

# Can we trust monopolistic firms as suppliers of vaccines for the avian influenza?

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## Abstract

Using a simple monopoly model, this note analyses the incentives of a vaccine producer. Since a vaccine tends to eradicate the disease for which it is intended, it also tends to destroy its own market. This means that monopolistic producers may, in a socially non-optimal way, be tempted to delay the introduction of vaccines against new infections until the disease has spread.

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## 1 Introduction

The world has suffered from outbreaks of pandemics at irregular intervals and during the twentieth century, it has happened three times. The Spanish flu of 1918-19 killed about 40 million people within one year. Mortality was concentrated to healthy individuals in the age range of 15 to 35. The pandemics of 1957-58 and 1968-69 were milder and caused two and one million deaths worldwide, respectively.<sup>1</sup> Contrary to the Spanish flu, deaths were concentrated to people at the end of their lifespan.

During 2004/2005, large parts of Asia experienced unprecedented outbreaks of the avian influenza in poultry, caused by the H5N1 virus. This has lead the WHO to conclude that a pandemic may be imminent. The director-general of the WHO makes the judgement that "the world moved closer to a (further) pandemic than it has been at any time since 1968" (WHO, 2005). It is not predictable how severe the avian influenza will be, once it starts spreading from

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<sup>1</sup>The number of deaths was also reduced by the fact that, by this time, antibiotics were available to treat secondary infections.

human to human. However, it is of concern that the virus is highly lethal in its present form, with a mortality rate of around 50 percent.<sup>2</sup>

Vaccines are the most important medical intervention for preventing influenza during a pandemic. The production of vaccine involves a substantial fixed cost in terms of research and development and thereafter a low marginal production cost (DiMasi et al. 1991).<sup>3</sup> The market for vaccine is therefore characterised by a limited number of firms. There are, for instance, two manufacturers of influenza vaccine for the U.S. market<sup>4</sup> and in several European countries, there is one manufacturer supplying the market.

This paper points out a problem concerning the economic incentives of vaccine producing firms: they may be biased to delay the sales of vaccines against new infections in a socially non-optimal way.

Several market failures in the market for vaccine may lead to the under-consumption of vaccine, as noted by Kremer (2001a). First, there is the positive externality associated with the reduced disease transmission by a vaccinated person. Second, a limited number of vaccine producers can lead to monopolistic pricing behaviour, even if this problem is mitigated by the fact that governments are large buyers of vaccine. There are also market failures affecting the research and development of vaccines. The development and production of a new vaccine typically involves a large initial investment in R&D and production capability, and thereafter a relatively low marginal cost of production. Possibilities to design around vaccine patents may make it difficult to recoup the initial investments. Governments, which are large purchasers of vaccine, may also be tempted to use their regulatory power to obtain vaccine at a low cost (Kremer 2001a). Nadiri (1993) and Mansfield et al. (1977) estimate the social return to the development of a vaccine to be twice the private return, whereas Kremer (2001a) estimates that the return may be ten to twenty times for e.g. a vaccine against malaria.

Kremer and Snyder (2003) make the point that producers may prefer to develop drug treatments instead of vaccines, since a vaccine reduces or stops the spread of a disease, and it is not possible to extract rents for a vaccine from the yet unborn. In contrast, a drug does not prevent the spread of the disease, which means that each coming generation will require the drug.

Geoffard and Philipson (1997) show how it is difficult to eradicate a disease in steady-state by vaccination since once a large fraction of the population has been vaccinated, the demand for vaccine falls in the remaining population. This tends to make it unprofitable for firms to continue supplying vaccines and it likewise makes it difficult for the government to achieve vaccination of the whole population through vaccine subsidies.

This note analyses the profit maximising choices of a monopoly producer of a new vaccine.

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<sup>2</sup>The cumulative number of confirmed human cases of avian influenza A/(H5N1) according to WHO since 28 January 2004 to date (January 2006) is 160. The mortality among those 160 is 85 cases. In almost all cases, the infection has spread from animals to humans.

<sup>3</sup>The marginal production cost of a flu vaccine is actually higher than for many other vaccines, since flu vaccine is produced in incubated eggs, which are difficult and costly to handle.

<sup>4</sup>These are Chiron Corporation and Aventis Pasteur.

The producer sets the price of the vaccine but also decides on the point in time for introducing it on the market, given that the infection spreads according to a simple law of motion for an epidemic. The trade-off for the producer is that the willingness of non-infected individuals to pay for vaccine increases with the number of infected, while the number of individuals demanding vaccine decreases as more individuals become infected. It is shown that the profit maximising solution to this problem is far from the socially optimal one. Introducing forward looking agents does not eliminate the problem of a time-lag for the introduction of a vaccine, unless consumers have very low, or producers very high, time discount rates. Moreover, forward looking behaviour greatly increases the monopoly rents.

Naturally, there are many reasons why firms may act less cynically than what is suggested by this model. There are reputation effects and competition from potential entrants, but it is also the case that pharmaceutical firms operate in a government-regulated environment. Nevertheless, an awareness of the incentives for monopolistic firms to delay the introduction of vaccines against new infections is important, especially so when the disease in question is serious. A particularly troubling case is the threatening avian influenza pandemic.

## 2 A Simple Model

The constant population,  $N$ , consists of infected,  $I_t$ , and susceptible,  $S_t$ , individuals at time  $t$ . Individuals are randomly matched at each point in time, implying the following law of motion for an epidemic (Anderson and May 1991)<sup>5</sup>

$$\frac{dI_t}{dt} = \beta I_t S_t, \quad (1)$$

where  $\beta$  is a transmission parameter related to a multitude of epidemiological, environmental and social factors. Solving this equation using that  $N = S_t + I_t$ , and normalising  $N \equiv 1$  gives

$$I_t = \frac{1}{1 + \psi e^{-\beta(t-t_0)}}, \quad (2)$$

where  $I_t$  is the share of the population that is infected, and  $\frac{1}{1+\psi}$  represents the share infected at time  $t_0$ . Figure 1 numerically illustrates the spread of an epidemic for  $\beta = 0.1$  and  $\psi = 100000$ . Initially, the disease spreads slowly but it accelerates sharply when a sufficiently large share of the population is infected. Finally, when almost everyone is infected, the spread of the infection slows down sharply.

Agents understand the dynamics of the infection given by (2), and they discount time by  $\delta$ . Individuals are randomly matched, and the probability of being infected at a point in time,

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<sup>5</sup>A couple of simplifications are employed here: Since our interest is in a rather rapid epidemic, natural deaths and births are unimportant compared to stocks and are therefore abstracted away. Second, our setup implies that everyone eventually becomes infected. This is one of the simplest cases in the literature on epidemics. Adding a law of motion for recovery greatly complicates the (transitional) dynamics, without altering the qualitative results of this paper.

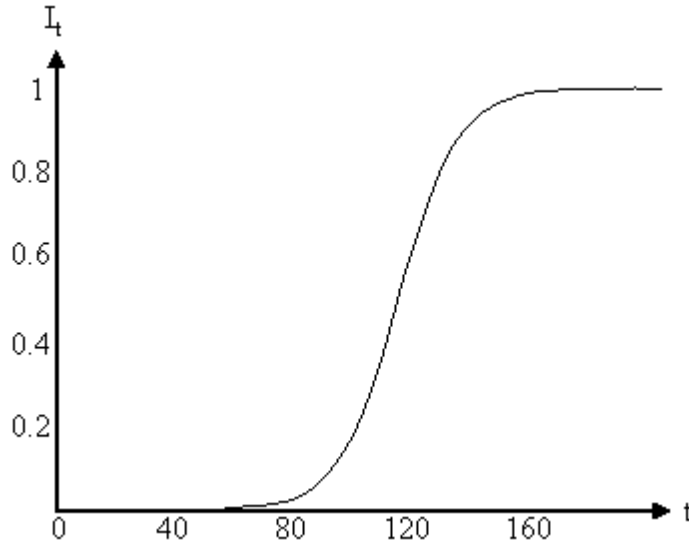


Figure 1: The dynamics of the infection ( $\beta = 0.1$ ,  $\psi = 100000$ )

conditional on not being infected at that time (the hazard rate), for a particular individual is

$$\lambda_t = \frac{\beta I_t S_t}{1 - I_t} = \beta I_t. \quad (3)$$

There is a linear demand curve for vaccine at time  $t$

$$X_t = (1 - I_t) (a_t - \gamma p_t), \quad (4)$$

incorporating that only the non-infected demand vaccine.  $\gamma$  is normalised to one in what follows, without any effect on the qualitative results. The intercept of the demand curve,  $a_t$ , is assumed to depend on how harmful the infection is,  $h$ , and the integral of future hazard rates discounted by the subjective time discount rate  $\delta$ :<sup>6</sup>

$$a_t = \int_{s=t}^{\infty} e^{-\delta(s-t)} h \lambda_s ds = \int_{s=t}^{\infty} \frac{h \beta e^{-\delta(s-t)}}{1 + \psi e^{-\beta s}} ds. \quad (5)$$

This integral has no simple analytical solution, and the general case must therefore be handled by numerical simulation.

The vaccine is supplied by a monopolist that, at time  $t_0$ , has sunk the fixed cost  $F$  to possess the knowledge and production capacity to quickly supply vaccine at a marginal cost of  $c$ . His profit function is given by

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<sup>6</sup>The notion that the demand for vaccine increases with the perceived risk of being infected is supported by empirical evidence by e.g. Philipson (1996) who uses U.S. data to show how demand for vaccine against measles is prevalence elastic.

$$\pi_t = pX_t - cX_t - F. \quad (6)$$

The profit maximising price at any point in time, given the linear demand curve, is

$$p_t^* = \frac{a_t + c}{2}. \quad (7)$$

The monopolist chooses the price, but also the time for introducing the vaccine. The latter choice is non-trivial. The longer the firm waits, the higher the share of infected,  $I_t$ , and consequently, the higher is the willingness of the uninfected to pay. However, the larger is  $I_t$ , the smaller is the market for vaccine. Moreover, the firm discounts time at rate  $r$ . At  $t_0$ , the firm finds the optimal time for introducing the vaccine by maximising the discounted value of future profit with respect to  $t$ :

$$\max_{\{t\}} V_{t_0,t} = (p_t - c)(1 - I_t)(a_t - p_t)e^{-r(t-t_0)} - F. \quad (8)$$

Before turning to a numerical solution of this problem, it may be noted that it can be solved analytically when consumers have static expectations implying that demand is solely determined by the current spread of the infection,  $I_t$ . The integral in (5) in this case simplifies to

$$a_t = \frac{h\beta I_t}{\delta}, \quad (9)$$

and using this together with (7) gives (8) as

$$V_{t_0,t} = \left(1 - \frac{1}{1 + \psi e^{-\beta(t-t_0)}}\right) \left(\frac{h\beta}{2\delta(1 + \psi e^{-\beta(t-t_0)})} - \frac{c}{2}\right)^2 e^{-r(t-t_0)} - F. \quad (10)$$

This expression is plotted in Figure 2 ( $\psi = 100000, r = 0.03, c = 0.1, \beta = 0.1, h = 200, \delta = 0.05, F = 1$ ) for some parameter values.

Initially, the infection spreads slowly (c.f. Figure 1), and because of the low demand at these levels of  $I_t$ , the firm will not be able to recover its costs. The monopolist will, at this stage, not even be able to cover its variable cost, which means that the best outcome is  $-F$ , as shown by the horizontal line in Figure 2.<sup>7</sup> However, as the increase in the number of infected accelerates, the price increase leads to a sharp increase in profit as shown in the figure. Finally, as  $I$  approaches  $N$ , the demand for vaccine drops towards zero, with falling profit as a consequence.

The location of the peak in Figure 2 is given by the interior maximum of (10) w.r.t.  $t$ :

$$t^* = -\frac{1}{\beta} \ln \left( \frac{\frac{h\beta}{\delta} - c}{c\psi} - \frac{\frac{h\beta}{\delta}(\ln(1+r) + 2\beta) + c\beta - \sqrt{\left(\frac{h\beta}{\delta}\right)^2(2\beta - \ln(1+r))^2 + c\beta(10\frac{h\beta}{\delta}\ln(1+r) + 4\frac{h}{\delta}\beta^2 + c\beta)}}{2c\ln(1+r)\psi} \right). \quad (11)$$

From this expression, it can be seen that a higher  $\psi$  means it takes longer before the interior maximum is reached. This is the case simply because a lower fraction of the population infected

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<sup>7</sup>Using (2) and (7), the monopolist will not be able to charge a price equal to or above the marginal cost before time

$$\tilde{t} = -\frac{1}{\beta} \ln \left( \frac{\frac{h\beta}{\delta} - c}{c\psi} \right).$$

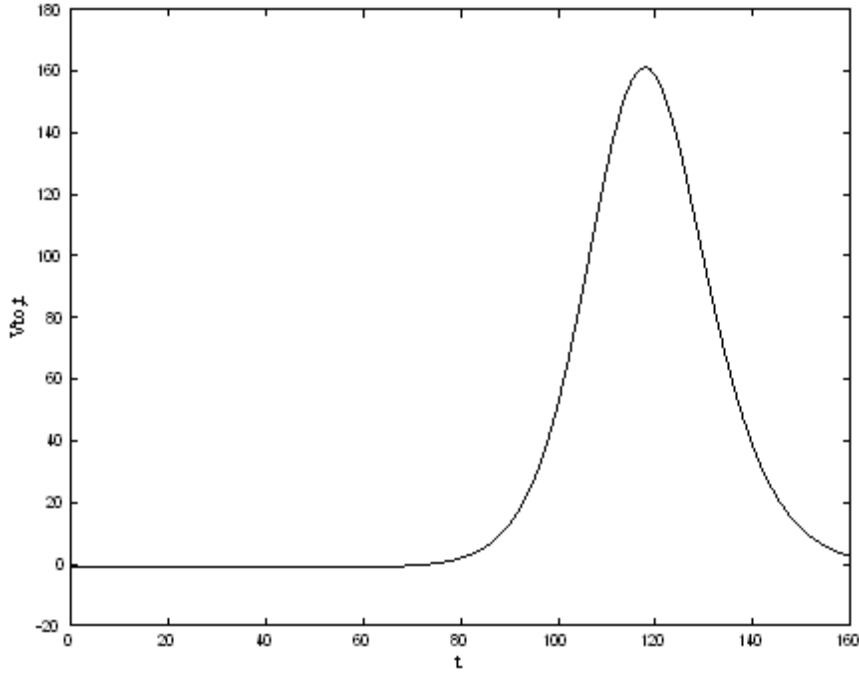


Figure 2: The value of introducing the vaccine at time  $t$  ( $\psi = 100000, r = 0.03, c = 0.1, \beta = 0.1, h = 200, \delta = 0.05, F = 1$ )

at  $t_0$  implies a longer time period before the infection takes off. It is also clear from the expression that  $F$  does not affect the profit maximising point in time to introduce the vaccine. It only affects the monopoly profit. For the remaining parameters, comparative static results are unrevealing and we therefore turn to a numerical investigation of the general case.

Figure 3 ( $\psi = 100000, r = 0.03, c = 0.1, \beta = 0.1, h = 200, \delta = 0.05, F = 1$ ) compares consumers with static expectations and forward looking consumers. Accounting for forward looking behaviour has two effects. First, it greatly increases the profit of the monopolist, compared to the case with myopic consumers. This happens because the consumers' willingness to pay increases as they internalise the higher risk of being infected in the future. Second, it makes it optimal for the producer to introduce the vaccine at an earlier date. However, as illustrated in the figure, there may still be a significant time lag before the vaccine is sold.

The reason for this is that the firm waits for the sharp increase in hazard rates seen in Figure 1, before releasing the vaccine. When the discount rate is lower, future hazard rates are better internalised by consumers, which implies a higher willingness to pay for vaccine at  $t_0$ , and less reason for delaying vaccine sales from the firm's point of view. Figure 4 ( $\psi = 100000, r = 0.06, c = 0.1, \beta = 0.1, h = 200, F = 1$ ) shows how the delay in vaccine sales decreases towards zero with a falling  $\delta$ . Clearly, in the limiting case when consumers do not discount time,  $\delta = 0$ , firms will always release the vaccine immediately, as long as the monopolist discounts time.<sup>8</sup>

<sup>8</sup> Actually, the discount rate of consumers must be slightly above zero for convergence of the integral that

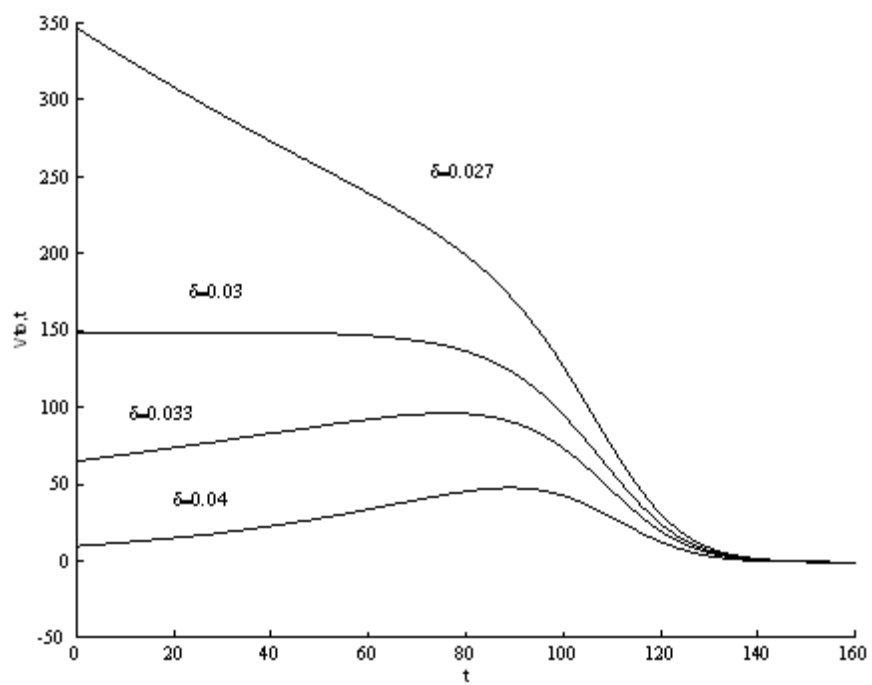
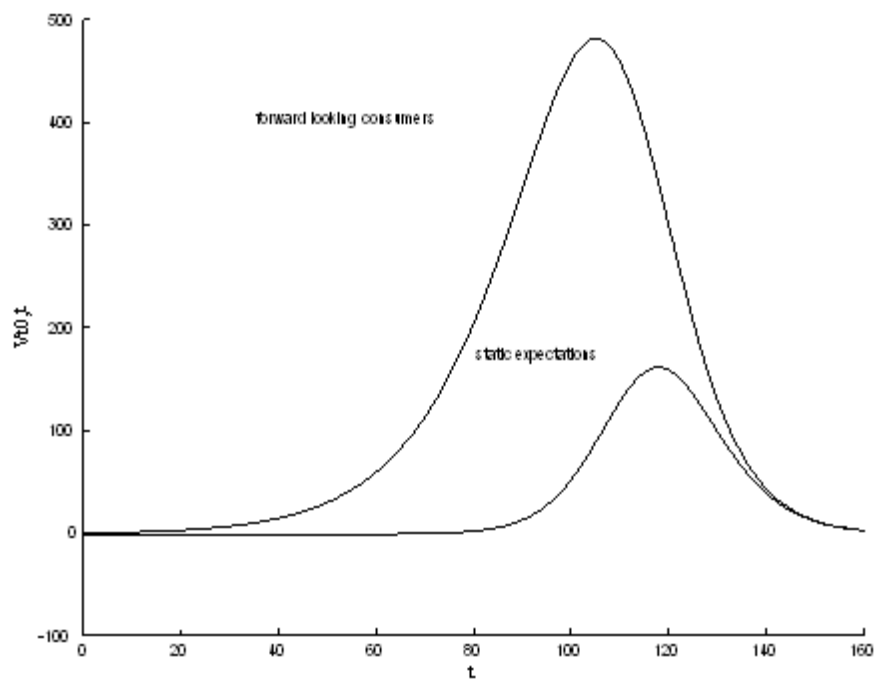


Figure 3: The effect of the time discount rate of consumers  $\delta$  ( $\psi = 100000, r = 0.06, c = 0.1, \beta = 0.1, h = 200, F = 1$ ).

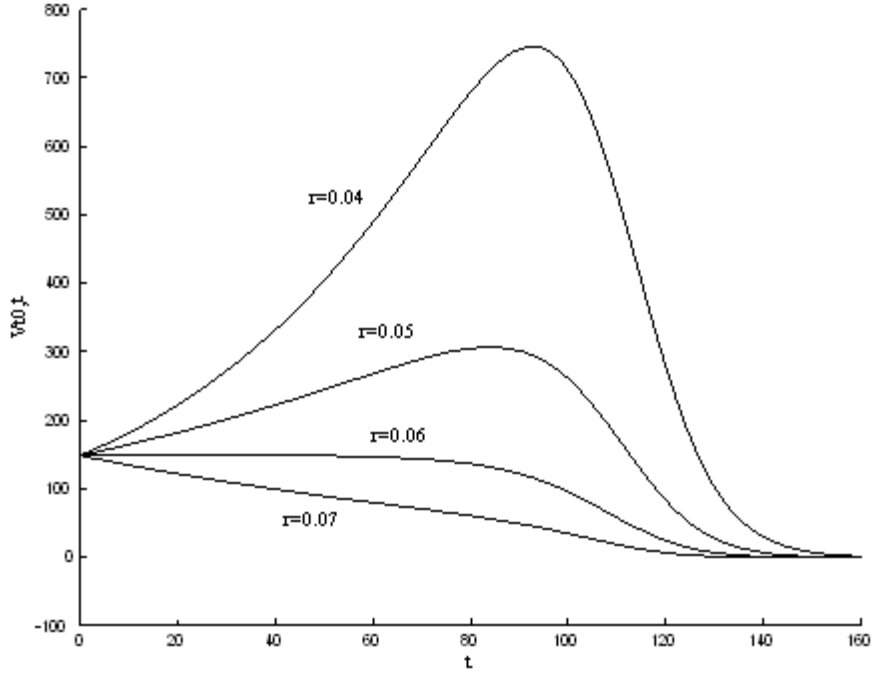


Figure 4: The effect of the firm's time discount rate  $r$  ( $\psi = 100000, \delta = 0.03, c = 0.1, \beta = 0.1, h = 200, F = 1$ ).

The effect of the time discount rate of the firm,  $r$ , is similar to but opposite to the effect of  $\delta$ . Figure 5 ( $\psi = 100000, \delta = 0.03, c = 0.1, \beta = 0.1, h = 200, F = 1$ ) illustrates the effect of  $r$  on  $V_{0,t}$ . A high discount rate erodes the present value of future returns and therefore pushes the firm towards an early release of the vaccine. One interpretation of  $r$ , stepping slightly outside the model, is that it measures the degree of competition in the vaccine market. A higher degree of competition implies that it is more likely that a competitor will release a competing vaccine at any point in time. This makes the producer holding the vaccine more impatient. Figure 5 shows a numerical example of how the time-lag in releasing the vaccine becomes shorter, and the monopoly profit lower, as the firm's discount rate increases.

Further numerical solution of the model shows that a higher  $\beta$ , which implies a faster spread of the disease, results in a shorter time period before the vaccine is released and increases the monopoly profit. A higher  $h$  increases the monopoly profit, with no effect on the time lag.

Finally, a higher marginal cost of producing vaccine increases the time lag before introducing the vaccine. The reason for this is that the firm makes a trade off between price and volume, when choosing the profit maximising time to sell the vaccine. A higher marginal production cost makes a high volume relatively less compelling, and therefore pushes the firm in the direction of higher price and lower volume.

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determines  $a_t$ .

## 2.1 Price discrimination

The monopolist producer may be able to price discriminate. Consider the case of perfect price discrimination, which implies that the monopoly profit is  $(1 - I_t)(a_t - c)^2/2$ , and that the discounted value of introducing the vaccine at  $t$  is

$$V_{t_0,t}^{discr.} = \frac{1}{2}(1 - I_t)(a_t - c)^2 e^{-r(t-t_0)} - F. \quad (12)$$

This may be compared to the value without price discrimination, which from (7) and (8), may be written

$$V_{t_0,t} = \frac{1}{4}(1 - I_t)(a_t - c)^2 e^{-r(t-t_0)} - F. \quad (13)$$

Thus, perfect price discrimination increases monopoly profits, but it does not alter the profit maximising delay in introducing the vaccine  $t^*$ .<sup>9</sup> The reason for this is that  $t^*$  is chosen to maximise the (discounted) area below the demand curve, whereas the degree of price discrimination only affects the share of the consumer surplus that can be appropriated by the firm.

## 2.2 Some welfare considerations

It is clear that, when compared to the counterfactual of a monopoly producer, a social planner could improve welfare. First, if the monopoly rent suffices to motivate the fixed cost of developing a vaccine the planner, who takes the entire consumer surplus into account, will always want to incur the development cost. Moreover, if the planner supplies the vaccine, he will always choose to introduce it at  $t = 0$ . Thus, the planner solution is  $p^{plan} = c$ ,  $t^{plan} = 0$ .<sup>10</sup>

In a case where a monopolist does not develop a vaccine due to very high fixed costs, it is still possible that a planner would choose to do so. First, in contrast to the not perfectly price discriminating monopolist, the planner takes the entire consumer surplus into account and second, the harm of the infected enters the planner's calculation.

## 3 Conclusions

This paper makes a simple point: Vaccine developers and producers may have an incentive to delay the introduction of a vaccine against a new disease until it has spread, if the willingness to pay for vaccine by the non-infected individuals increases with the spread of the disease. When consumers are forward looking, they are more willing to pay for the vaccine at an early date. However, unless consumers have a very low time discount rate or the vaccine producer a high time discount rate, it will still be optimal for the producer to delay the sales of vaccine. The delay will also increase in the marginal production cost of the vaccine.

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<sup>9</sup>It is easily shown that this result also holds when  $\gamma$  is not normalised to one.

<sup>10</sup>Here, I abstract from other externalities, such as reduced disease transmission. Taking this into account implies that vaccines should be supplied below the marginal cost.

Naturally, in reality, there are a number of factors limiting this type of behaviour by firms. Pharmaceutical firms may have important goodwill capital to defend, which could be seriously affected if it were revealed that a firm was stalling the introduction of an important vaccine. Second, delayed sales imply a risk of a competitor entering the market. Finally, the firms operate in a market where governments are very present as buyers and regulators, which may limit the scope for socially harmful practises.

Nevertheless, it is important for governments to realise the existence of this incentive problem. Vaccine production is globally concentrated to relatively few firms and in many countries, there is virtually only one supplier. The problem noted here also becomes more important when the disease in question is grave. A case of particular concern is the threatening pandemic in avian influenza.

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