# What do Index Options Teach us About Covid-19?

Jens Jackwerth

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Abstract

Risk-neutral distributions of the S&P 500 inform about the Covid-19 pandemic beyond what one can learn from index values and the market fear gauge VIX alone. We learn that, on February 20, 2020, the index did not reflect the impending crisis yet. Only on March 16, 2020, was the full impact visible, with a pronounced bimodality for longer-maturity options showing a sizeable crash scenario. The corresponding physical distribution is more symmetric and features a high-volatility crash scenario instead. Firms bought crash protection ahead of the index crash, while retail customers bought it as the index was already recovering.

Keywords: Risk-neutral distributions, Covid-19, option pricing

JEL: G01, G13

Jens Jackwerth is from the University of Konstanz, PO Box 134, 78457 Konstanz, Germany, Tel.: +49-(0)7531-88-2196, Email: jens.jackwerth@unikonstanz.de. I thank Ben Golez, Jim Hodder, Manuel Leininger, and Marco Menner for helpful comments.

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## Introduction

Faced with the rising toll of the Covid-19 pandemic, society tries to learn about the crisis from limited information. As it became apparent that the pandemic would have major economic consequences, financial markets reacted strongly. For example, the S&P 500 index dropped by 34% from February 19, 2020, through March 23, 2020. Such a decline indicates investor concern about negative consequences for the US and Global economies, but the information is aggregated so that much detail is lost. In effect, we look at a single value (the index) that is the discounted expectation of uncertain future index values. In a similar vein, the VIX[1] provides a gauge of investor uncertainty about future index values; but we again have a single value that provides important but not detailed information.

This paper goes a major step further and uses the pricing of options on the S&P 500 index to estimate an implicit distribution of future index values, the risk-neutral distribution. Since a large number of market participants are buying and selling these index options, we wind up with an average or "representative investor" risk-neutral distribution. As investors are typically risk averse, the risk-neutral distribution includes both a probabilistic assessment of future index values (formally, their physical probabilities) and a risk adjustment (resulting in larger risk-neutral probabilities for painful outcomes and reduced probabilities for beneficial outcomes).

I use the richness of risk-neutral index distributions to address questions about crash expectations during the Covid-19 and other pandemics, including the timing and extent to which those

[1] The Chicago Board Options Exchange Volatility Index (VIX) is a widely used market fear gauge measuring annualized option-implied volatility in %.

distributions reflect concerns about a potential market crash. I also examine option trade data reflecting how risk-averse investors attempt to protect themselves against adverse index movements.

When did markets impound the economic impact of the Covid-19 pandemic?

Distributions on dates prior to February 20, 2020, do not display noticeable concerns about economic consequences of the pandemic. Leading up to February 28, 2020, the risk-neutral index distributions indicate the beginnings of concern, even though February 28, 2020, is over a month after the first US case and about two months after the outbreak started in Wuhan. A much stronger reaction can be seen in the risk-neutral distribution for March 16, 2020. This finding is consistent with Ramelli and Wagner (2020), who find that mainly the few stocks with strong exposure to China were affected early during the pandemic. Investors realized only belatedly that many other stocks in the S&P 500 were also affected by the pandemic.

What risk-neutral scenarios did the option market view as likely?

The March 16, 2020, data imply a bimodal (two-hump) distribution of potential outcomes. That distribution can be replicated by a 40% chance of an outcome from a distribution of very adverse (crash) results coupled with a 60% chance of an outcome from a normal scenario distribution. The mid-point of the crash scenario is located 1,461 index points below that of the normal scenario, while this distance is typically around 600 index points (typical days also have crash scenarios, but only mild ones).

How does the physical scenario differ from the risk-neutral one?

When I remove the implicit risk adjustment, the physical distribution for the crash scenario morphs into a pervasive high-variance scenario but one that overlaps a rather low-variance normal scenario. The distance between the scenario mid-points shrinks to 300 index points because the physical distribution only accounts for the likelihood of a crash but not for investor risk aversion. Risk-averse investors find crashes painful, and risk-neutral distributions account for this through higher risk-neutral probabilities of crash outcomes. By examining the physical distribution from longer maturity options, investors do not seem to expect a full price recover for the index until some time beyond December 2020.

Which option traders bought crash protection?

Firms that are members of the Option Clearing Corporation did so over the four weeks leading up to March 16, 2020 – in time to protect themselves against the losses in the index during this time. Retail customers tried to protect themselves one month later during the four weeks leading up to April 16, 2020, but lost out as the market recovered over that period.

How did the index react to other virus outbreaks?

The index did not react at all to SARS and H1N1, but possibly somewhat to Ebola. The index reacted only to Covid-19 with a strong downward move because the Covid-19 death toll exceeds the ones of the earlier outbreaks by a factor of more than 100, and the resulting economic impacts have been enormous.

## Background on the Covid-19 pandemic

To provide some cursory background, the very first Covid-19 case occurred on November 17, 2019, but it was not immediately recognized as that.[2] The first confirmed case was on December 1, 2019, and more sporadic cases were reported as December wore on. Toward the end of the year, hospitals and infectious disease centers around Wuhan, China, knew about a pneumonia of unknown cause. On January 3, 2020, the genetic sequence of the virus was first decoded, and US officials had first knowledge of the virus. Online discussion about the virus was suppressed in

[2] https://en.wikipedia.org/wiki/Timeline_of_the_2019%E2%80%9320_coronavirus_pandemic_from_November_2019_to_January_2020

China on January 7, 2020. The US Centers for Disease Control and Prevention (CDC) issued a travel warning that same day.

On January 8, 2020, Chinese scientists publicly announced the new virus, and the World Health Organization (WHO) and the European Centre for Disease Prevention and Control posted their first risk assessments. On that same day came the first public notice on the Chinese state broadcaster CCTV about a new viral outbreak. By the end of January 2020, the WHO had issued several reports, cases spread to countries other than China, and the first confirmed US case occurs on January 20, 2020.[3]

February 2020 saw a steady flow of information about new cases, detailed in daily WHO updates.[4] The pace of new infections rose into the hundreds for Italy, Iran, and South Korea (China was always far above those numbers) beginning February 21, 2020.

March 2020 saw a steady worsening of the crisis, and the WHO finally declared it a pandemic on March 12, 2020.[5] At this time, led by the lock-down of Italy on March 9, 2020, more and more countries closed schools, restricted gatherings, and closed borders. The United States passed a $2.2 trillion emergency stimulus package on March 26, 2020. Wide-spread lock-downs continued through April with only minimal relaxations toward the end of April and more relaxations during May 2020, with the US moving faster than Europe.[6]

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[3] https://en.wikipedia.org/wiki/2020_coronavirus_pandemic_in_the_United_States

[4] https://en.wikipedia.org/wiki/Timeline_of_the_2019%E2%80%9320_coronavirus_pandemic_in_February_2020

[5] https://en.wikipedia.org/wiki/Chronology_of_the_2019%E2%80%9320_coronavirus_pandemic_in_March_2020

[6] https://en.wikipedia.org/wiki/Responses_to_the_COVID-19_pandemic_in_April_2020, https://en.wikipedia.org/wiki/Responses_to_the_COVID-19_pandemic_in_May_2020

## Covid-19 and the S&P 500 index

Figure 1 shows levels of the S&P 500 index and annualized levels of option implied volatility (VIX). There was definitely information available about Covid-19 on January 17, 2020 – yet option markets reacted only slightly on February 20, 2020 with a small increase in the VIX from around 13 to 16 (2,247 cumulative deaths recorded by that time[7]). The VIX then increased at first slowly, then considerably starting February 27, 2020, and continued until the middle of March 2020. With the WHO's declaration of the pandemic on March 12, 2020, the VIX broke 75, and the S&P 500 dropped from 2741 to 2481, for a 9.51% daily loss. In the risk-neutral distributions we see a full-blown reaction on March 16, 2020 (7,180 cumulative deaths). Thereafter, the VIX moves down to about 40 on April 16, 2020 (147,789 cumulative deaths), and the S&P 500 recovers to around 2800. By May 26, 2020 (351,979 cumulative deaths), the VIX fell farther to below 30, and the S&P 500 stabilized at around 3000.

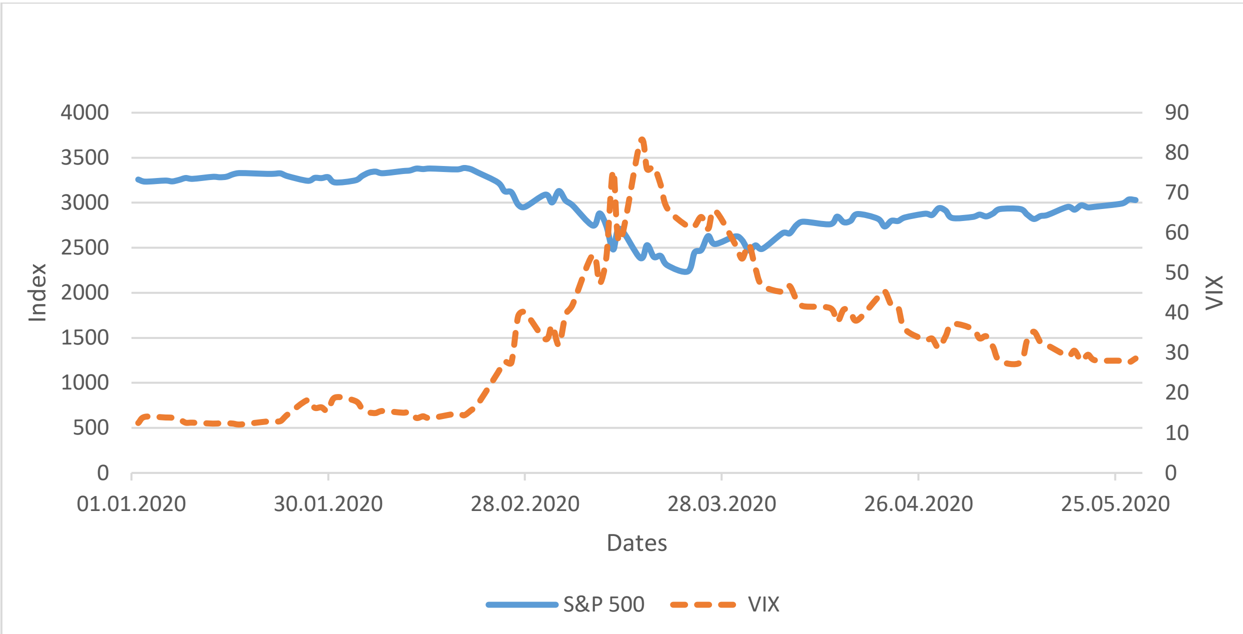
## Contribution to the literature

This paper contributes to an understanding of the impact of the Covid-19 virus on the economy. There is a growing number of papers on the subject. Nguyen (2020), Ramelli and Wagner (2020), and Yan, Stuart, Tu, and Zhang (2020) document the impact of the crisis on different industries. Yilmazkuday (2020) investigates the reaction of the S&P 500 index to Covid-19 related deaths. Croce, Farroni, and Wolfskeil (2020) determine the price of pandemic-infection risk. Cheng (2020) documents the evolution of VIX futures in comparison to VIX. He finds a temporary undervaluation of the VIX futures during late February and early March of 2020.

[7] https://www.worldometers.info/coronavirus/coronavirus-death-toll/

Figure 1. S&P 500 and VIX

Levels of the S&P 500 (left scale) and the VIX (right scale in annualized %) from January 2, 2020, through May 29, 2020.




To these basically historical studies, I add this study of the richness of options on the index, which inform us about the complete risk-neutral distribution of future index values. Hanke, Kosolapova, and Weissensteiner (2020) plot percentiles of risk-neutral distributions for several markets across time. Koijen and Gormsen (2020) also use forward-looking information, but from dividend futures on the index instead of options, to analyze forecasts of economic growth. Their findings, like mine, point to a collapse of market expectations in the middle of March 2020. Landier and Thesmar (2020) dovetail the findings of Koijen and Gormsen (2020) through analyst forecasts of earnings growth at the firm level. Short-term growth expectations collapsed around the middle of March 2020 but less so than the lower bounds in Koijen and Gormsen (2020) suggest. Giglio, Maggiori, Stroebel, and Utkus (2020) document changing expectations through investor surveys.

This short paper describes data and methodology in Section 1, and presents the results in Section 2. Section 3 concludes.

## 1. Data and Methodology

I collect midpoint implied volatilities for call options on the S&P 500 index from January 2, 2020, through May 28, 2020, from Thomson Reuters Datastream. The put options data are incorrect, and depict flat volatility smiles every day. The option maturities vary from 3 through 36 months, and strike prices range from 1600 through 4200. I also collect open/close data from the Chicago Board Options Exchange (CBOE) that details who has been buying or selling which kind of option.

I further collect adjusted closing prices of the S&P 500 from yahoo.com and the monthly dividend yield from https://www.multpl.com/s-p-500-dividend-yield/table/by-month.

As interest rates, I use constant-maturity Treasuries from the H.15 release of the Federal Reserve System, linearly interpolated to match the option maturities.

I recover the risk-neutral densities following Jackwerth (2004). I collect option-implied volatilities $\{\overline{\sigma}_i\}_{i=1}^{I}$, where $\overline{\sigma}_i$ denotes the Black-Scholes implied volatility of an option with strike price $K_i$. Given a smoothness parameter $\lambda$, I solve an optimization problem as follows to obtain an implied volatility curve $\{\sigma\}_{j=1}^{J}$ on a fine grid:

$$\min_{\sigma_i} \sum_{j=0}^{J} (\sigma_j'')^2 + \frac{(J+1)\lambda}{I\Delta^4} \sum_{i=0}^{I} (\sigma_i - \overline{\sigma}_i)^2. \tag{1}$$

The grid is given by $\Delta = 50$, which defines the distance between two consecutive strike prices from 0 to 6500; $\sigma_j''$ denotes the numerical approximation to the second derivative of the implied volatility curve.

Equation (1) has a straightforward closed-form solution for $\{\sigma\}_{j=1}^{J}$ (see Jackwerth 2004). By varying over $\lambda$ I can choose a reasonable trade-off between smoothness (sum of the second derivatives over $j$) and fit (sum of the squared errors over $i$). A value of 0.003 for the complete trade-off term $\left(\frac{(J+1)\lambda}{I\Delta^4}\right)$ works well empirically. Finally, the smooth implied volatilities curve is translated into a call option price curve, whose second derivative is the risk-neutral distribution (see Breeden and Litzenberger 1978):

$$q(K_i) = R_f \frac{\partial^2 \, Callprice(K)}{\partial K^2} |_{K=K_i}, \tag{2}$$

where $R_f$ is the gross interest rate.

## 2. Results

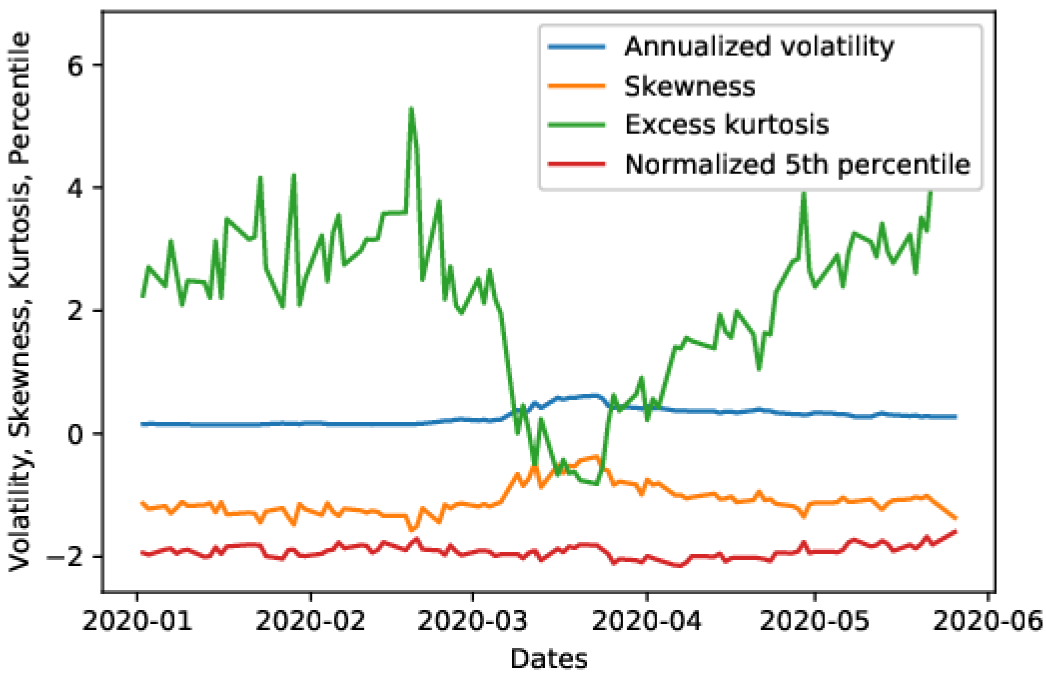
I pose five questions and answer them using the forward-looking information embedded in option prices.

### 2.1. When did markets learn about the economic impact of the virus?

Figure 2 provides an overview of the pandemic and shows time-series of daily moments of the risk-neutral distribution maturing on June 19, 2020, from January 2, 2020, through May 26, 2020. Annualized volatility starts at around 0.15, rises somewhat after February 20, 2020, then rises quickly in early March, reaches a high of 0.62 on March 23, 2020, before slowly falling back to levels of around 0.30. This pattern closely mimics the discussion of VIX in Figure 1. Skewness (standardized) follows a broadly similar pattern as it becomes less negative during the height of the crisis. Investors fear a crash and allocate more probability to low outcomes, fattening the typically long left tail of the risk-neutral distribution. The resulting distribution is more symmetric and less negatively skewed. The pattern in excess (standardized) kurtosis is similar again. The initially fat-tailed risk-neutral distribution (excess kurtosis above two, driven by the stubby right tail) loses its kurtosis during the height of the crisis before slowly regaining it thereafter. As the risk-neutral distribution becomes more symmetric, the thinning of the normally stubby right tail leads to the loss of kurtosis. Changes in the left tail are not driven by the far left tail, as the 5th percentile (standardized by volatility) remains very stable at around -2.

Figure 2. Moments of risk-neutral distributions of S&P 500 index options with maturities of June 19, 2020

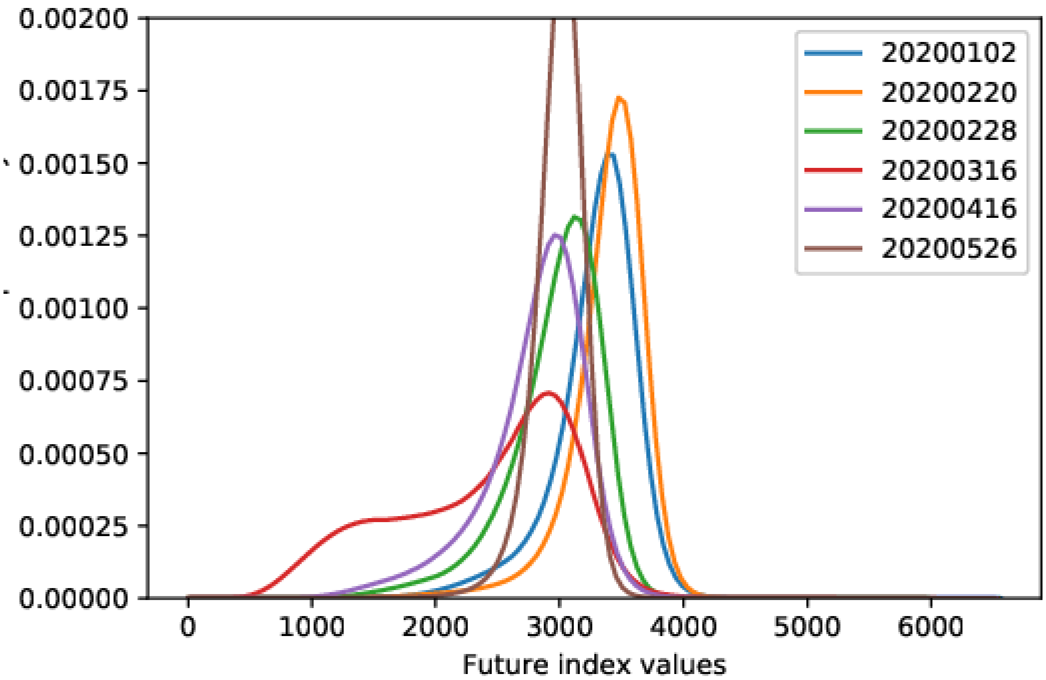
Annualized volatility, skewness, excess kurtosis, and the normalized fifth percentile value (divided by the volatility) of risk-neutral distributions from January 2, 2020, through May 26, 2020. Maturity is always June 19, 2020.




Next, I retell the story of the pandemic with the help of select risk-neutral distributions that showcase investor concerns about the pandemic. Figure 3 shows risk-neutral distributions of S&P 500 index values on six different days, for options maturing June 19, 2020. The blue line shows the distribution on January 2, 2020, which is typical for this index. I next depict the yellow distribution on February 20, 2020, as the intermediate distributions look rather similar and do not add further insight. The distribution on February 20, 2020, shows much the same shape as the blue one on January 2, 2020, with some rightward shift, because the index increases (from 3258 to 3373), while tightening somewhat as times-to-maturity become shorter (from about six to four months).

Figure 3. Risk-neutral distributions of S&P 500 index options with maturities of June 19, 2020

Risk-neutral distributions on January 2, 2020, February 20, 2020, February 28, 2020, March 16, 2020, April 16, 2020, and May 26, 2020.




The green line shows the distribution on February 28, 2020. This distribution is markedly different from the one on February 20, 2020. We see first evidence of the pandemic as the index falls to 2954, and the distribution shifts to the left. On March 16, 2020, we see a pronounced effect of the pandemic. The severe leftward shift of the red distribution occurs because the index falls to 2386 from a high of 3386 on February 19, 2020. The distribution becomes less left-skewed in the process as the large left tail, which accounts for possible further market crashes, balances the rest of the distribution. Only the risk-neutral distribution contains this information; simply knowing the index level is not enough. At the same time, the VIX shoots up to an annualized value of 83 from 14 one month earlier. Markets seem to have fully appreciated the severity of the pandemic only on March 16, 2020. Even though the WHO had issued several reports on the topic by the end of January 2020 and infections had been registered in several countries outside China by that date, markets waited another two months to reflect their full assessment of the unfolding crisis.

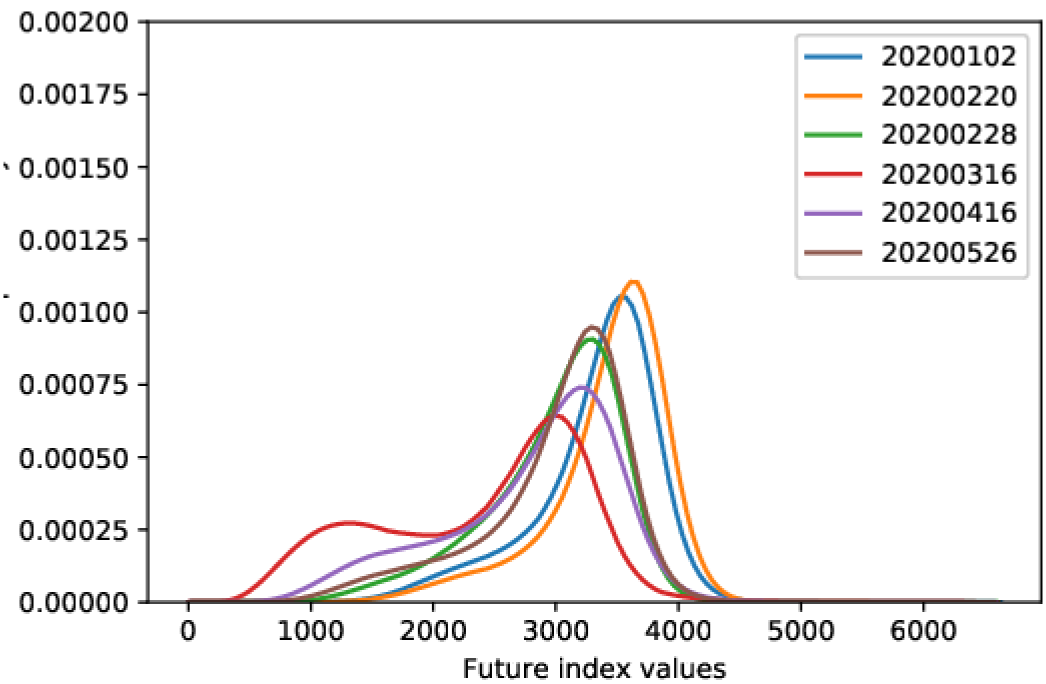
But why the long wait? Ramelli and Wagner (2020) document that sectors more exposed to China were affected earlier, less exposed sectors later. The S&P 500 index contains some sectors with large exposure to China and many domestic sectors with small exposure. Thus, the initial reaction of the index was small. Only when investors realized that the crisis was not solely confined to stocks with large exposure to China but affected most US stocks did the index react strongly. Incidentally, on March 12, 2020, the WHO declared a pandemic, clearly marking that the whole world was affected by then.

The next two distributions of Figure 3 on April 16, 2020, (purple) and May 26, 2020, (brown) reflect the subsiding fear of a market crash as volatility decreases and the index recovers to 2800 and 2992. The brown distribution has less than one month left to maturity and is thus very concentrated and peaked.

Lengthening the maturities to almost one year (December 18, 2020), Figure 4 shows a similar picture. Interestingly, the distribution on March 16, 2020 now hints at a bimodal distribution.[8] I explore the two components of this distribution next.

Figure 4. Risk-neutral distributions of S&P 500 index options with maturities of December 18, 2020

Risk-neutral distributions on January 2, 2020, February 20, 2020, February 28, 2020, March 16, 2020, April 16, 2020, and May 26, 2020.



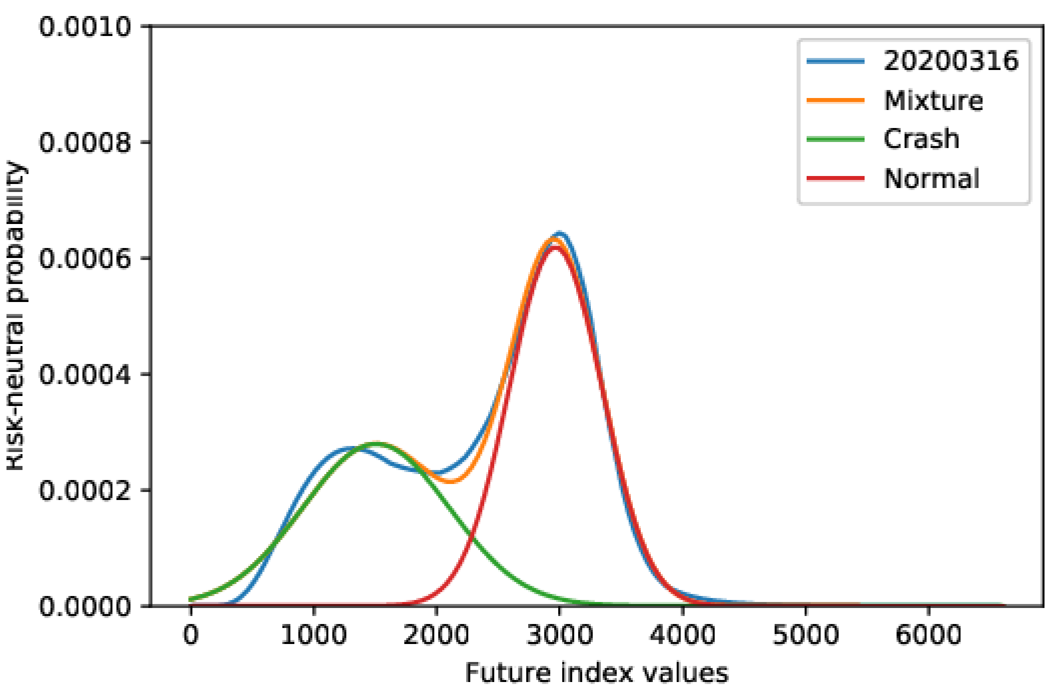

[8] Other maturities (September 18, 2020, December 17, 2021, and December 16, 2022) have fewer observations (drastically so for the long-dated maturities) and do not add new insight, so I do not report them separately.

## 2.2. What scenarios did the option market view as likely?

In Figure 5 I fit a mixture of two normal distributions to the risk-neutral distribution from Figure 4 on March 16, 2020 with maturity date on December 18, 2020.[9]

Figure 5. Risk-neutral distribution and mixture of S&P 500 index options with maturities of December 18, 2020

The risk-neutral distribution on March 16, 2020, and a fitted mixture of normal distributions. Also depicted are the two components of that mixture, Crash and Normal.

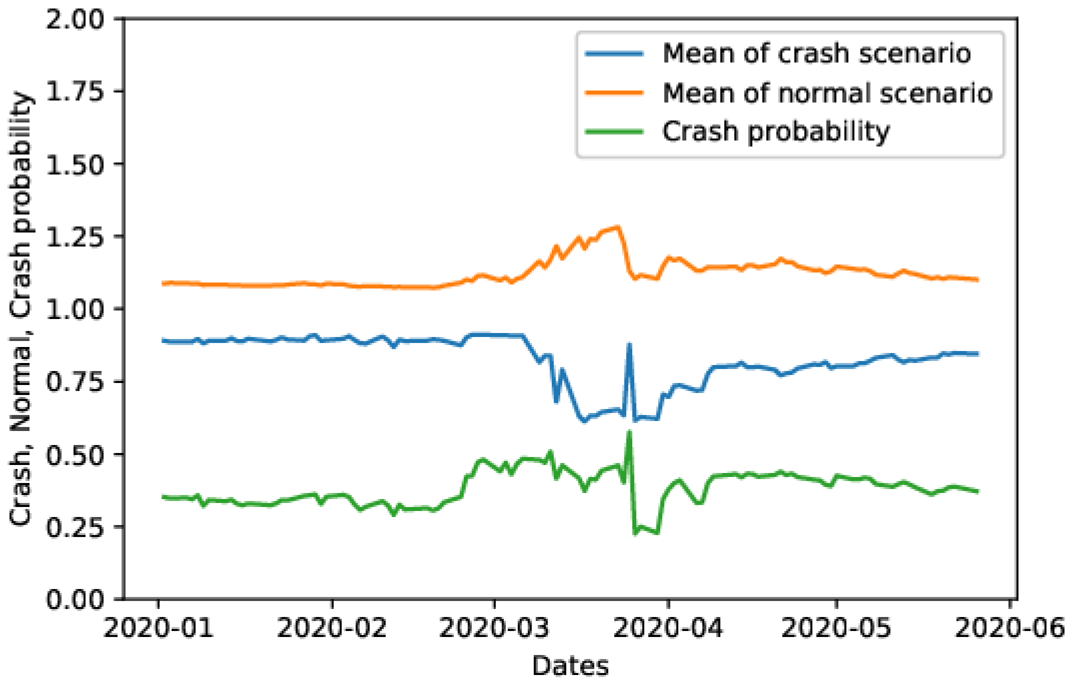



[9] I use the Broyden-Flechter-Goldfarb-Shanno (BFGS) method in Python. See Melick and Thomas (1997) for similar fits of two lognormal distributions.

At the height of the crisis, the market views two scenarios as likely. In 42% of cases, a severe crash scenario over the next nine months is centered at a fairly catastrophic expected future index value of 1,505 with a standard deviation of 597. In the other 58% of cases, the index recovers to almost pre-crisis values (2966) with a standard deviation of 376. The crash scenario mean is located 1461 index points below that of the normal scenario, while the distance was only around 600 on January 2, 2020, and February 20, 2020, whence I fit mixtures to those risk-neutral distributions.

Figure 6. Bimodality for maturity December 18, 2020

Means of the crash and the normal scenarios (both scaled by the underlying) and probability of the crash scenario of mixtures of normal distributions fitted to the risk-neutral distributions from January 2, 2020, through May 26, 2020. Maturity is always December 18, 2020.



I next study the time-series of decompositions of the risk-neutral distribution into crash and normal scenarios. Figure 6 shows the means of the crash and the normal scenarios (both scaled by the underlying) and the probability of the crash scenario from January 2, 2020, through May 26, 2020. The maturity date is always December 18, 2020.

The decomposition of the risk-neutral distribution follows the evolution of the moments of the risk-neutral distribution. The crash scenario becomes more probable (close to 50%, up from about a third) after February 20, 2020, when VIX starts to increase from around 16. The mean of the crash scenario remains unchanged at about 90% of the index value, and the mean of the normal scenario remains unchanged at about 110%. During this time leading up to the height of the crisis, only the probability of the crash scenario increased.

A novel insight is the divergence of crash and normal scenarios during the height of the crisis from March 3, 2020, through March 24, 2020. The crash scenario is now somewhat less likely (40%) but it is located at only 65% of the index value while the normal scenario is located at about 125%. The increased uncertainty about the pandemic manifests itself in a widened bimodal distribution. With the start of April 2020, the risk-neutral distribution signals less uncertainty. The crash scenario rises from 70% to 85% of the index value while the normal scenario falls from 115% to 110%, and the crash scenario keeps a probability of about 40%.

### 2.3. How do the physical scenarios differ?

All risk-neutral values are somewhat difficult to interpret as the drift under the risk-neutral distribution is the risk-free rate and not the sum of risk-free rate and market risk premium. Thus, I turn momentarily to the physical distribution.

The pricing kernel (accounting for risk-aversion of investors) relates physical probabilities $p$ to risk-neutral probabilities $q$. I assume a particularly simple power utility specification for the pricing kernel of a representative investor, and the relation becomes:

$$p(r) \;=\; \frac{q(r)\, E(u\prime(r))}{R_f\, u\prime(r)}, \tag{3}$$

where $r$ is the gross return cum dividends on the index, $R_f$ the gross interest rate, and marginal power utility $u'(r) \;=\; r^{-\gamma}$. Bliss and Panigirtzoglou (2004) suggest a value for the risk aversion coefficient of $\gamma = 4$, while Jackwerth and Menner (2020) suggest a value of $\gamma = 3$ for their more recent sample from April 1986 through December 2017. The latter paper shows in statistical tests that future index returns are compatible with such a physical distribution. Thus, I use $\gamma = 3$ for computing physical distributions.[10] Since I am looking at the distribution on a day with very high volatility[11], which might make a representative investor more risk-averse than normal, I alternatively use $\gamma = 5$.

Figure 7 decomposes the long-maturity physical distribution on March 16, 2020, again into two scenarios. The crash scenario now morphs into a high-volatility distribution covering extreme crashes and booms, with an expected future index value of 2824 and a very high standard deviation of 755. The chance of experiencing this high-volatility scenario is 38%. The normal scenario also takes center ground with an expected value of 3111 but a much lower standard deviation of only 304, covering 62% of cases. The distance between the two scenario means is only 287 index points, much lower than the risk-neutral distance of 1,461. The crash appears much less threatening under

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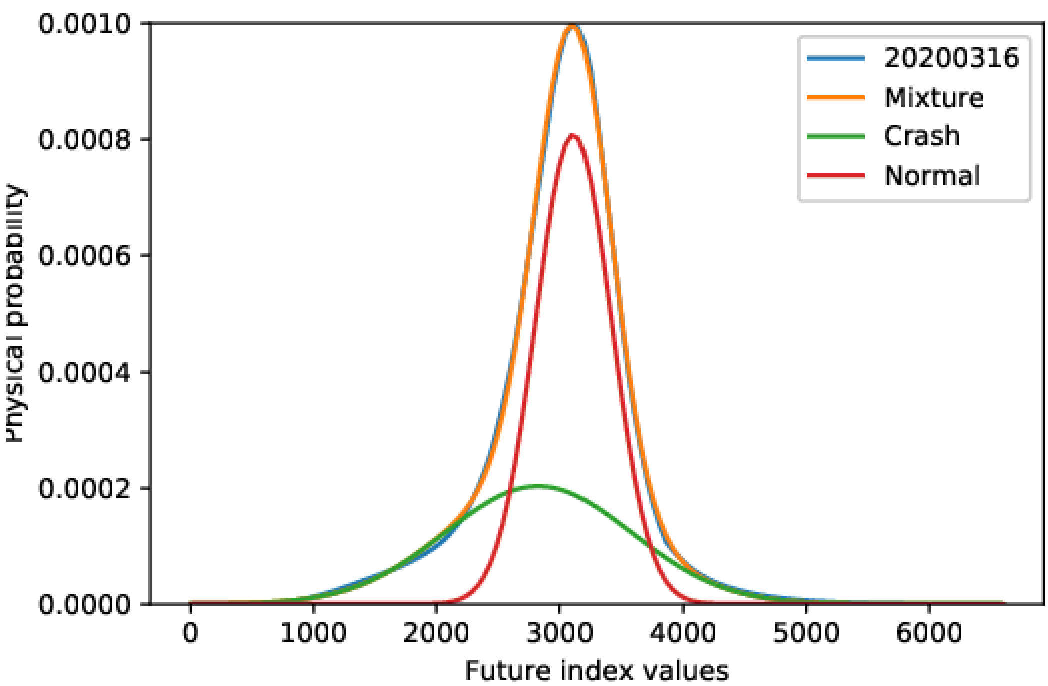
[10] There is some discussion about the fit of such a simple pricing kernel instead of a tilde-shaped one for short maturities, but at longer horizons of more than a half-year, the simple power utility pricing kernel appears sufficient. See, e.g., Cuesdeanu and Jackwerth (2018).

[11] VIX is at 83 – far above typical values in the range of 10 to 20.

the physical distribution, which only records the frequency of low index values, whereas the risk-neutral distribution also accounts for the economic pain experienced by risk-averse investors during a crash.

Figure 7. Physical distribution and mixture of S&P 500 index options with maturities of December 18, 2020

The physical distribution on March 16, 2020, and a fitted mixture of normal distributions. Also depicted are the two components of that mixture, Crash and Normal. Note that the mixture completely hides the physical distribution.




Looking at the overall expected future index value of 3009, the market on March 16, 2020, expects index values to need more than nine months to recover to pre-crisis levels (3386 on February 19, 2020). Increasing the risk aversion coefficient to $\gamma = 5$ deemphasizes the crash scenario somewhat

(35%), while the boom scenario gains further in importance. The corresponding unreported figure is similar to Figure 7.

### 2.4. Which option traders bought crash protection?

For each option trader category (Option Clearing Corporation member firms "Firm", broker/dealers "BD", professional customers such as hedge funds and large banks "Procust", retail customers "Cust", and market makers "MM"), I collect for each call strike price the daily net demand on the Chicago Board Options Exchange.[12] I add demand at nearby strike prices up to the midpoint between neighboring strike prices (and widening the intervals toward the ends of the range). As positive call option demand implies a positive delta (sensitivity of the option with respect to the index), I subtract the corresponding put option demand (which implies negative delta) to arrive at an aggregate demand for buying delta. Because option demand fluctuates daily, I aggregate the demand through the four weeks leading up to a particular date.

The resulting (four-week) buying delta demand measures total exposure to the index due to option positions (at a particular strike price) of a particular trader category. Positive buying delta demand of customers means that customers stand to gain from their option position if the index goes up. Negative buying delta demand of firms means that firms hedge long exposure to the index through a (partially) offsetting position in options.

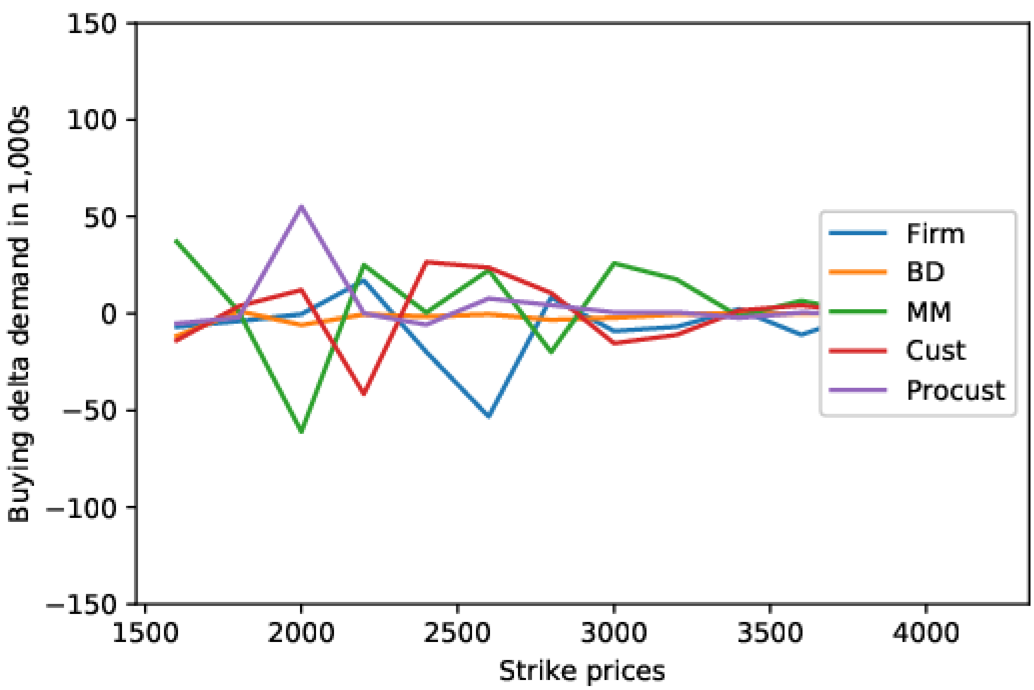
I start with the short maturity (June 19, 2020). My first date is February 20, 2020, and during the four weeks leading up to it, firms, professional customers, retail customers, and market makers buy

[12] Technically, I add newly opened purchases (open buys), subtract sales of earlier purchases (close buys), subtract outright sales (open sells), and add repurchases of earlier sales (close sells) to find the total net option demand in terms of contracts (one contract is for 100 underlying options).

and sell options at different strikes in moderate amounts without any discernable pattern. Broker/dealers always trade very little. I skip February 28, 2020, as the four-week sample heavily overlaps with the previous sample.

Figure 8. Buying delta demand for the four weeks leading up to March 16, 2020, for maturity June 19, 2020

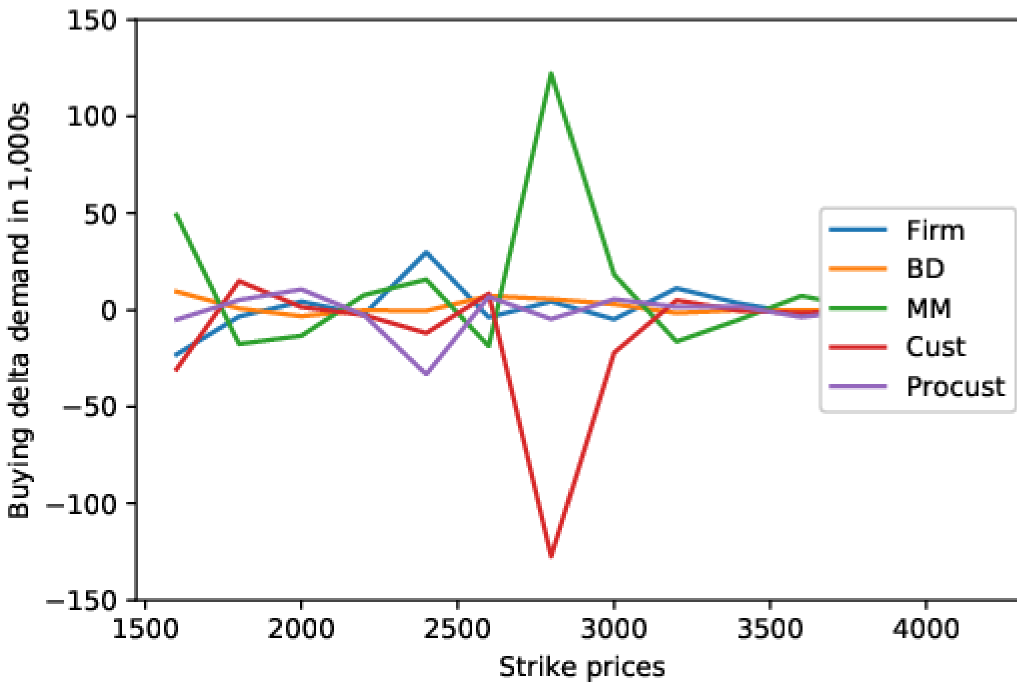
Buying delta demand (in 1,000s) is call open buy – call close buy – call open sell + call close sell - put open buy + put close buy + put open sell – put close sell for firms (Firm), broker/dealers (BD), market makers (MM), retail customers (Cust), and professional customers (Procust).




On March 16, 2020, for options maturing on June 19, 2020, Figure 8 shows some moderate selling of delta by firms (strike 2600) as retail customers and market makers demand that delta. These firms gained during the downturn of the index over the those weeks. Professional customers even demanded delta (strike 2000), while retail customers sold some smaller amount of delta (strike 2200). Overall, customers were exposed to the falling market during those weeks.

Figure 9. Buying delta demand on April 16, 2020, for maturity June 19, 2020

Buying delta demand (in 1,000s) is call open buy – call close buy – call open sell + call close sell - put open buy + put close buy + put open sell – put close sell for firms (Firm), broker/dealers (BD), market makers (MM), retail customers (Cust), and professional customers (Procust).




The picture changes on April 16, 2020, (see Figure 9), when retail customers massively sell delta (strikes 2400 and 2800) over the preceding four weeks, and market makers absorb large quantities of delta. Interestingly, the retail customer demand for selling delta arises only after the index losses in mid-March 2020. Customers were concerned about aftershocks but ended up buying (no longer needed) protection in a recovering market.

On May 26, 2020, option demand is low and no clear pattern emerges. Compared with the June 19, 2020, maturity, there is much less activity in the options maturing on December 18, 2020, and no clear pattern of options demand emerges.

### 2.5. How does Covid-19 compare to the SARS, H1N1, and Ebola outbreaks?

I study three further virus outbreaks and use the sample times for each outbreak from Baker, Bloom, Davis, Kost, Sammon, and Viratyosin (2020): SARS (April 2003 – August 2003), H1N1 (March 2009 – May 2009), and Ebola (October 2014 – January 2015). For each outbreak, I plot the daily S&P 500 during the sample, the daily VIX, and the number of deaths during the month prior to each monthly sample date.[13] I also plot the risk-neutral distributions with 184 days-to-maturity for the S&P 500 index options for each monthly sample date. The data stem from OptionMetrics, and the distributions are from Menner and Jackwerth (2020).

In unreported figures, I find that SARS and H1N1 did not register at all in the VIX, the S&P 500, or the risk-neutral distributions. These findings are in line with Baker et al. (2020), who measure news coverage related to stock market jumps. For their sample of virus outbreaks prior to Covid-19 (including SARS, H1N1, and Ebola), the authors find only a tiny effect on US stock market volatility.

[13] SARS: https://www.who.int/csr/sars/country/en/

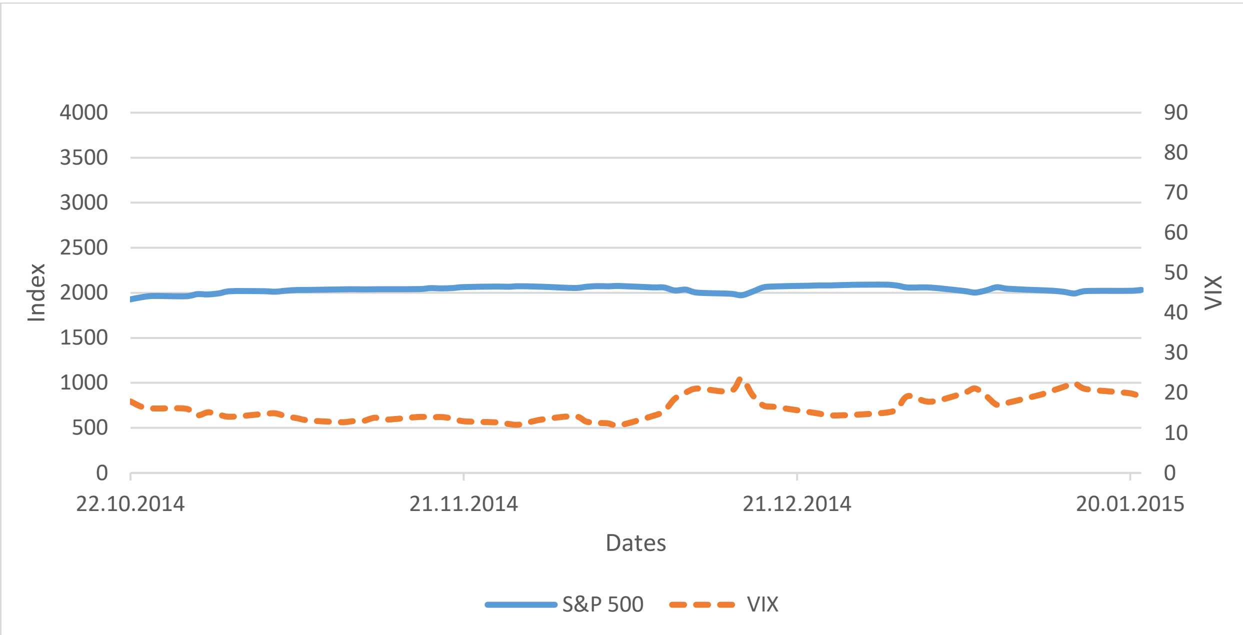
H1N1: https://www.who.int/csr/disease/swineflu/updates/en/

Ebola: https://www.cdc.gov/vhf/ebola/history/2014-2016-outbreak/case-counts.html

Some death statistics contradict each other on the original websites because of discarded cases and revised numbers.

Figure 10. S&P 500 and VIX during Ebola

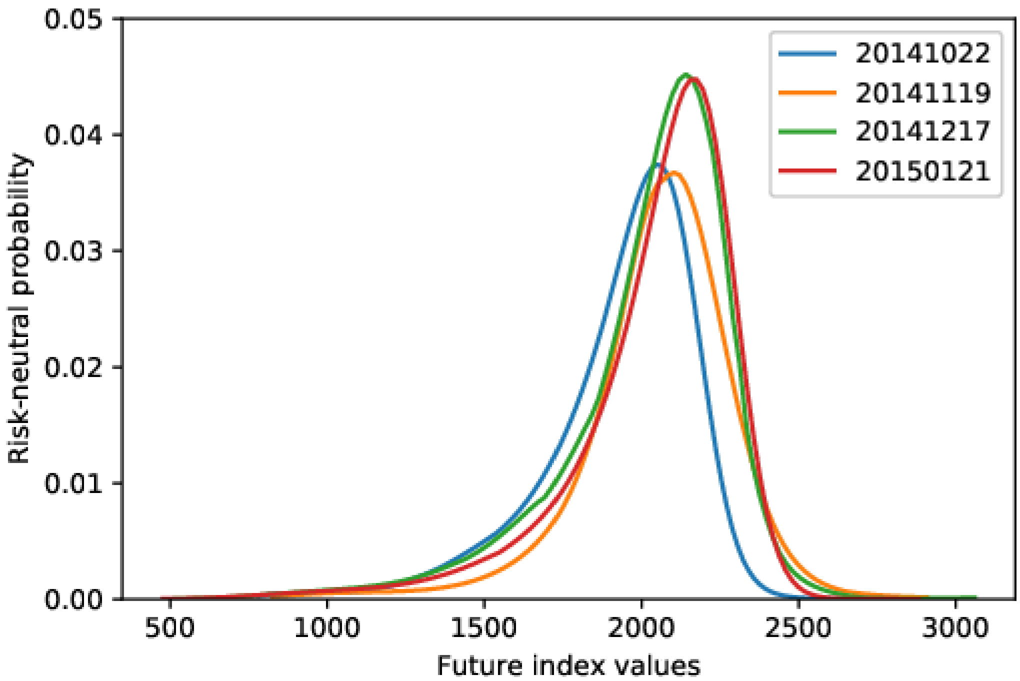
Levels of the S&P 500 (left scale) and the VIX (right scale in annualized %) from October 22, 2014, through January 21, 2015.




For Ebola there were 2515 deaths in the month prior to October 22, 2014, 438 prior to November 19, 2014, 1494 prior to December 17, 2014, and 2465 prior to January 21, 2015. The strong increase of deaths in December 2014 after the lull in November could have been the cause of an increase in VIX (see Figure 10) ahead of December 17, 2014. The index falls during the second week of December before recovering. VIX remains elevated around the end of 2014 and into January 2015. The risk-neutral distributions in Figure 11 reflect the increased volatility with fatter left tails suggesting increased concerns about crashes. The market patterns are consistent with a mild market reaction to the Ebola outbreak, yet I caution that other explanations are possible.

Figure 11. Risk-neutral distributions of S&P 500 index options with 184 days-to-maturity during Ebola

Risk-neutral distributions on October 22, 2014, November 19, 2014, December 17, 2014, and January 21, 2015.




## 3. Conclusion

Index option prices translate into risk-neutral distributions, which contain richer information than index and VIX values. The risk-neutral distributions of the S&P 500 index show the full impact of the Covid-19 pandemic on the index only on March 16, 2020, almost two months after the first news about the pandemic. The nine-months risk-neutral distribution on that day is bimodal, showing a 40% chance of a severe crash scenario. In terms of the physical distribution, the crash scenario turns into a more moderate high-volatility scenario centered much closer to the actual index level. The expected future index value on March 16, 2020, is 3009, suggesting that by the end of 2020, the index will not have recovered its previous high of 3386.

Firms managed to sell exposure to the falling market through option positions during the four weeks leading up to March 16, 2020. Retail customers only established such positions one month later as the market was already recovering. Other virus outbreaks such as SARS and H1N1 do not show up in the index, the VIX, or the risk-neutral distributions, but possibly there is some evidence of the Ebola outbreak.

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