC focuses on the production of a single vaccine: for example, a pneumococcal AMC is a mechanism that ensures the development and distribution of a pneumococcal vaccine only. AMCs depend upon donors, a first committee, and a second committee of medical experts. The first committee is responsible for deciding which vaccine will be funded the AMC by evaluating which neglected diseases would most feasibly benefit the most from vaccine development. The second committee creates conditions that the drugs registered under the AMC must satisfy.

Suppose the first committee decides the AMC will fund vaccines for disease D. The donors must promise to back the development of said vaccine, and commit to an amount of funding F such that for any given big pharmaceutical firm, the potential revenues of selling the vaccine combined with F creates a market with similar revenues[1] to average first world pharmaceutical markets. This commitment is intended to incentivize firms to participate in third world markets. Notice that firms are guaranteed the certainty of participating in

[1]The authors of Making Markets for Vaccines [1] make clear that the goal of the AMC is to generate third world markets with first world revenues, not profits. This does not mean that firms will choose the market with the highest revenues. Firms are still assumed to be profit-maximizing.

this market if they produce the appropriate vaccine for D, and can expect the portion of the market they claim to depend upon how their own production capabilities, just as would be the case in an average first world pharmaceutical market.

Firms can then choose whether they want to produce the specified vaccine or not. If a firm wishes to register under the AMC, the firm's developed drug must must satisfy the second committee's conditions in order to be funded by the AMC. If a firm invests in developing a vaccine D that does not satisfy these requirements, the AMC will not fund its distribution. This ensures uniformity and a threshold for effectiveness across the vaccines that the AMC will support, which is important especially if there are multiple firms involved.

It is important to note that firms are expected to choose a market to serve far in advance of receiving funding; development and clinical trials may take up to ten years or more, and firms cannot register with an AMC until they have actually developed the vaccine in question. This is not asimilar to what happens in average first world pharmaceutical markets: firms are not necessarily guaranteed profits at the time that they decide to begin developing, say, painkillers, but they know that there is a market that they will be able to serve when the product is developed.

A firm that does develop the vaccine properly for D will then receive funding as follows. Under the AMC, the firm will be subsidized for every unit of the vaccine sold at some low price p_l for up to X units. Recall that requiring this low price p_l ensures access for third world consumers with low incomes. In essence, AMCs ensure participating firms that a pre-determined number of treatments X will be purchased from the firms at a high price p_h equal to the sum of p_l and the subsidy per unit.

Example 5.1 *Let $p_l = \$1$. Suppose the manufacturing firm receives a subsidy of \$14 per unit sold. Then the effective price the firm is receiving per unit sold is $p_h = \$15$.*

This process can be done over a number of years until the firms registered under the AMC contribute a total of X units of the vaccine. In this process there is an implicit incentive for firms to supply developing country markets before developed country markets. The highest number of units demanded would be in developing countries. In the interest of earning the highest possible net present value of funds from the AMC, firms would likely front load the distribution of their vaccine to developing country populations where they can sell as many units as possible and therefore receive as much funding as possible early on.

Afterwards, the manufacturers must either continue selling their vaccines at p_l, or they must license their technology to other generic manufacturers.

5.1.2 Key Properties of AMCs

1. Under AMCs, manufacturing firms are in control of the products they develop: they can choose to develop the AMC's specified vaccine, or they can develop any other product they would have developed in the absence of the AMC. It is just that the decision of whether to produce a developed or developing country treatment is no longer trivial, since both markets are similar in size.

2. For firms that choose to produce the AMC's specified vaccine, they must compete with each other to produce the vaccine the fastest to claim a portion of the market share.

3. Firms must produce vaccines that satisfy the AMC's requirements. All firms registered under the AMC sell at p_l and receive a fixed amount of subsidy per unit until the firms collectively sell X units.

4. The AMC mechanism design provides an implicit monetary incentive for firms to serve the population that demands the most units of the drug, not the population

that can pay the most for the drug.

5. Although donor funds are committed in the initial stages, the funds are only spent if the desired product is produced.

Properties 1 and 2 are essential in showing that AMCs are designed to mimic first world pharmaceutical markets. In an average developed country drug market, manufacturing firms ultimately decide whether or not to develop the products they develop, the market rewards the firms that produce the drug the fastest. Notice that both these properties are maintained under AMCs.

Finally, Properties 4 and 5 demonstrate that under the AMC, firms' payments are closely tied to their results. This ensures that the funds will not be wasted on vaccines developed that do not meet the second committee's requirements, and therefore there is no incentive for firms to produce drugs below the second committee's standards. Furthermore, because funds are committed but not necessarily set aside or spent until the drug is produced, funds need not be accounted for on each donor's balance sheets until the vaccine is appropriately and fully developed.

5.1.3 AMC Timeline

In order to generate third world drug market revenues that mimic first world revenues, assume that the singular demand curve for the developed country drug, drug 2, is equivalent to the MSB curve in developing country markets: $D(Q) = (a + E) - Q$.

Then the detailed timeline model from Theorem 4.1 can now be applied to the AMC as follows.

Before this stage begins, the first committee decides what vaccine should be produced, and the second committee provides detailed requirements that the developed vaccines must

Time ↓ Donors provide funds, and the firm draws MC_1, MC_2

satisfy. Donors such as world governments or private foundations like the Bill & Melinda Gates Foundation commit to funding F such that the potential revenues of selling the vaccine combined with F creates a market with similar revenues to average first world pharmaceutical markets.

↓ The patent-complement solves its optimization problem, (PC):

AMCs specify their subsidies in terms of the high selling price p_h and the low selling price p_l, such that $S_{unit} = p_h - p_l$. Note too that the AMC will have to specify a ceiling X of units to be subsidized.

1. The patent-complement maximizes its objective function using the first order condition:

$$\begin{aligned} PC(Q_1) &= S(Q_1) - \lambda \cdot S_{total}, \quad \text{where } S_{total} = S_{unit} \cdot Q_1 \\ &= (a+E)Q_1 - \frac{Q_1^2}{2} - \lambda(p_h - p_l)Q_1 \\ &= -\frac{Q_1^2}{2} + [(a+E) - \lambda(p_h - p_l)]Q_1 \\ \Rightarrow \quad PC'(Q_1) &= -Q_1 + (a+E) - \lambda(p_h - p_l) = 0 \\ \Rightarrow \quad Q_1^* &= (a+E) - \lambda(p_h - p_l) \end{aligned}$$

2. If possible, the patent-complement chooses $S_{unit} = p_h - p_l$ such that $Q^* = Q_1^*$.

   It is shown in Appendix A that the social optimum Q^* is $Q^* = (a+E) - MC_1$.

Therefore, to satisfy $Q^* = Q_1^*$, the patent-complement should choose p_h, p_l such that

$$\lambda(p_h - p_l) = MC_1$$

In order to ensure Q^* units are produced, the AMC will then set $X = Q^*$.

3. Solve the firm profit maximization problem to determine expressions for Q_1 and Q_2.

The firm's maximization problems are

$$Q_1 = \arg\max_{q_1} f_1 = \arg\max_{q_1}(p_h - MC_1)q_1 \tag{4}$$
$$Q_2 = \arg\max_{q_2} f_2 = \arg\max_{q_2}(D(q_2) - MC_2)q_2 \tag{5}$$

Eqn (4) produces a discontinuous solution because if $p_h > MC_1$, the firm's marginal benefits will always exceed its marginal costs, and it will therefore produce as many units as possible:

$$Q_1 = \begin{cases} 0 & p_h < MC_1 \\ X & p_h \geq MC_1 \end{cases}$$

However, because the AMC would certainly be ineffective if $p_h < MC_1$, assume the contrary. Thus,

$$Q_1(MC_1, S_{unit}) = X, \quad X \leq a + E$$

Eqn (5) is the familiar monopoly profit maximization problem. From basic microeconomic theory it is known that the monopolist will choose to produce Q_2 where

marginal revenues are equal to marginal costs: $MR = MC$ gives

$$MR = (a + E) - 2Q_2 = MC_2$$
$$Q_2(MC_2) = \frac{(a + E) - MC_2}{2}$$

4. If possible, adjust S_{unit} such that $Q_1^* = Q_1(MC_1, S_{unit})$ and $f_1 = f_2$.

   Here this is immediately possible, since $Q_1^* = Q^* = X = Q_1(MC_1, S_{unit})$.

   Given Q_1 and Q_2, the firm's profits in each market are

$$\begin{aligned}
f_1^* &= (p_h - MC_1)Q^* \\
&= (p_h - \lambda(p_h - p_l))Q^* \quad \text{since the subsidy was chosen s.t. } MC_1 = \lambda(p_h - p_l) \\
&= [(1 - \lambda)p_h + \lambda p_l]Q^*, \quad \lambda < 1 \\
f_2^* &= [(a + E) - 2Q_2 - MC_2]Q_2 \\
&= [(a + E) - \frac{(a + E) - MC_2}{2} - MC_2] \cdot \frac{(a + E) - MC_2}{2} \\
&= \frac{\big((a + E) - MC_2\big)^2}{4}
\end{aligned}$$

   To equate the two profits, the AMC need only adjust p_h and p_l such that they maintain the relationship $S_{unit} = p_h - p_l$ but each of p_h and p_l are increased in magnitude until $f_1^* = f_2^*$.

Thus the AMC announces $S_{unit} = p_h - p_l = MC_1$ such that $f_1^* = f_2^*$, and $X = Q^*$.

The firm observes the announcement, and produces either Q_1 or Q_2:

Notice that the AMC solved its own problem in the previous stage using backwards induction techniques, and maximized the firm's profits in both markets in order to strate-

gically choose S_{unit} and X. Thus Q_1 and Q_2 for the firm are, by design,

$$\begin{aligned} Q_1 &= \arg\max_{q_1} f_1 = \arg\max_{q_1}(p_h - MC_1)q_1 = Q^* = X \\ Q_2 &= \arg\max_{q_2} f_2 = \arg\max_{q_2}(D(q_2) - MC_2)q_2 = \frac{(a+E) - MC_2}{2} \end{aligned}$$

and profits have been equated across markets already. The firm is therefore indifferent between markets, and will randomly choose one to enter. For example, the probability of the firm entering either market might be 0.5.[2]

Outcome: Drug 1 or Drug 2 is produced with a certain deadweight loss

Because the focus of this paper is on outcomes under development of neglected disease drugs, consider the outcome if the firm randomly chose to produce Drug 1. In this case, under the AMC there is zero deadweight loss! An application of the model to the AMC design for a single firm allowed the patent-complement to set $Q^* = Q_1^* = Q_1 = X$.

Theorem 5.1 *Assume there exists one firm and one AMC, and that the assumptions given for the model hold. Then it is possible for the AMC to be designed such that the firm produces the socially optimal quantity of the vaccine required.*

5.2 The Health Impact Fund

5.2.1 Mechanism Design

The second patent-complement under consideration in this paper is the Health Impact Fund, as proposed by Aidan Hollis (Calgary) and Thomas Pogge (Yale). The HIF is similar to the AMC in that it requires its donors to commit to funding that creates markets similar

[2] An even probability divide need not be the case. For example, if a firm is very invested in its corporate social responsibility image, the probability that it would enter the third world market may be 0.7 instead.

in size to first world drug markets. But the HIF is also very different from the AMC in other ways. Hollis and Pogge loosely describe the HIF as a "comprehensive AMC" [6] because it does not target specifically vaccines but is open to funding all types of treatments. This means that the market determines what drugs are produced under the HIF. The HIF Book which details the HIF proposal thus far proposes funding the development of two drugs a year, amounting to funding commitments of $6 billion a year.

How exactly can the market "determine" what drugs to produce? When the HIF announces its available funding F, the pool F creates a market that pharmaceutical firms have an incentive to participate in. Firms can then decide which market they wish to develop drugs for. Again, this means that firms must make their decision far in advance of registering under the HIF, as registration will only be permitted around market approval in major markets.

The HIF depends upon donors and a single committee. The committee is responsible for evaluating how the donors' funding will be distributed among the firms registered under the HIF, which is a defining feature of the HIF.

Suppose that at the start of a year, donors commit $6 billion for the HIF to distribute. The distinguishing feature of the HIF is how its funding is distributed. At the end of each year, each firm will receive a share of the total funding equal to the share of the assessed health impact of their registered drugs. That is, a firm that provides Q health benefits in a year where the total health benefits provided by the HIF is equal to Q_{total} will receive $\frac{Q}{Q_{total}}$ of the available funding. The accuracy of this calculation is the the responsibility of both the firms and the HIF: the committee evaluates the health impact of each firms' drug based on the sales data provided by the firms. The firms are expected to cover the cost of the committee's health impact assessment as well.

Health impact is measured in life-years, which are standardized measures of health impact in health economics. Two commonly used units are are quality-adjusted life years

and disability-adjusted life years, or QALYs and DALYs respectively. The HIF Book suggests using QALYs to measure health impact of drugs. The idea is that a drug that improves a consumer's life from poor to good health for x years is said to provide health benefits of x QALYs per person; that is, a drug that has a health impact of x QALYs per consumer is a drug that adjusts the quality of a single consumer's life by x years.

Example 5.2 *Suppose there are two firms registered under the HIF in a year, Firm 1 and Firm 2. Assume the firms produce different drugs: Firm 1's drug has health benefits of 10 QALYs each, and Firm 2's drug has health benefits of 5 QALYs each. Suppose that by the end of the year, each firm has distributed 100 units of their respective drugs. Then Firm 1's total health impact is 1000 QALYs, and Firm 2's total health impact is 500 QALYs. The total health impact of all registered HIF firms is 1000 + 500 = 1500 QALYs.*

Each firm then receives a portion of funding F equal to the proportion of total health impact they provided. Firm 1 will receive $\frac{1000}{1500}F = \frac{2}{3}F$ and Firm 2 will receive $\frac{500}{1500}F = \frac{1}{3}F$ such that F is completely distributed by the end of the year. The process starts again in the next year, with donors again committing some funding F.

Measuring health impact is bound to be a very complicated process. It is possible to estimate the impact of drugs that have similar existing counterparts by using the data available on the existing drugs. But how can one estimate the impact of a completely new drug? Over the past few decades there have been improvements to methods of determining QALYs, although there is no fixed or standard method of measurement yet. Recent literature appears to suggest that health economists are moving away from using QALYs, since many view QALYs as a convenient but impractical measure of health benefits [9]. However, there is no firm consensus on whether QALYs are still legitimate [7]. In light of this, since the HIF Book specifically uses QALYs to measure health impact, I will assume that drug benefits can always be measured in QALYs which can be transformed into quantity of drugs consumed, in order to maintain the Q notation used in the model for quantity of

drug produced.

Example 5.3 *Suppose a drug D has constant health benefits of y QALYs per person, and a firm produces 100 units of D. Then it is equivalent to say that the firm has produced $100y$ QALYs or 100 units of the drug.*

This method of distributing funds only considers the health benefits of a single treatment with respect to other treatments made available under the HIF. This means that firms are incentivized to develop drugs that will generate maximum health benefits, deterring firms from taking advantage of the HIF by developing drugs that are cheap or easy to develop and distribute to millions of people in third world countries, but that provide minimal health benefits to these populations.

Example 5.4 *Suppose there are two firms registered under the HIF, Firm 1 and Firm 2. Firm 1 decides it wishes to register a common painkiller from developed countries under the HIF, and distributes it to 1 million consumers in developing countries. Firm 2 decides to develop a highly effective vaccine for a neglected disease, and distributes it to 1 million consumers in developing countries as well. Suppose Firm 2's vaccine provides 10 times more health benefits than Firm 1's common drug. Although Firm 1's drug reached the same number of people as Firm 2's vaccine, Firm 1 will only receive $\frac{1}{11}$ of the available funding F, while Firm 2 will receive ten times the funding that Firm 1 received.*

In this sense, the HIF rewards firms based on the *incremental* health benefits of their drugs over the other registered products, rather than for their health benefits with respect to all drugs in the world.

Unlike the AMC, there is no upper bound on the number of units of a drug that HIF registered firms can produce. Instead, registered firms must sell the drug they have chosen to produce for ten years at long run marginal cost. Afterwards, the firms must permit the HIF to license their developing technology to generic manufacturers.

5.2.2 Key Properties of the HIF

1. Under the HIF, manufacturing firms are in control of the products they develop: they can either develop drugs that can be registered under the HIF, or they can produce drugs for developed country drug markets.

2. The HIF rewards innovators based on the incremental health benefits of their products over the other registered products. Specifically, firms that generate Q QALYs in a given year will receive proportion $\frac{Q}{Q_{total}}$ of the total funding F available.

3. Under the HIF, firms must sell their registered drug at long run marginal cost for ten years.

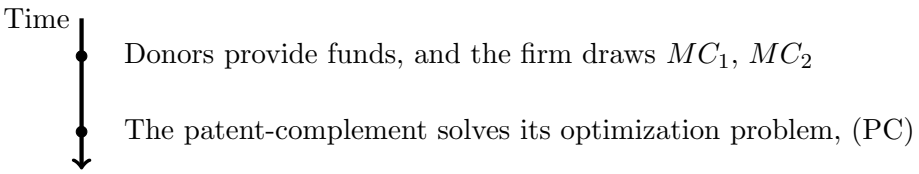
4. There is an implicit incentive for firms to develop drugs that provide maximum health impact, and therefore to serve developing country markets first.

Property 1 gives the key feature of the HIF that distinguishes it from the AMC: the HIF distributes funding to its registered firms based on health benefits. So in a sense the market determines what drugs are produced, and in choosing what drugs to develop firms are implicitly also determining the amount of funding they will receive.

Much like Property 5 of AMCs, Property 4 shows that HIF registered firms' payments are linked to their results. In order to receive the largest possible portion of the available funding F, firms should aim to develop drugs with the highest health benefits.

5.2.3 HIF Timeline

The detailed timeline from Theorem 4.1 can be applied to the HIF as follows. Please note that any repeated algebra that was detailed under the AMC Timeline will not be explicitly shown here again.



The HIF is responsible for specifying its total funding for the period, F. In the event that there are two or more firms registered, the HIF may also provide Q_{total} from the previous year. However, in the single firm case, the HIF mechanism reduces down to a special case much more than the AMC does.

When there is only one firm, provided the HIF and the firm can estimate the number of units (or transformed QALYs) that will be produced by the end of the year, the effective per unit subsidy becomes $S_{unit} = F/Q_{total}$, where $Q_{total} = Q_1$ of the firm.

1. The patent-complement maximizes its objective function:

$$\begin{aligned} PC(Q_1) &= S(Q_1) - \lambda \cdot S_{total}, \quad \text{where } S_{total} = S_{unit} \cdot Q_1 \\ &= (a+E)Q_1 - \frac{Q_1^2}{2} - \lambda\big(\frac{F}{Q_{total}} \cdot Q_1\big) \\ &= -\frac{Q_1^2}{2} + (a+E)Q - \lambda \cdot F, \quad \text{since } Q_{total} = Q_1 \\ \Rightarrow \quad PC'(Q_1) &= -Q_1 + (a+E) = 0 \\ \Rightarrow \quad Q_1^* &= (a+E) \end{aligned}$$

   Note that $(a+E)$ is the maximum possible number of units that can be demanded given the demand curve $MSB(Q) = (a+E) - Q$.

2. If possible, the patent-complement chooses $S_{unit} = p_h - p_l$ such that $Q^* = Q_1^*$.

   This is no longer possible: $Q_1^* = a + E \neq (a+E) - MC_1 = Q^*$. Therefore it is not possible to satisfy the optimal social quantity constraint.

3. Solve the firm profit maximization problem to determine expressions for Q_1 and Q_2.

Just as before, the firm's maximization problems are

$$Q_1 = \arg\max_{q_1} f_1 = \arg\max_{q_1}(p_h - MC_1)q_1 \tag{6}$$

$$Q_2 = \arg\max_{q_2} f_2 = \arg\max_{q_2}(D(q_2) - MC_2)q_2 \tag{7}$$

Recall that the HIF requires registered firms to sell their products at marginal cost, MC_1. Since the firm will be required to sell at MC_1 and will receive subsidy F/Q_1, the effective price the firm will receive per unit will be $MC_1 + S_{unit}$. In other words,

$$p_l = MC_1$$
$$p_h = MC_1 + S_{unit} = MC_1 + F/Q_1$$

Then Eqn (6) becomes

$$Q_1 = \arg\max_{q_1}(\big(MC_1 + \frac{F}{q_1}\big) - MC_1)q_1 = \arg\max_{q_1} F$$

which is meaningless as F does not depend on Q_1. A reasonable interpretation is result is to say that the firm will want to maximize Q_1 since clearly $p_h > MC_1$. Therefore,

$$Q_1(MC_1, S_{unit}) = a + E$$

Once again, Eqn (7) yields

$$Q_2(MC_2) = \frac{(a+E) - MC_2}{2}$$

4. If possible, adjust S_{unit} such that $Q_1^* = Q_1(MC_1, S_{unit})$ and $f_1 = f_2$.

   Although it was impossible to set $Q_1^* = Q^*$, the condition $Q_1^* = Q_1(MC_1, S_{unit}) = a + E$ is already satisfied.

Now given Q_1 and Q_2, the firm's profits in each market are

$$\begin{aligned} f_1^* &= F \\ f_2^* &= \frac{\big((a+E) - MC_2\big)^2}{4} \end{aligned}$$

It is trivial that the profit under market 1 is equal to F, since there is only one firm registered to receive a portion of F. To equate the two profits, the HIF need only set F to equal the potential monopoly profits in market 2.

Thus, the HIF announces $F = \frac{\big((a+E)-MC_2\big)^2}{4}$.

- The firm observes the announcement, and produces either Q_1 or Q_2:

Given the HIF's announcement, by design the firm is again indifferent between markets, and will randomly choose one to enter.

- Outcome: Drug 1 or Drug 2 is produced with a certain deadweight loss

Consider the outcome if the firm randomly chose to produce Drug 1. Because the firm would not produce the socially optimum quantity $Q^* = (a+E) - MC_1$, the HIF for a single firm results in a deadweight loss of DWL $= \frac{MC^2}{2}$. Please refer to Appendix A for a graphical presentation and derivation of the deadweight loss.

Theorem 5.2 *Assume there exists one firm and one HIF, and that the assumptions given for the model hold. Then the HIF will not be able to provide appropriate incentives to induce the firm to produce the socially optimal quantity of the vaccine required.*

5.3 Results

The following table summarizes the resulting quantities under the single firm HIF and AMC. Please see Appendix B for derivations.

Property	AMC	HIF
Low selling price, p_l	p_l	MC_1
Effective price, p_h	p_h	$\frac{F}{Q_{total}} + MC_1$
Subsidy, S_{unit}	$\frac{MC_1}{\lambda}$	$\frac{F}{Q_{total}}$
PC max quantity, Q_1^*	$(a+E) - \lambda(p_h - p_l)$	$a+E$
Firm's quantity, Q_1	X	$a+E$
Social optimum, Q^*	$(a+E) - MC_1$	$(a+E) - MC_1$
Upper bound, X	$(a+E) - MC_1$	–
Final Q_1^*	$(a+E) - MC_1$	$a+E$
Final $PC(Q_1^*)$	$\frac{((a+E)-MC_1)^2}{2}$	$\frac{(a+E)^2}{2} - \lambda \cdot F$
F required	$(p_h - p_l) \cdot Q^*$	F
DWL	0	$\frac{MC_1^2}{2}$

Table 1: Summary of HIF and AMC single firm outcomes

To best compare the quantities across the columns above, assume that the marginal costs drawn under each mechanism are the same. The key differences between the two mechanisms are in bold: the final quantity realized, the final value of the patent-complement objective function, the deadweight loss produced, and the upper bound X.

Under the AMC, the final quantity realized is equal to the optimal social quantity where marginal social benefits are equal to marginal social costs. However, under the

HIF, the final quantity realized surpasses the optimal social quantity. This inefficiency generates a positive deadweight loss under the HIF but not under the AMC. These results were summarized previously in Theorems 5.1 and 5.2.

Recall that the patent-complement's primary goal is to maximize its objective function, which quantifies market welfare penalized by the opportunity cost of using the funds for drug 1 versus other investment alternatives, subject to profit and optimal social welfare constraints. It appears as though the realized $PC(Q)$ is higher under the AMC than the HIF: firstly, $((a+E)-MC_1)^2 < (a+E)^2$; secondly, although $\lambda < 1$, F is an extremely large value, and hence $-\lambda F$ would significantly lower the value of $PC(Q)$ in the HIF case.

This results suggest that in the single firm case the AMC also boasts better welfare implications than the HIF. Thus, the incentives provided under the AMC induce different and more efficient behaviour from registered firms than the HIF; the AMC can be viewed as a Pareto improvement upon the HIF.

Why does this difference occur? The difference can be attributed to the upper bound X imposed under the AMC but not under the HIF. Notice that in the mechanism model for the AMC, the ability of the AMC to impose an upper bound on subsidized units was crucial to ensuring $Q^* = Q_1^* = Q_1$. If an upper bound were imposed under the HIF framework, this equality could be ensured as well; however, as it stands, such a restriction would not fit well into the HIF framework since it is built upon market determination of drug production.

5.4 Limitations and Assumption Validity

The analysis discussed is of course restricted by the numerous assumptions made for the mechanism model. The weakest assumptions were those made on consumer demand and firm participation.

Firstly, for simplicity, the consumers' marginal social benefit curve was defined as a shift of the marginal private benefit curve up by the positive externality, E. To compare across the developing country market 1 and the developed country market 2, it was assumed that the demand curve in market 2 was equivalent to the MSB in market 1. It is very plausible however that these demand curves are different, which would make the summary results in Table 1 difficult to compare, but may produce different results.

Secondly, patent-complements assume that there exist big pharmaceutical firms, presumably in developed markets, that are willing to participate in the patent-complement. The altruistic nature of first world consumers creates a market that these firms can serve. But is it always in the best interest of the first world countries to consider serving such markets? Note that the only concern of the patent-complement is that there are incentives provided for third world drug markets to be served, whereas first world countries may wish to consider alternative ways in which their firms and funds could be applied. Suppose the pharmaceutical firm in question resides in a developing country. In order to truly justify the participation of this firm in third world drug markets, the expected size of the positive externality to first world consumers from third world markets must exceed the consumer surplus these consumers would receive in first world drug markets. Whether or not this holds depends upon the demand functions and marginal costs chosen.

6 Conclusion

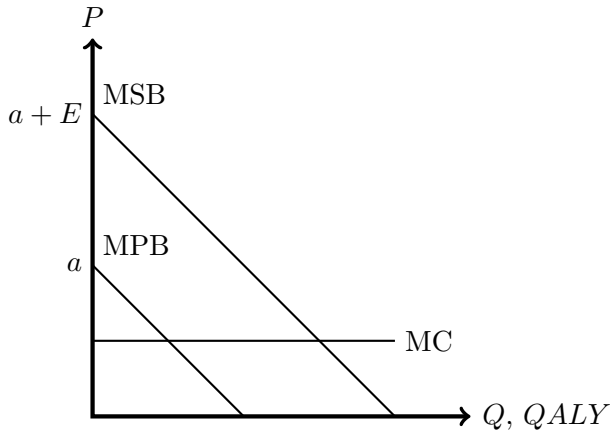
The mechanism model developed successfully answered the question posed at the start of this paper: how do incentive mechanism designs under the AMC and the HIF lead to different behaviour? The timeline framework in the model clearly identifies the cause of the separation in behaviour to be the inclusion or exclusion of a restriction on the total quantity of drugs subsidized under the patent-complement design. Note that the model also allows potential donors or patent-complement committees to estimate the social welfare loss, defined to be the deadweight loss resulting from implementing certain mechanisms. It is especially important that the model is able to identify inefficiencies between designs to allow committees to choose or design the most efficient possible mechanisms.

This analysis also provides rudimentary theoretical reasoning as to why the AMC is currently in pilot stage, whereas the HIF is merely in proposal stage. With the existence of an AMC that already functions as a Pareto improvement upon the proposed HIF, it is conceivable that the current HIF design is preventing it from being presented as a fully "comprehensive" AMC.

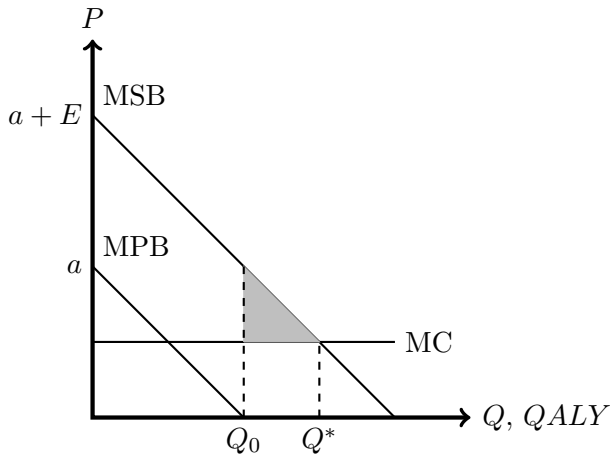
Of course, the current model is restricted by the many assumptions imposed on all participants involved in patent-complement designs. Further work can be done to relax these restrictions and develop a more flexible model with the potential to identify further ways in which certain designs affect firm behaviour. Regardless, continuing progress in developing ways to assess solutions to the neglected disease problem is essential to accelerating global progress in aiding developing country populations suffering from the neglected disease problem.

Appendix A

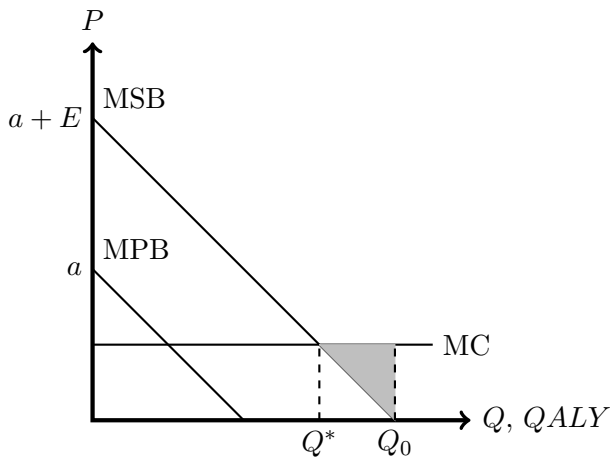
It is useful to consider the graphical interpretation of the MSB/MPB/MSC story to obtain an expression for the deadweight loss is defined to be deadweight loss only. Plotting constant MC, $MSB(Q) = (a+E)-Q$ and $MPB(Q) = a-Q$ yields the following diagram:



The x-axis can be measured either in Q, or using a transformation $QALY(Q)$. If quantity Q_0 is distributed where Q_0 is less than social optimum Q^*, the deadweight loss can be graphed as the shaded region below:



Similarly, if $Q_0 > Q^*$, as is the case under the HIF for a single firm, the deadweight loss can be graphed as the shaded region below:



The HIF Model Outcome section makes use of the computed DWL shown in the above figure. To compute this, notice that $Q_0 = a + E$. Since Q^* occurs at the intersection of MSB and MSC,

$$\begin{aligned} MSB(Q^*) &= MSC(Q^*) \\ (a+E) - Q^* &= MC \\ Q^* &= (a+E) - MC \end{aligned}$$

Therefore the shaded DWL triangle area is

$$\begin{aligned} \text{DWL} &= \frac{1}{2}(Q_0 - Q^*)(MC) \\ &= \frac{1}{2}[(a+E) - (a+E) + MC)](MC) \\ &= \frac{1}{2}MC^2 \end{aligned}$$

Appendix B

The derivation for the deadweight loss under the HIF is given in Appendix A. The final $PC(Q_1^*)$ quantities in Table 1 are obtained as follows.

For the AMC, since the final Q_1 is Q^*,

$$\begin{aligned}
PC(Q^*) &= (a+E)Q^* - \frac{(Q^*)^2}{2} - \lambda(p_h - p_l)Q^* \\
&= [(a+E) - \lambda(p_h - p_l)]Q^* - \frac{(Q^*)^2}{2} \\
&= [(a+E) - \lambda \cdot \frac{MC_1}{\lambda}]Q^* - \frac{(Q^*)^2}{2}, \quad \text{since the firm sets } MC_1 = \lambda(p_h - p_l) \\
&= ((MC_1 + Q^*) - MC_1)Q^* - \frac{(Q^*)^2}{2}, \\
&\qquad \text{since } Q^* = (a+E) - MC_1 \text{ implies } (a+E) = MC_1 + Q^* \\
&= \frac{(Q^*)^2}{2} \\
&= \frac{((a+E) - MC_1)^2}{2}
\end{aligned}$$

For the HIF, since the final Q_1 is $Q_{total} = Q_1 = a + E$,

$$\begin{aligned}
PC(Q_1) &= (a+E)Q_1 - \frac{(Q_1)^2}{2} - \lambda \cdot S_{unit} \cdot Q_1 \\
&= (a+E)^2 - \frac{(a+E)^2}{2} - \lambda \cdot \frac{F}{Q_1} \cdot Q_1 \\
&= \frac{(a+E)^2}{2} - \lambda F
\end{aligned}$$

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