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The economics of vaccination

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HIGHLIGHTS

- Several economic models of vaccination are analyzed.
- Equilibrium vaccination is compared to socially optimal vaccination.
- Features of diseases, vaccines and markets that lead to inefficiencies are identified.

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ABSTRACT

The market for vaccinations is widely believed to be characterized by market failures, because individuals do not internalize the positive externalities that their vaccination decisions may confer on other individuals. Francis (1997) provided a set of assumptions under which the equilibrium vaccination pattern is socially optimal. We show that his conditions are not necessary for the welfare theorem to hold but that in general, the market yields inefficiently low vaccination uptake. Equilibrium non-optimality may obtain if (i) agents can recover from infection, (ii) vaccines are imperfect, (iii) individuals are ex ante heterogeneous, (iv) vaccination timing is inflexible or (v) the planning horizon is finite. Apart from the case with heterogeneity, inefficiencies result from the presence of strategic interaction.

1. Introduction

For many important infectious diseases, the main tool used in the quest for management or eradication lies in vaccination against infection. Yet, while there is no doubting the private and public benefits from widespread vaccine uptake, there are important fundamental questions about vaccination markets (and vaccination demand) that remain unanswered.

Vaccinations are generally believed to be prima facie examples of actions with strong positive externalities. The idea driving this belief is beguilingly simple. If someone is vaccinated against an infectious disease, then this individual ceases to be a source or conduit of infection to other individuals.[2] Once positive external effects from vaccination are recognized, it follows naturally that if these are not properly internalized by individuals, then there is a strong case for public intervention, since a self-interested individual would tend to under-vaccinate relative to the socially optimal level.[3] This line of thinking, although intuitively appealing, turns out to depend delicately on the details of the environment, i.e. on the characteristics of the population, the disease and the available vaccine. In a controversial paper, Francis (1997) shows, using an infinite horizon susceptible-infected-removed model of epidemics without spontaneous recovery, that the market for vaccinations is efficient (i.e. it induces the socially optimal outcome) if individuals are ex ante homogeneous, the vaccine is perfect and vaccination can be taken at any point in time. The Francis welfare theorem goes against the grain of the general understanding of the properties of vaccination markets. In fact, Francis (1997) himself seems reluctant to claim any generality of the result, and indeed provides a long list of modifications to the model that could potentially alter his counter-intuitive finding.[4,5] Despite a growing literature on the

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[2] In epidemiology, the well-known concept of herd immunity, i.e. that a disease can be eradicated without vaccinating the entire population, is itself a reflection of the idea of externalities in vaccination.

[3] For an interesting instance of private individuals over-vaccinating in equilibrium relative to the social optimum, see Liu et al. (2012).

[4] Curiously, he does not pinpoint the central properties driving his result.

[5] A result related to that of Francis (1997) holds in an SI (susceptible-infected) model with non-vaccine prevention, as shown in Toxvaerd (2009).

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economics of vaccination, we believe that there are many facets of vaccination markets that are not yet fully understood. Furthermore, a better understanding of the role of externalities in decentralized vaccination decisions may also inform policy recommendations. Specifically, we will seek to answer the following two questions: (i) are decentralized vaccination markets efficient in the sense that they maximize social welfare? and (ii) if not, what is the source of the inefficiencies?

In addressing these questions, we will conduct a formal analysis by drawing heavily on methods and insights from economics. We do so for two distinct reasons. First, in answering what an "optimal" policy is, one must explicitly identify and address the basic tradeoffs that must be resolved. In practice, this means that one must not focus only on the direct costs of infection, but also on broader social costs to the economic environment and the costs involved in controlling the disease. The tools of economics are explicitly developed to analyze this kind of tradeoffs.[6] Second, when dealing with decentralized markets in which individuals make (possibly) non-coordinated decisions on whether to get vaccinated, one must explicitly model individual decision making. In doing so, it must be recognized that individuals do not merely respond passively in a privately optimal way to what other individuals do, but may also be strategically sophisticated and take into account their conjectures about other individuals' future actions. In considering such situations, economics and game theory again provide the adequate tools of analysis. There is ample evidence that individual behavior is critical for understanding aggregate disease evolution, as emphasized by Auld (2003), Reluga (2010), Fenichel et al. (2011) and Fenichel (2013).

In this paper, we analyze under what conditions the Francis welfare theorem holds. We argue that there are two central features of the Francis (1997) framework that lead equilibrium vaccination decisions to coincide with the social optimum. These are that (a) individuals are ex ante homogenous and (b) that there is no strategic interaction in vaccination decisions. Our results suggest that his welfare theorem is highly sensitive to assumptions that are made about the properties of the disease, the vaccine, and the market.

Before explaining the reasons for these results, we start by explaining why the welfare theorem is true under the sufficient conditions of Francis (1997). When there is an infinite horizon, the vaccine is perfect, there is no possible recovery and the vaccination timing is perfectly flexible, then there are no strategic interactions. This is because an individual's optimal vaccination policy (under decentralized decision making) is myopic in the sense that if the current prevalence is at or above a critical value, then it is optimal to vaccinate; otherwise, it is optimal not to vaccinate. A consequence of this is that, no matter what other individuals are currently doing or will do in the future, the individual's optimal policy is the same. That is, the individual's decision is independent of the actions of other individuals. Moreover, when individuals are ex ante identical, they have the same optimal policy. But this implies that a decentralized equilibrium has to be symmetric. Last, because of symmetry, all individuals are perfectly protected against infection at the same time (because they all vaccinate at the same time) and hence there are no external effects in equilibrium.[7] As a consequence, the equilibrium under decentralized decision making is socially efficient. Clearly, this result rests in an important way on the ex ante homogeneity of the population, as recognized by Gersovitz (2003) and Kessing and Nuscheler (2003). Ex ante heterogeneity also is central to the study by Veliov (2005), while Fenichel (2013) emphasizes that endogenous (ex post) heterogeneity may have important effects on the social optimality of equilibrium levels of social distancing (i.e. infection reducing strategies).

Given the insight we have just outlined, it is easy to see why relaxing ex ante homogeneity may invalidate the welfare theorem. With heterogeneous agents, it is again the case that an individual's optimal policy under decentralized decision making is myopic; therefore, there are no strategic interactions. However, because of heterogeneity, the different individuals' critical prevalence values differ, which means that an equilibrium is not symmetric. But asymmetry implies that there are external effects in equilibrium, because non-vaccinated individuals are influenced by the decisions of vaccinating individuals. Hence, the equilibrium in this case need not be socially efficient.

It is a priori less clear what role is played by the assumptions of an infinite planning horizon, by the impossibility of recovery or by the perfect flexibility in vaccination timing. In each of these cases, it turns out that an individual's optimal policy under decentralized decision making is not myopic. Thus in any time period, the individual's decision depends on the prevalence in that time period as well as on the expected prevalence in future time periods. But since the prevalence in future time periods depends on the actions of other individuals, strategic interactions are present. As a result, there are external effects; thus equilibrium vaccination decisions are not generally socially efficient.

We note that when there are strategic interactions, the equilibrium may or may not be ex post symmetric. This means that heterogeneity is a sufficient but not a necessary condition for decentralized equilibrium vaccine uptake to be socially inefficient. This finding also serves to emphasize that while ex ante heterogeneity is indeed an important source of inefficient vaccine uptake, the presence of strategic interactions (which we show can stem from multiple sources) represents a distinct source for possible inefficiencies, even when the population is homogeneous. This finding is important, because it shows that wrong policy conclusions may result from a single-minded focus on homogeneity/symmetry.

As we will argue in detail below, the Francis welfare theorem holds under a special (but by no means contrived) set of assumptions. Nonetheless, its importance lies in the fact that these modeling assumptions are the natural starting point of any analysis of vaccination externalities. The welfare theorem therefore serves as a benchmark for the economics of vaccination, against which one can compare less stylized and more realistic models. In particular, our analysis makes clear that it is unhelpful simply to assert that decentralized vaccination decisions involve "externalities", since the nature and causes of externalities (and therefore their possible remedies) depend in delicate ways on the chosen modeling assumptions.

1.1. Related literature

The economic control of vaccination markets was first studied formally by Hethcote and Waltman (1973) and Morton and Wickwire (1974). In these papers, and in many subsequent contributions building on this work (such as Veliov, 2008 and Hansen and Day, 2011), a central planner controls the vaccination decisions of each and every individual in the population in order to maximize some criterion of social welfare. In doing so, they not only uncovered the basic tradeoffs involved in disease control, but they also established the benchmark of optimality that any policy intervention should be measured against. These early papers did not consider individual decision making and hence did not

[6] For nice illustrations of the kind of tradeoffs that disease control involves, see e.g. Smith et al. (2009) and Keogh-Brown et al. (2010).

[7] The fact that immune individuals are unaffected by others' vaccination decisions (and indeed by any changes in disease prevalence) was first noted by Brito et al. (1991), where they used this insight to show that mandatory vaccination of the entire population would not be socially optimal.