A Shot in the Arm: The Effect of COVID-19 Vaccine News on Financial and Commodity Markets *

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Abstract

We analyze the impact of COVID-19 vaccine announcements by leading vaccine companies on the financial and commodity markets from January to December 2020. We show that the vaccine announcements had varied and economically significant impacts on asset prices. The announcements moved interest rates, stock markets in the U.S. and numerous other countries as well as commodities used in transportation and some agricultural commodities. We show that the stock and commodity markets that experienced larger declines at the beginning of the pandemic receive a larger boost from good vaccine news. We also find that the vaccine news affects stock returns through changes in the expectations of the corporate cash flows and the expected equity risk premium.

Keywords: COVID-19 vaccine; stock market; interest rates; commodities
JEL classification: F31; G12; G14; G15; I10; Q41

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1 Introduction

After the first COVID-19 case was reported in China in December 2019, the virus quickly spread around the globe. The first case in the U.S. was confirmed on January 21, 2020. The World Health Organization declared a global health emergency on January 30, 2020 and a global pandemic on March 11, 2020. As investor optimism turned to fear almost overnight, stock markets plummeted. The S&P 500 index plunged approximately 34% over 23 trading days starting on February 20, 2020, the fastest drop of this magnitude in the U.S. stock market history. Governments issued restrictions limiting the movement of people to stave off the pandemic. The global economy shrank by 4.3% in 2020, declining 5.4% in advanced economies, 3.6% in the U.S., 7.4% in the Euro area, and 2.6% in emerging markets with China recording its lowest recent growth of 2.0% (World Bank, 2021). Fiscal policymakers adopted the largest stimulus packages in history and central banks reduced interest rates to near zero and expanded large-scale asset purchases. These measures helped ease the financial market stress, but fiscal and monetary policies alone were not able to eliminate the underlying problems in the economy: the virus preventing workers from working and consumers from consuming due to government restrictions, illness, or health concerns. In absence of drugs for effectively treating the virus on a large scale, it quickly became apparent that the solution to the global recession would depend on the development of effective vaccines rather than economic policy because the development of vaccines held a promise of ending the pandemic and returning economic activity to normal.[1]

The news about the race to develop a vaccine has captivated the world. This effort culminated in the vaccine being administered to the first patient outside of clinical trials on December 8, 2020 (BBC, 2020). We study how financial and commodity markets reacted

[1]For example, when asked "And do you think a steady recovery is really possible until a vaccine's developed...?" in a press conference as of April 29, 2020, Jerome Powell, the Chair of the Federal Reserve of the United States, responded: "...the performance of the economy depends on the path of the virus and the success of the measures we take to control it, our success in reopening the economy, and also the time it takes to develop new drugs. And our tools, the things that we do, don't affect any of those things." He also stated: "We're going to just provide the support that we can with the tools that we have, and we're going to keep doing that until—until the recovery's well under way." (Federal Open Market Committee, 2020).

to announcements about the development of the vaccines. The vaccine news influences investor expectations about the future course of the pandemic. Understanding the reaction of the financial and commodity markets to the vaccine news is therefore useful for predicting the economic impact of future pandemics and calibrating policy responses to them. More specifically, our paper answers four research questions that have not been studied in the previous literature.

First, when the COVID-19 crisis started in March 2020, the Federal Reserve responded to the pandemic-induced recession by an extremely accommodative monetary policy, cutting its benchmark policy rate to zero in two unscheduled meetings.[2] The Federal Reserve subsequently stated that its policy decisions would depend on the course of the pandemic. Development of effective vaccines influences the course of the pandemic. Therefore, our first research question asks how the COVID-19 vaccine news, and thus the expected course of the pandemic, affect expectations of future monetary policy. Because interest rate changes affect stock prices, analyzing the effect of vaccine news on interest rates helps us better understand how the news about the COVID-19 vaccines influences the stock market, which is the focus of our next question.

Second, through what channels does information about the expected course of the pandemic influence the stock market? Boyd, Hu, and Jagannathan (2005) note that economic news influences stock prices by affecting expectations of future corporate earnings, the risk-free interest rate, and the equity risk premium. All these three types of information could play a role in the market reaction to the COVID-19 vaccine news: The pandemic has affected corporate earnings in many industries, the Federal Reserve responded by reducing the risk-free interest rates, and judging from the large increase in volatility during the stock market crash of February-March 2020 (Baker et al., 2020), it is also likely that the pandemic affected investor risk appetite and, therefore, the equity risk premium.

The third research question that we answer is to what extent the reaction to vaccine

[2] Clarida, Duygan-Bump, and Scotti (2021) present the timeline of the Federal Reserve's policy response.

news differs across international stock markets. Economies of different countries have been affected differently by the pandemic. We examine whether there are substantial differences between stock market reactions to COVID-19 vaccine news in North and South America, Europe, Africa, Asia, and Australia. Several countries in the Asia-Pacific region adopted the "zero-COVID" strategy and their economies were less affected by the spread of the disease, perhaps attenuating the importance of the vaccine news for these economies. At the same time, these countries are integrated into the global economy, giving their economies exposure to COVID-19 in spite of the zero-COVID strategy. Therefore, the extent to which the stock market reactions to vaccine news differ across countries is an empirical question.

Our fourth research question focuses on the commodity markets. Commodities serve as key inputs in production. Furthermore, investors substantially increased their exposure to commodities in recent years (for example, Henderson, Pearson, and Wang (2015)). The COVID-19 pandemic affected demand for many commodities and produced large movements in commodity prices. We therefore investigate to what extent news about the COVID-19 vaccines moved prices of different commodities.

To answer these research questions, we include all four vaccines approved in the European Union (EU), the U.K., or the U.S.: The Moderna, Oxford-AstraZeneca, and Pfizer-BioNTech vaccines were the clear front-runners from early in the development process (McKinsey & Company, 2020) and Johnson & Johnson vaccine caught up to them.[3] Our sample includes 140 vaccine announcements from January to December 2020.

Overall, our analysis shows that the news about the COVID-19 vaccines provided a metaphorical shot in the arm – a boost with a sudden, positive impact – for financial and commodity markets. In particular, our analysis yields the following results. First, the reac-

[3]More than 200 COVID-19 vaccines have been in development, but only these four vaccines were clear front-runners in the approval process in the EU, the U.K., or the U.S. (Sas, 2021). Other companies (for example, the pharmaceutical company Merck) initially appeared to be competing in the development; however, they quickly fell behind. Also, our main analysis does not examine announcements about vaccines not approved in EU, the U.K., or the U.S. but approved in other countries. Two such vaccines with the largest market are the Sinopharm-BIBP and Sinovac vaccines developed in China. We discuss a robustness check in Section 5 to confirm that our results are not driven by announcements about these vaccines.

tion of the nominal interest rates increases with the bond maturity and operates through the expected real interest rates (rather than through expected inflation). The positive effect of vaccine news on the expected real interest rates shows that expectations of monetary policy depend in part on the course of the pandemic.[4] Second, we find that the positive response of stock returns to the vaccine news is driven by information about both future corporate earnings and equity risk premium (but not the risk-free rate). Third, the impact of the vaccine news on the international stock markets is far from uniform: the stock markets in the U.S., U.K., EU, Canada, Mexico, Brazil, South Africa, and Nigeria react to the announcements but stock markets in Asia and Australia do not. Fourth, in the commodity markets, commodities used in transportation (crude oil, gasoline, corn, soybeans, and soybean oil) and agricultural commodities cocoa, coffee, and cotton react to the vaccine announcements while precious metals gold and silver, construction commodities copper and lumber, and agricultural commodity wheat are unaffected. We show that the heterogeneity in the reaction of stock and commodity markets to the vaccine announcements is related to what happened in the markets at the beginning of the pandemic: the markets that experienced larger declines at the beginning of the pandemic receive a larger boost from good vaccine news.

The effect of the announcements on the interest rates, stock prices, and commodities is economically significant. For example, the S&P500 index returns were on average higher by about 0.9% on the 57 days with important vaccine news than on other days, adding up to an increase of approximately 50% during our sample period. The total S&P 500 index return was approximately 13% in this period, which shows that the effect of the announcements more than offsets negative average returns recorded on days without the announcements.

The remainder of the paper is organized as follows. The next section reviews the related literature and highlights our four contributions. Section 3 describes the vaccine announcement data and the market data. After presenting our methodology, Section 4 reports and

[4]Hanson and Stein (2015) show that monetary policy decisions have a strong effect on long-term real interest rates. This finding, along with our finding that real rates are affected by vaccine news, suggests that vaccine news affects expectations of future monetary policy.

discusses our results. Section 5 discusses robustness checks where we test for potential effects of other events unrelated to our vaccine announcements. Section 6 briefly concludes.

2 Literature Review

Numerous papers have begun the study of how the COVID-19 pandemic affected the economy and financial markets without focusing on the effect of the vaccine news. For example, Baker et al. (2020) document an unprecedented negative reaction of the stock market. The reaction of the stock market is also studied by Alfaro, Chari, Greenland, and Schott (2020), Ashraf (2020), Papadamou, Fassas, Kenourgios, and Dimitriou (2020), Zaremba, Kizys, Aharon, and Demir (2020), Zhang, Hu, and Ji (2020), Ding, Levine, Lin, and Xie (2021), and O'Donnell, Shannon, and Sheehan (2021). Yarovaya, Matkovskyy, and Jalan (2022) find that COVID-19 impacted not only stock markets but also 10-year bonds, precious metals, and cryptocurrencies.

Several papers study the role of the COVID-19 vaccine. Hong, Wang, and Yang (2021) use an epidemiological model with transmission-rate shocks in an asset-pricing framework that includes disease mitigation and vaccine arrival to quantify the economic damage of COVID-19. Hong, Kubik, Wang, Xu, and Yang (2021) estimate a damage function utilizing revisions of industry earnings forecasts and show that the economic damage is nonlinearly affected by the vaccine. Sockin (2020) builds a macroeconomic model where households are averse to uncertainties about health and discusses that vaccines can affect stocks via investor risk aversion and equity risk premium. O'Donnell, Shannon, and Sheehan (2022) study nine international stock indices as well as a world stock index and find that positive changes in these indices are associated with growth in the COVID-19 vaccination programs.

The three studies most related to our paper are Acharya, Johnson, Sundaresan, and Zheng (2021), Chan, Chen, Wen, and Xu (2022), and Gräb, Kellers, and Mezo (2021). Acharya et al. (2021) create a "vaccine progress indicator," a continuous variable based on progress of the vaccines and related news, document the relation between the expected time to distribution of the vaccine and the U.S. stock returns and show that this relationship is stronger in industries that are more affected by the pandemic; they also estimate the value of a vaccine in an asset-pricing framework. Chan et al. (2022) expand the analysis to 50 stock markets and report results aggregated for two groups of countries: a group of countries developing vaccines and a group of countries not developing vaccines, with further distinction between developed and emerging economies within the groups. They show a heterogeneous impact of vaccine news on the first day of the trials: the stock market reaction for the developed economies group is stronger than that of the emerging economies. Gräb et al. (2021) use the Good Judgement website forecasts of when the vaccine will become available and report that increased beliefs in the vaccine availability positively affected stocks of some industries more than other industries, with the Euro area experiencing larger gains than the U.S.

Our paper contributes to this literature in four ways. First, we analyze the interest rate markets which allows us to show how the COVID-19 vaccine news affects expectations of future monetary policy. Second, as discussed in the Introduction, we provide an explanation of the U.S. stock market results: our decomposition of the aggregate stock market returns shows that the price impact is driven by both the expected corporate earnings and the equity risk premium (but not the risk-free rate). Third, we provide results for a larger set of stock markets while using all as well as selected important COVID-19 vaccine announcements by leading vaccine companies; this expands Acharya et al. (2021) who study only on the U.S. stock market while using the vaccine progress indicator and Chan et al. (2022) who report results for a *group* of countries developing vaccines and a *group* of countries not developing vaccines in response to vaccine announcements only at the beginning of clinical trials. We contribute to the literature by showing that important announcements about the vaccine discovery, development of clinical trials, government authorization as well as funding impacted the financial markets. The vaccine announcements affected stock markets in the

U.S., U.K., EU, Canada, Mexico, Brazil, South Africa, and Nigeria while the stock markets in Asia, and Australia remain unaffected. Finally, we analyze commodity markets and show that the impact of the COVID-19 vaccine news is also rather varied across commodities. To explain this heterogeneity in results in both stock and commodity markets, we show that markets that experienced larger declines at the beginning of the pandemic have a larger positive response to good vaccine news than markets that experienced smaller initial declines.

3 Data

3.1 Vaccine Announcement Data

Table A1 in the Online Appendix[5] lists the date, time, and title of the vaccine announcements collected from the official websites of the institutions that developed the COVID-19 vaccines.[6] There are 21, 58, 25, and 36 announcements for the Johnson & Johnson, Moderna, Oxford-AstraZeneca, and Pfizer-BioNTech vaccines, respectively, resulting in 140 announcements. The first vaccine announcement is on January 23, 2020 and the last one is on December 31, 2020. If an announcement occurs on a non-trading day, or after 16:00 Eastern Time (ET), we modify the announcement date to equal the following trading day when we analyze the impact on, for example, the U.S. stock market. For example, consider an announcement on a trading day Thursday. If the announcement is released before 16:00 ET, the announcement date is that Thursday. If the announcement is released at 16:00 or later, the announcement date is the following Friday if that Friday is a trading day; if the Friday is not a trading day, the announcement date is the following trading day such as the following Monday.

For two announcements (#82 and #100) we do not have a time stamp. Both of these

[5]This Appendix is available in the supporting materials section online and on the author website listed in the author contact information.

[6]The websites are `www.J&J.com/media-center/press-releases` for the Johnson & Johnson vaccine, `investors.modernatx.com/news-releases` for the Moderna vaccine, `www.astrazeneca.com/media-centre/press-releases.html` and `www.ox.ac.uk/news` for the Oxford-AstraZeneca vaccine, and `www.pfizer.com/news/press-release/press-releases-archive` for the Pfizer-BioNTech vaccine. For some announcements, the websites do not show a time stamp, and we obtain the time stamp from news sources such as Reuters.

announcements were released on Sundays and we therefore place them in the following Mondays. On some days there is more than one announcement. Column "Day" shows how multiple announcements combine into a single trading day when more than one announcement occurs on the same day (or on consecutive days if there are announcements that occur on weekends, on holidays, or after the U.S. stock market closed at 16:00 on the previous trading day such as announcements#17 released at 17:55 on a Thursday and #18 released at 13:07 on a Friday). There are 102 trading days with announcements. Figure 1 shows the timeline of these announcements.

137 announcements bring positive news about the vaccines, such as announcement #7 *"Moderna Announces First Participant Dosed in NIH-led Phase 1 Study of mRNA Vaccine (mRNA1273) Against Novel Coronavirus"* for the Moderna vaccine on March 16, 2020. Three announcements (#48, #72, and #86) bring negative news, such as announcement #86 *"Johnson & Johnson Temporarily Pauses All Dosing in Our Janssen COVID-19 Vaccine Candidate Clinical Trials"* about the Johnson & Johnson vaccine on October 12, 2020. Two negative announcements (#72 and #86) occur on days when there also is a positive announcement (#71 and #87). Because negative and positive announcements have opposite effects on the markets and could confound our results, we eliminate these announcements (#71, #72, #86, and #87) from our data. We also eliminate the one remaining negative announcement (#48) for consistency.[7] Our data then includes 135 positive announcements that took place on 99 U.S. stock market trading days.

[Insert Figure 1 here]

3.2 Financial and Commodity Market Data

Our analysis includes a variety of asset classes. For interest rates, we include the 2-year, 5-year, 10-year, and 30-year Treasury constant maturity rates. We also include 2-year and

[7] As a robustness check, we repeat our analysis while including this negative announcement. These results (available upon request) are almost identical to the reported results without this negative announcement.

3-year overnight indexed swaps that indicate what the markets expect the federal funds rate to be in two and three years, respectively.[8]

For stock markets, we include the S&P 500 as the U.S. stock index (and verify the results with Dow Jones Industrial Average (DJIA) and NASDAQ-100 indices). From Europe, we include the European stock market index EuroStoxx600 and indices for the five largest economies that comprise the EuroStoxx600: CAC40 from France, DAX from Germany, FTSE MIB from Italy, IBEX35 from Spain, and FTSE100 from the United Kingdom. From Asia, we include the Asian stock market index S&P Asia 50 and indices for China (Shanghai), Hong Kong (Hang Seng), India (BSE-Sensex), Japan (Nikkei225), and South Korea (KOSPI200). We also include indices for six other stock markets: FTSE/JSE Top 40 for South Africa and NSE 30 for Nigeria that are the two largest stock markets in Africa; Bovespa for Brazil, which is the largest stock market in South America; Toronto TSX 300 for Canada and Dow Jones Mexico for Mexico as the remaining two stock markets in North America; and S&P/ASX 200 index for Australia.

For commodity markets, we include energy, precious metal, construction as well as agricultural commodities. In energy commodities, we include the three largest markets:[9] crude oil, natural gas, and gasoline. In metal commodities, we also include the three largest commodity markets: gold, copper, and silver. Gold and silver are the two largest precious metal markets and copper is the largest base metal market. Since copper is predominantly used in the construction industry (Garside, 2021), we also include lumber as another construction commodity. In agricultural commodities, we include the four largest commodity markets: corn, soybeans, soybean oil, and wheat. In addition, we include cocoa, Arabica coffee, and cotton. We use futures prices for the commodities. Because futures contracts become increasingly illiquid close to their expiration (which is especially the case in lumber that is less liquid than the other commodity markets), we use the next-to-maturity contracts when

[8] Lloyd (2021) shows that overnight indexed swap rates reliably measure the interest rate expectations.

[9] See the Chicago Mercantile Exchange website (`https://www.cmegroup.com`) for the commodity futures market size information.

their daily trading volumes exceed the nearby contract volumes.

We obtain daily closing prices, P_t, for the stock, and commodity markets from Genesis Financial Technologies except for S&P/ASX 200 that is from Bloomberg. The Treasury rates are from the Federal Reserve Economic Data (FRED) database of the Federal Reserve Bank of St. Louis, and the overnight indexed swaps are from Bloomberg. We use daily prices rather than intraday (for example, minute-by-minute) prices because they make our identification more precise. Our identification relies on accurately assigning the vaccine announcements to time intervals when the announcements were first received by the markets. While the announcement times in Table A1 come from the official websites of the organizations developing the vaccines, without historical data for real time news coverage we do not know the exact time when the announcements became publicly available. Therefore it is not possible to accurately assign the vaccine announcements to intraday intervals. Using daily rather than intraday data also allows us to analyze a larger set of markets: Many of the announcements were released when some markets are closed (for example, international stock markets), and some markets do not have readily available intraday data (for example, overnight indexed swaps) or are relatively illiquid at intraday intervals (for example, the lumber futures market).

We compute the asset log return, R_t, as $R_t = ln(P_t/P_{t-1}) * 100$. For the interest rates, we use changes in yields instead of returns: $\Delta yield_t = yield_t - yield_{t-1}$. Table 1 shows summary statistics from January 22, 2020 (so that we can compute the return on January 23, 2020 when the first vaccine announcement occurred) to December 31, 2020.

[Insert Table 1 here]

4 Methodology and Empirical Results

This section describes our methodology for analyzing the impact of the vaccine announcements and shows our empirical results. Section 4.1 describes the methodology and shows the results for the U.S. stock market. Section 4.2 then answers our four research questions related to the monetary policy, explanation for the U.S. stock market reaction, international stock markets, and commodity markets.

4.1 Methodology and Empirical Results for the U.S. Stock Market

In this section we explain our methodology for analyzing the impact of the vaccine announcements and show results for the U.S. stock market. We begin by estimating the following equation using the ordinary least squares (OLS):

$$R_t = \alpha_0 + \sum_{l=1}^{L} \alpha_l R_{t-l} + \beta Ann_t + \epsilon_t, \tag{1}$$

where R_t is the S&P 500 index log return on day t, α_0 is a constant, and the return lags account for possible autocorrelation of returns. The optimal number of return lags, L, is determined with the Schwarz information criterion, resulting in seven lags.[10] Ann_t is an indicator variable that takes on the value of one if there is an announcement about any of the four vaccines on that day and zero otherwise.[11] Since our sample includes only positive news about the vaccine development as described in Section 3.1, a positive coefficient on the announcement indicator variable, β, means that the good news increases the return.

Column (1) of Table 2 reports results for our sample period from January 22, 2020 to December 31, 2020. The coefficient on the announcement indicator variable is statistically significant, which means that the stock market returns are higher on days with the vaccine announcements. The stock market looks to the vaccine announcements in hopes of the

[10] The high number of lags in our sample period is driven by the stock market crash at the beginning of the pandemic. We verify that the number of lags does not affect our results by estimating equation (1) with zero, one, and two lags. The results, available upon request, are similar to the results in Table 2.

[11] Gu and Hibbert (2021) use a similar methodology to examine the effect of changes in the probability of Brexit on financial and commodity markets.

economy rebounding, which increases the stock prices.[12,13]

[Insert Table 2 here]

Our sample contains all announcements about the vaccines published by the institutions developing the vaccines on their websites. However, it is conceivable that some announcements are more important and therefore impact the markets more strongly. We select announcements if they pertain to one of the following five selection criteria: 1) funding for the vaccine development (10 announcements such as announcements #1 and #3), 2) research and discovery stage or three phases of clinical development[14] (40 announcements such as announcements #4 and #6), 3) initiation of collaboration between institutions developing the vaccines (2 announcements #8 and #24), 4) government supply agreements signed with the U.S. or the European Commission (13 announcements such as announcements #36 and #47), or 5) government authorization (5 announcements such as announcements #114 and #124).

In many announcements, the content is clear from the title. For example, the title of announcement #4 *"Moderna Ships mRNA Vaccine Against Novel Coronavirus (mRNA1273) for Phase 1 Study"* is clearly about phase 1 of the vaccine development. In some announce-

[12] As a robustness check, we estimated equation (1) with additional terms for leads and lags of Ann_t to test for any potential impact that the vaccine announcements might have in the days preceding or following the announcements. The results (available in the Online Appendix) show that the return leads and lags are not significant, which means that the vaccine announcements do not affect prices in the days preceding or following the announcements.

[13] In addition to analyzing the impact of the vaccine announcements on the stock market index, we analyze the impact on stock prices of the companies that developed the vaccines. The results (available in the Online Appendix) show that the vaccine announcements moved stock prices of all four companies involved in development of the vaccines that have been approved in the U.S. (BioNTech, Johnson & Johnson, Moderna, and Pfizer) but not AstraZeneca.

[14] There are several stages in vaccine development (World Health Organization, 2004; Center for Disease Control and Prevention, 2021). During the research and discovery stage, also referred to as the exploratory and preclinical stage, the initial vaccine candidate is developed. During the clinical trials of Phase 1, a small number of people is tested to assess the safety and immune response. During Phase 2, a larger number of people is tested, and vaccine properties are verified. During Phase 3, thousands of people are tested for efficacy and safety. After successfully completing these stages, the vaccine developer seeks a regulatory review and approval. In a public health emergency, such as the COVID-19 pandemic, the review process is expedited, and the regulatory agencies issue an emergency authorization for the vaccine. The vaccine development process can also be accelerated by some phases occurring simultaneously rather than consecutively with, for example, Johnson & Johnson combining Phases 1 and 2 (Levine, 2020).

ments, however, the content is unclear from the title, for example, announcement #6 title *"Pfizer Outlines Five-Point Plan to Battle COVID-19"*. We read the entire text of all announcements to understand the content and classify the announcements accordingly. While reading the announcements, we also identified eight announcements that were duplicates of previous announcements in the sense that important information from previous announcements was to a great extent being repeated. Following the efficient market hypothesis, we did not include these duplicate announcements among our selected announcements since information is most impactful when received by the markets for the first time.[15]

There are then 70 announcements meeting the above five selection criteria, comprising 12, 21, 18, and 19 announcements about the Johnson & Johnson, Moderna, Oxford-AstraZeneca, and Pfizer-BioNTech vaccines, respectively. These announcements are marked in the Column "Selected" in Table A1 with the number in parentheses indicating which of the above five selection criteria was used.

One of these selected announcements (#71) is eliminated when we eliminate negative announcements as described in Section 3. There are also 12 instances when two or three such announcements fall into the same trading day (#10 and #12, #17 and #18, #28 and #29, #45 and #46, #49 and #50, #73 and #74, #84 and #85, #90 and #91, #99, #100 and #102, #123 and #124, and #130 and #133). Therefore, we have 57 U.S. stock market trading days on which the selected announcements occurred.

Figure 2 compares S&P 500 return densities between these 57 trading days with selected announcements and on the other 183 trading days in the sample. The days with the selected announcements have a much larger mass in the positive territory, indicating that returns tend to be higher on the selected announcement days.

[Insert Figure 2 here]

Column (2) of Table 2 reports the regression results with these selected announcements.

[15]These announcements are: #7 duplicating #4, #14 duplicating #8, #58 duplicating #36, #60 duplicating #45, #79 duplicating #77, #81 duplicating #73, #112 and #140 duplicating #102, and #121 duplicating #106.

The coefficient on the vaccine announcement variable is more than twice as large as the coefficient in Column (1): 0.878 compared to 0.409, indicating that the selected announcements are indeed especially impactful.[16] The remainder of the paper therefore uses this set of impactful announcements in the analysis explaining the U.S. stock market results in Section 4.2.2 and in the analysis of other markets in Sections 4.2.1, 4.2.3, and 4.2.4.

To gain a perspective on the economic significance of the Table 2 results, it is useful to note that all intercept estimates are negative, although statistically insignificant. This indicates that the mean stock market returns were negative on days without vaccine news. The S&P 500 index increased by approximately 13% in our sample period. According to our regression results, the average stock returns were positive only on the vaccine announcement days. Multiplying the coefficient estimate (0.878) by the number of trading days with the important vaccine announcements (57) indicates that the cumulative U.S. stock market return on the important vaccine announcement days was approximately 50%, which more than offsets the negative returns incurred on days without the important vaccine announcements and translates into trillions of dollars of shareholder value.[17]

We also conduct an industry-level analysis. Using data for returns on 12 industry portfolios from Kenneth French's website,[18] we find that the coefficient on the announcement indicator variable is statistically significant at 1% level in regressions for all 12 industries. Industries most affected by the pandemic have the largest coefficient estimates: The coefficient magnitude ranges from 0.816 for Telecommunications that was not majorly impacted by the pandemic to 2.758 for Energy that was severely impacted. These results are not tabulated

[16] As a robustness check, we analyze the impact on the DJIA and NASDAQ-100 indices. The coefficients on the announcement indicator variable for these indices are also statistically significant at 1% level and are slightly higher (0.933 and 0.900, respectively, compared to 0.879 for the S&P 500 in Column (2) of Table 2). These results are available upon request.

[17] This calculation follows the methodology of Lucca and Moench (2015) who measure how much the daily S&P 500 return was impacted by the Federal Open Market Committee (FOMC) meetings. Lucca and Moench (2015) regress the return on an indicator variable taking on the value of one if there is an FOMC meeting and the value of zero if there is no FOMC meeting and then add up the average returns on the announcement days (measured by the coefficient on the FOMC meeting indicator variable) to compute the total impact that the FOMC meetings have on the return. Following this methodology, we multiply our coefficient estimate 0.878 by the number of important vaccine announcement days, 57, to arrive at 50.1%.

[18] `http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/index.html`

for conciseness but are available upon request.

4.2 Empirical Results for Our Four Research Questions

4.2.1 How Does Vaccine News Affect Interest Rates?

When the COVID-19 crisis started in March 2020, the Federal Reserve cut its benchmark policy rate to zero in two unscheduled meetings. The Federal Reserve subsequently stated that its policy decisions would depend on the course of the pandemic. Development of effective vaccines influences the course of the pandemic. This section therefore focuses on our first question: To what extent does the COVID-19 vaccine news, and, therefore, the expected course of the pandemic, affect expectations of future monetary policy? This question is important in its own right. Furthermore, since monetary policy affects the equity market, answering this question helps us explain what drives the reaction of stock prices to vaccines news.

We analyze the U.S. Treasury yields and overnight indexed swap rates with various maturities to answer this question. We again determine the number of lags for each market using the Schwarz information criterion, which results in zero lags for all markets except for two lags for the 2-year overnight indexed swap, three lags for the 3-year overnight indexed swap, and eight lags for the 2-year Treasury; the lag coefficient estimates are again not reported for conciseness but are available upon request. We then estimate equation (1) for each market using the set of impactful vaccine announcements used in Column (2) of Table 2.

Table 3 reports the results. The vaccine announcements impact all maturities of the Treasuries. The positive effect of the vaccine news likely reflects expectations of tighter monetary policy as the pandemic abates and the economy recovers with the aid of the vaccines. The coefficients increase with maturity, ranging from less than a basis point in the 2-year Treasury yield to two and a half basis points in the 30-year Treasury yield. According to the expectations theory of the interest rate term structure, the bond yield is determined by the expected short-term rates during the life of the bond. Since in our sample period most investors expected the short-term rates to stay at the zero lower bound for most of the next two years, the response of the 2-year Treasury is marginal.[19] However, if market participants expect the Federal Reserve to start increasing the federal funds rate or reducing its bond purchases before the bond maturity date, the rates will respond to news that are important for monetary policy decisions. That is the case in our data where the impact increases with maturity, with the higher coefficients on the longer maturities reflecting investors expecting a lift-off from the zero lower bound as a part of the expected monetary policy tightening. The estimated impacts of vaccine news are economically significant. For example, for the 5-year, 10-year, and 30-year Treasury yields, these estimates are close to half of the standard deviation of daily yield changes shown in Table 1.

[Insert Table 3 here]

This finding is supported by the results for the overnight indexed swaps (OIS) that indicate what the markets expect the federal funds rate to be at the OIS maturity. For example, the 2-year OIS indicates the rate that investors expect to hold in two years in contrast to the 2-year Treasury that reflects the investors' expectations of the average rate over the two years. Our results show statistically significant coefficients for both the 2-year and 3-year OIS. The coefficient on the 2-year OIS exceeds the coefficient on the 2-year Treasury approximately by a factor of four, again indicating that investors expect a lift-off and that vaccine announcements matter for the expectations of the lift-off timing.

The above interest rate results in Table 3 show the impact of the vaccine announcements on nominal interest rates. This impact, especially for the longer term Treasuries, combines two effects: the expected future inflation and real interest rate. We obtain the breakeven inflation rates from the FRED database. These breakeven inflation rates measure what market participants expect inflation to be in the next ten and thirty years, respectively. We regress the two breakeven inflation rates on the vaccine announcement indicator variable.

[19]Similarly, Swanson and Williams (2014) show that medium-term interest rates became unresponsive to U.S. macroeconomic news during the zero lower bound episode that followed the financial crisis of 2008-2009.

The coefficients estimates are positive but not statistically significant. This indicates that vaccine news affects interest rates primarily by moving expectations of the real rates. These results are not tabulated to save space but are available upon request.

4.2.2 What Drives the Reaction of Stock Prices?

Section 4.1 shows that the vaccine announcements move the stock market. Through what channels does information about the expected course of the pandemic influence the stock market? This section answers this question. News announcements move stock prices if the announcements convey information about the expected corporate cash flows or the expected return (consisting of the risk-free interest rate and the equity risk premium) used to discount the cash flows (for example, Boyd et al. (2005)). We investigate which of these three channels drives the reaction of the stock markets to the vaccine announcements by decomposing the aggregate stock returns. Introduction of effective vaccines alters the expected course of the pandemic. It is conceivable that stocks of firms in some industries, for example, stocks of hospitality and energy companies, could be affected by the pandemic through company expected earnings. However, pandemic-related news may also affect stock prices by influencing the risk-free interest rate and the equity risk premium. Therefore, by analyzing what drives the reaction of stock prices to vaccine news we shed light on the channels through which the pandemic influences equity prices.

We estimate the daily cash flow news and the discount rate news for the S&P 500 index using the return decomposition approach proposed by Campbell and Shiller (1988). Campbell and Shiller (1988) derive the following accounting identity that decomposes the unexpected stock returns into news about future dividends and future discount rates:

$$r_{t+1} - E_t r_{t+1} = (E_{t+1} - E_t) \sum_{j=0}^{\infty} \rho^j \Delta d_{t+1+j} - (E_{t+1} - E_t) \sum_{j=1}^{\infty} \rho^j \Delta r_{t+1+j} = N_{CF,t+1} - N_{DR,t+1}, \quad (2)$$

where r_{t+1} is a log stock return, E_t and E_{t+1} are expectations at time t and $t+1$, Δd_{t+1} is a one-period change in the log dividends, ρ is a constant discount factor, $N_{CF,t+1}$ is news about future cash flows, and $N_{DR,t+1}$ is news about future discount rates. To construct the time series of the aggregate cash flow news and the aggregate discount rate news, we follow Atilgan, Bali, and Demirtas (2015) and estimate the first-order vector autoregression (VAR). Results of this VAR estimation are provided in the Online Appendix.

We then estimate OLS regressions of the estimated cash flow news and discount rate news on the vaccine news indicator variable. Table 4 presents the results. The cash flow news component responds positively to good news about vaccines, with the coefficient estimate of approximately 0.34%, significant at the 10% level, indicating that the expected cash flows increase in response to good news about the vaccine.

[Insert Table 4 here]

The coefficient on the discount rate news is negative (-0.59%), significant at the 1% level. This means that the discount rate news component falls in response to good news about the vaccines. The discount rate is a sum of the risk-free rate and the equity risk premium. We therefore further analyze which of these two channels affects the discount rate. Our results for the interest rates in Table 3 show that the risk-free rate increases in response to positive vaccine news. The negative coefficient estimate for the discount rate news in Table 4 is therefore driven by the equity risk premium decreasing in response to positive vaccine news (rather than being driven by the risk-free rate).

This conclusion about the equity risk premium decreasing in response to positive vaccine news is confirmed by our analysis of the Chicago Board Options Exchange's (CBOE) Volatility Index (VIX). We compute the change in the VIX, i.e., $VIX_t - VIX_{t-1}$. We determine the optimal number of lags using the Schwarz information criterion, which results in three lags. We then estimate equation (1) using the VIX change as the dependent variable. The coefficient on the announcement indicator variable is statistically significant at 1% level. As expected, it has a negative sign, which is the opposite sign compared to the coefficient for the S&P 500 returns in Table 2 because it is well known that VIX changes are negatively correlated with stock returns. This finding supports our result showing that the negative coefficient estimate for the discount rate news in Table 4 is driven by the equity premium decreasing in response to positive vaccine news. The negative coefficient for the VIX supports this conclusion because the VIX is a high-frequency proxy for the equity risk premium (Martin, 2017).

Taken together, these results mean that the positive response of stock returns to the vaccine news documented in Table 2 is driven by information about future corporate cash flows and equity risk premium (but not the risk-free rate). This analysis helps explain, for example, why the broad stock indices declined dramatically and experienced extreme volatility at the beginning of the pandemic (Baker et al., 2020). Understanding the channels through which the pandemic influences equity prices is useful for policy makers trying to alleviate market dislocations caused by future pandemics. Bernanke and Kuttner (2005) show that monetary policy news influences stock prices primarily by affecting the equity premium and the expected corporate cash flows. Therefore, monetary policy can reduce the negative effect of pandemics on equity prices and the resulting contractionary spillovers to the real economy.

4.2.3 Does the Stock Market Reaction Differ Across Countries?

To what extent are international stock markets affected by vaccine news? Since economies of different countries have been affected differently by the pandemic, the extent to which their stock markets react to vaccine news is an empirical question. This section therefore examines whether there are differences in reactions across countries.

Because these markets operate in different time zones and observe different holidays and closing times, we adjust the announcement dates and times shown in Table A1 to place the announcements in the correct trading days. The number of trading days (shown in Table 1) therefore varies across the markets. For example, consider an announcement released on a trading day at 12:00 noon Eastern Time (ET). As explained in Section 3.1, for the U.S. stock market the announcement date is that trading day since the U.S. stock market is open from 9:30 ET to 16:00 ET. However, this announcement might fall into a different trading date for markets in other countries. Consider, for example, the stock market in France. That stock market has trading hours from 9:00 Central European Time (CET) to 17:30 CET. The announcement released at 12:00 Eastern Time (which is 18:00 CET due to a six-hour difference between the ET and CET) arrives after the French stock market trading hours and, therefore, the announcement date is the following trading day.

We also determine the number of lags for each market using the Schwarz information criterion, which results in zero lags for all stock indices except for the stock indices in Brazil with one lag; Italy, Nigeria, and Spain with two lags; Australia with three lags; and Canada with seven lags. The lag coefficient estimates are again not reported for conciseness but are available upon request.

We estimate equation (1) for each market using the set of impactful vaccine announcements used in Column (2) of Table 2. Table 5 Panel a) reports the results for the European stock markets. The coefficient on the vaccine announcement variable is significant. The magnitude of the coefficients ranges from 0.751 in Spain to 0.849 in Italy and compares to the coefficient of 0.878 for the U.S. in Column (2) of Table 2.

[Insert Table 5 here]

Interestingly, the reaction of the stock markets in Panel b) and c) is more varied. The vaccine announcements are not significant in the stock markets in Asia in Panel b) of Table 5 except for South Korea that is significant at the 10% level. In Panel c), the stock markets in Brazil, Mexico, and Canada react to the announcements, the stock markets in Nigeria and South Africa show statistical significance at 10% level, and the stock market in Australia does not react to the announcements. What might explain this heterogeneity in the reaction across the stock markets? The following analysis investigates this question.

We estimate equation:

$$R_{i,t} = \alpha_0 + \alpha_1 R_{i,t-1} + \beta_1 Ann_t + \beta_2 Ann_t * PANDEMIC_i + \theta_i + \epsilon_{i,t}, \quad (3)$$

where in comparison to equation (1), there are two modifications. First, instead of estimating the model for an individual stock market as in equation (1), we include all 19 stock markets (18 stock markets shown in Table 5 and the U.S. stock market shown in Table 2) in a combined panel data set. $R_{i,t}$ is then the log return for the given market i on day t and θ_i stands for the market-specific random effects (i.e., cross-section random effects). Second, to measure the extent to which the market was affected by the initial pandemic-related crisis, we include a variable $PANDEMIC_i$, which is the log return for the given market i from January 31, 2020 to March 22, 2020.[20] We standardize the $PANDEMIC_i$ variable by subtracting the cross-sectional mean and dividing by the standard deviation of the return. To simplify interpretation, we multiply this $PANDEMIC_i$ variable by -1 so that a larger value of the $PANDEMIC_i$ variable indicates that the market experienced a larger decline at the beginning of the pandemic. Again, to simplify interpretation, the $PANDEMIC_i$ variable, is demeaned by subtracting its cross-sectional mean and divided by its cross-sectional standard deviation; the zero value of the $PANDEMIC_i$ variable for a market i then means that the initial pandemic effect for this market is average of all 19 markets. This $PANDEMIC_i$ variable is multiplied by our announcement indicator variable. The coefficients are then interpreted as follows. The coefficient β_1 on the announcement variable indicates the impact of good vaccine news on the market with an average (rather than zero) initial pandemic decline. A positive (negative) estimate of coefficient β_2 on the interaction term indicates that the impact of good vaccine news is stronger (weaker) in markets that experienced larger declines at the beginning of the pandemic.

We estimate this equation for the sample period from March 23, 2020 (i.e., after the end of the sample period from January 31, 2020 to March 22, 2020 used to compute the $PANDEMIC_i$ variable)[21] to December 31, 2020 using a random effects panel estimator

[20]We follow Acharya et al. (2021) who analyze the impact of vaccine development on returns of industry portfolios. They include returns on the industry portfolios at the beginning of the pandemic (from February 1, 2020 to March 22, 2020) to show that industry portfolios that experienced the largest declines in returns at the beginning of the pandemic benefited the most from vaccine development.

[21]As can be seen from Table A1 in the Online Appendix, this sample period excludes five selected announcements that occurred on January 23, February 11, February 24, March 13, and March 17.

with standard errors corrected for correlations across markets.[22] We determine the optimal number of lags for this panel data set, which turns out to be one lag. The lag coefficient estimate is again not reported for conciseness but is available upon request. There are 205 trading days and 19 markets. This is an unbalanced panel because some markets are closed on some days due to holidays as discussed above; the total number of panel observations is 3,735.

Column (1) of Table 6 shows the results. The coefficient estimate on the announcement variable of 0.453 means that the market with an average initial pandemic decline increased by 0.453 upon receiving good vaccine news. We are most interested in the coefficient on the interaction term multiplying the announcement variable by the $PANDEMIC_i$ variable. The coefficient is positive, which means that markets experiencing larger declines at the beginning of the pandemic benefited from good news about vaccines more than markets experiencing smaller declines at the beginning of the pandemic. Specifically, the coefficient value of 0.139 means that for one-standard deviation (which equals 10.2% for the stock markets) increase in the initial pandemic effect, the average effect of good vaccine news increases by 0.139%.

[Insert Table 6 here]

There are many reasons why the stock markets experienced different declines at the beginning of the pandemic and therefore different reactions to vaccine news as evidenced by the results in Table 5. For example, some countries in Asia such as China adopted a "zero-covid" strategy and quickly enforced strict measures such as economy shutdowns, population lockdowns, mask mandates, distancing, and contact tracing. Although many countries eventually abandoned this strategy as the delta variant of the COVID-19 virus proved too contagious to eradicate the disease, the strategy was in effect in our sample period in 2020 (The Economist, 2021) and the health situation (and in turn the economy and stock markets) in these countries did not deteriorate as much as in the U.S. and Europe. The vaccine announcements were

[22] As a robustness check, we repeat the analysis with cross-sectional fixed effects and with the pooled ordinary least squares estimator. The results, available upon request, are almost identical.

then not as impactful as in the U.S. and Europe where they were perceived as game-changers for the dire health situation. In addition, some countries announced that they would not be using the Johnson & Johnson, Moderna, Oxford-AstraZeneca, and Pfizer-BioNTech vaccines (for example, China made it clear that it would rely on its Sinopharm-BIBP and Sinovac vaccines) or experienced delays in the vaccine rollout (for example, Australia lagged behind the U.S. and Europe in the vaccinations (BBC, 2021)). The vaccine announcements were therefore not as relevant for the markets in Asia and Australia as in the U.S. and Europe.[23]

4.2.4 Which Commodities Are Affected by Vaccine News?

Commodities serve as key inputs in production. Furthermore, investors substantially increased their exposure to commodities in recent years (for example, Henderson et al. (2015)). The COVID-19 pandemic affected demand for many commodities and produced large movements in commodity prices. This section therefore investigates our fourth research question: To what extent did the news about the COVID-19 vaccines move prices of different commodities?

We again determine the number of lags for each market using the Schwarz information criterion, which results in zero lags for all markets except for one lag for corn and soybeans, two lags for lumber, and four lags for crude oil; the lag coefficient estimates are again not reported for conciseness but are available upon request. We then estimate equation (1) for each market using the set of impactful vaccine announcements used in Column (2) of Table 2. The number of trading days again varies across these markets because the markets have different holidays and closing times.

Table 7 reports the results. The COVID-19 pandemic caused a global recession and one could therefore hypothesize that all commodities will be affected by the economic slump and therefore boosted by positive vaccine news. This indeed seems to be the case for two energy

[23]In addition to Table 6 that explains the heterogeneity in the stock market reaction across countries by the initial pandemic effect, we analyze whether the stock market reaction varies between developed and emerging economies. The results (available in the Online Appendix) show that there is no statistically significant difference between developed and emerging economies.

commodities (crude oil and gasoline) and several agricultural commodities (cocoa, coffee, corn, cotton, soybeans, and soybean oil) but this impact is not shared by one energy commodity (natural gas), precious metals (gold and silver), construction commodities (copper and lumber), and one agricultural commodity (wheat). What drives this heterogeneity in results? We repeat the panel regression analysis conducted in Section 4.2.3. Column (2) of Table 6 shows the results. Again, the positive coefficient on the term interacting our announcement variable with the $PANDEMIC_i$ variable is positive, which means that the markets that experienced larger declines at the beginning of the pandemic showed a larger positive reaction to good vaccine news. Specifically, the coefficient value of 0.57 means that for one-standard deviation (which equals 29.1% for the commodity markets) increase in the initial pandemic effect, the average effect of good vaccine news increases by 0.57%.

[Insert Table 7 here]

There are many reasons why the commodity markets experienced different declines at the beginning of the pandemic and therefore different reactions to vaccine news as evidenced by the results in Table 7. As the COVID-19 pandemic hit, governments implemented restrictions to limit the movement of people. Workers were encouraged to telecommute and transportation industries such as the airline industry suffered devastating losses. Consequently, demand for commodities used in transportation plummeted. Good news about the COVID-19 vaccine therefore brought hope that the demand for transportation will increase again and these commodity markets will recover. This is reflected in the positive coefficient for the crude oil in Table 7 since 66% of crude oil is used for transportation purposes (U.S. Energy Information Administration, 2021). The coefficient is economically meaningful with the coefficient of approximately 45% of the standard deviation of the daily return in Table 1, which is especially noteworthy given the fact that crude oil prices were extremely volatile in our sample period as indicated by the rather high standard deviation in Table 1. The gasoline price impact mirrors that of the crude oil since 44% of crude oil is refined into gasoline, making it the most consumed crude oil product (U.S. Energy Information Administration, 2021). Corn and soybean oil (and to a lesser effect soybeans) are similarly affected because they are used in biofuels: 40% of corn is processed into ethanol (Foley, 2013) and soybean oil is the main component of biodiesel (U.S. Energy Information Administration, 2019).

The pattern of commodity prices plunging at the onset of the COVID-19 pandemic and then experiencing a rise was not limited to commodities used in transportation industries. Demand for cotton plunged since retail shopping for clothes was limited (Liu, 2020). Good news about the COVID-19 vaccines then brought hope that the textile industry will rebound, which is reflected in the positive coefficient estimate for cotton. The cocoa and coffee commodity markets experienced similar trends: the demand for cocoa and coffee declined as restaurants shuttered their doors at the onset of the COVID-19 pandemic (IHS Markit, 2020). Good news about the COVID-19 vaccines then signaled that the restaurant industry will revive and demand for the cocoa and coffee will increase.

The positive impact of good COVID-19 vaccine news is, however, not shared by other commodities. For example, natural gas futures prices are not significantly affected by the vaccine news. Whereas the global consumption of crude oil declined by about 16% in the second quarter of 2020, natural gas consumption during the same period was stable (World Bank, 2020). As a result, the effect of the COVID-19 pandemic on natural gas prices was relatively small. Copper and lumber are not significantly affected by the vaccine announcements. This may be due to the relative fortune that the construction industry experienced during the pandemic. Although some construction such as office building construction suffered during the pandemic, other construction such as residential construction led the industry into a boom (Smith, 2021). Construction is the largest user of copper accounting for 43% of copper use (Garside, 2021) and construction also accounts for a majority of lumber use. Since the demand for these construction commodities did not collapse as the demand for the transportation commodities, the vaccine news announcements do not seem to play as large a role in these construction commodities as in the transportation commodities.

Gold and silver also show insignificant coefficients. Precious metals play a multitude of roles in the economy. For example, gold, in addition to being a commodity used in industrial production, played the role of a safe haven asset as well as a hedge for the equity markets at various phases of the COVID-19 recession (Akhtaruzzaman, Boubaker, Lucey, & Sensoy, 2021). Gold is also viewed as an inflation hedge and its prices may be driven by investor psychology, exacerbated by price pressure from large gold holdings in gold exchange-traded funds (ETF) (Erb, Harvey, & Viskanta, 2020). It is perhaps due to a combination of these factors that the vaccine announcements did not impact the gold price.

5 Robustness Checks

We already noted in Section 3.1 that our results are robust to including a negative announcement and in Secton 4.1 that our results for the U.S. stock market are robust to the choice of the stock market index (Dow Jones Industrial Average and NASDAQ-100 indices rather than the S&P 500 index), the number of lags (zero, one, and two lags rather than the seven lags determined by the Schwarz information criterion), and any potential price moves that might occur on days preceding or following the announcements. This section discusses additional robustness checks.

One potential concern about our equation (1) is that the results might be driven by other events unrelated to our vaccine announcements. Therefore, we conduct robustness checks to test whether our results for the U.S. stock market are robust to such other events. Specifically, we control for announcements about vaccines developed in China, the U.S. macroeconomic news announcements, a general measure of COVID-19 related uncertainty, and the U.S. daily COVID-19 cases. Our results (available in the Online Appendix) are robust in all these tests.

While we cannot test for all important news that arrived during our sample period (for example, news about the U.S. presidential elections, climate policy regulations, infrastructure spending, etc.), we are encouraged to know that for this news to be an omitted variable biasing our results upward, it would have to be systematically released on our vaccine announcement days (rather than both on announcement and non-announcement days) *and* the news would have to be systematically positive for the markets (rather than the news being positive on some days and negative on other days). In reality, it is likely that the markets received news both on the vaccine announcement and non-announcement days and the news was a mix of positive and negative news, making an upward bias in our results unlikely.

6 Conclusion

We study how financial and commodity markets react to announcements about the development of the Johnson & Johnson, Moderna, Oxford-AstraZeneca, and Pfizer-BioNTech vaccines, the four COVID-19 vaccines approved in the EU, the U.K., or the U.S. We show that the vaccine announcements had interesting, varied, and economically significant impacts on asset prices. The announcements affected interest rates, stock markets in the U.S., U.K., EU, Canada, Mexico, Brazil, South Africa, and Nigeria (but not in Asia and Australia) as well as commodities used in transportation and some agricultural commodities (but not precious metals and construction commodities). We show that the heterogeneity in reaction of stock and commodity markets to the vaccine announcements is driven by what happened in the markets at the beginning of the pandemic: the markets that experienced larger declines at the beginning of the pandemic receive a larger boost from good vaccine news. We also offer an insight into the stock market reaction using a decomposition of the S&P 500 index returns into cash flow news and discount rate news; we find that the vaccine news affects stock returns through changes in the expectations of the corporate cash flows and the expected equity risk premium (rather than the risk-free rate). Overall, our results underscore how important developments in science such as microbiology can exert substantial influence across a wide range of markets. This substantial influence of the vaccine announcements is remarkable especially since it occurred in spite of uncertainties about the willingness of individuals to get vaccinated, continued efficacy of vaccines, and effectiveness of vaccines against new variants of the virus.

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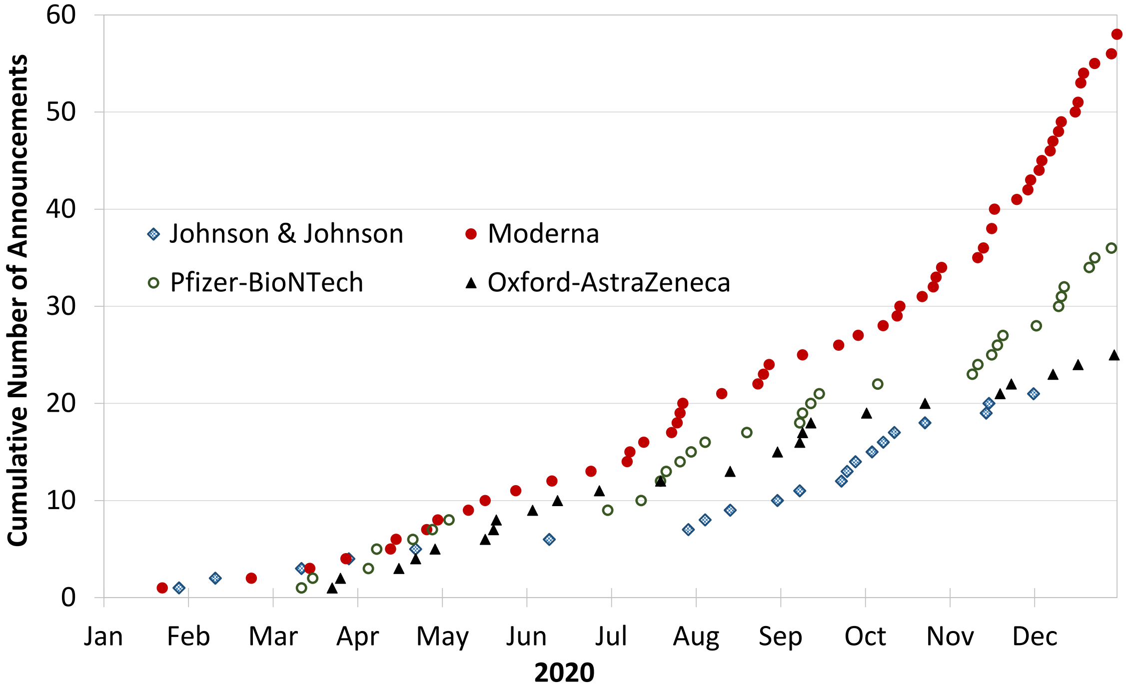
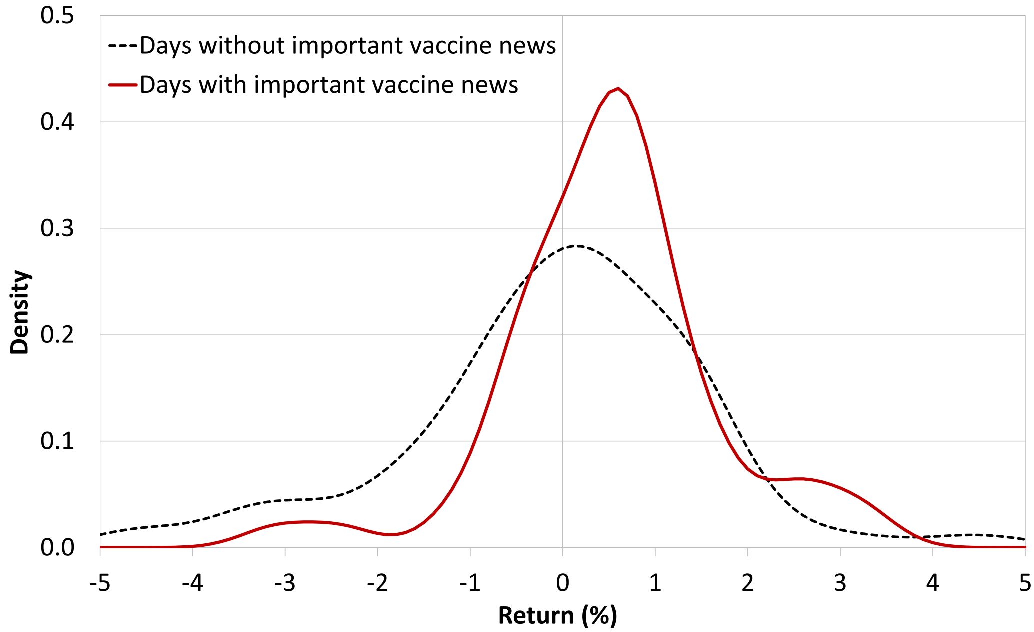
Figure 1: Timeline of Vaccine Announcements



This figure shows the cumulative number of vaccine announcements (indicated by markers) for the four vaccines from January 23, 2020 to December 31, 2020.

Figure 2: S&P 500 Return Densities



This figure shows kernel densities of the S&P 500 log returns on 57 days with impactful vaccine announcements and on the other 183 days. The bandwidth is selected using the Sheather and Jones (1991) method.

Table 1: Summary Statistics

Market Type	Market	Median	Mean	Stnd Dev	Min	Max	Obs.
Interest rates	2-year Treasury	0.000	-0.006	0.03	-0.25	0.12	238
	5-year Treasury	0.000	-0.005	0.04	-0.22	0.17	238
	10-year Treasury	0.000	-0.004	0.06	-0.21	0.29	238
	30-year Treasury	0.000	-0.002	0.07	-0.31	0.29	238
	2-year overnight indexed swap	-0.001	-0.005	0.12	-1.17	1.06	246
	3-year overnight indexed swap	-0.001	-0.005	0.12	-1.12	1.00	247
Stocks	US - S&P500	0.24	0.05	2.24	-12.77	8.97	240
	Europe - EuroStoxx600	0.11	-0.02	1.81	-12.19	8.17	244
	France - CAC40	0.03	-0.04	2.12	-13.10	8.28	243
	Germany - DAX	-0.01	0.01	2.15	-13.06	10.41	240
	Italy - FTSE MIB	0.12	-0.03	2.20	-16.14	8.55	241
	Spain - IBEX35	0.05	-0.07	2.21	-15.15	8.23	243
	U.K. - FTSE	0.06	-0.07	1.91	-11.51	8.67	240
	Asia - S&P50 Asia	0.25	0.11	1.60	-5.35	6.86	245
	China - Shanghai Composite	0.11	0.06	1.34	-8.04	5.55	229
	Hong Kong - Hang Seng	0.08	-0.01	1.50	-5.72	4.78	234
	India - BSE-Sensex	0.28	0.06	2.09	-14.10	8.60	237
	Japan - Nikkei 225	-0.01	0.06	1.65	-6.27	7.73	232
	South Korea - KOSPI 200	0.21	0.11	1.86	-7.98	8.76	234
	Nigeria - NSE 30	0.03	0.10	1.29	-5.70	5.92	235
	South Africa - FTSE/JSE Top 40	0.02	0.01	2.45	-14.38	9.17	237
	Brazil - Bovespa	0.09	0.01	2.93	-16.00	13.02	235
	Canada - Toronto TSX 300	0.19	0.02	2.14	-12.35	11.96	238
	Mexico - Dow Jones Mexico	-0.04	-0.01	1.60	-6.54	8.22	247
	Australia - S&P/ASX 200	0.12	-0.03	1.93	-10.20	6.77	241
Commodity	Crude oil	0.32	-0.08	7.05	-56.86	24.06	245
	Gasoline	0.52	-0.06	5.00	-26.50	19.29	245
	Natural gas	-0.07	0.12	4.35	-10.48	25.42	245
	Gold	0.19	0.08	1.38	-5.11	5.77	245
	Silver	0.14	0.16	2.96	-12.35	7.27	245
	Copper	0.18	0.10	1.47	-7.18	3.83	245
	Lumber	0.55	0.22	3.17	-14.70	7.87	240
	Cocoa	0.06	-0.03	1.71	- 5.08	5.26	240
	Coffee	0.00	0.06	2.34	-7.36	6.29	240
	Corn	0.16	0.09	1.27	-3.55	3.83	240
	Cotton	0.08	0.05	1.48	-5.47	5.17	240
	Soybeans	0.15	0.15	1.02	-3.23	3.15	240
	Soybean oil	0.13	0.11	1.46	-5.38	3.35	240
	Wheat	-0.09	0.04	1.60	-3.59	5.13	240

This table shows the summary statistics for the daily log return $R_t = ln(P_t/P_{t-1}) * 100$ where P_t is the closing price on day t except for the Treasuries and overnight indexed swaps where we use changes in yields, $\Delta yield_t = yield_t - yield_{t-1}$. The sample period is from January 22, 2020 to December 31, 2020. The Obs. column shows the number of observations, which are the trading days for each market. The markets differ in the number of trading days due to holidays.

Table 2: Impact of Vaccine Announcements on U.S. Stock Market

	(1)	(2)
Announcement	0.409*	0.878***
	(0.230)	(0.220)
Constant	−0.163	−0.120
	(0.155)	(0.165)
Trading days	240	240
Trading days with announcement	99	57

Column (1) shows the results of estimating equation (1) that regresses the daily log return, R_t, on a constant, seven lags of return, and an indicator variable that takes on the value of one if there is a vaccine announcement on that day and zero otherwise. The log return is computed as $R_t = ln(P_t/P_{t-1}) * 100$ where P_t is the closing value of the S&P500 on day t. Column (2) shows the results of estimating equation (1) using a set of vaccine announcements selected as described in Section 4.1. The OLS regression is used. For conciseness, the return lags are not reported and are available upon request. The sample period is from January 22, 2020 to December 31, 2020. White (1980) standard errors are shown in parentheses. *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.

Table 3: Impact of Vaccine Announcements on Interest Rates

	2-year Treasury	5-year Treasury	10-year Treasury	30-year Treasury	2-year OIS	3-year OIS
Announcement	0.006*	0.018***	0.022***	0.025***	0.026***	0.029***
	(0.003)	(0.006)	(0.008)	(0.009)	(0.010)	(0.010)
Constant	−0.005**	−0.009***	−0.009**	−0.008*	−0.015*	−0.016**
	(0.002)	(0.003)	(0.004)	(0.005)	(0.008)	(0.007)
Trading days	237	238	238	238	246	247
Trading days with ann.	56	56	56	56	57	57

This table shows the results of estimating equation (1) that regresses the yields defined as $\Delta yield_t = yield_t - yield_{t-1}$ on a constant and an indicator variable that takes on the value of one if there is a vaccine announcement on that day and zero otherwise. We include two lags for the 2-year overnight indexed swap (OIS), three lags for the 3-year OIS, and eight lags for the 2-year Treasury based on the Schwarz information criterion; the lags are not reported for conciseness but are available upon request. The estimation uses the set of vaccine announcements selected as described in Section 4.1. The number of trading days varies across markets because of opening hours and holidays observed in these markets; the 2-year OIS has one missing observation in the FRED data source. The OLS regression is used. The sample period is from January 22, 2020 to December 31, 2020. White (1980) standard errors are shown in parentheses. *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.

Table 4: Impact of Vaccine Announcements on Cash Flow and Discount Rate News

	Cash Flow News	Discount Rate News
Announcement	0.338*	−0.592***
	(0.176)	(0.141)
Constant	−0.125	0.156
	(0.120)	(0.095)

The right column shows the results of a simple regression of the daily cash flow news, N_{CF}, on a constant and an indicator variable that takes on the value of one if there is a vaccine announcement on that day and zero otherwise. The left column shows the results of a similar regression with the discount rate news, N_{DR}, used as the dependent variable. The vaccine announcements are selected as described in Section 4.1. The OLS regression is used. The sample period is from January 22, 2020 to December 31, 2020 in both columns and contains 240 trading days, including 57 days with vaccine announcements. White (1980) standard errors are shown in parentheses. *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.

Table 5: Impact of Vaccine Announcements on Other Stock Markets

Panel a): Stock markets in Europe

	Euro Stoxx600	CAC40	DAX	FTSE MIB	IBEX35	FTSE100
Announcement	0.709***	0.798**	0.805**	0.849***	0.751**	0.778***
	(0.268)	(0.316)	(0.336)	(0.298)	(0.335)	(0.287)
Constant	−0.193	−0.226	−0.189	−0.226	−0.237	−0.256*
	(0.132)	(0.154)	(0.154)	(0.164)	(0.154)	(0.139)
Trading days	244	243	240	241	243	240
Trading days with ann.	58	58	58	58	58	58

Panel b): Stock markets in Asia

	S&P50 Asia	Shanghai	Hang Seng	Nikkei225	KOSPI200	BSE Sensex
Announcement	0.352	−0.029	0.265	0.006	0.471*	0.242
	(0.244)	(0.177)	(0.234)	(0.260)	(0.269)	(0.317)
Constant	0.023	0.064	−0.076	0.059	−0.001	0.003
	(0.116)	(0.109)	(0.111)	(0.123)	(0.142)	(0.157)
Trading days	245	229	234	232	234	237
Trading days with ann.	58	56	57	58	54	57

Panel c): Other stock markets

	FTSE/JSE Top 40	NSE 30	Bovespa	Dow Jones Mexico	Toronto TSX 300	S&P/ ASX200
Announcement	0.640*	0.321*	1.209***	0.739***	0.804***	−0.057
	(0.372)	(0.180)	(0.371)	(0.223)	(0.230)	(0.274)
Constant	−0.139	−0.018	−0.286	−0.183	−0.197	−0.013
	(0.182)	(0.089)	(0.221)	(0.117)	(0.142)	(0.125)
Trading days	237	235	235	247	238	241
Trading days with ann.	56	57	56	57	57	60

This table shows the results of estimating equation (1) that regresses the daily log return, R_t, on a constant and an indicator variable that takes on the value of one if there is a vaccine announcement on that day and zero otherwise. We include one lag for Bovespa, two lags for FTSE MIB, IBEX35 and NSE 30, three lags for S&P/ASX200, and seven lags for TSX 300 based on the Schwarz information criterion. The lag coefficient estimates are not reported for conciseness but are available upon request. The log return is computed as $R_t = ln(P_t/P_{t-1}) * 100$ where P_t where P_t is the closing price on day t. The number of trading days varies across markets because of opening hours and holidays observed in these markets. The OLS regression is used. The sample period is from January 22, 2020 to December 31, 2020. White (1980) standard errors are shown in parentheses. *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.

Table 6: Heterogeneity in Vaccine Announcement Impact Across Stock and Commodity Markets

	(1) Stock Markets	(2) Commodity Markets
Announcement	0.453***	0.667***
	(0.155)	(0.183)
Announcement*PANDEMIC	0.139**	0.571***
	(0.071)	(0.213)
Constant	0.092	0.048
	(0.091)	(0.096)
Number of time periods (Trading days)	205	202
Number of cross-sections (Markets)	19	14
Total panel observations	3,735	2,795

This table shows the results of estimating equation (3) that regresses the log return, $R_{i,t}$ for market i on day t, on a constant, an indicator variable that takes on the value of one if there is a vaccine announcement on that day and zero otherwise, and an interaction term multiplying this vaccine announcement variable by a variable $PANDEMIC_i$, which is the log return for market i from January 31, 2020 to March 22, 2020. We standardize the $PANDEMIC_i$ variable by subtracting the cross-sectional mean and dividing by the standard deviation of the return and then multiply the standardized variable by -1. Column (1) uses a panel data set of 19 stock markets and Column (2) uses a panel data set of 14 commodity markets. The log return for each market is computed as $R_{i,t} = ln(P_t/P_{t-1}) * 100$ where $P_{i,t}$ is the closing value of the given market i on day t. The estimation uses a set of vaccine announcements selected as described in Section 4.1. The random effects panel estimator is used. The sample period is from March 23, 2020 to December 31, 2020. Standard errors corrected for correlations across markets are shown in parentheses. *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.

Table 7: Impact of Vaccine Announcements on Commodity Markets

Panel a): Energy, precious metal, and construction commodities

	Crude Oil	Gasoline	Natural Gas	Gold	Silver	Copper	Lumber
Announcement	2.929***	2.227***	0.581	−0.152	−0.289	0.109	0.488
	(0.923)	(0.587)	(0.635)	(0.225)	(0.469)	(0.203)	(0.465)
Constant	−0.788	−0.611	−0.019	0.117	0.231	0.068	0.068
	(0.489)	(0.389)	(0.323)	(0.096)	(0.215)	(0.111)	(0.234)
Trading days	245	245	245	245	245	245	240
Trading days with ann.	59	59	59	59	59	59	57

Panel b): Agricultural commodities

	Cocoa	Coffee	Corn	Cotton	Soybeans	Soybean Oil	Wheat
Announcement	0.584**	0.713**	0.389**	0.537**	0.243*	0.523**	0.215
	(0.260)	(0.339)	(0.189)	(0.237)	(0.150)	(0.219)	(0.261)
Constant	−0.174	−0.112	−0.012	−0.077	0.069	−0.002	−0.001
	(0.125)	(0.175)	(0.104)	(0.104)	(0.074)	(0.107)	(0.114)
Trading days	240	240	240	240	240	240	240
Trading days with ann.	58	58	57	57	57	57	57

This table shows the results of estimating equation (1) that regresses the daily log return, R_t, on a constant and an indicator variable that takes on the value of one if there is a vaccine announcement on that day and zero otherwise. We include one lag in corn and soybeans, two lags of return in lumber, and four lags in the crude oil based on the Schwarz information criterion. The lag coefficient estimates are not reported for conciseness but are available upon request. The log return is computed as $R_t = ln(P_t/P_{t-1}) * 100$ where P_t is the closing price on day t. The estimation uses the set of vaccine announcements selected as described in Section 4.1. The number of trading days varies across markets because of opening hours and holidays observed in these markets. The OLS regression is used. The sample period is from January 22, 2020 to December 31, 2020. White (1980) standard errors are shown in parentheses. *, **, and *** indicate statistical significance at 10%, 5%, and 1% levels, respectively.