The Value of Medical Innovation in the Fight Against COVID-19 in the United States[1]

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Abstract

A longstanding economic literature argues that the total welfare loss of a disease comes not only from the direct effects of the disease itself, but also the costs of preventing the disease. This paper assesses how new medical innovations for COVID-19—specifically vaccines and therapeutics—reduced both types of losses. These rapidly developed medications and vaccines yielded enormous value in the US and abroad and are likely among the most important innovations in recent history. We find that in their first year of widespread use, these innovations saved at least 699,110 life years in the US, conferring a direct economic benefit of around $371.6 billion. In addition, the reduction in mitigation strategies to avoid COVID-19 infections (e.g., lockdowns, quarantine measures, social distancing) that resulted from the availability of vaccines and therapeutics led to a value of $933.1 billion in increased economic activity in the U.S. Thus, while these innovations had a tremendous impact on population health, an even greater amount of value resulted from enabling the return of economic activities through the lessening of efforts to prevent infection.

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Section 1: Introduction

Accurately measuring the burden of disease has important implications for public policy, including developing appropriate public health efforts to control disease and signaling priorities for the research and development of new medical innovations. Most current methods take a limited perspective primarily focused on the direct harms of addressing the disease itself, which could include the costs of diagnosis and treatment, the costs of living with the disease sequelae, and the losses associated with its resultant morbidity and mortality (Jo, 2014; Kenkel and Fabian, 1994; Ramsey and Sullivan, 2003; World Bank, 1993; Yang et al., 2020).

The impact of medical innovation against COVID-19 on alleviating morbidity and mortality has been well documented. However, the benefits in terms of individual and population health are only part of the value. In particular, traditional methods assessing the damages of a disease underestimate the total burden because they ignore the resources expended to prevent the disease from occurring in the first place. Philipson (1995) lays out how the economic analysis of taxation can be applied to quantitatively assess the total burden of a disease, inclusive of both direct disease impacts and preventive costs. A tax imposes a burden in terms of revenue paid but also an “excess burden” on top of that revenue from costly behavior undertaken to prevent paying the tax. To illustrate, a million-dollar tax on airline tickets would generate no tax revenue but have an enormous excess burden through distorting travel. Similarly, polio currently imposes a minimal disease burden in the US, with nearly all its economic burden resulting from preventive measures such as vaccinations. Thus, a disease imposes a liability not only from its incidence, but also from resources invested in efforts to avoid it. Simply put, a disease can impose harm that extends to unaffected individuals, if it induces those individuals to engage in preventive behaviors that have potentially undesirable clinical and economic effects.

The purpose of this paper is to assess the impacts of new medical innovations for COVID-19, including both vaccines and therapeutics. The total economic burden of the disease is defined as the costs of disease itself and disease prevention. COVID-19 has clearly imposed a tremendous mortality burden, with over 1 million deaths in the US and 6.3 million deaths worldwide as of June 2022. In addition, the highly contagious nature of COVID-19 makes private and public efforts to control the disease—such as self-isolation, social distancing, and population-wide lockdowns—extremely costly. As a result, the new medical innovations are valuable not only because they reduce COVID-19 mortality and morbidity (i.e., direct health impact) but also because they allow society to reduce or avoid costly mitigation strategies aimed to reduce its spread.

The paper first assesses the impacts of the new medical innovations on the total mortality burden in the US, concentrating on the joint effects of treatments and vaccines after the wide distribution of the vaccines in the first quarter of 2021. We focus on how much innovations reduced excess mortality, defined as the extent to which overall mortality differed from that in the past. This measure of excess mortality thus includes other causes of mortality beyond COVID-19 that prevention efforts may have affected. For example, to prevent infection with COVID-19, individuals may have been less inclined to visit the doctor to undergo routine care prior to the availability of vaccines and therapeutics, and therefore may have missed detection of other health concerns that increase risk of mortality. In the first year following widespread vaccine adoption, we find that these new innovations saved roughly 99,873 lives in terms of reduced excess mortality and at least 699,110 life years. Using traditional valuation metrics from the economic literature for the value of a life year this implies a corresponding economic value of around $371.6 billion over a one-year period.

The paper then considers the less recognized benefits of these new medical innovations due to a reduced need for mitigation efforts to lower the infection rate. We rely on a literature showing that efforts to prevent COVID-19 were associated with large amounts of foregone economic activities (Mulligan, 2021; Polyakova et al., 2020; Walmsley et al., 2021). We find that the new medical innovations to fight COVID-19 enabled the restoration of $933.1 billion in economic activities in the U.S.

Thus, we find that while these innovations had tremendous impacts on individual and population health, the vast majority of their total value generated over the first year came from their impacts on reducing isolation efforts to prevent the disease, thereby increasing economic activities.

Section 2: The Impacts of Medical Innovation on COVID-19 on Health Outcomes: Mortality

Many dimensions of new medical innovations for COVID-19 make them valuable tools to reduce adverse health outcomes associated with the virus, including morbidity and mortality of the disease itself (comprising acute disease and "long COVID"), delayed care for other diseases, anxiety and other mental health conditions, and indirect impacts on care givers and family members. We focus our assessment of the direct health impacts of the disease on excess mortality as it incorporates COVID-19 mortality but also mortality induced by preventive measures against the disease.

2.1 Excess Deaths Avoided by COVID-19 Innovations

The treatments and vaccines were developed in record time, partly due to Operation Warp Speed, which helped support their development, expedited assessment, and launch. To evaluate reductions in mortality attributable to newly available COVID-19 vaccines and therapeutics, we first estimate the number of lives saved each month by COVID-19 innovations for the first year following widespread use of the vaccines, which we classify as the first product year.

Given the impacts of COVID-19 and vaccination on various aspects of life, like social interactions capable of influencing mortality outside of COVID-19 mortality, we focus on excess deaths rather than COVID-19 related deaths to calculate lives saved. Excess deaths are reported by the CDC as deaths in excess of the previous years' cyclical levels of mortality during the same period. Therefore, if preventive activities affected other behaviors driving health outcomes, such as isolation affecting mental health and suicides or reduction in traffic fatalities, this is considered through the excess mortality metric. We consider the total impacts of both treatments and vaccines on excess deaths over one year after mass COVID-19 vaccinations took place, specifically from April 1, 2021 to March 31, 2022. We compare excess deaths over this period against a counterfactual represented by the latter half of 2020 in which COVID-19 vaccines were not yet widely available.

For the purposes of our study, we define mass vaccination as more than 60% of the population age 65 years and older having received at least one dose of COVID-19 vaccines, which occurred by end of March 2021 (Nguyen et al., 2021).

We calculate the (monthly) counterfactual as the monthly average of excess deaths through the second half of 2020, from July 1, 2020 to December 31, 2020, and then multiply the average by 12 to estimate the average annual number of excess deaths for full-year comparisons. For the counterfactual, we focused on the latter part of 2020, as it seems unlikely the public prevention efforts characterized by wide economic shutdowns in the spring of 2020 would be repeated going forward.

The CDC (2022a) reports excess deaths on a weekly basis by calculating the difference between the observed deaths and expected deaths by week (negative differences are set to zero). To categorize the weekly data into months, we add up the count of deaths for weeks with no overlapping months (for example, July 18th to 25th), and calculate the daily average for weeks with overlapping months (for example, November 28th to December 5th) to attribute the days to each month. For example, for the week ending on December 5th, 2020, the total number of excess deaths is 19,327 with a daily average of 2,761, so we allocate 13,805 excess deaths to December 2020 (5 days) and 5,522 excess deaths to November 2020 (2 days). In this manner, we were able to achieve more precise estimates of monthly excess deaths.

Compared to the second half of 2020, the observed excess deaths mostly fall below the counterfactual, except for August to October 2021, and January 2022, possibly due to the outbreak of new variants (Figure 1). In total, the number of excess deaths in the first product year is 514,122, while the counterfactual is 613,995 with a monthly average of 51,166, indicating a total of 99,873 lives saved by COVID-19 innovations in the first product year. The trend of monthly lives saved is exhibited in Figure 2.

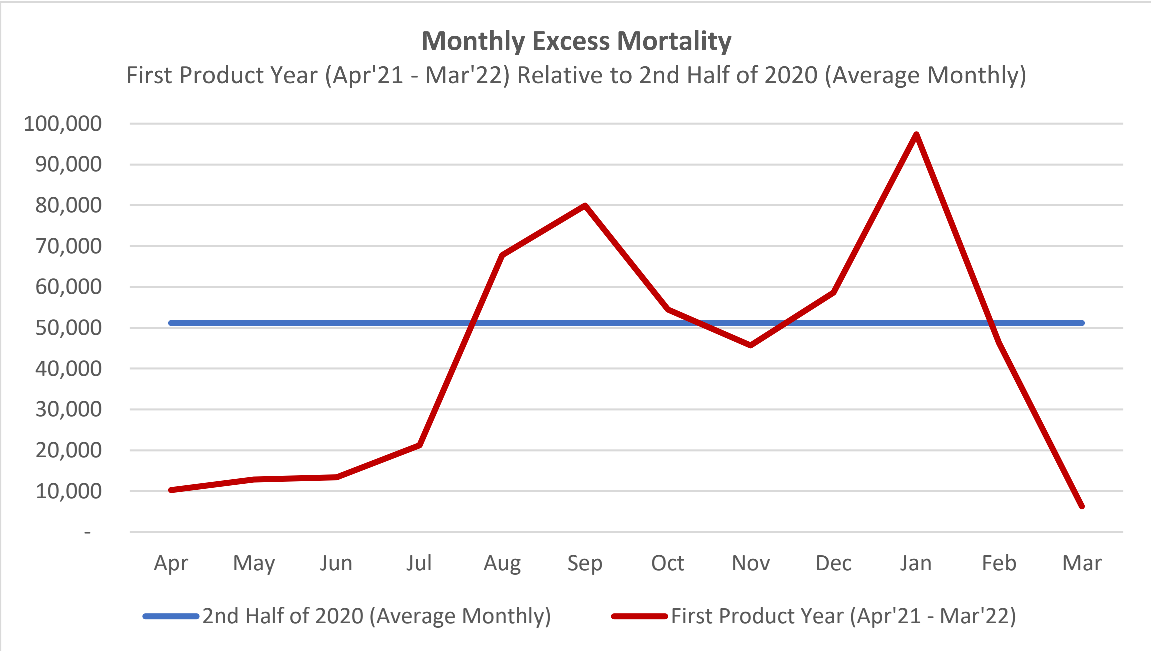

Figure 1. Monthly Excess Mortality:
First Product Year from April 2021 to March 2022 vs. Monthly Average from July 2020 to December 2020

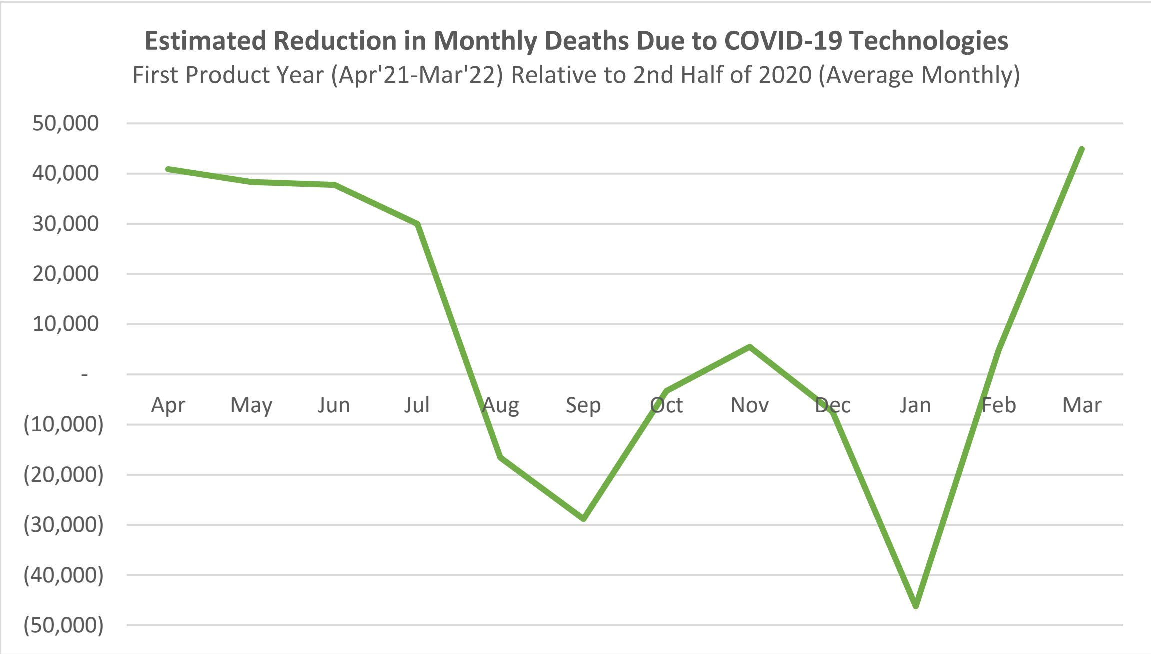

Figure 2. Monthly Lives saved by COVID-19 Innovations:
First Product Year from April 2021 to March 2022 compared to Monthly Average from July 2020 to December 2020

Alternative analyses simulating the effects of actual and hypothetical vaccination rates on COVID-19 deaths, rather than excess mortality, include Steele et al. (2022), Schneider et al. (2021), and Zong et al. (2022). These studies differ from ours by not taking into account the counteracting effect on mortality caused by vaccines reducing other forms of prevention, which enabled the resumption of economic activity. This is the central effect discussed in this paper and the evidence clearly indicates that such activity rose dramatically. Innovations reducing case-fatality rates do not have as large overall mortality effects when the innovation raises activity and consequently potential transmission, as well as potentially other causes of death associated with increased activity. This partly explains our lower overall mortality effects compared to these studies.

2.2 Average Value of Life Years Saved by COVID-19 Innovations

We translate the estimated reduction in excess mortality into the number of life years saved due to COVID-19 innovations using Ugarte et al. (2022), who estimates an average of 8 statistical life years lost per death assuming a hypothetical life expectancy of 80 years. However, we multiply the number of deaths by 7 years considering actual life expectancy was 79 years in the US in 2019 (World Bank, 2022). We choose 2019 since it is the latest year before COVID-19. Since the US life expectancy has been steadily increasing before 2019, assuming a 79-year life expectancy also makes our estimates conservative, as we expect current life expectancy would be even higher in the absence of COVID-19.

There is a reduction of 99,873 excess deaths for the first product year since the vaccine launch compared to the counterfactual. These 99,873 lives saved translate into 699,110 statistical life years saved. We calculate the valuations of life years based on the value of statistical life year (VSLY) literature reported in Philipson and Durie (2021) (See Appendix 1). Table 1 reports the values of life years gained using the different approaches to monetize the value of life years commonly used in the literature and summarized in that paper. We find that the mean value of the 699,110 statistical life years saved due to COVID-19 innovations is $346 billion, the median is $371.6 billion, the maximum is $485.3 billion, and the minimum valuation is $106.3 billion.

Table 1: Value of Lives Saved in Comparison to 2020 Second Half Counterfactual ($ Billion)

	Wage Compensation	Driving Behaviors	Government	Meta-analysis: Stated-Preference	Meta-analysis: Multiple Methods	Meta-analysis: Wage Compensation	Overall
mean	369.4	275.9	390.7	399.7	301.8	324.2	346
median	366.1	260.4	405.5	399.7	295.0	373.9	371.6
max	405.2	461.0	413.7	402.2	402.6	485.3	485.3
min	324.6	106.3	351.2	397.3	214.4	130.2	106.3

2.3 Age-dependent Value of Life Years Saved by COVID-19 Innovations

Instead of using the average values for all deaths, and since VSLY is age-dependent, we consider age-dependent valuations. Using data from Ruhm (2021) and Ugarte et al. (2022), we calculate the age specific life years lost and the associated values in Table 2. Appendix 2 explains these calculations in further detail. The aggregate value of lives saved is $540.7 billion using the age-dependent VSLY. With the other VSLY estimates reported in the table, which do not account for age-dependence, the maximum value is $642.7 billion while the minimum is $140.8 billion.

Table 2: Age Groups: Value of Lives Saved Comparison to 2020 Second Half ($ Billion)

	Age-dependent VSLY	Min VSLY	Max VSLY	Mean VSLY	Median VSLY
Age: <25	19.6	10.0	45.8	32.6	35.1
Age: 25-44	128.4	40.0	182.4	130.1	139.7

Age: 45-64	299.5	66.9	305.5	217.8	233.9
Age: ≥ 65	93.2	23.9	109.0	77.7	83.5
Total	540.7	140.8	642.7	458.3	492.1

Section 3 The Impacts of Medical Innovation on Economic activities

Our next step was to estimate the impacts of COVID-19 innovations on increased economic activities resulting from reductions in mitigation strategies to prevent the spread of infection. According to a 2021 United Nations Development Programme (UNDP) analysis, GDP per capita is strongly associated with the proportion of people vaccinated against COVID-19, with a $7.9 billion increase in global GDP for every million people vaccinated. It is also suggested that the economic recovery rate is faster for countries with higher vaccination rates, and that upper-middle-income countries are likely to make stronger than expected recoveries due to greater use of vaccines (UNDP, 2021).

To measure the economic effects of COVID-19 innovations on U.S. GDP, we compare GDP one year following the wide distribution of vaccines against a counterfactual period, in a similar manner as lives saved above. Quarterly real U.S. GDP data (billions of chained 2012 dollars, seasonally adjusted at annual rates) from US Bureau of Economic Analysis (BEA, 2022) were used. Assuming the monthly real GDP is distributed equally within one quarter, we calculate the seasonally adjusted monthly real GDP estimates by dividing the quarterly data by 3. From April 2021 to March 2022, a total real GDP of $19.6 trillion in the U.S. is reported. The counterfactual is established using the same time period as in section 2.

Using the monthly average real GDP of the second half of 2020 as the counterfactual, the result is $18.7 trillion in total, with a monthly average of $1.6 trillion. This implies real GDP for the first product year is $0.9 trillion higher compared to the counterfactual, with an average increase of $77.8 billion per month (Figure 3, 4, reported in BEA standards of seasonally adjusted in 2012 dollars).

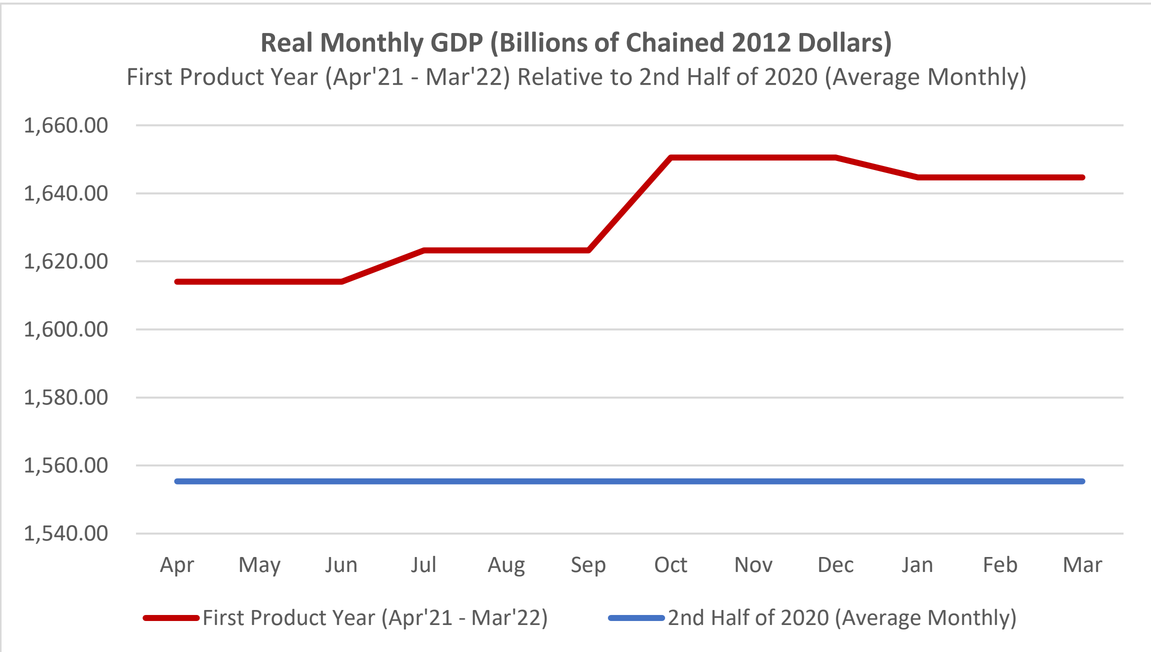

Figure 3. Real Monthly GDP:
First Product Year from April 2021 to March 2022 vs. Monthly Average from July 2020 to December 2020

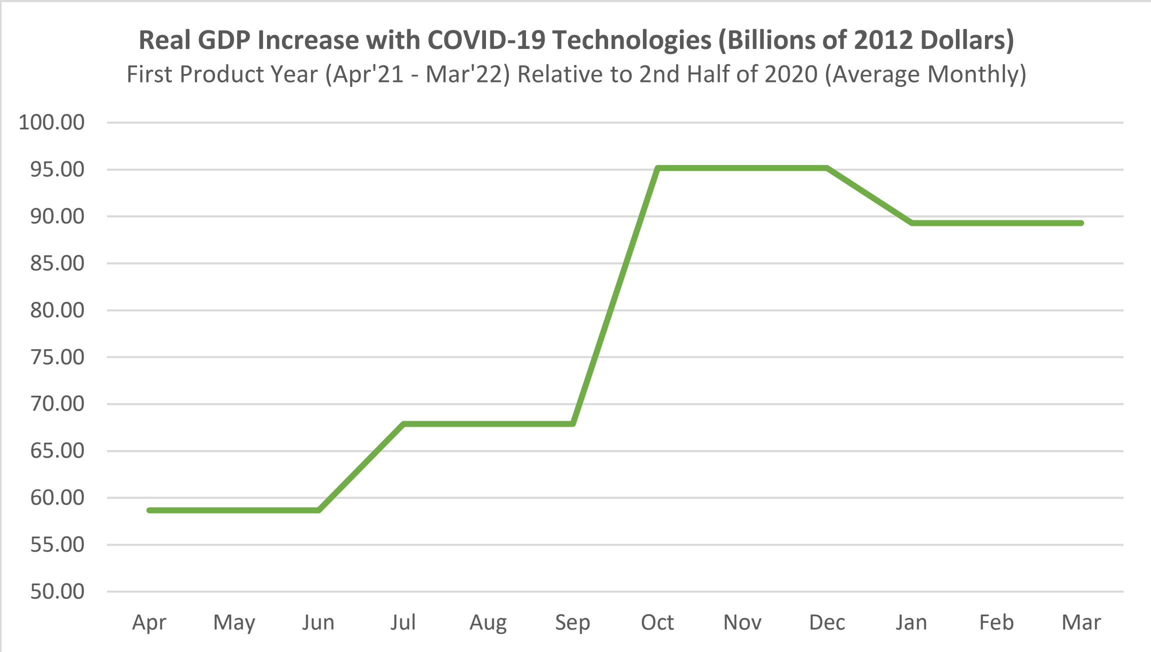

Figure 4. Real GDP Increase with COVID-19 Innovations:
First Product Year from April 2021 to March 2022 vs. Monthly Average from July 2020 to December 2020

As shown above, the innovations delivered an enormous value, both in terms of improved individual and population health outcomes and from a reduction in mitigation strategies aimed at preventing the spread of disease. A comparison between the value of increased economic activities ($933.1 billion) to the value of life years saved can be seen in Figure 5 which uses a median value of lives saved ($431.9 billion; calculated as the average of values using average life years and age-based life years per death with median VSLY of $531,501). The share of the overall value that is taken up by increased real GDP is more than two thirds, or 68.4%. Therefore, analyses that only measure the value of health gains are incomplete as they miss the significant value the new innovations have delivered in terms of indirect benefits.

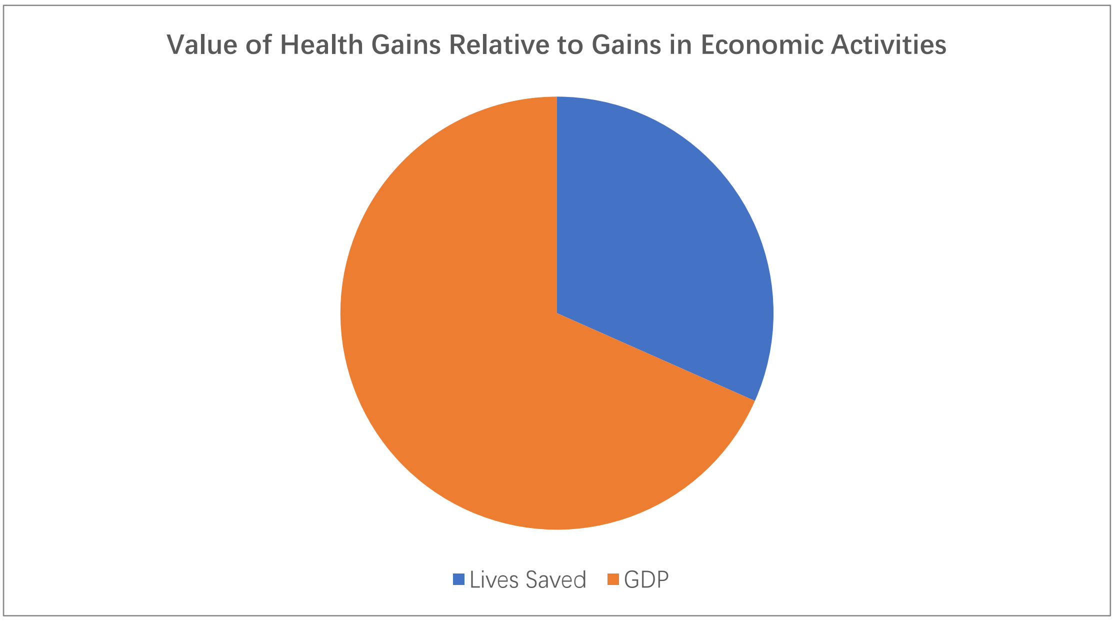

Figure 5. Median Values of Lives Saved vs GDP after widespread adoption of COVID-19 vaccines - Compared to July 2020 to

Section 4 Concluding Remarks

The launch of COVID-19 treatment and vaccine innovations yielded enormous value in the US and globally, to a point where it is hard to think of another single product that has been more valuable from both a clinical and economic perspective.

There is a longstanding economic literature which argues that the total welfare loss of a disease comes not only from the direct effects of the disease itself, but also the costs of preventing the disease from occurring in the first place. This paper analyzed the value of COVID-19 innovations in reducing both of these harms. Using an economic welfare metric, despite the enormous gains in reduced mortality and morbidity, we found that a large share of their total benefit came from reductions in preventive isolation and physical distancing efforts, which enabled the resumption of economic activities. These innovations saved at least 699,110 life years in the US, which according to standard valuation metrics conferred an economic benefit of $371.6 billion. However, these medical innovations also enabled a widespread reduction in activities previously undertaken to avoid COVID-19 infections (e.g., lockdowns, quarantine measures, social distancing), resulting in $933.1 billion in increased economic activity. Thus, while these innovations had tremendous impacts on population health, an even larger share of their total value came from enabling the resumption of economic activities by providing an alternative to isolation and physical distancing efforts as a means to prevent infection.

These findings corroborate the growing evidence base on the value of COVID-19 innovations. Using case fatality estimations, the Centers for Disease Control and Prevention (CDC) estimates that COVID-19 vaccinations prevented 235,000 deaths from December 1, 2020, to September 30, 2021 (Steele et al, 2022). The Commonwealth Fund reports that vaccines prevented 2.3 million deaths from December 2020 to March 2022 (Schneider et al, 2022). Another study projects that COVID-19 vaccines will generate $5 trillion in societal value over 3.5 years beginning in December 2020, including $1.4 trillion in gains to US GDP (Kirson et al, 2022).

The interpretation of a disease as a tax is helpful in explaining the finding that mortality does not make up a large share of the total value. Because new treatments and vaccines both lower the negative clinical and financial consequences of an infection, their availability lowers the gains from engaging in preventive isolation and physical distancing efforts. This was indeed the case with economic activities picking up after vaccine distribution. However, foregoing physical distancing measures results in a counteracting effect that raises total mortality. This is the disease analog to a tax rate reduction raising tax revenues due to a growth in the underlying tax-base, sometimes referred to as the Laffer Curve. For a disease, the tax rate is the negative impacts of an infection, and the tax base is the set of people exposing themselves to a potential infection. Because exposure rises as the case-fatality rate falls with new innovations, overall mortality may not respond as much to the new innovations.

These findings offer several implications. First, the large societal value of these innovations to the US, and their much larger global value measured in trillions, swamp the total value accruing to the innovators, which are in the tens of billions. If innovators capture a very small share of the value they bring to market, this suggests society will be harmed from introducing price controls or reducing intellectual property rights in TRIPS that reduce their innovative activities. Innovations that enable previously infeasible treatment outcomes reduce so called quality-adjusted prices, since prior to innovation the improvement in quality enabled by a new treatment could not be purchased at any price. For example, before highly active antiretroviral therapy (HAART) innovations were marketed in 1996, HIV-positive individuals could not buy a longer life at any price. Therefore, price controls on medical products often raise, as opposed to lower, quality adjusted prices. The successive innovations in the past that ultimately led to the successful COVID-19 innovations, many of which would not have been marketed had government price controls been in effect at the time, are a vivid illustration of these economic principles. The biopharmaceutical industry has continued to invest in highly effective antiviral treatments and vaccines to fight current and emerging variants. The value these R&D investments bring to society highlight the importance of continuing to promote a strong and agile industry that attracts investment and continues to drive scientific advances to be prepared against infectious disease and other health challenges that burden society, such as cancer and neurological diseases.

Second, these findings illustrate that traditional metrics used in health technology assessments (HTA) and value assessments of medical innovations, such as cost per quality-adjusted life year (QALY), will tend to underestimate the value of new medical innovations. Such methods are typically confined to the value of direct health improvements and exclude the impacts of new innovations on preventive activities and economic outcomes. However, outside formal HTA agencies such as the National Institute for Health and Care Excellence in the U.K. or the Institute for Clinical Economic Review in the US, there are emerging approaches to capture broader dimensions of value in HTA, including efforts by the Innovation and Value Initiative, Pharmaceutical Value within the University of Colorado and the Patient-Driven Values in Healthcare Evaluation (PAVE) and the Center for Enhanced Value Assessment of Tufts Medical Center, which have specifically explored the broader value of COVID-19 innovations.

Lastly, future research is needed to better understand whether the beneficial impacts of these new COVID-19 innovations may have been larger than average for many marginalized and disadvantaged populations given not only their higher risk of comorbidities but also their larger representation among industries which cut economic activities more to prevent infections.

Future evaluations may also consider the effects of new innovations to fight COVID-19 on long-run outcomes that we currently do not have sufficient data to evaluate and therefore are not captured. For example, by enabling schooling to resume, the innovations had long run learning and earning effects on students. Such assessments will add to the broader value of these new innovations in addition to the large gains in health outcomes they have enabled.

Lastly, the analysis was conducted for the first year of widespread adoption of the vaccines even though therapeutics were marketed earlier and had separate effects from those analyzed. A fuller analysis of therapeutics based on the availability before and after vaccine launches would be useful to assess their additional value.

References

Aldy, J. E. and W. K. Viscusi (2008). Adjusting the value of a statistical life for age and cohort effects. *The Review of Economics and Statistics 90*(3), 573–581.

Ashenfelter, O. and M. Greenstone (2004). Using mandated speed limits to measure the value of a statistical life. *Journal of political Economy 112*(S1), S226–S267.

BEA (2022). Gross Domestic Product. https://www.bea.gov/data/gdp/gross-domestic-product [Accessed: 2022-05-29].

CDC (2022a). Excess Deaths Associated with COVID-19. https://www.cdc.gov/nchs/nvss/vsrr/covid19/excess_deaths.htm [Accessed: 2022-06-6].

CDC (2022b). Trends in Number of COVID-19 Cases and Deaths in the US Reported to CDC, by State/Territory. https://covid.cdc.gov/covid-data-tracker/#trends_dailycases [Accessed: 2022-06-6].

Jo, C. (2014). Cost-of-illness studies: concepts, scopes, and methods. Clinical and molecular hepatology 20(4), 327.

Kenkel, G. S. T. D. S. and R. G. Fabian (1994). Valuing health for policy: An economic approach. University of Chicago Press.

Mulligan, C. B. (2021). Economic activities and the value of medical innovation during a pandemic. Journal of Benefit-Cost Analysis 12(3), 420–440.

Kirson, N., Swallow, E., Lu, J., Mesa-Frias, M., Brookhard, B., Maynard, J., Shivdasani, Y., Lefebvre, P. (2022). The societal economic value of COVID-19 vaccines in the United States. Journal of Medical Economics, 25:1,119-128

Nguyen, K. H., P. Lu, S. Meador, M.-C. Hung, K. Kahn, J. Hoehner, H. Razzaghi, C. Black, and J. A. Singleton (2021). Comparison of covid-19 vaccination coverage estimates from the household pulse survey, omnibus panel surveys, and covid-19 vaccine administration data, united states, March 2021. *CDC AdultVaxView*.

Philipson, T. (1995). The welfare loss of disease and the theory of taxation. Journal of Health Economics 14(3), 387–395.

Philipson, T. and T. Durie (2021). Issue brief: A review of the scientific literature on the value of health. *Working Paper*.

UNDP (2021). Impact of vaccine inequity on economic recovery. https://data.undp.org/ vaccine-equity-archive/impact-of-vaccine-inequity-on-economic-recovery/ [Accessed: 2022-05-29].

Polyakova, M., G. Kocks, V. Udalova, and A. Finkelstein (2020). Initial economic damage from the covid-19 pandemic in the United States is more widespread across ages and geographies than initial mortality impacts. Proceedings of the National Academy of Sciences 117(45), 27934–27939.

Ramsey, S. and S. Sullivan (2003). The burden of illness and economic evaluation for copd. European Respiratory Journal 21(41 suppl), 29s–35s.

Ruhm, C. J. (2021). Excess deaths in the United States during the first year of covid-19. Technical report, National Bureau of Economic Research.

Schneider, E. C., A. Shah, P. Sah, S. M. Moghadas, T. Vilches, and A. Galvani (2021). The US covid-19 vaccination program at one year: how many deaths and hospitalizations were averted. *Commonwealth Fund*.

Steele, M.K., Couture, A., Reed, C., Iuliano, D., Whitaker, M., Fast, H., Hall, A.J., MacNeil, A., Cadwell, B., Marks, K.J. and B.J., Silk (2021). Estimated number of covid-19 infections, hospitalizations, and deaths prevented among vaccinated persons in the US, December 2020 to September 2021.

Ugarte, M. P., S. Achilleos, A. Quattrocchi, J. Gabel, O. Kolokotroni, C. Constantinou, N. Nicolaou, J. M. Rodriguez-Llanes, Q. Huang, O. Verstiuk, et al. (2022). Premature mortality attributable to covid-19: potential years of life lost in 17 countries around the world, january–august 2020. *BMC public health 22*(1), 1–13.

Viscusi, W. K. (2018). Best estimate selection bias in the value of a statistical life. *Journal of Benefit-Cost Analysis 9*(2), 205–246.

Walmsley, T., A. Rose, and D. Wei (2021). The impacts of the coronavirus on the economy of the United States. Economics of disasters and climate change 5(1), 1–52.

World Bank (1993). Investing in health: World development report.

World Bank (2022). Life expectancy at birth, total (years) - United States. https://data.worldbank.org/indicator/SP.DYN.LE00.IN?locations=US [Accessed: 2022-05-30].

Yang, W., J. L. Hamilton, C. Kopil, J. C. Beck, C. M. Tanner, R. L. Albin, E. Ray Dorsey, N. Dahodwala, I. Cintina, P. Hogan, et al. (2020). Current and projected future economic burden of parkinson's disease in the US. npj Parkinson's Disease 6(1), 1–9.

Zong, M., M. Kshirsagar, R. Johnston, R. Dodhia, T. Glazer, A. Kim, D. Michael, S. Nair-Desai, T. C. Tsai, S. Friedhoff, and J. M. L. Ferres (2022). Estimating vaccine-preventable covid-19 deaths under counterfactual vaccination scenarios in the United States.

Appendix1: Value of Life Years (VLSY) Assumptions.

We calculate the valuations of life years based on the value of statistical life year (VSLY) literature reported in Philipson and Durie (2021). Generally, VSLY is measured with four methods: the wage compensation for risky jobs, the willingness to drive with higher risk, stated risk preferences and government calculations. Based on papers discussed in Philipson and Durie (2021), we consider all mechanisms in individual studies and/or meta-analyses. A summary of studies reported in Philipson and Durie (2021) is displayed in Table A1. Across all categories discussed in Philipson and Durie (2021), we consider the maximum, minimum, mean and median values (Table A2), and calculate the corresponding value of statistical life years saved. The maximum and the minimum estimates are provided by corresponding VSLY in Viscusi (2018), a meta-analysis on the wage compensation method, and Ashenfelter and Greenstone (2004), an individual study on driving behaviors.

Table A1. Descriptive Statistics of the Value of a Statistical Life Year Across Studies

	Count	Mean	St. Dev.	Median	Min	Max
Academic Papers	11	$491,950	$128,518	$512,422	$152,112	$659,458
Meta-Analyses	12	$471,050	$152,880	$529,043	$186,234	$694,141
Government Agencies	5	$558,812	$36,774	$580,000	$502,356	$591,823
Total	28	$494,932	$133,130	$531,501	$152,112	$694,141

Source: Philipson and Durie (2021)

Table A2: VSLY Summary in Philipson and Durie (2021) ($)

	Wage	Driving	Government	Meta-analysis: Stated-Preference	Meta-analysis: Multiple Methods	Meta-analysis: Wage Compensation	Overall
mean	528,426	394,680	558,812	571,786	431,645	463,742	494,932
median	523,684	372,470	580,000	571,786	422,021	534,894	531,501
max	579,567	659,458	591,823	575,270	575,896	694,141	694,141
min	464,236	152,112	502,356	568,302	306,641	186,234	152,112

Appendix 2- Age Specific Life Years Saved and Their Values

Our calculations of age-specific values of life years saved can be summarized into three steps. First, we categorize the lives saved into four age groups (≤25, 25-44, 45-64 and ≥65) based on Ruhm (2021), which provides data on the numbers of excess deaths in each age group from March 2020 to February 2021. We calculate the percentages of excess deaths within each age group, and assume this distribution remains the same for lives saved and for different time periods. The percentages can be seen in Table A3. We multiply percentages by the number of total lives saved to obtain the numbers of lives saved in each age group.

Table A3: Age Distribution in Deaths (Ruhm,2021)

	Excess Deaths	Excess Death Percentage	Excess Deaths (Lower Bound)	Excess Death (Lower Bound)	Excess Deaths (Upper Bound)	Excess Death Percentage (Upper Bound)
Age: <25	6,707	0.0108	4,493	0.0076	8,920	0.0136
Age: 25-44	39,253	0.0630	34,917	0.0593	43,589	0.0663
Age: 45-64	125,011	0.2007	118,929	0.2020	131,093	0.1994
Age: ≥ 65	452,051	0.7256	430,292	0.7310	473,810	0.7207
Total	623,022	1.0000	588,631	1.0000	657,412	1.0000

Second, we calculate the life years per death for each age group using data from Ugarte et al. (2022), which also provides the total numbers of life years lost and the total numbers of deaths for different ages from January to August 2020. We divide the total numbers of life years lost by the total numbers of deaths in each age group to estimate the life years per death for different ages as shown in Table A4. Again, since the average life expectancy in US is 79 years rather than 80 years used by Ugarte et al. (2022), we subtract one year from life years per death for each age group. Because the age divisions in Ugarte et al. (2022) and Ruhm (2021) are not consistent in the categorization of the threshold ages (for example, 25 and 45), we assume the effect of these threshold ages are minimal and such difference can be ignored. Similarly, we also assume these life years per death estimates can be applied to different time periods. For each age group, we multiply the number of lives saved by the corresponding life years per death to arrive at the life years saved for the specific age group.

Table A4: Life Years Per Death for Each Age Group (Ugarte et al. (2022))

	Total Deaths	Total Life Years Per Death	Life Years Per Death	Life Years Per Death-1
Age: <25	414	25,808	62	61
Age: 25-44	5,245	224,320	43	42
Age: 45-64	33,640	772,470	23	22
Age: ≥ 65	145,784	461.665	3	2
Total	185,083	1,484,263	8	7

Third, we multiply the number of life years saved in each age group by the value of an age-dependent statistical life year (VSLY), in order to get the value of life years saved for the specific age group. Aldy and Viscusi (2008) estimate a VSLY of $296,933 for 18-year-olds, $680,402 for 54-year-olds, and $593,867 for 62-year-olds. We assume the ≤25 group to have the same VSLY as 18-year-olds ($296,933); the 45-64 group to have the same VSLY of 54-year-olds, ($680,402); the 25-44 group to share the average VSLY of the ≤25 group and the 45-64 group ($488,668); and the ≥65 group to have the same VSLY as 62-year-olds ($593,867). In addition, we also consider the overall maximum, minimum, mean and median VSLY across all papers discussed in Philipson and Durie (2021) for sensitivity, as shown in Table A5.

With 99,873 lives saved, the numbers of life years saved in each age group are 65,948, 262,824, 440,130, and 157,016, for the youngest to the eldest group respectively. A total of 925,918 life years are saved according to the age-dependent measure, greater than the average value measure of 699,110 life years saved. Multiplying by the VSLY in Table A5, the estimated values of life years saved in each age group are exhibited in Table 2, summing up to $540.7 billion using the age-dependent VSLY. With the other VSLY estimates, the maximum value is $642.7 billion while the minimum is $140.8 billion.

Table A5: Age Groups: Value of Statistical Life Year (VSLY)

	Age-dependent VSLY	Min VSLY	Max VSLY	Mean VSLY	Median VSLY
Age: <25	296,933	152,112	694,141	494,932	531,501
Age: 25-44	488,668	152,112	694,141	494,932	531,501
Age: 45-64	680,402	152,112	6941,41	494,932	531,501
Age: ≥ 65	593,867	152,112	694,141	494,932	531,501

Table 2 (From Main Text): Age Groups: Value of Lives Saved Comparison to 2020 Second Half ($ Billion)

	Age-dependent VSLY	Min VSLY	Max VSLY	Mean VSLY	Median VSLY
Age: <25.0	19.6	10.0	45.8	32.6	35.1
Age: 25-44	128.4	40.0	182.4	130.1	139.7
Age: 45-64	299.5	66.9	305.5	217.8	233.9
Age: ≥ 65	93.2	23.9	109.0	77.7	83.5
Total	540.7	140.8	642.7	458.3	492.1