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Economic losses of pandemic risk

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Pandemic risk: how large are the expected losses?

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Abstract

There is an unmet need for greater investment in preparedness against major epidemics and pandemics. The arguments in favour of such investment have been largely based on estimates of the losses in national incomes that might occur as the result of a major epidemic or pandemic. Recently, we extended the estimate to include the valuation of the lives lost as a result of pandemic-related increases in mortality. This produced markedly higher estimates of the full economic loss that might occur as the result of a future pandemic. We parametrized an exceedance probability function for a global influenza pandemic and estimated that the expected number of influenza-pandemic-related deaths is about 700,000 per year. We calculated that the expected annual losses from pandemic risk to be about 500 billion United States dollars – or 0.6% of global income – per year. This estimate falls within – but towards the lower end of – the Intergovernmental Panel on Climate Change’s estimates of the value of the losses from global warming, which range from 0.2% to 2% of global income. The estimated percentage of annual national income represented by the expected value of losses varied by country income grouping: from a little over 0.3% in high-income countries to 1.6% in lower-middle-income countries. Most of the losses from influenza pandemics come from rare, severe events.

Introduction

Few doubt that major epidemics and pandemics will strike again and few would argue that the world is adequately prepared. Since the 2013–2016 Ebola virus disease outbreak in western Africa, the United States National Academy of Medicine 1 and several other groups 2–4 have pointed to gaps – and the need for greater investment – in preparation against epidemics and pandemics, of Ebola virus disease and other infectious diseases.
Attempts to justify greater investment have mostly been based on estimates of the industrial and macroeconomic losses attributable to influenza pandemics.\textsuperscript{5-11} We have recently extended the loss assessment to include a valuation of the lives lost as a result of the increases in mortality resulting from influenza-pandemic risk.\textsuperscript{12} The inclusion of such a valuation increased the estimated full economic loss attributable to modelled pandemic risk several fold. Below, we discuss our method and summarize our findings. Box 1 presents the definition of several of the terms we are using in this paper.

Valuing lives
Most previous economic studies on global influenza pandemics have focused on income losses – through reductions in the size of the labour force and productivity, increases in absenteeism and, importantly, as the result of individual and social measures that interrupt transmission but disrupt economic activity. While measures such as the per-capita gross national income include the effect of pandemics on income, they also exclude the value of changes in mortality risk to individuals. If, in assessments of investments in pandemic preparedness and mitigation, we neglect this dimension of loss, we will underestimate the value of such investments – relative to alternative uses of public finances.

The broader approach that we recently applied, to the assessment of economic losses attributable to pandemic influenza, factors in the intrinsic loss associated with increases in mortality.\textsuperscript{12} In effect, this approach assigns a dollar value to small changes in mortality probabilities, using values derived from empirical studies of how individuals and societies actually value changes in mortality risk.\textsuperscript{13-16} This approach has already been employed extensively in environmental economics\textsuperscript{13,14} and has also been used in global health, by \textit{The Lancet} Commission on Investing in Health.\textsuperscript{15,16}

Past literature
\textbf{Economic losses from influenza}
We searched Google Scholar and PubMed\textsuperscript{®} for studies on the economic losses from influenza. Almost all of the previous studies examined economic losses in terms of income and ignored the value of – and the loss associated with – mortality risk. The World Bank, for example, generated estimates of global income losses under different
influenza pandemic scenarios.\textsuperscript{10,11} It found that a pandemic of the same severity as the 1918 influenza pandemic might reduce global gross domestic product by about 5\% and that the disruptive effects of avoiding infection would account for about 60\% of that reduction. Another study of the consequences of a range of pandemic severities included an extremely severe scenario that would lead to income losses of over 12\% of gross national income worldwide – including losses of over 50\% of the gross national incomes of lower-income countries.\textsuperscript{5} We found other integrative estimates of the magnitude of pandemic risk in two partially proprietary sources.\textsuperscript{17,18}

Several studies have examined specific dimensions of the economic impacts of annual influenza, such as direct costs – e.g. medical and hospitalizations costs – and indirect costs – e.g. lost earnings due to illness and productivity costs. There are examples of such studies based in the Americas,\textsuperscript{6,7,19–22} Asia\textsuperscript{8,23} and Europe.\textsuperscript{24,25} Other models have added an estimated value of the intrinsic undesirability of nonfatal illness or of pandemic fear, as seen in the population response to severe acute respiratory syndrome in Asia.\textsuperscript{8} Media coverage may also lead populations to overreact to mild pandemics.\textsuperscript{9}

We found only two articles that included estimates of the loss from the elevated mortality associated with influenza pandemics.\textsuperscript{8,19} Of the 10 studies included in a recent systematic literature review on the costs of influenza,\textsuperscript{26} only one\textsuperscript{19} took account of the value of mortality risks.

**Value of a statistical life**

One strand of economic research has examined the intrinsic value of mortality risks, which is commonly expressed as the so-called value of a statistical life. This value is derived either from questionnaires that canvass how much compensation an individual would demand, to accept a small increase in the probability of their death,\textsuperscript{1} or from quantitative studies of the labour market that investigate the trade-offs between small fatality risks and income.\textsuperscript{2,27}

Beyond influenza, the value of mortality risks has been included in estimating the costs of vaccine-preventable diseases\textsuperscript{28} and in evaluating the economic burdens posed by rheumatic heart disease.\textsuperscript{29} Far more studies have assessed the burden of specific environmental risk factors.\textsuperscript{13,14}
The value of a statistical life, which is sometimes expressed as the value of a standardized mortality unit – i.e. an increase in the annual risk of death of 1 in 10,000 – varies by both the age and income of the individual involved.\textsuperscript{15,16,27} In general, the value of mortality is elastic to age and to income – i.e. younger individuals place a higher value on mortality than older individuals, and higher-income individuals generally value mortality more than lower-income individuals. The main findings of our recent study appeared consistent when, in robustness and sensitivity checks, we used estimates that were unconditional on age and estimates with varying income elasticity with respect to the value of mortality.\textsuperscript{12}

**Expected-loss framework**

Given the uncertain nature of an influenza pandemic – in terms of both when it may occur and how large the mortality risks will be – we applied an expected-loss framework that accounts for the uncertainty over a long period of time.\textsuperscript{7} An expected-loss framework incorporates information on the risk of an uncertain event – e.g. a pandemic – with information on the severity or value of that event – e.g. the increase in mortality. Although it has been estimated that the 2013–2016 Ebola virus disease outbreak led to about 11,300 deaths,\textsuperscript{30} the death toll from a severe influenza pandemic might be 2500 times higher than this.\textsuperscript{12} In any given year, however, the risk of a severe influenza pandemic is much smaller than that of an Ebola epidemic. The use of an expected-loss framework allows policy-makers to compare the expected losses associated with events with relatively high annual probability but low mortality – e.g. an Ebola outbreak – with those of events with relatively low probability but high mortality – e.g. the 1918 influenza pandemic.

**Exceedance probability function**

Expected-loss frameworks are commonly used, by actuaries in the insurance industry, to calculate the size of premiums – e.g. for flood or health insurance. To value the consequences of uncertain events appropriately, the insurance industry estimates so-called exceedance probability functions. These functions generate estimates of the probability that, over a specified time frame, losses from an uncertain event – e.g. an influenza pandemic – would exceed any specified level. For our analysis, we developed an exceedance probability function for a global influenza pandemic. To parameterize the
function, we turned to historical data on global influenza pandemics since the 1700s.\textsuperscript{31–34} Six pandemics in this period led to excess mortality rates ranging between 0.03\% and 0.08\% of world population. In 2017, this range would be the equivalent of between 2 million and 6 million excess deaths globally. A modelling exercise for the insurance industry concluded that the annual risk of an influenza outbreak on the scale of the 1918 pandemic lies between 0.5\% and 1.0\%.\textsuperscript{18} For more severe pandemics, we fitted a parametrized exceedance probability function to modelled data that had been previously reported.\textsuperscript{18,35}

\textit{Model calibration}

Following common practice in the insurance industry, we defined risk, \( r(s) \), in terms of the annual probability of a pandemic having a severity exceeding \( s \) and the return time for \( s \) as the expected number of years before a pandemic of at least severity \( s \) will occur. If \( t(s) \) is the return time, then \( t(s) = r(s)^{-1} \). For example, if the annual probability of a pandemic of severity at least \( s \) is 1\%, then its return time will be 100 years.

If we had access to a function \( r(s) \) showing exceedance probability as a function of severity, our analysis could proceed using the expected value of severity of all pandemics. Because \( r(s) \) is the complementary cumulative of the density for \( s \), we would have expected value of:

\[
    s = \int_0^\infty r(s) \, ds \quad (1)
\]

We calibrated this model using historical estimates of the frequency and severity of influenza pandemics, which we obtained from our literature search on PubMed\textsuperscript{®} and Google Scholar. For mortality data relating to the 1918 influenza pandemic, we also searched the libraries at Harvard University and the University of Hawai‘i for historical documents and life tables. Studies were restricted to those with abstracts in English.

Like other economic studies of pandemic influenza, we identified two main influenza pandemic scenarios in terms of aggregate mortality: moderate and severe. Our review classified the 1918 pandemic as severe. As the world population in 1918 was about 1830 million and historical data indicate that there were at least 20 million pandemic-related deaths in that year, the excess death rate associated with the pandemic was at least 1.1\%. A closer examination of the data from India indicate that the true
global rate was probably far higher than 1.1% – the pandemic led to 14 million deaths in India\textsuperscript{36–38}, and it seems implausible that India accounted for 73% of all of the pandemic-related deaths at a time when it had 18% of the world population. However, to be conservative, we chose to use an excess mortality rate of 1.1% in our model of a severe pandemic. In the corresponding model for moderate pandemics, we used a global aggregate excess mortality rate of 0.05%, as seen in historical moderate pandemics.\textsuperscript{39}

Our calibration pointed to a very fat-tailed distribution. Thus, compared with an exponential function, the hyperbolic family of complementary cumulative distributions provided more natural candidates for $r(s)$. We parameterized the hyperbolic function in terms of its expectation and the fatness of its tail.\textsuperscript{40} Thus:

$$r(s) = \frac{1}{m} (1 - f s)^{-1 + \frac{1}{1 - f}}$$

where $1/m$ is the expected value of $s$, and $f$ indicates the fatness of the tail – with smaller values implying a fatter tail. Our calibration indicated that $m$ had a value of 1.8 and $f$ a value of $-2$. It had previously been estimated that, in 2015, a 1918-type pandemic would have killed 21 million to 33 million people, with a return time of 100–200 years.\textsuperscript{35} Our models produced similar values. Recent estimates of influenza and pneumonia mortality\textsuperscript{18,31} are also consistent with our all-cause mortality estimates. Our estimates are based on assumptions that are probably quite conservative. Substantially greater severities and likelihoods have been discussed elsewhere.\textsuperscript{5,35,41,42}

**Mortality-inclusive economic losses**

We used our estimated exceedance probability function and empirically estimated values for small changes in mortality risk to calculate the expected – i.e. mortality-inclusive – economic losses associated with a moderate or severe influenza pandemic. At 2013 values, the expected losses for 2015 amounted to about 500 billion United States dollars (US$) – i.e. about 0.6% of global income – per year.\textsuperscript{12} The estimated proportion of annual national income represented by the losses varied according to country income grouping, from a little over 0.3% in high-income countries to 1.6% in lower-middle-income countries (Table 1).

The expected-loss framework distinguishes between the loss associated with a certain event that occurred – e.g. the mortality that occurred as a result of the 1918
influenza pandemic – and the expected loss associated with an uncertain event over a period of risk exposure. The expected loss combines both the risk of a moderate or severe pandemic and the losses from that event should the event occur. The expected-loss framework thus produces estimates of expected losses of an uncertain event, rather than actual losses of a certainly occurring event. We estimated the expected number of pandemic-related deaths to be just over 700,000 per year. This level of mortality is on a similar scale to that attributable to other – more certain – causes of death, including other major infectious causes of death.¹²

Importantly, we concluded that most of the expected loss from influenza pandemics results from extreme events. One effort to estimate exceedance probability functions indicated that, among all pathogens that can cause a pandemic, influenza virus was likely to be the predominant cause of pandemic-related mortality.¹⁸ The implication is clear: any efforts at pandemic preparedness need to be most strongly focused on influenza and on preparation for a severe scenario.

Our results present losses much higher than those found in studies limited to income losses. Income losses have been estimated to represent around 15% and 50% of the total economic losses associated with a severe pandemic and a mild pandemic, respectively.⁵,¹¹ In previous studies, across modelled pandemics of all severities, mean income losses were estimated to be US$ 80 billion per year⁵,¹¹ – i.e. about 16% of our estimate of total pandemic-related costs.

Climate change
In terms of the percentage of global income, our estimate of total pandemic-related costs (0.6%) falls within the corresponding Intergovernmental Panel on Climate Change’s estimates of the costs of global warming (0.2–2.0%).⁴³ However, the magnitude of future global warming and the associated economic losses are still uncertain.⁴⁴,⁴⁵ The same is true for future pandemics. Many of the hundreds of studies on the potential costs of climate change⁴⁶ have been hampered by the wide variation in estimates of the so-called social cost of carbon.⁴⁷ If this cost is set at about US$ 120 per tonne, the cost of the carbon dioxide emissions in 2013 would have been about 1% of global income.⁴⁶,⁴⁸ As in many previous attempts to estimate the economic losses associated with a pandemic, many previous attempts to estimate the social costs of carbon have focused on national
income accounts – without any explicit valuation of the increases in mortality resulting from climate change. The mortality-associated costs of climate change may be relatively small, however, since the slowness of climate change should allow for some compensatory human adaptation.

Limitations
Our study had several limitations. First, we ignored the intrinsic undesirability of nonfatal illness and/or pandemic fear. Intense media coverage may lead populations to overreact to mild pandemics. Second, our estimates of future pandemic risk and severity – and the economic estimates on which these epidemiological estimates are based – are relatively crude – partly because pandemics remain rare and uncertain events. Future modelling should lead to improved estimates over time. Third, the assignment of monetary value to small changes in mortality risk – and, particularly the relationship between valuation of such risk and both individual income and age at death – remains controversial. However, the results of sensitivity analyses, in which we applied a range of assumptions on these parameters, indicated that our main findings were reasonably robust.

Policy development
In addition to pathogens of pandemic potential, an expected-loss framework may also be applied usefully to malaria and other diseases that have fluctuating incidence. As cases of the disease become rarer as the result of effective interventions, malaria becomes less visible politically and financially, and policy-makers in some countries may have responded by reducing control efforts prematurely. Policy-makers – and the societies they serve – could benefit by using an expected-loss framework to estimate the losses associated with uncertain and rare events across the full range of potential outcome severities. This could lead to appropriate and beneficial adjustments to each policy-maker’s sense of risk and sense of value and to improved national policies on epidemic and pandemic preparedness. A recent United States National Academy of Medicine report argued that, given the risks we estimated, policy attention has fallen short. National efforts at pandemic preparedness have benefits beyond national borders. Some have therefore argued that, for the global good, resources for development assistance should be used to provide incentives for national investments and international collaborations in such preparedness.
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Competing interests:
None declared.

References


Box 1. Definition of terms used in this article

Loss
The consequences of a pandemic, in terms of lost income or lost lives.

Costs
The expenditures made to prepare for – or recover from – a pandemic.

Pandemic risk
The estimated probabilities that, in any given year, pandemics of varying degrees of severity will occur.

Pandemic severity
Excess deaths per population attributable to a given influenza pandemic.

Expected annual losses
Defined in the probabilistic sense, as the sum, across severities, of the losses associated with a pandemic of any given severity multiplied by the probability that a pandemic of that severity will occur in the coming year.

Note: This nomenclature accords with that of the insurance industry.

Table 1. Mortality and economic losses of influenza-pandemic risk, 2015

<table>
<thead>
<tr>
<th>Variable</th>
<th>Country income group</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Lower-middle</td>
</tr>
<tr>
<td>Expected mortality (thousands of deaths/year)</td>
<td>120</td>
<td>390</td>
</tr>
<tr>
<td>Expected annual economic losses (% of GNI/year)</td>
<td>1.1</td>
<td>1.6</td>
</tr>
</tbody>
</table>

GNI: gross national income.

a Data are based on modelled risk of either a moderate or severe pandemic in 2015.12

b Both loss of national income and intrinsic loss associated with elevated mortality.