Theme Papers

Eradication versus control: the economics of global infectious disease policies

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Abstract A disease is controlled if, by means of a public policy, the circulation of an infectious agent is restricted below the level that would be sustained by individuals acting independently to control the disease. A disease is eliminated if it is controlled sufficiently to prevent an epidemic from occurring in a given geographical area. Control and elimination are achieved locally, but a disease can only be eradicated if it is eliminated everywhere. Eradication is plainly a more demanding goal, but it has two advantages over control. First, the economics of eradication can be very favourable when eradication not only reduces infections but also avoids the need for vaccinations in future. Indeed, when eradication is feasible, it will either pay to control it to a fairly low level or to eradicate it. This suggests that, from an economics perspective, diseases that are eliminated in high-income countries are prime candidates for future eradication efforts. Second, the incentives for countries to participate in an eradication initiative can be strong; indeed they can be even stronger than an international control programme. Moreover, high-income countries typically benefit so much that they will be willing to finance elimination in developing countries. Full financing of an eradication effort by nation-states is not always guaranteed, but it can be facilitated by a variety of means. Hence, from the perspective of economics and international relations, eradication has a number of advantages over control. The implications for smallpox and polio eradication programmes are discussed.

Keywords Communicable disease control/economics; Poliomyelitis/prevention and control; Smallpox/prevention and control; Public policy; Financing, Organized; International cooperation; Cost-benefit analysis; Game theory; Developed countries; Developing countries (*source: MeSH, NLM*).

Mots clés Lutte contre maladie contagieuse/économie; Poliomyélite antérieure aiguë/prévention et contrôle; Variole/prévention et contrôle; Politique gouvernementale; Organisation financement; Coopération internationale; Analyse coût-bénéfice; Théorie des jeux; Pays développé; Pays en développement (*source : MeSH, INSERM*).

Palabras clave Control de enfermedades transmisibles/economía; Poliomielitis/prevención y control; Viruela/prevención y control Política social; Cooperación internacional; Organización del financiamiento; Análisis de costo-beneficio; Teoria del juego; Países desarrollados; Países en desarrollo (*fuente: DeCS, BIREME*).

Arabic

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Voir page 687 le résumé en français. En la página 687 figura un resumen en español.

Introduction

Policies for the control or eradication of an infectious disease presume an ability to break the chain of transmission and in this paper I assume that this can be done by means of an available vaccine. Policies for the control or eradication of a vaccine-preventable disease also presume the need for government intervention. Indeed, to an economist, control is perhaps best defined as a public policy that restricts the circulation of an infectious agent beyond the "competitive" level — that is, beyond the level that would result from spontaneous, individual behaviour to protect against infection. Elimination is achieved by high control. (In the language of mathematical epidemiology, the reproductive rate of the disease must be lowered to one (*1*).) Control and elimination are achieved locally, whereas eradication is global. Control is always feasible (by quarantine if not by immunization), though easier to achieve in some environments than in others, with differences in climate, population density, infrastructure, culture and governance being especially important. Elimination, by contrast, is not always feasible; and eradication is even harder to achieve. Eradication requires that a disease be eliminated everywhere (and at the same time), and so it succeeds or fails depending on whether the target disease can be eliminated from the locality with the least favourable conditions. In the current effort to eradicate polio, this might

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be the state of Kano in Nigeria (*2*). Eradication also requires supplementary immunization, especially in countries bordering still-endemic regions. And, finally, eradication requires effective global surveillance. Hence, while control and eradication may in some sense be thought of as being on a continuum (with elimination falling somewhere in between), the biological, technical and organizational challenges of eradication are far greater.

But eradication also has advantages over control. Though control is almost always desirable (because vaccination benefits susceptible people and not just the people who get vaccinated — a positive externality), the economics of eradication can be even more favourable. Moreover, the incentives for international cooperation can also be stronger for eradication. This paper uses both economic theory and game theory to uncover these advantages. The purpose is to show when, and why, global policies on infectious diseases should pursue a goal of eradication rather than control.

Preconditions for eradication

A number of prerequisites must be satisfied for eradication to be worthy of consideration (*3*–*5*). Most essentially, eradication must be technically and biologically feasible, yield a benefit in excess of the cost, and have political commitment behind it. In this paper I take the view that the epidemiological requirements for eradication have been met. My focus is on the latter two prerequisites: the economics and the institutional challenges of eradication.

How important are these considerations compared with the epidemiological preconditions for success? It is sobering to recall that the success of the smallpox effort was hardly assured even after the disease had been eliminated everywhere but the horn of Africa — that is, even after the epidemiological requirements for eradication had been amply demonstrated. As the team that led the effort later recalled, "The gap between success and failure … was a narrow one, and the issue was often favourably decided by fortuitous and unpredictable political developments and with only marginally adequate resources" (*6*). A more recent assessment of earlier eradication efforts draws a similar conclusion. "Of the lessons learned in the past 85 years," the commentary begins, "none is more important than the recognition that societal and political considerations ultimately determine the success of a disease eradication effort" (*7*).

These same challenges persist. The polio eradication initiative is expected to reduce global incidence to 0 by around 2005, but it is experiencing many of the same kinds of financial problems as the earlier smallpox effort. As noted in a recent WHO report, "The central importance of sufficient funding to the ultimate success of the Global Polio Eradication Initiative became acutely evident in early 2003 when, for the first time since 1999, it was necessary to cancel or postpone eradication activities due to a lack of financing" (*8*). And while the death toll caused by measles makes this disease a worthy future candidate for eradication, according to an expert panel, "The major obstacles to measles eradication are not technical but perceptual, political, and financial" (*9*). Plainly, a lot depends on understanding how these obstacles can be overcome when eradication is economically justified.

Economics of eradication versus control

Control protects the individuals who are vaccinated and offers a measure of protection to others in the community (herd immunity). Eradication, by contrast, spares future generations the risk of infection and so renders future vaccination unnecessary. Eradication is thus an investment.

But when should a disease be eradicated rather than controlled? Suppose that a disease is already being controlled at a level so high that a slight increase in the vaccination rate would eradicate the disease. What would be the consequences of increasing the vaccination rate above this high level? In the short run, costs would increase, and a few additional infections would be prevented. Once the disease was eradicated, however, there would be no further need to vaccinate, yielding society a huge "dividend" (the present value sum of the costs of avoided future vaccinations). Intuitively, welfare would be maximized either by controlling the disease at a relatively low level or by eradicating it. Maintaining a very high level of control can never be optimal, given the technical feasibility of eradication (*10*).

The example of smallpox illustrates how large the gains from eradication can be. If 1967 is used as a base year — a year in which smallpox, though eliminated in developed countries, still killed 1.5–2 million people in developing countries — the benefits of eradication to the world were about US$ 1.35 billion annually (*6*). The total expenditure for the eradication programme — an incremental cost above the cost of control — was about US$ 100 million (the total of all international funding made available to the programme (*6*)), incurred over a period of about 10 years. Very roughly, a one-time cost of about US$ 100 million saved the world about US$ 1.35 billion a year. Using a discount rate of 3%, this implies a benefit–cost ratio for global eradication of about 450:1. Smallpox eradication was an extraordinarily good deal for the world.

Another relevant example is the current initiative to eradicate wild polioviruses by 2005. Polio has already been eliminated from most of the world and so the epidemiological preconditions for eradication are plainly satisfied. Moreover, the economics of polio eradication (as compared with control) are favourable, provided vaccination (by means of the live–attenuated oral polio vaccine) can be ended after incidence of the disease has fallen to 0 and eradication has been certified (*5*, *11*, *12*). This is now the Polio Eradication Initiative's strategy (*8*), and it has the advantage of reducing the risk of infection from circulating vaccine-derived polioviruses while at the same time improving the long-term economics of eradication.

The "initial conditions" can also be important. A smaller number of people need to be vaccinated over the course of an eradication campaign when a disease first emerges than when it is established. It is thus possible that economics would favour eradication in the early stages of the emergence of a new disease but not after the disease had reached a steady state (*10*). There are good epidemiological reasons for eradicating severe acute respiratory syndrome (SARS) before it becomes established (*13*), but economics also leans in the direction of swift action.

Incentives for eradication versus control

The essential feature of eradication is that each country's decision to eliminate is likely to depend on whether all other countries eliminate. Decisions are interdependent, making disease eradication a "game." The most basic concept in game theory is the Nash equilibrium, named after the theorist, John Nash, who developed the concept. A Nash equilibrium describes a situation in which no player can gain by making a different choice, given the choices made by every other player (Box 1).

Box 1. **Game theory, the Nash equilibrium and infectious diseases**

A game is played whenever people interact. Human interactions are fundamental to the transmission of infectious diseases, and so game theory can help explain the need for, and limitations of, policies to control infectious diseases.

The most fundamental concept in game theory is the Nash equilibrium. Players are in a Nash equilibrium if, given the choices made by others, each player has no incentive to change his or her choice.

When do you choose to be vaccinated?

Probably when the risk of getting infected is relatively high and the vaccine is safe. The risk of getting infected depends on whether other people with whom you are likely to come into contact can transmit the disease. If enough others are vaccinated, then you benefit from herd immunity and may choose not to be vaccinated. Depending on the virulence and transmissibility of a disease, and the perceived safety of the vaccine, different levels of community protection can be a Nash equilibrium.

In the infectious disease game, the players are countries, and depending on the costs and benefits of eradication, four different situations, each supporting different kinds of Nash equilibria, are possible (*14*).

- First, the net benefits of eradication for the world as a whole may be negative, making control, but not eradication, an equilibrium.
- Second, the net benefits of elimination may be so great that every country chooses to eliminate a disease unilaterally, making eradication, but not control, an equilibrium.
- Third, it may not pay any state to eliminate a disease unilaterally, given that others have not eliminated the disease, and yet it may pay every state to eliminate the disease once all others have done so. In this case, eradication is a "coordination" game. For this kind of game there are two equilibria. In one, every country controls but does not eliminate the disease. In the other, every country eliminates the disease and the disease is therefore eradicated. Only the latter equilibrium is globally efficient.
- Finally, it may not pay the "last" state to eliminate a disease even after all others have done so, and yet the net benefits of eradication may be positive to the world as a whole. In this case, eradication is a "prisoner's dilemma." There will exist a unique equilibrium that is globally inefficient.

The latter two situations are plainly the most interesting. If eradication were a coordination game, we could not rely on unilateralism alone to sustain the better equilibrium, but nor would the demands on the international system be very great. To have an incentive to eliminate, each country would need only to be assured that all other countries would eliminate. If eradication were a prisoner's dilemma, however, then implementation of eradication — the globally efficient policy — would require third party enforcement (*14*).

The distinction is crucial, because WHO lacks the power of enforcement. Article 21 of the WHO Constitution authorizes the Organization to adopt regulations "designed to prevent the international spread of disease," but it does not permit punishment of states that fail to comply; and in the entire history of WHO, Article 21 has been invoked only twice (*15*). WHO has instead relied on making recommendations that can only be enforced by means of moral persuasion. In the past, these efforts have largely failed (*15*), though the Organization's response to the SARS outbreak marked a dramatic turn. By issuing travel alerts, and then subsequently being given the formal approval to do so, WHO has essentially extended its authority (*16*).

What we do not yet know is whether this new authority will extend to other areas. The circumstances of SARS were special: it was (and remains) a huge threat, partly because everyone in the world is susceptible and partly because there is no vaccine to protect against infection. However, WHO is employing a similar approach to polio eradication, choosing to " 'name names' — a strategy informally referred to as shame and blame. … If a country or province is slacking off, [WHO's polio team will] tell them — and the world — that they are risking a US$ 3 billion investment and needlessly causing more children to be paralysed" (*2*).

What were the economics of smallpox eradication for individual countries? Rich countries gained tremendously. The United States, for example, saved about US$ 150 million a year in avoided vaccination costs (*17*). Poor countries also gained. India, for example, gained about the same as the United States though for different reasons (India gained mainly from avoided infections, not avoided vaccination costs), while the incremental costs to India of elimination were only about US$ 17 million (*18*). Rich countries, of course, eliminated smallpox even before the eradication initiative was launched, whereas many poor countries did not. But this failure to eliminate was not for a lack of incentives. It was rather a consequence of administrative failings. Many poor countries — India included — tried to eliminate smallpox on their own but failed. They simply lacked the technical and managerial expertise needed to achieve the goal (*6*). For this reason, smallpox eradication required international cooperation and not only coordination. The way in which this was achieved is explained in the next section.

How does the geography of control differ from that of eradication? Disease control is a strategic substitute. As one country increases its control of a disease, other countries have an incentive either not to change their control policies or to decrease control. This is because control by one country reduces the risk of importing infections, and as the risk of imports falls, so does the local incentive to control the disease. The Nash equilibrium of the disease control game is thus likely to be characterized by too little control overall. Improvements in this situation would likely make all countries better off (at least all countries that control to a level short of elimination), but implementation of a global programme for control would also require enforcement, which, as noted before, is a potential problem. Rather than promote control directly, it may be better to lower the cost of vaccination (perhaps through bulk purchases of vaccines). Doing this would increase the incentive to control and so increase control indirectly.

Financing eradication versus control

Countries are strongly asymmetric — some are rich and some are poor — and for that reason disease outcomes vary widely. For example, many industrialized countries have eliminated measles

within their borders, whereas measles kills about 750 000 children a year in developing countries. Since elimination protects high-income countries from imports, they cannot gain directly by financing control in developing countries. Offers by high-income countries to finance measles control would essentially constitute aid.

Eradication is different. If poor countries were unable to eliminate a disease on their own or as part of a coordinated effort, or if they lacked the incentive to do so, rich countries might have an incentive to finance a global eradication programme. In doing so, rich countries would earn a return on their investment (the eradication dividend), while poor countries would also become better off.

Rich countries would not need to pay the entire cost. Poor countries are likely to have some incentive to control a disease on their own. Rich countries would need only pay the cost of reducing incidence from the current level (which may already be low, depending on the poor country's own incentives to control) to 0. Indeed, this is precisely how the smallpox eradication campaign was financed (*6*). Rich countries paid only about a third of the total cost of eliminating smallpox from developing countries. In the current effort to eradicate polio even the poorest countries pay between a quarter and a half of the costs of local implementation (*5*).

The binary nature of eradication helps facilitate international financing: eradication saved the United States about US$ 150 million per year. Assuming a 3% discount rate, the present value of the benefit of eradication to the United States was thus around US$ 5 billion. As also mentioned previously, the total cost of international financing was about US$ 100 million. The United States thus had a strong incentive to finance the global eradication programme all by itself (the benefit–cost ratio to the United States of paying the full cost of international financing would be 50:1). Of course, this is not to say that the United States would necessarily be the only contributor. Indeed, other countries did contribute to the smallpox eradication effort. However, because the United States would do better by financing the entire effort even if other countries contributed nothing, we can be sure that eradication must have been a Nash equilibrium.

This is an encouraging observation, for it tells us that eradication can be supported even by the anarchic international system. However, financing for the smallpox eradication campaign proved miserly. While the United States contributed more than any other country, financing requirements were only met after other countries (especially Sweden) stepped into the breach.

There are two likely explanations for the difficulty in raising finance internationally (*19*). First, while a country like the United States had an incentive to finance the entire eradication effort even if no other country did so, it may have been reluctant to pay the entire bill, partly in the hope, and perhaps expectation, that others would contribute and partly because of the belief that, since the benefits of eradication would be shared, the costs ought to be shared too. Second, though eradication promised huge net benefits to individual countries, the gains would be diffused internally. Though no political constituency would oppose eradication, none would necessarily lobby strongly for it either.

Financing problems also plague the polio eradication initiative, which now faces a US$ 130 million shortfall for 2004–05 (*8*). Any past expenditure on polio eradication is discounted, and therefore irrelevant to any decision to eradicate that starts from today. The world as a whole is expected to save US$ 1.5 billion a year once vaccination is discontinued, of which the United States would save about US$ 230 million, assuming that vaccination ceases (*20*). In present value terms, the benefit of eradication to the United States would be about 33 times this value. Hence, it appears that if countries are able to stop vaccinating, then polio eradication would be a Nash equilibrium and so would be achievable by existing international institutions. This situation is similar to the earlier smallpox experience, but there are three important differences. First, support from Rotary International and other foundations lowered the cost to governments of financing the effort. Second, the involvement of these organizations also provided domestic political pressure for enhanced state financing. Finally, the polio eradication initiative learned from the smallpox experience and professionalized its approach to fund-raising (*5*).

Conclusions

Compared to control, eradication of a vaccine-preventable infectious disease is a high-risk goal but one that also has a number of advantages. Aggregate welfare is maximized either when a disease is controlled at a relatively low level or when it is eradicated. Control at a very high level will not be globally optimal (in the sense of maximizing the present value sum of net benefits) when eradication is feasible. Diseases already controlled at a very high level in rich countries are thus prime candidates (from the perspective of economics) for global eradication. The eradication of these diseases would benefit the rich countries substantially and so make it attractive for them to finance a global effort.

The international system is not well suited to implementing interventions that require enforcement, but this failing helps to make eradication an attractive policy goal. In some cases, eradication will require only coordination among countries. In other cases, cooperation will be required, but the binary nature of eradication (as contrasted with control), coupled with the strong asymmetry between rich countries and poor countries, helps make full financing of an eradication effort compatible with the self interests of states even without international enforcement. The smallpox experience teaches that full financing is not guaranteed, but the polio campaign shows how strategies and tactics can be used to improve the campaign's chances of success. ■

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Résumé

Eradication ou lutte : l'économie des politiques mondiales relatives aux maladies infectieuses

Une maladie est maîtrisée si, au moyen d'une politique publique, on a réduit la circulation d'un agent infectieux au-dessous du niveau qu'atteindraient des personnes agissant indépendamment pour lutter contre la maladie. Une maladie est éliminée si elle est suffisamment maîtrisée pour éviter qu'une épidémie ne se produise dans une région géographique donnée. La lutte et l'élimination sont réalisées localement, mais une maladie ne peut être éradiquée que si elle est éliminée partout dans le monde. L'éradication est à l'évidence un objectif plus difficile à atteindre, mais qui présente deux avantages par rapport à la lutte. Tout d'abord, l'économie de l'éradication peut être très avantageuse lorsque non seulement elle réduit le nombre d'infections, mais permet également d'éviter le recours aux vaccinations dans le futur. En effet, lorsque l'éradication est réalisable, il sera payant soit de lutter contre la maladie de façon qu'elle atteigne un niveau assez faible, soit de l'éradiquer. Cela laisse à penser que, d'un point de vue économique, les maladies qui sont éliminées dans des pays à revenu élevé sont les premières candidates pour les efforts d'éradication futurs. Ensuite, pour les pays, les incitations à participer à une initiative d'éradication peuvent être fortes ; en effet, elles peuvent même être plus fortes qu'un programme de lutte international. En outre, les pays à revenu élevé en tirent généralement un tel bénéfice qu'ils seront désireux de financer l'élimination dans les pays en développement. Le financement complet d'un effort d'éradication par des Etats-nations n'est pas toujours garanti, mais il peut être facilité par divers moyens. Par conséquent, du point de vue de l'économie et des relations internationales, l'éradication présente un certain nombre d'avantages par rapport à la lutte. On évoque ici les incidences que cela a sur les programmes d'éradication de la variole et de la poliomyélite.

Resumen

Erradicación frente a control: economía de las políticas mundiales contra las enfermedades infecciosas

Una enfermedad se considera controlada cuando, por medio de una política pública, se consigue limitar la circulación del agente infeccioso por debajo del nivel en que se mantendría si los individuos actuaran por su cuenta para controlar la enfermedad. Una enfermedad se considera eliminada cuando se controla suficientemente para evitar que se declare una epidemia en una determinada zona geográfica. El control y la eliminación se consiguen a nivel local, mientras que para hablar de erradicación de la enfermedad hay que haberla eliminado en todas partes. La erradicación es claramente una meta más exigente, pero presenta dos ventajas respecto al control. Primero, la rentabilidad de la erradicación puede ser muy importante si ésta no solo reduce las infecciones sino que además evita la necesidad de nuevas vacunaciones en el futuro. En efecto, cuando la erradicación es factible, compensa controlar la infección para reducirla a un nivel bastante bajo o erradicarla. Esto lleva a pensar que, desde una perspectiva económica, las enfermedades que se han eliminado en los países de ingresos altos son las principales candidatas para los futuros esfuerzos de erradicación. Segundo, los incentivos para que los países participen en una iniciativa de erradicación pueden ser muy poderosos; de hecho, pueden ser más poderosos que en el caso de un programa internacional de control. Además, los países de ingresos altos suelen beneficiarse tanto de ello que estarán dispuestos a financiar la eliminación en los países en desarrollo. La plena financiación de los esfuerzos de erradicación por los Estados-nación no siempre está garantizada, pero puede verse facilitada por diversos medios. En consecuencia, desde la perspectiva de la rentabilidad y de las relaciones internacionales, la erradicación tiene varias ventajas sobre el control. Se examinan las implicaciones para los programas de erradicación de la viruela y de la poliomielitis.

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