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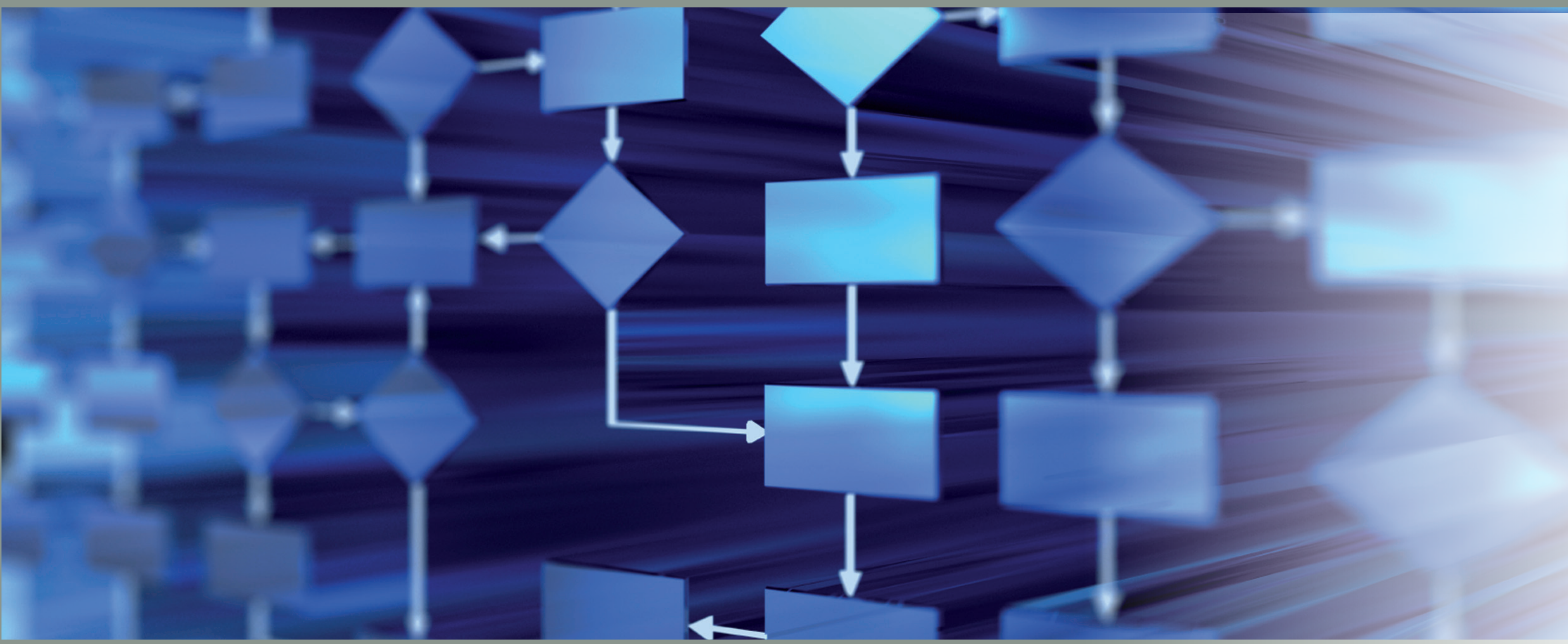
Calculating private and social returns to COVID-19 vaccine innovation

Carsten Fink



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Calculating private and social returns to COVID-19 vaccine innovation[1]

Carsten Fink[2]

Abstract:

What is the return to COVID-19 vaccine innovation? This paper seeks to quantify both private and social returns, using available data on commercialized vaccines and certain assumptions about the pandemic's epidemiological path as well as the economic costs of containment measures. The calculations reveal high returns to innovation. In the baseline scenario, the social benefit of vaccine innovation amounts to 70.5 trillion United States (U.S.) dollars globally, exceeding its private benefit by a factor of 887. The calculations bear on the private and public incentives to invest in vaccine innovation.

JEL Classification: O35, O38, I18

Keywords: *Innovation, COVID-19, Social return, Public health*

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Disclaimer:

The views expressed in this article are those of the author and do not necessarily reflect the views of the World Intellectual Property Organization (WIPO) or its member states.

[1] The research underlying this paper was completed in early November 2021.

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I. Introduction

Investments in innovation generate benefits for society that go beyond the financial rewards reaped by successful innovators. In economic parlance, the social return to innovation often exceeds its private return. A higher social return results from so-called innovation spillovers – consumers, competing firms, and future innovators benefitting from an innovation beyond the price they pay for it.

Is it possible to quantify returns to innovation? Companies investing in innovation surely have some expectations about future returns. Even if innovation is risky, they can evaluate the demand for new products and technologies if they succeed. Estimating the social return to innovation is far more difficult. As innovations spread through the economy, capturing the varied spillovers poses numerous measurement challenges. As time goes by, the truly unpredictable consequences of groundbreaking innovations further amplify this challenge.

Nonetheless, a few academic studies exist that have attempted to calculate a social return to specific historical innovations. Crafts (2004) has quantified the contribution of steam technology to economic growth in Great Britain in the late 18th and 19th century. Oliner and Sichel (2003) have estimated the contribution of information and communication technologies (ICTs) to the United States of America (U.S.) growth in the last quarter of the 20th century. While insightful, these studies only capture the growth contributions in the technology-producing sectors; they ignore possible productivity spillovers in other sectors of the economy. Beyond these studies on specific technologies, Jones and Summers (2020) have estimated the social return to all innovative activities for the U.S. economy, arguing that the economy-wide approach nets out the many spillovers due to innovation. They find this return to be high – even under conservative assumptions, 1 U.S. dollar spent on innovation produces economy-wide benefits equivalent to 4 U.S. dollars and more.

This paper seeks to quantify the private and social returns to COVID-19 vaccines globally. In contrast to most other innovations, the immediate social benefits from these vaccines are well-defined and quantifiable. By halting the pandemic, COVID-19 vaccines save lives and prevent other adverse health outcomes. In addition, they reverse the economic output losses caused by the pandemic's containment measures. Nonetheless, putting numbers on the returns is far from straightforward. It runs into several data constraints, and requires making assumptions about alternative epidemiological paths and their consequences. The quantification presented here are thus not a reliable estimate of innovation returns, but rather as an informed thought experiment, which offers insights into orders of magnitudes.

The paper finds that the social return to COVID-19 vaccine innovation is high and far exceeds the private return reaped by the vaccine innovators. This is hardly a surprising insight. However, putting numbers on the social return underlines the sheer magnitude of the innovation's benefit. In addition, the quantification exercise sheds some light on the relative importance of the factors that determine returns and on public and private innovation incentives. The paper proceeds as follows. Section II presents the baseline calculations of private and social returns and explains the assumptions behind those calculations. Section III considers alternative scenarios and evaluates how they would change the calculated returns. Section IV discusses several additional socio-economic consequences of the pandemic that are difficult to quantify but affect the social benefit of vaccine innovation. Section V offers a few concluding remarks.

II. Baseline calculation

We start with a baseline calculation of the private and social returns to COVID-19 vaccines. This estimation relies on several assumptions about the revenues realized by vaccine makers, the manufacturing costs, the innovation costs, the health benefits of vaccination campaigns and the economic benefits from controlling the pandemic's spread.

Private return

We define the private return to COVID-19 vaccines (*PR*) as

$$PR = \frac{(R - C)}{V} - 1$$

whereby *R* denotes the revenue realized by vaccine makers due to COVID-19 vaccines; *C* the costs of manufacturing the vaccines; and *V* the innovation costs for successful and failed vaccines.

To estimate the revenue *R* accruing to vaccine makers, we use as a point of departure the world's population, which, according to the United National Population Fund stands at 7,875 billion in 2021. It is uncertain what share of the world's population will eventually receive a vaccination. The most advanced national vaccination campaigns have reached a share of 75 percent and more, mindful that this share is still far lower in many developing economies. The 75 percent "frontier" share could still rise, especially as vaccination campaigns are extended to children, and governments and employers introduce vaccination mandates and incentives. Vaccination hesitancy, in turn, could result in a lower share in certain countries. Either way, for the baseline calculation, we stick to the 75 percent benchmark and assume that 5,906 billion people will eventually be vaccinated.

The prices of vaccines vary, not only between the different vaccine products available, but also for the same vaccine depending on the purchaser. In addition, most vaccines require (at least) two jabs, with the Johnson & Johnson vaccine requiring only a single jab.

As most vaccine procurement contracts are confidential, comprehensive price information is unavailable. However, various media reports have pointed to price ranges for five of the key vaccines authorized, so far. These price ranges are reported in Table 1, along with estimated 2021 production volumes. Using the mean prices for each vaccine, we calculate a weighted average price of 22.1 U.S. dollars per person, with per person production volumes serving as weights. This is clearly an imperfect estimate. It does not include all the vaccines authorized, so far, and the mean of published price ranges may not reflect actual prices paid. In addition, new vaccines may enter the market and vaccine makers may adjust their prices, depending on a variety of market forces. That said, for the purpose of this paper, the price of 22.1 U.S. dollars per person estimate seems like a reasonable estimate.[3]

[3] In the case of BioNTech/Pfizer, the figures presented in Table 1 are consistent with Pfizer's announcement that it expects COVID-19 vaccine sales to top US$ 33.5 billion in 2021.

Table 1: Price ranges and estimated 2021 production volumes for key vaccines

Vaccine manufacturer	Price range (in US$), per person	Estimated 2021 production volume (billion doses)
BioNTech/Pfizer	30-39	2.10
Moderna	30-36	1.00
AstraZeneca	4.3-10	1.96
Johnson & Johnson	10	0.60
Sinovac	27.2	3.67

Sources: Price ranges were taken from The Guardian; estimated 2021 production volumes were taken from the New York Times (for BioNTech/Pfizer and Moderna), Airfinity (for AstraZeneca and Sinovac) and Reuters (for Johnson & Johnson).

Taken together, the assumption that 5,906 billion person will be vaccinated at a price of 22.1 U.S. dollars per person, implies total private revenues of 130.5 billion U.S. dollars.

We next turn to the manufacturing cost *C*. Estimating *C* is difficult, for several reasons. Different vaccines rely on different technology platforms with varying manufacturing complexity. In addition, manufacturing costs have a variable and a fixed-cost component. The former reflects the input of raw materials and labor, whereas the latter consists of the costs of building the necessary production capacity along the vaccine supply chains. No systematic and comparable data exist on these cost components for the different vaccines authorized, so far. Kazaz et al. (2021) rely on Moderna's 2020 financial statement to derive an estimate of unit variable costs of 4.68 U.S. dollars per dose for Moderna's mRNA vaccine. In the absence of any further information, we extrapolate this estimate to all vaccines and ignore, for now, the fixed production cost. Mindful of the single dose regime for the Johnson & Johnson vaccine, this yields a manufacturing cost of 8.62 U.S. dollars per person. For 5,906 billion persons, this sums to 50.9 U.S. dollars billion.

Again, this is a crude estimate. Vaccines based on mRNA technology are the most complex to manufacture. Other vaccines may be cheaper to produce.[4] In addition, given the novelty of the mRNA vaccine platform, there may well be learning opportunities to lower the unit variable cost.

The final element is to estimate the innovation cost *V*. This cost consists firstly of R&D spending. Many – but not all – of the vaccine manufactures received substantial public funding to support their R&D. The U.S., through operation Warp Speed, provided most funds, but Germany, the United Kingdom (U.K.), the European Union and many other high-income economies also made available substantial resources for vaccine R&D. The Global Health Center of the Graduate Institute documents R&D investments into COVID-19 vaccines of 6.6 billion U.S. dollars, of which around 91 percent represent public funding.[5] This figure does not include vaccine R&D investments funded internally by pharmaceutical companies, which are not publicly disclosed. Some companies, such as Moderna, received substantial public funding,

[4] That said, it is worth noting that AstraZeneca has stated that its vaccine will be sold on a cost basis and the 8.62 U.S. dollars per person estimate lies within the 4.3 to 10 U.S. dollars price range of its vaccine.

[5] See the COVID-19 Vaccine R&D Investments database by the Global Health Center of the Graduate Institute. Note that some funding may include investments to scale-up manufacturing capacity. At the same time, the 6.6 billion U.S. dollars figure does not include advance purchase commitments by governments that served to reduce the R&D investment risks of companies.

whereas others, such as BioNTech/Pfizer, entirely self-funded their R&D. The 6.6 billion U.S. dollars figure thus underestimates total investments in vaccine R&D, possibly substantially so.

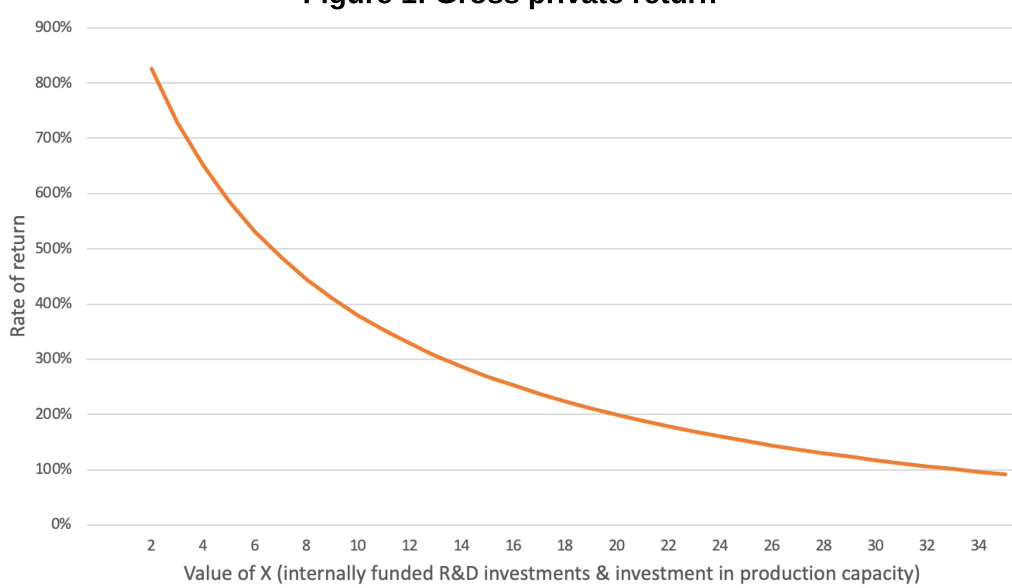
In addition to the R&D cost, at least part of the fixed costs of building vaccine production capacity should count towards the overall vaccine innovation cost. The variability of biological processes makes large-scale vaccine manufacturing a technological complex undertaking. The COVID-19 vaccines of BioNTech/Pfizer and Moderna, in particular, were the first ones relying on mRNA technology. Again, governments supported the building up of vaccine manufacturing capacity, notably while the vaccines' clinical trials were still ongoing. However, there are no comprehensive data on public and private investments in production capacity. In addition, not all of these investments would relate to activities that fall under the definition of innovation, as commonly defined.[6]

In light of the above, we will take innovation costs to be "6.6 billion U.S. dollars + X", whereby X captures the privately funded investments into R&D and relevant investments into vaccine production capacity. Taken together, the above parameter values imply the following private rate of return:

$$PR = \frac{(130.5 - 50.9)}{6.6 + X} - 1$$

with figures expressed in million U.S. dollars. Figure 1 depicts this rate of return depending on different values of X. The higher X, the lower the private return. Given that the cost estimate excludes fixed "non-innovative" production costs, the return should be seen as a gross return, rather than the net profit accruing to vaccine makers.

Figure 1: Gross private return



[6] See the OECD's Oslo Manual (OECD/Eurostat, 2018).

Figure 1 suggests a high private return to vaccine innovation, even with a large value of X and substantial fixed production cost. This implies the presence of strong private incentives to invest in vaccine innovation. One may thus speculate whether public funding was really necessary to promote innovation. However, it is important to note that Figure 1 offers an ex-post perspective on the private return of a successful innovation. At the outset, there was substantial uncertainty about how long the development of vaccines would take and how effective they would be.[7] Indeed, several COVID-19 vaccines have failed clinical trials.[8] Public funding of R&D and advance purchase commitments likely helped to lower the incipient R&D risk faced by innovating companies.

Social return

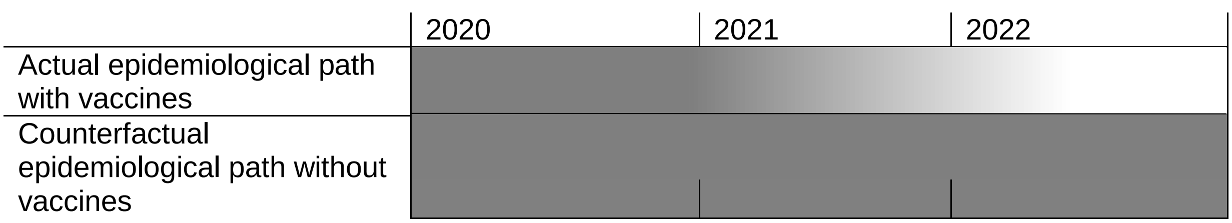
We define the social return to COVID-19 vaccines (*SR*) as

$$SR = \frac{(L + O)}{V} - 1$$

whereby L denotes the value of saved lives and saved health impairments and *O* as the “recovered” output from the lifting of containment measures.

Estimating the value of saved lives and the avoidance of health impairments due to COVID-19 infections requires, first of all, a counterfactual scenario of how many people would have died and suffered so-called long COVID-19 symptoms in the absence of a vaccine. Figure 3 illustrates the actual and counterfactual epidemiological paths. Vaccination rollouts started in late 2020, so the social benefit of vaccines only began to accrue from this point onwards. Due to constrained manufacturing capacity and limited infrastructure, it will take until 2022 and possibly longer to complete vaccination campaigns. During this time, vaccines protect a growing share of the population, implying a growing social benefit.

Figure 3: Actual and counterfactual epidemiological paths in the baseline scenario



In the baseline scenario’s counterfactual path, the pandemic would last for three years – mirroring the Spanish flu – during which time the world’s population would be fully exposed to the virus, as was the case in 2020.

How many infection cases would vaccines prevent relative to the counterfactual scenario? To answer this question, it is first instructive to ask how many people have already contracted the virus. As of September 2021, the official infection case count stood at 232 million, which would suggest a global infection share of only 3 percent. The official death toll stood at 4.7 million.[9]

[7] See, for example, https://www.ibm.com/blogs/watson-health/how-long-will-a-vaccine-really-take.

[8] https://www.nytimes.com/interactive/2020/science/coronavirus-vaccine-tracker.html

[9] See https://coronavirus.jhu.edu/map.html, visited on September 27, 2021.

However, these statistics undercount the true number of infection and death cases. Infection counts rely on positive COVID-19 tests, yet not every infected person is tested – especially if there are no disease symptoms. Similarly, the official death count only captures the death of patients diagnosed with COVID-19 and excludes deaths from other causes that still may be attributable to COVID-19.

A more complete picture of COVID-19 mortality emerges from studies of so-called excess mortality, which estimate the extent to which the number of deaths from all causes during a crisis exceeds expected levels under non-crisis conditions. Making a global estimate of excess mortality deaths during the pandemic is not straightforward, however, as many countries – especially poorer ones – do not compile the required mortality statistics. Relying on mortality statistics for 84 countries and model predictions for the rest of the world, The Economist magazine estimates the number of deaths caused by COVID-19 to lie between 9.7 million and 18.3 million people, with a single best estimate of 15.6 million deaths.[10]

What infection shares do these mortality estimates imply? While still heavily debated in the public health literature, published meta-analysis of studies conducted around the world point to an infection fatality rate (IFR) of between 0.27 percent and 0.68 percent.[11] Assuming a mid-point IFR of 0.475 percent, 15.6 million deaths would imply that 3.28 billion people – or 41 percent of the world's population already contracted COVD-19. Estimated IFRs vary considerably across age group and location, however, and applying two mid-point estimates of wide ranges leave considerable scope for error. At the same time, the 41 percent share is broadly consistent with a study that estimates the infection share in the U.S. based on antibody tests performed in samples of the population. This study concluded that, in 2020 alone, roughly one-third of the U.S. population contracted the virus.[12]

For the purpose of calculating the social return to innovation, our baseline scenario assumes that the COVID-19 vaccination campaigns have and will have protected 30 percent of the world's population from contracting the virus. This assumption is based on the logic that, per the above, roughly 35 to 45 percent of the population has already contracted the virus and that global herd immunity begins at 65 to 75 percent. Thus, without vaccination an additional 2.4 billion people would and will have contracted COVID-19. Taking again the mid-point IFR estimate of 0.475 percent, this would imply a total of 11.2 million deaths.

Aside from fatalities, it is important to account for the social benefit of long COVID-19 impairments preempted by vaccinations. One study conducted in the U.K. found that 6 percent of infected persons reported experiencing at least one of 29 symptoms linked with COVID-19 for 12 weeks or more.[13] Applying this figure to the assumed 30 percent share of the world population contracting COVID-19 in the absence of vaccination campaigns implies around 142 million persons affected by long COVID-19 ailments.

What is the economic value of saved lives and avoided health impairments? There is a sizeable body of literature on the average value of a statistical life (VSL).[14] This concept does not seek

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[10] https://www.economist.com/graphic-detail/coronavirus-excess-deaths-estimates

[11] See Meyerowitz and Katz (2020) and Ioannidis (2021).

[12] See Pei et al. (2021).

[13] See Whitaker *et al* (2021).

[14] Cutler and Summers (2020) similarly employ VSL estimates to evaluate the social cost of the pandemic in the US. In estimating the social value of COVID-19 vaccines for the United States, Hemel and

to put a “price tag” on an identifiable human life. It rather captures the money-mortality risk trade-off, as revealed in decisions that entail varying mortality risks. For example, wage price premiums for occupations with higher fatality risk – combined with data on actual fatalities – are one way to calculate the VSL. Viscusi (2021) argues that the risk of contracting COVID-19 is comparable to various occupational fatality risks. Based on meta-analysis of available VSL estimates, he uses a focal value of 11 million U.S. dollars per person for the U.S. In line with evidence that the VSL varies proportionately with income, we derive a VSL for the world of 3 million U.S. dollars per person.[15] With 11.2 million lives saved due vaccination, this implies a social benefit of 33.6 trillion U.S. dollars.

Estimating the social benefit of preempted long COVID-19 impairments is more difficult, as those impairments vary in type, severity and length. The literature does not yet provide any valuation of the morbidity effects associated with COVID-19 infections. In the absence of more rigorous evidence, we apply a share of 6 percent to the VSL estimate for the world for each person suffering long COVID-19 impairments. The 6 percent share represents the lower bound of the morbidity component of a VSL estimate based on the risk of fatal job injuries.[16] With 142 million avoided long COVID-19 cases due to vaccination, this implies an additional social benefit of 25.5 trillion U.S. dollars. We thus arrive at a value of V equal to 59.1 trillion U.S. dollars.

We turn next to the “recovered” economic output from the lifting of containment measures. Just as with saved lives, an estimate of the avoided output loss requires a counterfactual scenario of how the world economy would have fared if there were no vaccines. One way to arrive at such an estimate is to consider the decline in output in 2020, before the start of most vaccination campaigns. In January 2020, unaware of the pandemic’s impact, the IMF predicted the world economy to grow by 3.3 percent in 2020.[17] World output actually declined by 3.2 percent that year.[18] This implies a growth decline of 6.5 percent, which can be reasonably attributed to the pandemic’s containment measures. With global GDP at around 87.8 trillion U.S. dollars, this implies an output loss of around 5.7 trillion U.S. dollars per year.

The world economy is set to recover in 2021, with the lifting of containment measures due to widespread vaccination as a key contributing factor. We assume that without vaccination the world economy’s output would have been 5.7 trillion U.S. dollars per year below its non-pandemic potential for the full duration of the pandemic. With the assumed three-year duration, this implies a total output loss of 17.1 trillion U.S. dollars. Subtracting the output loss during the pandemic’s first year when vaccines were not available, implies a social benefit O attributable to vaccines of 11.4 trillion U.S. dollars. One could argue that this overestimates the “recovered” output strictly due to vaccination, as lockdown measures continued to be in place in 2021 while vaccinations were being rolled out. At the same time, the duration of the pandemic could have

Ouellette (2021) use valuations of quality-adjusted life-years (QALYs). The VSL approach, however, better captures the mortality risk of COVID-19 infections and lends itself to easier extrapolation at the global level.

[15] Meta-regression analysis of studies on the cross-country income elasticity suggests a unitary elasticity (Viscusi, 2021). The world estimate applies the ratio of US GDP per capita to world GDP per capita to the 11 billion U.S. dollars estimate. GDP per capita data are from the World Bank’s World Development Indicators database and, for the world, rely on PPP values. All data are for 2019.

[16] See Gentry and Viscusi (2016).

[17] https://www.imf.org/en/Publications/WEO/Issues/2020/01/20/weo-update-january2020

[18] https://www.imf.org/en/Publications/WEO/Issues/2021/07/27/world-economic-outlook-update-july-2021#Projections

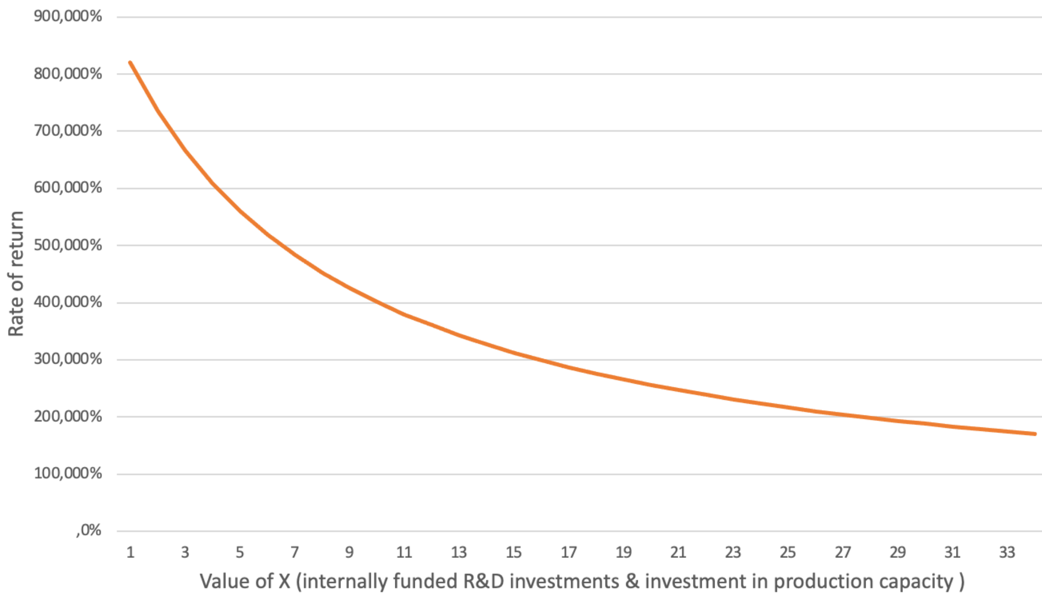
easily exceeded three years in the counterfactual scenario, especially if lockdown measures had prolonged the attainment of herd immunity. Overall, our estimate of the global output loss appears conservative in comparison to similar estimates.[19]

Taken together, the above parameter values imply the following social rate of return:

$$SR = \frac{(59{,}100 + 11{,}400)}{6.6 + X} - 1$$

with figures expressed in billions of U.S. dollars.[20] Figure 2 depicts this rate of return depending on different values of X.

Figure 2: Social return



It is clear that even with high values of X, the social return to vaccine innovation is extremely high – likely, in excess of 100,000 percent. The high social return is primarily due to the value of reduced mortality and morbidity caused by the pandemic. In other words, the most direct human health benefits of vaccines exceed the economic output gain from lifting social-distancing measures.

The social return is also far greater than the private return. To be precise, investments in vaccine innovation yield a social benefit of 70.5 trillion U.S. dollars, which exceeds the private

[19] The IMF's Chief Economist predicted a cumulative output loss of 22 trillion U.S. dollars over 2020 to 2025 (https://www.imf.org/en/News/Articles/2021/01/28/tr012621-transcript-of-the-world-economic-outlook-update-press-briefing). Castillo et al (2021) employ a "conservative measure" of 1 trillion U.S. dollars of global monthly harm.

[20] One may argue that the innovation cost, *V*, in the social return calculation should include the costs of administering the vaccines. Given the speed and scale of vaccination campaigns, they arguably entailed substantial public sector innovation. See Section 2.6 in OECD/Eurostat (2018). Including the costs of administering the vaccines would lower the social return, but it would remain extraordinarily high for any realistic value of those costs.

benefit to vaccine makers by a factor of 886.[21] This high multiple provides another rationale for public funding for vaccine R&D: at the outset, the social benefit from the development of successful vaccines were predictably very large, even if these vaccines had not been privately profitable.

III. Alternative scenarios

The baseline calculation presented in the previous section suffers from imperfect data and relies on broad and debatable assumptions. This section considers several alternative scenarios and evaluates how they would change the calculated returns.

Cumulative nature of innovation

The successful COVID-19 vaccines were the outcome of dedicated investments in research and clinical development. However, their invention and development relied crucially on scientific and applied knowledge generated prior to the pandemic. This includes the knowledge gained from years and, indeed, decades of vaccine research, and scientific advances in biochemistry, molecular biology, medicine and related fields.[22] A broader view would even include advances in information and communication technologies, which are crucial to the operation of scientific labs and the sharing of data among researchers.

The COVID-19 vaccine research efforts, in turn, have generated valuable knowledge that may spur future scientific advances and pharmaceutical inventions. For example, the success of the BioNTech/Pfizer and Moderna vaccines proved the effectiveness of the mRNA vaccine technology, which could be the basis for vaccines against other infectious diseases and may even help in fighting diseases such as cancer and rare genetic conditions.[23]

One may argue that the generation of prior and future knowledge should be included in the calculation of social returns. To the extent that prior and future knowledge are appropriated within the same companies, there would also be a case for including them in the calculation of private returns. Attempting to do so, however, raises the intricate problems of selecting relevant prior investments in knowledge and not knowing about future uses of newly acquired vaccine knowledge. In addition, the same knowledge may give rise to variety of technologies – each with their own private and social benefit – which defies the idea of a product or technology-specific return to innovation.

From this view, we confine investments in knowledge to the specific COVID-19 related innovation efforts, but alert the reader that the inclusion of prior knowledge investments would naturally lower returns and the inclusion of future knowledge benefits would raise returns.

COVID-19 variants and booster jabs

The baseline calculation assumed that the administration of two vaccine doses – or one in the case of the Johnson & Johnson vaccine – to 75 percent of the world's population would lead to the attainment of herd immunity and thus end the pandemic. The emergence of virus variants and the waning effectiveness of vaccinations question these assumptions. More infectious

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[21] Technically, the 886 multiple is the ratio of $L+O$ divided by $R-C$.

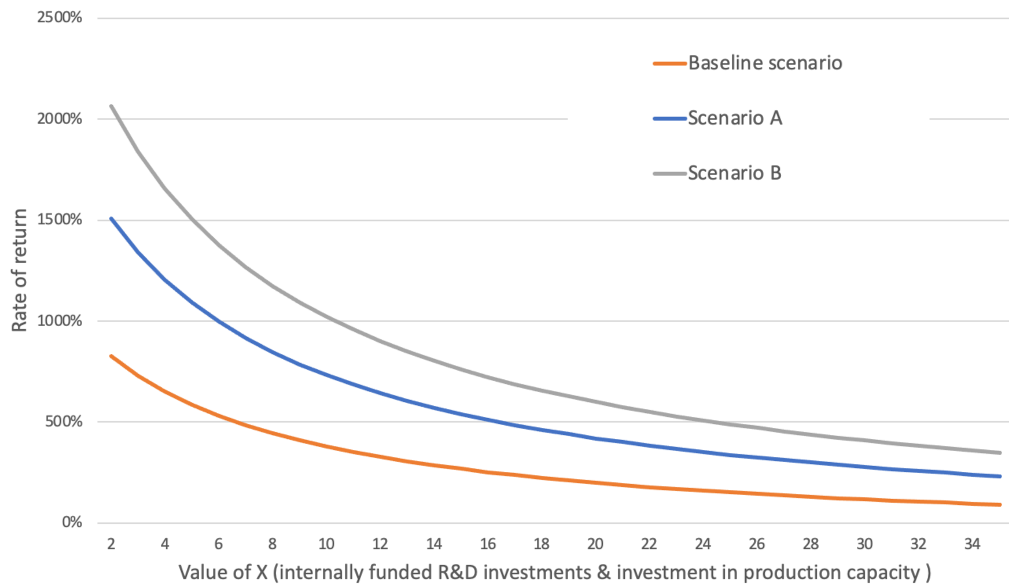
[22] WIPO (2022) offers a perspective on some of the research conducted prior to the pandemic.

[23] https://www.the-scientist.com/news-opinion/the-promise-of-mrna-vaccines-68202

variants of the virus may imply a higher herd immunity threshold and undermine the effectiveness of existing vaccines. Some countries have already embarked on booster vaccination campaigns to uphold immunity in the vaccinated population. Vaccine manufacturers, in turn, are adapting their vaccines to account for new virus variants. In the most pessimistic scenario, global herd immunity will never be achieved and regular booster jabs will become the norm.[24]

How do variants and the need for booster jabs affect the private return to COVID-19 vaccines? Administering more jabs to more people would increase the revenue, *R*, realized by vaccine makers. Assuming that the unit manufacturing cost per vaccine stays the same, Figure 3 depicts the gross private return under two alternative scenarios : (A) herd immunity at 85 percent and one booster jab; and (B) herd immunity at 95 percent and two booster jabs.

Figure 3: Gross private return – alternative scenarios



The higher revenue in the alternative scenarios implies an outward shift of the gross private curve relative to the baseline scenario. Whether the gross private return is higher or lower in the alternative scenarios depends on the value of X. The emergence of new mutants has prompted additional R&D activities and clinical trials for adapted vaccines. Future variants may require additional such efforts. Yet even high levels of additional R&D spending would continue to generate considerable private returns, suggesting continued strong private innovation incentives for adapting COVID-19 vaccines to new mutants.

As pointed out in the previous section, competitive market forces and technological learning would invariably affect the pricing and cost structures in COVID-19 vaccine markets and could significantly affect private returns – especially in the long-term, if booster jabs were to become a regular necessity.

How do variants and the need for booster jabs affect the social return to COVID-19 vaccines? The answer hinges on how the emergence of virus variants would have affected the pandemic's

[24] https://www.nature.com/articles/d41586-021-00728-2

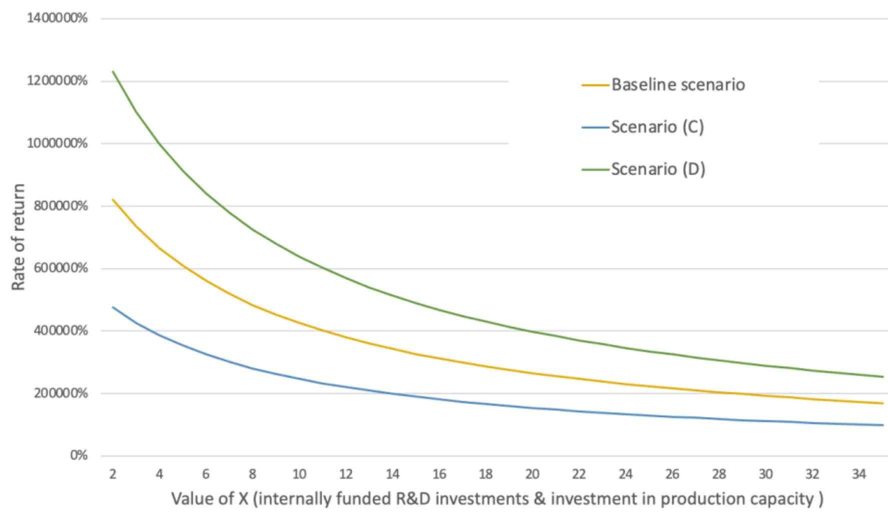
counterfactual epidemiological path. One may argue that virus mutations are a normal feature of a pandemic and are thus part of the baseline scenario outlined in the previous section. Indeed, the Spanish flu mutated to become deadlier as the pandemic progressed.[25] In this case, the only variable affecting the social return is the additional R&D investment to adapt vaccines to the different virus mutants. Instead, one may argue that virus mutations imply a different epidemiological path than the one assumed in the baseline scenario – a subject to which we turn next.

Actual and counterfactual epidemiological path

One of the most uncertain inputs into the calculation of the social return is the share of the world population, which COVID-19 vaccines protect from infection. The baseline scenario assumed a share of 30 percent, partly based on the estimate that 30 to 40 percent of the world's population already contracted this virus. However, the wide parameter ranges behind this latter estimate suggest that the true infection share could be considerably lower but also considerably higher. As pointed out above, significant uncertainty also exists about the world's herd immunity threshold that would end the pandemic. Thus, Figure 4 presents the social return curve under two alternative assumptions: (C) vaccines protecting only 15 percent of the world's population and a pandemic duration of 3 years; (D) vaccines protecting 45 percent of the world's population and a pandemic duration of 4 years. All other parameters are the same as in the baseline scenario.

[25] See https://www.livescience.com/1918-flu-variant-deadlier-later-waves-lung-tissue.html.

Figure 4: Social return – alternative scenarios



Scenario (C) moves the social return curve inward, as a lower infection share implies a smaller socio-economist cost of the pandemic and thus a smaller benefit of vaccines from fighting it. Scenario (D) implies the opposite and the longer duration of the pandemic amplifies the outward shift of the social return curve.

By way of summary, Table 2 shows the ratio of social to private benefits in the baseline and various alternative scenarios. They continue to suggest very high multiples, even in the mutually contradictory case whereby global herd immunity requires 95 percent of the world's population to be immune, yet only 15 percent would contract the virus in the counterfactual pandemic without vaccines.

Table 2: Ratio of social to private benefits

	Baseline scenario • Global herd immunity: 75% • Booster jabs: 0	Scenario (A) • Global herd immunity: 85% • Booster jabs: 1	Scenario (B) • Global herd immunity: 95% • Booster jabs: 2
Baseline scenario • Global infection rate: 30% • Pandemic duration: 3 years	887	511	379
Scenario (C) • Vaccine protection share: 15% • Pandemic duration: 3 years	515	297	220
Scenario (D) • Vaccine protection share: 45% • Pandemic duration: 4 years	1,330	766	569

IV. Other socio-economic effects

The calculation of the social return in the previous two sections relied on the first order socio-economic effects of COVID-19 vaccines: they protect against infection and its consequences, and they restore the ‘normal’ course of economic activity. At the same time, there are other far-reaching consequences of the pandemic for societies and economies, which may ultimately affect the social return to vaccine innovation. These additional socio-economic effects are hard to quantify, and their significance is still difficult to predict, as they may only materialize in the medium to long-term. Without claiming to be comprehensive, this section briefly points to several such other effects.

Curtailed access to healthcare

The pandemic has curtailed access to healthcare – partly due to the social-distancing measures imposed around the world and partly due to overwhelmed healthcare systems. This has meant that patients suffering from other communicable and non-communicable treatments could not always receive the necessary medical treatment – sometimes with tragic consequences.[26]

There is also evidence that the pandemic has caused a drop in routine childhood vaccinations. According to the WHO, 3.7 million fewer children received such vaccinations in 2020 compared to 2019.[27] Some of the affected children may well receive these routine vaccinations in later

[26] Note that excess mortality statistics would capture deaths not directly caused by COVID-19, but indirectly attributable to it.

[27] See https://www.who.int/news/item/15-07-2021-covid-19-pandemic-leads-to-major-backsliding-on-childhood-vaccinations-new-who-unicef-data-shows.

years, with little consequences for their health. However, other children are bound to be exposed to preventable diseases such as measles, polio or meningitis. More dramatically, insufficient childhood vaccinations could lead to future disease outbreaks in different parts of the world.

Educational loss

The prolonged closure of schools in many countries has affected learning outcomes. In Latin America, for example, UNICEF has estimated that school closures affected 114 million students. On average, children lost 158 days of face-to-face schooling.[28] Remote learning is unlikely to have compensated for the lack of face-to-face teaching. According to a World Bank report, there is preliminary evidence of growing learning poverty – defined as the percentage of 10-year-olds unable to read and understand a simple text.[29] Even more dramatically, UNICEF estimates that more than 3 million children in Latin America may permanently drop out of school due to pandemic hardships.[30] Overall, school closures are bound to have exacerbated inequalities in educational outcomes. Limited access to digital technologies in poorer regions and by poorer households has disproportionately constrained the ability of students from low-income families to participate in remote learning offerings.

Labor market hysteresis

The pandemic's economic crisis caused unemployment to spike around the world. Regular unemployment insurance and special unemployment assistance programs instituted in response to the pandemic cushioned the hardship inflicted on affected workers. While the economic recovery in 2021 has caused unemployment rates to fall again, economists have long worried that temporary unemployment spells may become permanent. In particular, affected workers may lose skills and firms' decision to hire workers differs from their decisions to retain workers.[31] For these reasons, many European governments instituted job protection schemes that preempted the laying off of workers affected by the crisis. It is too early to assess the extent of labor market hysteresis due to the pandemic. However, it is worth noting that the length of the economic crisis and associated unemployment spells may play an important role in hysteresis outcomes. To the extent that vaccination campaigns shortened the economic crisis, they may have reduced the damage inflicted on labor markets.

Fiscal effects

The pandemic has had drastic effects on the fiscal position of governments around the world. On the one hand, falling economic activity has prompted declining tax revenues. On the other hand, governments have stepped in to cushion the adverse consequences of the economic fallout and to fund the public health response to the pandemic. The result has been widening fiscal deficits, reaching 11.7 percent of GDP in 2020 for advanced economies, 9.8 percent for emerging market economies, and 5.5 percent for low-income developing countries. The global

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[28] See https://www.unicef.org/press-releases/114-million-children-still-out-classroom-latin-america-and-caribbean.

[29] See https://www.worldbank.org/en/news/press-release/2021/03/17/hacer-frente-a-la-crisis-educativa-en-america-latina-y-el-caribe.

[30] See https://www.unicef.org/press-releases/114-million-children-still-out-classroom-latin-america-and-caribbean.

[31] See Baldwin (2020).

public debt-to-GDP ratio reached 97.3 percent in 2020, 13 percentage points higher than the level projected before the pandemic.[32]

With interest rates near zero and at historical lows, the increase in the debt-to-GDP ratio in advanced countries appears fiscally sustainable. The fiscal policy space is narrower in emerging market and low-income economies, with some of them in growing debt distress. A full-blown debt crisis has been avoided so far, partly due to IMF and World Bank funding and partly due to easy monetary policies by central banks in advanced economies that have supported capital flows to emerging economies. This could still change, as central banks phase out accommodative monetary policies.

Aside from possible concerns about fiscal sustainability, there are questions about whether COVID-19 related public spending may have crowded out other public investments with high social returns that governments would have undertaken without the pandemic.

Opportunity cost of vaccine innovation

The onset of the pandemic triggered substantial investments in medical R&D to fight the COVID-19 pandemic. While overall medical R&D is bound to have increased, an important question is to what extent COVID-19 oriented R&D has crowded out R&D to fight other diseases. As R&D skills are scarce, some re-orientation of R&D resources appears likely. Early evidence, for example, suggests that the pandemic is associated with a 5 percent reduction of clinical trials for diseases other than COVID-19.[33] A re-allocation of R&D resources may well be in societies' best interest, as the pandemic has shifted preferences for technological innovation. Nonetheless, it may come at the expense of diminished progress in the fight against other diseases.

V. Conclusion

This paper offers quantitative guidance on the private and social returns to COVID-19 vaccines. While insufficient data on vaccine R&D investments preclude their precise calculation, the returns are bound to be high. In addition, the social benefit far exceeds the private benefit – by a multiple of 887 in the baseline scenario.

The magnitude of the returns sheds light on the innovation incentives posed by the pandemic and the resulting shift in the direction of innovation. The prospects of high private returns and even higher social returns prompted substantial private and public investments in vaccine R&D. Successful COVID-19 vaccines may well have emerged without any public R&D funding support. However, public funding at the outset was crucial for lowering the investment risk and speeding up the development of vaccines. Government efforts also played an important role in coordinating clinical trials and scaling up manufacturing capacity in advance of regulatory approval – especially in the U.S.[34]

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[32] See IMF (2021).

[33] See Agarwal and Gaule (2021).

[34] See https://www.piie.com/blogs/trade-and-investment-policy-watch/heres-how-get-billions-covid-19-vaccine-doses-world.

The prospect of avoiding large-scale human suffering and lifting economically burdensome pandemic containment measures was the key motivation for the public support provided. The social return calculation suggests that the former benefit outweighs the latter. This finding also makes a case for public health containment measures in the absence of vaccinations or while vaccinations are being rolled out: the pandemic's mortality and morbidity costs exceed the output loss from social distancing.

One may reasonably question many of the assumptions and parameters underlying the calculation of R&D returns presented here. Our understanding of the pandemic's epidemiological path is still evolving. There is still considerable uncertainty about infection fatality rates and morbidity effects, which are bound to vary across populations with different demographic profiles. New vaccines may emerge. Competitive market pressures and technological learning will affect pricing and cost structures. As pointed out in the introduction, the main objective of the calculations presented here is to offer a first perspective on orders of magnitude. Future studies will offer more refined estimates.

As a final thought, anyone in 2019 expecting an innovation with an extraordinary social return to occur in 2020 would probably lament the state of the world in 2021. COVID-19 vaccines have "merely" softened the huge socio-economic costs imposed by the pandemic. In this regard, they differ from other groundbreaking innovations – such as the steam engine and ICTs mentioned in the introduction – that increased economic productivity and raised living standards. From this view, measures and innovations that prevent pandemics from breaking out in the first place may carry an even higher – yet largely invisible – social return.

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