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Expiration day effects of stock and index futures on the Warsaw Stock Exchange before and in the initial phase of the COVID-19 pandemic

1. Introduction

As important vehicles of hedging open positions on stock market, financial futures are constructed in a such manner that their prices and the prices of their underlying assets are strongly related. The stock and futures markets continually interact with each other so important events which significantly change stock prices indirectly can also influence prices of corresponding futures. Similarly, events which are related to the futures market may have an impact on stock market too, one of which is the expiration of derivatives.

Research on the influence of stock and index futures expiration on volume, prices, and the volatility of underlying assets have been conducted in reference to many spot markets around the world. Early studies on so called expiration day effects concerned U.S. market (Stoll, Whaley, 1986, 1987, 1990, 1991). Subsequently, such analyses have been extended to other markets such as Canadian, German, Spanish, Swedish, Australian, Korean, Polish, Taiwan, Indian or Vietnam (see e.g. Chamberlain et al., 1989; Stoll, Whaley, 1997; Aragó, Fernández, 2002; Park, Lim, 2004; Hsieh, Ma, 2009; Debasish, 2010; Chow et al., 2013; Xu, 2014; Wats, 2017; Gurgul, Suliga, 2020; Samineni et al., 2020; Suliga, 2021; Nguyen et al., 2022).

Many of these studies confirm that futures' expiration involves increased activity of investors on the spot market which can lead to a significant disturbance in

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the price formation process. The most frequently observed expiration day effects are abnormally high trading volume of underlying stocks and increased volatility of their prices (see e.g. Stoll, Whaley, 1987, 1990, 1991, 1997; Karolyi, 1996; Chay, Ryu 2006; Illueca, Lafuente, 2006; Hsieh, 2009; Debasish, 2010; Chay et al., 2013). On some markets, because of price pressure, stock prices fall unusually during expiration (e.g. Stoll, Whaley, 1986; Chow et al., 2003; Alkebäck, Hagelin, 2004; Vipul, 2005; Nguyen et al., 2022) or increase (Chamberlain et al., 1989; Chou et al., 2006; Bhaumik, Bose, 2007; Chuang et al., 2008; Narang, Vij, 2013; Suliga, 2020). Directly after the expiration, some researchers detected price reversal or so-called price shock (e.g. Stoll, Whaley, 1990, 1991; Schlag, 1996; Park, Lim, 2004; Vipul, 2005; Chay, Ryu, 2006; Hsieh, 2009; Chow et al., 2013) indicating that temporarily disturbed stock prices come back to the normal level, reflecting their intrinsic values.

The main cause of the occurrence of expiration day effects is cash settlement of financial futures. Such a procedure means that there is no physical delivery of the underlying asset from an issuer of a contract to a purchaser on expiration day, but appropriate cash flow is made between them. The direction and value of this cash flow depends on the final settlement price of a derivative which is calculated on the basis of the actual price of underlying stocks. It should be noted that in the case of index futures this is the only possible formula of final settlement but on most markets around the world stock futures are also cash settled (Dębski, 2010). This encourages investors with open positions on futures market to keep them until the expiration and to trade on the spot market on expiration day to influence or at least control the final course of a derivative.

One of two main groups of investors who can generate expiration day effects are speculators. Knowing that their loss or profit from expiring futures depends on underlying stock prices, they can try, by appropriate activity on a spot market, to not only reduce the risk of uncertainty of final settlement price of derivatives but also to designedly manipulate stock prices to bring about the final price of a contract at a level favorable from their point of view (Debasish, 2010; Narang, Vij, 2013). The leverage effect is an additional incentive to such activity which can be successful especially in case of stock futures with final course equal to a single value of underlying stock price (e.g. opening or closing price on expiration day). However, if the price does not reflect the real value of a stock, according to the Fama hypotheses of efficient markets, rational investors take advantage of this fact and their activity very quickly bring back the price to its normal level. Hence, such stock price distortion arising from futures expiration should only be temporary and significant price reversal or price shocks might occur just after the expiration day.

Anomalies on the stock market on the expiration days of futures can be also a result of an activity of arbitrageurs. If a mispricing between the underlying asset and its corresponding derivative occurs during contract's life, these investors exploit it and hold a short position in contract and a long position in its underlying asset or vice versa (this depends on the direction of a mispricing). Arbitrage strategies are often unwound on expiration day as no transaction on the futures market is needed in this case. It is only necessary to close a position on a stock market by selling (or buying previously short-sold) stocks. If arbitrageurs make up a relevant group on a market and if most of them unwind their positions in the same direction on expiration day, significant price effects might occur. This is especially true on markets where short selling of stocks in prohibited or severely restricted activity of arbitrageurs on expiration day can lead to a sharp fall of stock prices (Vipul, 2005), as only cash-and-carry arbitrage is possible to carry out while the opposite strategy (reverse cash-and carry) is limited by an inability to short sell stocks.

Expiration day effects, although temporary, are nevertheless undesirable. Artificially induced price changes misguide uninformed investors and distort the process of price discovery. For this reason, research on expiration day effects is still being conducted on many markets. If strong anomalies are detected, additional regulations are being introduced in an attempt to eliminate them. In the following years such studies are repeated to check if these regulations have had the desired effect (see e.g. Stoll, Whaley, 1991; Hsieh, Ma, 2009; Chay et al., 2013).

Especially on emerging market expiration day effects might be strong and adverse but as the market develops, anomalies should gradually diminish. On deep and liquid developed markets, successful manipulation as well as profitable arbitrage should be difficult to perform. Nevertheless, research on expiration day effects is being carried out for many markets in the world, differing in the degree of development.

On the Warsaw Stock Exchange, expiration day effects have been studied so far by Morawska (2004, 2007), Suliga (2017, 2020, 2021), Suliga and Wójtowicz (2019) as well as Gurgul and Suliga (2020). All these analyses confirmed the occurrence of undesirable anomalies on Polish stock market on days with the simultaneous expiration of stock futures, index futures and index options. However, in each of these articles, the research covers a period in which the Polish market was still perceived as emerging (i.e. period ending before or at most in 2017) while from 2018 one of the three biggest rating agencies – FTSE Russell – has classified Polish market as a developed one. Therefore, the question arises as to whether in recent years, which have not yet been covered by research, expiration day effects of futures have been still arising on the Warsaw Stock Exchange or if these anomalies completely disappeared with the development of the market?

Moreover, the COVID-19 pandemic broke out in 2020 and disturbed the stability of financial markets all over the world, leading to a sharp increase in stock price volatility around the world (Czech et al., 2020a), creating an unprecedented level of risk. The world's major indices fell sharply in March 2020 (e.g. Alam et. al., 2020; McKibbin, Fernando 2020; Dharani, 2022). Many companies experienced panic pressure to sell due to the growing fear of the spreading virus (Dharani, 2022). This certainly forced investors to search for new ways of hedging and thereby might have attracted more of them to the futures market (see e.g. Corbet et al., 2020). Therefore, the paper also considers whether the outbreak of the COVID-19 pandemic had a significant impact on the occurrence and strength of expiration day effects.

In this study we tackle the abovementioned questions and try to supply some answers. The paper extends the previous research on the impact of financial derivatives expiration on the Warsaw Stock Exchange, supplying a comprehensive analysis of the anomalies in the period 2018–2020. With the use of intraday data, all expiration day effects most mentioned in the literature are examined, that is: abnormally high trading volume and increased volatility of underlying stocks in expiration day as well as price reversal and price shock after the expiration. A comparison of the results obtained with those of previous research relating to Polish market allows us to assess the degree of the market's development. An important goal of the paper is to also answer the question of whether the strength of the effects significantly changed like-for-like in the initial period of COVID-19 pandemic. For this purpose, additional analysis of the anomalies is conducted in sub-periods (before and after March 2020).

The rest of the paper is organized as follows. Section 2 reviews existing literature. In section 3, the data and empirical methodology are presented. Section 4 describes and discusses the results of the research, while section 5 makes some concluding remarks.

2. Literature review

Most previous studies on expiration day effects concentrate on anomalies generated by the expiration of index futures which are the most popular derivatives on markets around the world (e.g. Herbst, Maberly 1990, 1991; Stoll, Whaley, 1997; Kan, 2001; Aragó, Fernández 2002; Chung, Hseu, 2008; Hsieh, 2009; Chow et al., 2013; Samineni et al., 2020; Batrinca et al., 2020; Nguyen et al., 2022). However, on many markets, a few different types of derivatives expire simultaneously and research related to them analyzes the cumulative impact of their expiration on a stock market (see e.g. Schlag, 1996; Chow et al., 2003; Alkebäck, Hagelin, 2004; Vipul, 2005; Chay, Ryu, 2006; Chuang et al., 2008; Xu, 2014; Mahalwala, 2016; Gurgul, Suliga, 2020). In the literature, the last hour of the day when index futures, index options and stock futures expire together is called the "triple witching hour". In this hour, anomalies on the stock market might be especially strong.

Potential expiration day effects of financial derivatives include increased trading volume of underlying asset, an unusual increase or decrease in price, abnormally high volatility and price reversal or price shock after the expiration. The existence of significant expiration day effects was confirmed for many markets. However, the type of the occurring anomalies, their duration and strength depend on many factors and thus vary between the markets. Importantly, some studies have shown that these anomalies can be very short-lived and their detection may require the use of high-frequency data, as stressed by Alkebäck and Hagelin (2004). Perhaps for this reason, in some of the analysis, which based on daily data, the occurrence of the expected expiration day effects was not confirmed (e.g. Kan, 2001; Samineni et al., 2020; Nguyen et al., 2022).

2.1. Volume effect

An unusual increase in investor activity on the spot market on expiration days of stock and index derivatives was detected in most earlier research. Firstly, it was confirmed by Stoll and Whaley (1986, 1987) in reference to the spot market in USA on the expiration days of futures on S&P 500 index and options on S&P 100 index in the 1980s. In following years, similar results were obtained for many other markets, e.g. Australian (Stoll, Whaley, 1997), German (Schlag, 1996), Indian (Vipul, 2005; Debasish, 2010; Mahalwala, 2016), Japan (Karolyi, 1996), Korean (Park, Lim, 2004; Chay, Ryu, 2006; Chay et al., 2013), Polish (Suliga, Wójtowicz, 2019; Gurgul, Suliga, 2020; Suliga 2021), Spanish (Illueca, Lafuente, 2006), Swedish (Alkebäck, Hagelin, 2004; Xu, 2014), Taiwan (Chou et al., 2006; Chuang et al., 2008). This anomaly was also detected in a wider, pan-European analysis conducted by Batrinca et al. (2020).

Some studies indicate that abnormally high trading volume may not only occur on the spot market on expiration days of derivatives but also on several days before the expiration. Such results were obtained e.g. by Alkebäck and Hagelin (2004) who studied expiration day effects of OMX index futures on Swedish market. They identify this effect with an activity of arbitrageurs who unwind their positions on stock market before the expiration to reduce the risk connected with the uncertainty about the final settlement price of derivatives. During the period under study (1988–1998), the final price of OMX futures was calculated as the weighted average of all index quotes from expiration day in which weights were equal to trading volumes of stocks.

Increased activity on the spot market directly before the expiration day, evinced in abnormally high trading volume, was also detected by Vipul (2005) and Debasish (2010) on the Indian market. These authors studied the anomalies generated by the simultaneous expiration of options and futures on Nifty index as well as option and futures on individual stocks. Final settlement price of these derivatives was equal to a weighted average price of underlying asset from the last 30 minutes of the last trading session. They also associate this early volume effect with the activity of arbitrageurs finalizing their strategies before the expiration day.

Agarwalla and Pandey (2013) claimed that in the case of final settlement procedures such as those mentioned above, it is impossible for arbitrageurs to assess in advance how to sell (buy) stocks during the trading session on expiration day to perfectly balance the open position in expiring futures. Thus, they often decide to close the position in stock market earlier in order to reduce the risk. This results in volume effects not only occurring on expiration day but also several days before this date.

Research on the volume effect indicates a close relationship between the duration of increased activity of investors on a spot market and a final settlement procedure. If final settlement price of futures is equal to a closing price of underling stock (level of an index at the close in case of index futures), investors' activity on the spot market usually increases during the last minutes of continuous trading as well as at the close (see e.g. Chay et al., 2013; Suliga, 2020). This is not surprising, as in such cases arbitrage strategies are mainly being finalized by holding open positions in futures until expiration and by placing an order to buy or sell stocks at the close on expiration day. Speculators who have open position in expiring futures also mainly trade on the stock market in the last minutes of a session. They certainly want to control the risk of an unfavorable final settlement price of derivatives but some authors (e.g. Alkebäck, Hagelin, 2004; Mahalwala, 2016) suggest that speculators may also deliberately manipulate stock prices to influence final price of futures. As this price depends on a single value of underlying asset, investor activity is concentrated in a very short period. A sudden, sharp increase in turnover at the end of the session may also result in unusual price changes.

On markets where the final settlement price of futures is calculated as an average price of an underlying asset from a short time interval, increased activity of investors on stock market can mainly be observed during the time when the final price of derivatives is being formed (e.g. Illueca, Lafuente, 2006; Fung, Yung, 2009; Gurgul, Suliga, 2020; Suliga, 2021). This also points to arbitrageurs' and speculators' attempts to control the final settlement price of expiring futures.

2.2. Price effects

The abnormal growth of investor activity on the spot market on expiration days often results in a significant increase in stock volatility. Many studies have confirmed that the volatility of the prices of underlying stocks (or indexes) of expiring futures is higher than normal on expiration days. Such results were obtained in reference to many markets i.a. Australian (Stoll, Whaley, 1997), Hongkong (Chow et al., 2003), Indian (e.g. Bhaumik, Bose, 2007; Narang, Vij, 2013; Wats, 2017), Korean (e.g. Chay, Ryu, 2006; Chay et al., 2013), Polish (e.g. Gurgul, Suliga, 2020; Suliga, 2020), Spanish (Illueca, Lafuente, 2006), Swedish (Alkebäck, Hagelin, 2004) or Taiwan (Chou et al., 2006).

In the case of the volatility effect, the research also indicates a close relationship between the procedure for calculating final prices of futures and the time and strength of the anomaly. The strongest changes may occur in the prices of stocks for which corresponding futures have a final price depending on a single value of an underlying asset (see e.g. Stoll, Whaley, 1987; Park, Lim 2004; Chay et al., 2013; Suliga, 2020; Suliga, 2021). There is then a high risk of market imbalance and another price effect – sharp fall or increase in stock prices. Such an anomaly is especially possible as a result of stock futures expiration. A significant change of single stock price, as an effect of arbitrageurs or speculators trading, is much more likely than unusual change of index level, which depends on the prices of many stocks.

If the short selling of stocks is prohibited on a market, this can be an additional factor which rise a risk of market imbalance and strong price anomalies (see e.g. Stoll, Whaley, 1986; Chow et al., 2003; Vipul, 2005; Debasish, 2010). The direction in which the price changes depends on which group of investors dominates on a spot market. If it is made up of arbitrageurs who finalize cash-and-carry strategies by placing orders to sell stocks on expiration day, the price can fall unusually. The activity of speculators can lead to an increase in stock prices as having long positions in expiring futures they can try to rise their final settlement prices by creating buying pressure on a stock market. The opposite actions of speculators with short positions in derivatives are limited by the number of stocks they hold and can sell. Vipul (2005) suggests that abolition of the restrictions on short selling would weaken price effects. This assumption was confirmed in reference to the Polish market by Suliga and Wójtowicz (2019) who examined the influence of the simultaneous expiration of stock and index futures on the Warsaw Stock Exchange during the period January 2001 – December 2016. They checked that after the introduction of new regulations abolishing most of the restrictions on short selling in May 2015, price effects of futures expirations significantly weakened.

In reference to price effects, the research confirms that the longer the time for final settlement of price formation, the less intense are the anomalies. When this price is calculated with the use of all underlying asset prices from the last trading session before the expiration, price effects either do not occur or are negligible: the volatility of prices can be slightly increased during all trading session but not lead to a significant market imbalance and sharp price changes (see e.g. Bollen, Whaley, 1999; Kan, 2001; Fung, Yung, 2009; Xu, 2014).

If the price of an underlying asset changes unusually on expiration day as an effect of arbitrageurs and speculators activity, such that it does not properly reflect the intrinsic value of an asset, this anomaly should only be temporal and disappear immediately after the expiration (Stoll, Whaley, 1986). The subsequent return of prices to a normal level can be observed as price reversal or price shock effect which are the last two of price effects of futures expiration.

A term price reversal was introduced by Stoll and Whaley (1986). They assume that if an underlying stock price (index level) is upset by futures expiration and unusually increased (or decreased), on the next day the price should change in the opposite direction, coming back to an equilibrium level. Thus, on expiration day and on the next day, rates of return should have opposite signs. Stoll and Whaley (1986, 1987) proposed a few measures of the effect. All of them are based on a comparison between the rate of return's sign on expiration day and the next day. The strength of the anomaly is measured by the magnitude of the rate of return from one of these two days (expiration day or the next day, depending on the measure).

The price reversal effect was not only detected on the USA market by Stoll and Whaley (1986, 1987, 1990, 1991) but also on other markets, e.g. German (Schlag, 1996), Korean (Park, Lim, 2004; Chay, Ryu, 2006; Chay et al., 2013) and Taiwan (Chou et al., 2006; Chuang et al., 2008; Hsieh, 2009; Chow et al., 2013). However, in many studies of this anomaly there have been no grounds for concluding that the direction in which underlying asset prices are changing, changes after the expiration of futures (see e.g. Karolyi, 1996; Stoll, Whaley, 1997; Kan, 2001; Chow et al., 2003; Alkebäck, Hagelin, 2004; Chung, Hseu, 2008; Fung, Yung, 2009; Hsieh, Ma, 2009; Debasish, 2010; Narang, Vij, 2013; Xu, 2014; Mahalwala, 2016; Samineni, 2020).

In research conducted on daily data, the reason for not detecting the anomaly might be their short-term nature. If the price of a stock returns to an equilibrium level at the opening of the first trading session after expiration day, the daily rate of return may not reflect this fact. What is more, Vipul (2005) notes that Stoll and Whaley's price reversal effect is insufficient to express all potential perturbations in the price formation process resulting from expiration of futures. For example, a strong upward (downward) trend in underlying asset price can be temporarily inhibited on expiration day (it does not necessarily have to be reversed). It would be an evident anomaly, but price reversal would not reflect it. Similarly, a weak trend in prices can be passingly strengthened on expiration day by arbitrageurs or speculators and price reversal would not capture this fact. Thereupon Vipul (2005) suggests measuring price anomalies by the price shock effect, which he defines as an unusually large difference between underlying asset returns on expiration day and the next day.

Vipul (2005) analyzed expiration day effects of Nifty index options and futures as well as individual stock options and futures on the Indian market during the period November 2001 – May 2004. He showed that impact of derivative expirations on stock returns was significant. This impact was reflected in price shock measures but was not detected in the research on the price reversal effect. On average, stock prices fell the day before expiration, stayed at this level on expiration day and rose after the expiration. The price reversal effect was not detected due to the lack of a specific pattern of price behavior on expiration day (systematic increases or systematic decreases in prices).

The price shock effect defined by Vipul (2005) was analyzed in the research conducted by Xu (2014), who studied expiration day effects of OMX index options and futures on the Swedish market. However, Xu (2014) slightly modified the measure of price shock proposed by Vipul (2005), as instead of the difference between stock return on expiration day and the next day, she used the absolute value of this difference. Such a modification is crucial if we assume that unusual price changes on expiration days generated by the activity of speculator and arbitrageurs do not have the same direction every time and if we draw our conclusions based on the average value of the measure.

The results of the study conducted by Suliga (2020) can be seen as a confirmation that price shock measures are more effective than price reversal measures in detecting price anomalies occurring after futures expiration. Using intraday data from January 2011 to March 2017, Suliga (2020) checked the existence of the effects in individual stocks quotes on Polish market after the expiration of stock and index futures. She calculated the measures proposed by Stoll and Whaley (1986) and Xu (2014) with the use of hourly stock returns: return from the last hour of trading session on expiration day and return from the first hour of the next trading session. On average, the effect of price shock was visible in the quotations of six out of fourteen shares included in the study in the period under study, while price reversal was only detected in case of three of them.

2.3. Earlier studies on expiration day effects on the WSE

In reference to the Polish equity market, research on expiration day effects was conducted by Morawska (2004, 2007). In recent years, such analyses were also carried out by Suliga (2017, 2020, 2021), Suliga and Wójtowicz (2019) as well as Gurgul and Suliga (2020).

Morawska (2002, 2007) studied expiration day effects in a very initial period of futures market existence on the WSE. She examined the influence of stock and index futures expiration on returns of WIG20 index as well as on trading volume of stocks from the index. In the first piece of research, Morawska (2004) analyzed each of the expiration days between December 2002 and March 2004 separately. She drew attention to arbitrage opportunities on the market and to signs indicating that arbitrage strategies were being finalized in expiration days. She also listed examples of the occurrence of price reversal effect in WIG20 index markings, increase in volatility of index level at the begining of the triple withing hour and large sell orders of all stocks from the index during this time. She concluded that during the period under study, expiration day effects were intensifying.

In the second mentioned piece of research, Morawska (2007) studied anomalies in WIG20 index markings in the period December 2002 – June 2006. On expiration days she detected significant growth in the trading volume of stocks from the index as well as abnormal increase in volatility of intraday returns of the index. The results did not confirm the existence of price reversal effect. Although during the period under study futures on individual stocks and MIDWIG index futures expired on the same days as WIG20 futures, Morawska (2007) only focused on anomalies in WIG20 markings, as futures on WIG20 were the most popular derivatives in those years and their turnover accounted for over 97% of the entire futures' market turnover.

Suliga (2017) only studied the price reversal effect during the period January 2001 – December 2016. She examined the existence of this anomaly in WIG20, mWIG40 as well as individual stocks returns after simultaneous expiration of stock and index derivatives (WIG20 futures and options, mWIG40 futures and futures on individual stocks). Using daily data, she employed three different measures of price reversal. Each of them confirmed that this effect occurs in individual stock returns after derivatives expirations. However, none of the measures support the thesis about the occurrence of price reversal effect in WIG20 or mWIG40 returns.

The same research period was adopted by Suliga and Wójtowicz (2019), who used daily data to examine three expiration day effects of futures, namely: volume effect, volatility effect and price reversal. They employed two different methodologies. The first one was based on a comparison of the measures of effects between expiration days and control days, while the second was an event study. Their results confirmed that the trading volume of stocks from the WIG20 index and the mWIG40 index was abnormally high on expiration days but did not give any presumptions about a significant increase in the volatility of the returns of indexes or about the price reversal effect in index markings. In the case of individual stock, all three anomalies were detected. Additionally, Suliga and Wójtowicz (2019) divided the research period into two parts – before and after the introduction of new short-selling regulations in May 2015. Their results revealed that after the lifting of the substantial restrictions on short selling, expiration day effects lessened.

Gurgul and Suliga (2020) studied expiration day effects on WSE basing the research on high frequency data from the period January 2011 – March 2017. Using event study analysis, they checked that during the period under study on quarterly expiration Fridays trading volume of underling assets of stock and index futures, as well as volatility of their prices was abnormally high. However, an unusual rise in trading volume and volatility was mostly visible during the last hours of continuous trading and at the close. This observation confirmed that investor activity on the stock market increased during a crucial time for the final settlement prices of expiring futures. Dividing the research period into three parts, Gurgul and Suliga (2020) tried to check the impact of two events on the occurrence and strength of expiration day effects. The events were: introduction of new transaction system on April 15, 2013 and changes in short-selling rules on May 31, 2015. The strongest anomalies were detected in the second subperiod, which was interpreted as showing that expiration day effects intensified after the first event but were attenuated by the second one (which is consistent with the results obtained in this area by Suliga and Wójtowicz (2019)).

In the last two articles Suliga (2020, 2021) studied the impact of futures expirations on the marking of individual stocks which are underlying assets of stock futures. Most of them are also in one of the two indexes: WIG20 or mWIG40. As well as Gurgul and Suliga (2020) she used high frequency data and analyzed the anomalies in the same research period, namely January 2011 – March 2017. In the first research (Suliga 2020) all potential expiration day effects were analyzed, namely the increase of trading volume and volatility of stocks, unusual fall/rise in prices, price reversal and price shock. Suliga (2020) compared distributions of appropriate expiration day effects measures between expiration days and control days (the third Fridays of the months in which stock and index futures do not expire). The results revealed that anomalies (abnormal trading volume and abnormal volatility) were visible in the marking of all stocks under study during the time when transactions made on the stock market had a decisive influence on final settlement prices of derivatives. For one company (Asseco Poland), it was found that stock prices had a steady tendency to rise on expiration days during the last hour of continuous trading. Price reversal and price shocks were only detected in the case of the shares of a few companies.

In the second piece of research, Suliga (2021) employed linear models to identify factors which determine the strength of expiration day effects occurring in individual stock markings. The results suggest that the stronger the anomalies, the more positions in futures are opened before expiration. There is also a positive relationship between the strength of anomalies and the number of shares per contact: the larger the contact multiplier, the stronger the expiration day effects. The study also allowed us to check the impact of some events on expiration day effects. It partially confirmed the results obtained earlier by Gurgul and Suliga (2020) as well as by Suliga and Wójtowicz (2019). The estimated coefficients of liner models indicate that the implementation of new short-selling rules only weakened the anomalies occurring during the continuous trading phase but did not have any impact on the strength of the effects at the close. The last conclusion from the research was that the change of the transaction system WARSET to the faster and more efficient UTP system contributed to the weakening of trading volume effects and to the intensification of price reversal and price shock, which could be related to the development of high-frequency trading strategies.

One of the important goals of this article is to check the impact of another event, namely the outbreak of the COVID-19 pandemic on the occurrence and strength of expiration day effects on the Polish stock market.

3. Data and methodology

In this research we examine the existence of four expiration day effects, namely: the unusual increase in volume and in volatility, price reversal and price shock. The data set used in the study included tick-by-tick data from the period January 1, 2018 – December 31, 2020 containing price and trading volume of each transaction and the time of its conclusion (with an accuracy of 1 second). The data was used to calculate intraday trading volume and 5-minute returns of stocks which were underlying assets of stock futures in the research period. As stock and index futures expire quarterly, on the third Friday of March, June, September and December, there were 12 expiration days within the given period. Table 1 presents an alphabetical list of companies included in the research. It contains the full name of each company, an abbreviation of its name as well as information about the number of expiration days included in the research. Most of the analyzed stock futures were launched before 2018, therefore this number is 12. However, some of them were introduced to the market during the research period. In such cases, the number of expiration days assigned to an underlying stock is less than 12.

Table 1
Alphabetical list of companies included in the research

Name of the company and its abbreviation	Number of expiration days	Name of the company and its abbreviation	Number of expiration days
Alior Bank (ALR)	12	Kruk (KRU)	12
Asseco Poland (ACP)	12	LiveChat Software (LVC)	9
Bank Millennium (MIL)	12	LPP (LPP)	12
Bank Polska Kasa Opieki (PEO)	12	Lubelski Węgiel Bogdanka (LWB)	12
Biomed-Lublin (BML)	1	MBank Spółka Akcyjna (MBK)	12
CCC	12	Mercator Medical (MRC)	1
CD Projekt (CDR)	12	Orange Polska (OPL)	12
Ciech (CIE)	12	PGE Polska Grupa Energetyczna (PGE)	12
Cyfrowy Polsat (CPS)	12	PlayWay (PLW)	8
CI Games (CIG)	7	Polimex Mostostal (PXM)	12
Dino Polska (DNP)	12	Polskie Górnictwo Naftowe i Gazownictwo (PGN)	12
Enea (ENA)	12	Polski Koncern Naftowy Orlen (PKN)	12
Giełda Papierów Wartościowych w Warszawie (GPW)	12	Powszechna Kasa Oszczędności Bank Polski (PKO)	12
Grupa Azoty (ATT)	12	Powszechny Zakład Ubezpieczeń (PZU)	12
Grupa Eurocash (EUH)	12	Santander Bank Polska (SPL)	9
Grupa Lotos (LTS)	12	Tauron Polska Energia (TPE)	12
ING Bank Śląski (ING)	12	Ten Square Games	9
Jastrzębska Spółka Węglowa (JSW)	12	X-Trade Brokers (XTB)	1
KGHM Polska Miedź (KGH)	12	11 bit studio (11B)	4

This table contains basic information about companies which stocks are included in the study as underlying assets of stock futures. Full name of each company is presented with its abbreviation and information about the number of expiration days of corresponding stock futures which were included in the study.

To study expiration day effects, Stoll and Whaley (1986, 1987), pioneers of research in this area, defined appropriate measures of the anomalies and compared distributions of these values between expiration days and control days. In the following years this stream of research has been used by many authors (i.a. by Schlag, 1996; Chow et al., 2003; Alkebäck, Hagelin, 2004; Debasish, 2010; Chay et al., 2013; Xu, 2014; Suliga 2020). However, in recent years, various researchers have also proposed other methods of detecting anomalies generated on stock market by futures expiration. In reference to the Polish market, Suliga (2017) was first, who studied the anomalies employing event study methodology to classical expiration day effect measures. This research method was then used by Suliga and Wójtowicz (2019), as well as Gurgul and Suliga (2020) and is also applied in this article.

3.1. Measures of expiration day effects

In terms of earlier studies, expiration day effects mostly occur on the market during the time when spot transactions have a direct impact on final settlement prices of derivatives. On the WSE, the final prices of stock futures are calculated as the closing price of the underlying stock on expiration day. Such a settlement procedure might result in significant anomalies during the last minutes of continuous trading as well as at the close of the trading session on expiration day. However, stock futures expire simultaneously with WIG20 futures, mWIG40 futures and WIG20 options and most of the stocks which are underlying assets of stock futures are also in one of the two indexes: WIG20 or mWIG40. This should be kept in mind as it means that not only expiration of individual stock futures but also expiration of index derivatives may contribute to anomalies in stocks' quotations. On the Polish market, the final settlement prices of index futures and options are calculated as the arithmetic means of all index values from the last four of continuous trading and the value at the close on expiration day (after removing the five highest and five lowest). Thus, anomalies may also occur during the whole last hour of trading session on expiration days.

To identify the relationship between expiration effects and the settlement procedure of stock and index derivatives, the trading session was divided into three parts: before the last hour of continuous trading, in the last hour of continuous trading, at the close and during overtime. Expiration day effect measures were calculated separately in each of these intervals.

As a measure of the abnormal trading volume effect, the natural logarithm of turnover value $\ln(V_t)$ was used. The measure was calculated in three subperiods of a trading day separately: $\ln(V_{t,1})$ denotes log-volume from before the last hour of the continuous trading, $\ln(V_{t,2})$ – from the last hour of continuous trading and $\ln(V_{t,3})$ – at the close and during overtime.

Measures of the effect of increased volatility were also calculated for the three time intervals mentioned above. Before the last hour of continuous trading, as well as in the last hour of the continuous trading phase, the mean absolute deviation of the 5-min returns was employed as an indicator of stock price volatility (designated as $d_{t,1}$ and $d_{t,2}$ respectively), where:

$$d_{t,i} = \frac{1}{n_i}\sum_{k=1}^{n_i}\left|r_{t,k} - \overline{r}\right| \tag{1}$$

In equation (1) $r_{t,k}$ stands for 5-min returns from a given time interval, $\overline{r}$ is their arithmetic mean and n_i is their number.

Volatility at the close was estimated as the absolute value of a return at the close $|R_t^c|$, calculated as:

$$\left|R_t^c\right| = \left|\ln\left(P_{t,close}\right) - \ln\left(P_{t,close-5}\right)\right| \tag{2}$$

were $P_{t,close}$ is a closing price of a stock on day t and $P_{t,close-5}$ is the price of the last transaction concluded on day t in the continuous trading phase.

Previous research on expiration day effects on the Polish stock market have shown that the anomalies mainly occur on expiration days during the time when the final settlement prices of futures are being calculated, that is in the last hour of trading session and at the close. Therefore, to detect potential price reversal or price shock effect, data from this short time interval should be employed. In this paper we follow Suliga (2020) and use for the last to effects measures calculated with the use of one-hour returns:

$$REV_t^1 = \begin{cases} R_{t+1}^{fh} & if \quad R_t^{lh} < 0 \\ -R_{t+1}^{fh} & if \quad R_t^{lh} \geq 0 \end{cases} \tag{3a}$$

$$PS_t^1 = \left|R_{t+1}^{fh} - R_t^{lh}\right| \tag{3b}$$

$R_t^{lh} = \ln(P_{t,close}) - \ln(P_{t,close-60})$ is a logarithmic rate of return from the last hour of trading session on day t. $P_{t,close-60}$ is a price of the last transaction conducted on day t before the beginning of the last hour of continuous phase.
$R_{t+1}^{lh} = \ln(P_{t+1,open+60}) - \ln(P_{t,close})$ is a logarithmic rate of return from the first hour of trading on day $t+1$, where $P_{t+1,open+60}$ is a price of the last transaction concluded in the first hour of continuous trading on this day.

Using the measures described above, Suliga (2020) only detected price anomalies in the case of a few of the 14 stocks under study. To check if it is possible that these anomalies may be very short-lived and can already be observed at the opening of the trading session following the expiration of contracts, two additional measures were used, based on a comparison between the rate of return from the last hour of trading in expiration day R_t^{lh} and the rate of return realized between the close of the trading session on the expiration day and opening on the next trading day R_{t+1}^{co}:

$$REV_t^2 = \begin{cases} R_{t+1}^{co} & if \quad R_t^{lh} < 0 \\ -R_{t+1}^{co} & if \quad R_t^{lh} \geq 0 \end{cases} \tag{4a}$$

$$PS_t^2 = \left| R_{t+1}^{co} - R_t^{lh} \right| \tag{4b}$$

where $R_{t+1}^{co} = \ln(P_{t+1,open}) - \ln(P_{t,close})$

3.2. Event study analysis

As already mentioned, event study methodology was applied to study expiration day effects. The main assumptions and basics of this methodology can be found, among others, in Gurgul (2006) or Kothari and Warner (2006). In the research based on event study, four basic stages can be distinguished:

- defining the event,
- time frame determination (construction of pre-event and event window),
- the choose of the model which is then applied to estimate expected values of the analyzed variable in the event window,
- assessment of the effect of the event with the use of an appropriate test.

The main goal of this research is to assess the impact of derivatives expirations on trading volume, intraday volatility, and the prices of individual stocks which set underlying assets of expiring stock futures. Thus, the event is identified with an expiration of a single series of stock futures. As during the period under study (January 2018 – December 2020) there were 12 expiration days (the third Fridays of March, June, September and December) and more than 30 series of stock futures expired on each of these days, the total number of events is $N = 397$, as it comes from the data in Table 1.

As mentioned in section 2, some earlier studies revealed that anomalies in trading volume and volatility of stocks can not only be observed on the market on expiration days (denoted by $t = 0$) but also within a week before expiration.

However, Suliga and Wójtowicz (2019) detected some distortion in the turnover value of underlying stocks of futures also within two days following expiration day. Given these results, in the study of the first two anomalies, that is abnormal trading volume and abnormal volatility effect, an event window which begins on the fifth day before expiration and ends two days after it ($t = -5, \ldots, 2$) is used. As price reversal and price shocks may only occur after the expiration, in case of these effects event window is a lot shorter and only covers the expiration day and the previous day ($t = -1, 0$).

The estimation window should be as wide as possible but should not contain any confounding event and must not overlap the previous event window. As stocks and index derivatives expire on the WSE quarterly, we define an estimation window in the same way as Suliga and Wójtowicz (2019) as well as Gurgul and Suliga (2020), namely, it covers 45 days directly before the event window ($t = -50, \ldots, -6$). It also enabled us to compare our results with those obtained by the abovementioned authors.

Measures of expiration day effects defined in section 3.1 are treated as variables X_t, used in the event study. Thus:

$$X_t \in \left\{ \ln\left(V_{t,1}\right), \ln\left(V_{t,2}\right), \ln\left(V_{t,3}\right), d_{t,1}, d_{t,2}, \left|R_t^c\right|, REV_t^1, REV_t^2, PS_t^1, PS_t^2 \right\}$$

The event study analysis consists in testing whether values of the variables in the event window differ from their "normal" values. Thus AX_{it} is abnormal variable defined for the i-th event as the difference between X_{it} and its expected value $E(X_{it} \mid \Omega_{-6})$, conditional to the data set from the pre-event window (the set of the data Ω_{-6} available on day ($t = -6$):

$$AX_{it} = X_{it} - E(X_{it} \mid \Omega_{-6}) \tag{5}$$

Approximation of an expected value $E(X_{it} \mid \Omega_{-6})$ is calculated as mean value in the estimation window. Testing of the occurrence of the expiration effect on day $t = t_0$ in the event window is indetified with testing the hypotheses:

$$\begin{aligned} &H_0 : E\left(AX_{it_0}\right) = 0 \\ &H_1 : E\left(AX_{it_0}\right) \neq 0 \end{aligned} \tag{6a}$$

or

$$\begin{aligned} &H_0 : E\left(AX_{it_0}\right) = 0 \\ &H_1 : E\left(AX_{it_0}\right) > 0 \end{aligned} \tag{6a}$$

For this purpose, the Kolari–Pynnönen test is applied (see Kolari and Pynnönen 2011). Two-sided alternative hypothesis is used in the case of abnormal trading volume and the abnormal volatility effect. Earlier studies on these anomalies in relation to various markets revealed that during the period covered by the event window not only significant increase but also that a significant decrease of the analyzed variables is possible (see e.g. Stoll and Whaley 1986, Mahalwala 2016, Suliga and Wójtowicz 2019).

In the analysis of price reversal and price shock effects, a one-sided test with hypotheses (6b) is applied. This time, the aim of the test is to check if the price reversal effect is stronger after futures expiration than after other days, and if the changes in underlying stock prices are unusually large (which would mean that price shock occurs after expiration). In both cases, therefore, the interest is to check the occurrence of significantly positive abnormal values of the analyzed variables.

The construction of the test statistic and the procedure used to test the expiration effects with the Kolari-Pynnönen test will be described below, assuming an eight-day event window ($t = -5, \ldots, 2$), i.e. the window applied to study volume effect and volatility effect.

After calculating the values of abnormal variables AX_{it} for each event i and each day t in the pre-event window and the event window, these values are divided by their standard deviation from the pre-event window $S(AX_i)$. This brings to standardized abnormal variables SAX_{it} defined by the formula:

$$SAX_{it} = \frac{AX_{it}}{S(AX_i)} \tag{7}$$

where

$$S(AX_i) = \sqrt{\frac{1}{44}\sum_{t=-50}^{-6}\left(AX_{it} - \overline{AX_i}\right)^2} \tag{8}$$

is the standard deviation of forecast errors in the applied constant mean model and:

$$\overline{AX_i} = \frac{1}{45}\sum_{t=-50}^{-6} AX_{it} \tag{9}$$

To take account of the possibility of an event-induced increase in volatility, standardized abnormal variables SAX_{it} in the event window are divided by their cross-sectional standar deviation and thus adjusted standardized abnormal returns SAX'_{it} are obtained:

$$SAX'_{it} = \begin{cases} SAX_{it} & t = -50,\dots,-6 \\ SAX_{it} / S(SAX_t) & t = t_0 \end{cases} \tag{10}$$

where $t_0 \in \{-5, \dots, 2\}$ and $S(SAX_t)$ is a cross-sectional standard deviation of variables SAX_{it} on day t, given by the formula:

$$S(SAX_t) = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(SAX_{it} - \overline{SAX_t}\right)^2} \tag{11}$$

and N is the numer of events. If the null hypothesis of no expiration effect on day t_0 is true, SAX'_{it_0} are zero mean and unit variance random variables. It should be mentioned that the decision on which days t_0 in the event window variables SAX'_{it} should be adjusted, is made after the anasysis of appropriate plots of standard deviation (e.g. in case of volume effect the correction of volatility is made only for expiration day).

After calculation of SAX'_{it} the test is carried out for each day ($t_0 \in \{-5, \dots, 2\}$ separately, with the use of standardized ranks defined as:

$$U_{it} = \frac{rank\left(SAX'_{it}\right)}{47} - \frac{1}{2} \tag{12}$$

where $t_0 \in \Omega\{-50, \dots, -6, t_0\}$, $i = 1, \dots, N$ and $rank(SAX'_{it})$ is a rank of SAX'_{it} within the vector consisting of SAX'_{it_0} and adjusted standardized abnormal returns from the pre-event window. The null hypothesis of no event effect on day t_0 means that $E(U_{it_0} = 0)$. The generalized rank test constructed by Kolari and Pynnönen (2011) to test this hypothesis has test statistic τ_{grank} defined as:

$$\tau_{grank} = Z\sqrt{\frac{T-2}{T-1-Z^2}} \tag{13}$$

where:

$$Z = \frac{\bar{U}_{t_0}}{S_{\bar{U}}}, \quad \bar{U}_{t_0} = \frac{1}{N}\sum_{i=1}^{N} U_{it_0}, \quad S_{\bar{U}} = \sqrt{\frac{1}{46}\sum_{t\in\Omega}\bar{U}_t^2} \tag{14}$$

If the null hypothesis is true, the distribution of the τ_{grank} test statistic converges to t-student distribution with 44 degrees of freedom, when the sample size N increases to infinity.

3.3. Research hypotheses

Based on the results obtained in previous research on expiration day effects regarding various foreign markets as well as the Polish market, the main research hypotheses were formulated.

First of all, the studies show that the anomalies are highly probable when the final settlement price of the derivative is equal to a single price of an underlying asset (see e.g. Park, Lim, 2004; Bhaumik, Bose, 2007; Chuang et al., 2008; Narang, Vij, 2013). Considering the method of calculating the final settlement price of stock futures on the WSE, we suspect that despite the development of the market, expiration day effects occurred on expiration days during the whole period under study. Thus, we formulate the first hypothesis:

Conjecture 1: In the period 2018–2020 expiration of stock and index derivatives was accompanied by price and volume anomalies on the stock market.

We also phrase more detailed conjectures relating to each effect separately. Essentially, abnormally high trading volume occurring on the spot market on expiration days was detected on every market for which research was carried out. Suliga (2020, 2021) checked that in the period 2012–2017 this anomaly occurred on the WSE mostly during the time when the final settlement prices of stock and index futures were being calculated. We suppose that this has not changed in recent years, so the next two hypotheses are:

Conjecture 2: On expiration days, trading volume of underlying stocks increases significantly above expectations.

Conjecture 3: An unusual increase in trading volume on expiration days occurs during the last hour of continuous trading as well as at the close and during overtime.

As in the case of the effect of increased trading volume, research conducted on the basis of data from the period 2012–2017 confirmed the occurrence of the effect of increased volatility on the spot market of the WSE during the time of the formation of the final settlement prices of futures (see Gurgul and Suliga 2020, Suliga 2020). We suppose that the effect has not disappeared in the following years and formulate the following hypothesis:

Conjecture 4: Intraday volatility of stock prices is abnormally high on expiration days. The increase in volatility takes place during the last hour of continuous trading and at the close.

In reference to the price reversal effect, Suliga (2017) showed that this anomaly occurred on the WSE after futures expirations and that was stronger than after Fridays on which derivatives did not expire. However, it should be noted that the study conducted by Suliga (2017) covered a very long period (2001–2016) and all expiration days from this time were studied together. In another research (Suliga, 2020) she analyzed price reversal for each of the stock under study separately and found that on average, this anomaly was only unusually strong after futures expirations in case of 3 out of 14 companies. Research relating to other markets also indicates that price reversal is a phenomenon that occurs on the market not only after the expiration days of futures. Moreover, even if it occurs after expiration, it is not higher than after other days (see e.g. Alkebäck, Hagelin 2004; Hsieh, Ma, 2009; Debasish, 2010). Thus, we predict the following:

Conjecture 5: Price reversal is not a phenomenon that constantly accompanies the expiration of stock and index futures on the WSE and even if it occurs after the expiration, it is not unusually high.

As price shock is an effect analyzed in few studies (Vipul, 2005; Xu, 2014; Suliga, 2020), which do not give a clear answer to the question about its occurrence, it is not easy to formulate an unambiguous hypothesis regarding the occurrence of this anomaly on the WSE. In reference to the Polish market, the study on the price shock effect was carried out, to our knowledge, only by Suliga (2020). Using the measure PS_t^1, given by the equation (3b), Suliga (2020) detected this anomaly only in case of six out of 14 companies she considered. However, the examination carried out by Suliga (2020) for all companies together confirmed the occurrence of price shock effect on the WSE during the period under study (January 2012 – March 2017). In this research, in addition to the measure PS_t^1 we employ the measure PS_t^2 defined in equation (4b) to check if it is possible that price shock is a very short-lived effect and is already visible at the opening of the first trading session after futures expiration. We formulated the following preliminary hypothesis:

Conjecture 6: The price shock effect is visible in stock prices after stock and index futures expirations. On average, differences between the return from the last hour of the trading session on expiration day and the return from the beginning of the next trading session are higher than normal.

The final hypothesis concerns the impact of the outbreak of the COVID-19 pandemic on the occurrence and strength of expiration day effects on the WSE. The negative impact of this event on the Polish stock market was analyzed, among other markets, and confirmed in several studies (e.g. Ashraf, 2020; Czech et al., 2020a). In detail, functioning of the spot and futures markets of the WSE in the initial phase of the pandemic (March – May 2020) was studied by Czech et al. 2020b).[1]

Since futures contracts are used as tools to hedge open positions on a spot market and the pandemic has led to an increase in the risk of investing in shares, it could be suspected that the futures market attracted more hedgers in the initial phase of the pandemic, or at least encouraged existing hedgers to increase their positions on the market (cf. Corbet et al., 2020). The latter assumption seems to be consistent with the results obtained by Czech et al. (2020b) who checked that the futures market did not attract many new investors in March 2020 but was characterized by an increase in investor activity measured by the size of transactions. Thus, it can be assumed that the importance of the actions taken on expiration days by arbitrageurs and speculators during the COVID-19 pandemic, whose activity on spot market is perceived as a main source of anomalies, weakened considerably. What is more, the underlying instruments of futures only include the largest and most liquid companies from the main market. Meanwhile, Czech et al. (2020b) detected a retreat of investors in the initial phase of the pandemic from the main market to the New Connect market, i.e. to investment in shares of smaller companies. In May 2020, capitalization of the main market of GPW was 26.5% lower than in the same month of the previous year, while the capitalization of the New Connect market increased by 70.9% during the same period (see Czech et al., 2020b). This also suggests potential outflow from the main market of investors responsible for the occurrence of the anomalies. The above deliberations allow us to formulate the last hypothesis:

Conjecture 7: The outbreak of the pandemic COVID-19 has contributed to a significant weakening of expiration day effects on the WSE.

4. Empirical results

As described in detail in the previous section, the research on expiration day effects was conducted with the use of event study analysis. In this section, the results obtained for individual effects and for the three considered research periods are presented.

[1] We do not present a detailed analysis of the Polish spot and futures markets in the initial phase of the COVID-19 pandemic in this paper, so as not to unnecessarily lengthen an already long article. We only briefly present those aspects of the functioning of the market that, in our opinion, may shed light on the problem we are interested in: what impact the outbreak of the pandemic had on the strength of the expiration day effects.

4.1. Event study analysis for the period 2018–2020

At the beginning, the occurrence of the effects was checked for the period January 2018 – December 2020. Table 2 presents the results of the event study of the abnormal trading volume effect. As a measure of the activity of investors, in each of the tree specified subperiods of a trading session, the natural logarithm of turnover value was used. Values of the measure in the event window (starting 5 days before the expiration day and ending two days after it) were compared with their "normal" values, defined as an average value from the pre-event window (consisting of 45 days directly before the event window). In Table 2, the mean abnormal values of the log-turnover for each day in the event window are presented with corresponding values of the Kolari–Pynnönen test statistic τ_{grank}.

Table 2

The effect of abnormal trading volume

t	From opening to the last hour of continuous trading		In the last hour of continuous trading		At the close and in overtime	
	$\overline{A\ln(V_{t,1})}$	τ_{grank}	$\overline{A\ln(V_{t,2})}$	τ_{grank}	$\overline{A\ln(V_{t,3})}$	τ_{grank}
−5	0.150	1.251	0.036	0.295	0.051	0.553
−4	0.022	0.157	0.077	0.722	0.015	0.222
−3	0.142	1.138	0.084	0.536	0.195	1.205
−2	0.136	1.203	0.181*	1.982	0.140	0.789
−1	0.077	0.481	0.039	0.201	0.114	0.791
0	**0.106**	**0.921**	**1.123*****	**7.999**	**2.440*****	**7.500**
1	0.165	0.431	−0.071	−1.162	−0.066	−0.545
2	0.013	−0.265	−0.128	−1.642	−0.069	−0.656

This table presents the results of the event study analysis employed to detect abnormal trading volume effect. Log-volume of stocks, which are underlying assets of stock futures, was used to check the occurrence of the effect during three subperiods of a trading session: from opening to the last hour of continuous trading, during the last hour of continuous trading, at the close and during overtime. For each day in the event window (starting from the 5th day before expiration and ending on the 2nd day after it) and for each of the three subperiods, average abnormal trading volumes are presented with corresponding statistic values.

* and *** denote significance at the 10% and 1% levels, respectively.

The left-most part of the table contains average abnormal values of log-volume from before the last hour of continuous trading. They are all positive, but test statistic values suggest that none of the corresponding expected values of abnormal variable $A\ln(V_{t,1})$ differs significantly from zero. It means that during this part of a trading session activity of investors is not abnormally high on any of the days in the event window.

Results obtained in reference to the last hour of continuous trading are presented in the middle part of the table while the right part contains results for the closing phase and overtime. In these two parts of the table, averages obtained for $t = 0$ are positive. The test confirms the occurrence of a strong volume effect on the expiration day during the triple witching hour, indicating that expected values of the variable $A\ln(V_{0,2})$ are significantly positive (at a 1% level). Trading in shares which are underlying assets of stock futures, and which pose parts of the underlying indices of index futures, increases unusually during the time when final settlement prices of expiring derivatives are being shaped. This observation is fully consistent with the analogous results obtained by Gurgul and Suliga (2020) as well as by Suliga (2020) for the period 2012–2017. However, Gurgul and Suliga (2020) (as well as Suliga and Wójtowicz (2019) who performed a study in reference to a similar period but using daily data), detected an unusual increase in trading volume of stocks also on day $t = -1$ what indicated abnormal activity occurring on the stock market of the WSE already one day before expiration. In our research, only one significantly positive expected value of abnormal measure of the volume effect was detected before the expiration day – for day $t = -2$ in the last hour of continuous trading. However, it might be considered significantly different from zero only if a 10% significance level is assumed. All other averages presented in Table 2 which are related to days before expiration, are also positive but corresponding expected values of abnormal variables are found as insignificantly different from zero. This suggests that during the period under study, there could be still some increase in activity of investors on the spot market before expiration days connected with futures expiration, but it was certainly weaker than in previous years. Such an increase in trading volume on days directly before expiration can be a symptom of the early unwinding of arbitrage positions (Vipul, 2005; Debasish, 2010; Agarwalla, Pandey, 2013). Our results suggest, however, that in the process of time and with the development of the market, the occurrence of the volume effect was shortened and narrowed down mostly to the time interval in which trading on stocks has a direct impact on the final settlement prices of expiring futures. This observation fully confirms Conjectures 2 and 3.

In Table 3, the results of the analysis of the volatility effect are presented. Measures of this anomaly related to the three subperiods of a trading session were defined by equations (1) and (2). Test statistic values suggest that all the expected values of abnormal variables related to the days before the expiration ($t < 0$) are insignificantly different from zero. On expiration day ($t = 0$) significantly positive (at a 1% level) expected values were detected for abnormal measures of volatility in the last hour of continuous trading ($Ad_{t,2}$) as well as at the close ($A|R_t^d|$). Thus, similarly to the volume effect, the effect of abnormally high intraday volatility of stock prices does not occur before the expiration, while on expiration day it only appears during the time of the formation of final settlement prices of futures. This observation is a confirmation of Conjecture 4.

Test statistic value related to the average abnormal mean deviation of 5-min returns obtained one day after the expiration ($t = 1$) before the last hour of continuous trading indicates that expected value of corresponding variable $Ad_{1,1}$ is positive and significantly different from zero (at a 5% level). It can be a preliminary signal that prices temporarily distorted on expiration day return to their normal levels at the beginning of the first trading session after expiration, translating into an increase in volatility. As such a return can occur relatively quickly (Suliga, 2020) thus, except for this one value $\left(\overline{Ad_{1,1}}\right)$, in Table 3 there are no other significantly different form zero values related to the days after the expiration. This interpretation will be verified by the results of price reversal and price shock effects.

Table 3

The effect of abnormal volatility of 5-min returns

t	From opening to the last hour of continuous trading		In the last hour of continuous trading		At the close	
	$\overline{Ad_{t,1}}$ [%]	τ_{grank}	$\overline{Ad_{t,2}}$ [%]	τ_{grank}	$\overline{A\,\|\,R_t^d\,\|}$	τ_{grank}
−5	0.043	1.223	0.014	0.784	0.051	1.210
−4	0.034	0.446	0.031	0.359	−0.021	−1.241
−3	0.028	0.443	0.010	−0.759	−0.001	−0.292
−2	0.031	0.356	0.012	−0.080	−0.022	−1.099
−1	0.017	0.221	0.003	−0.296	−0.030	−0.796
0	**0.018**	**0.736**	**0.051*****	**3.636**	**0.384*****	**8.518**
1	0.038**	2.434	0.008	0.408	−0.005	0.051
2	0.011	0.683	0.008	0.841	0.008	0.055

This table presents the results of the event study analysis employed to detect abnormal volatility effect. Mean deviation of 5-min returns from before the last hour of continuous trading, mean deviation of 5-min returns during the last hour of continuous trading, as well as absolute values of returns at the close were used to check the occurrence of the effect during three subperiods of trading session. For each day in the event window (starting from the 5th day before expiration and ending on the 2nd day after it) average abnormal values of above-mentioned measures are presented with corresponding statistic values.
** and *** denote significance at the 5%, and 1% levels, respectively.

Table 4 presents the results of the event study analysis employed to detect price reversal and the price shock effect. This time event window contains only two days (t = –1,0). Due to the nature of the anomalies, the expected values of variables obtained for $t = 0$ are of particular interest. In the left part of Table 4 abnormal absolute values of the measures REV_t^1 and REV_t^2 of price reversal effect are presented with corresponding τ_{grank} test statistic values. On expiration day, both averages are very close to zero and test statistic values indicate that the expected values of considered variables are not significantly different from zero. Thus, the obtained results do not confirm the occurrence of a price reversal effect on the WSE during the period under study. However, the measures were defined with the use of intraday returns, namely: return from the last hour of trading session on the expiration day and return from the first hour or from the opening of the next trading session respectively (see eq. (3) and (4)). Thus, they allow to check if the anomalies only occur at the beginning of the first trading session after futures expiration.

Table 4

The effects of price reversal and price shock

	Price reversal measures				Price shock measures			
t	$\overline{AREV_t^1}$ [%]	τ_{grank}	$\overline{AREV_t^2}$ [%]	τ_{grank}	$\overline{APS_t^1}$ [%]	τ_{grank}	$\overline{APS_t^2}$ [%]	τ_{grank}
−1	−0.239	−0.296	−0.205	−0.899	−0.035	−0.174	−0.024	−0.655
0	0.075	0.228	−0.005	0.982	0.584***	4.083	0.502***	4.567

This table presents the results of the event study analysis employed to detect price reversal as well as price shock effect. For expiration day ($t = 0$) and for the previous day ($t = -1$) average abnormal values of measures given by equations (3a), (3b), (4a) and (4b) are presented with corresponding statistic values.

*** denote significance at the 1% level.

As already mentioned, the measure REV_t^1 was employed by Suliga (2020) who checked the occurrence of price reversal for individual stocks. However, Suliga (2020) used other methods in her research. She compared the distribution of the values of the measure between expiration and control days (defined as the third Friday of the months in which derivatives do not expire). Only in the case of 3 out of 14 companies under study were significant differences between the distributions found, suggesting that on average, share prices of these three companies reverse after derivative expirations and the reversal is significantly stronger than after other days. An analogous comparison made by Suliga (2020) for all the stocks together also indicated that in general there are grounds for assuming that after futures expiration slight price reversal on average take place, while after control days the direction of price change at the beginning of the next session is the same as at the end of the previous session. In Table 4, $\overline{AREV_t^1}$ calculated for $t = 0$ is slightly positive which also means that the value of the measure on expiration day is on average slightly higher than normally. However, the test statistic values indicate that this difference is insignificant. In conclusion, it should be stated that results obtained for price reversal measures support Conjecture 5.

Results presented in the right part of Table 4 show the weakness highlighted by Vipul (2005) of the measures of price reversal as tools for detecting anomalies in prices. While these measures do not confirm the occurrence of any unusual price changes, averages received on day $t = 0$ for both measures of price shock are positive and test statistic indicates that corresponding expected values are significantly higher than zero (at a 1% level). This confirms the occurrence of price shock effect on the WSE during the period under study as it was assumed in Conjecture 6: changes in prices between the triple witching hour and the beginning of the first trading session after derivatives expiration are abnormally high. This observation is probably the result of unusually large price changes occurring not only at the end of the trading session on the expiration day but also at the beginning of the next session. Indeed, at an earlier stage of this study (see Table 3) a significant increase in volatility was detected on day $t = 1$ in the initial hours of a trading session.[2]

4.2. Results of the analysis conducted in subperiods: before and in the initial phase of COVID-19 pandemic

To check if the outbreak of the COVID-19 pandemic has had an impact on the occurrence and strength of expiration day effects on the WSE, an event study analysis was conducted in two subperiods separately: January 2018 – December 2019 (Subperiod 1, before the pandemic, 254 events) and January 2020 – December 2020 (Subperiod 2, 143 events). As the first expiration day in 2020 was on the third Friday of March, the latter subperiod can be also described as March 2020 – December 2020 and identified with the initial phase of the pandemic.

[2] Price shock measures were calculated with the use of stock returns realized between expiration on the Friday and the subsequent Monday. Thus, one might surmise that the detected price shock is a sign of the weekday effect rather than expiration day effect. The use of eight-day event window (as was employed to the two previously considered effects), containing day $t = -5$, which is also a Friday, may dispel such a doubt, if the expected values of the measures assigned to this day would be insignificantly different from zero. We checked this using eight-day event window in calculations and anomalies were not detected five days before expiration. We decided, however, to present two-days event window in the article to shorten the notation and focus only on the days when price effects are expected to occur.

The results for abnormal trading volume effect are reported in Table 5. A comparison between Panel A (containing results for subperiod 1) and Panel B (results for subperiod 2) confirms the existence of the anomaly both before and at the beginning of the pandemic.

Table 5

The effect of abnormal trading volume in subperiods

		From opening to the last hour of continuous trading		In the last hour of continuous trading		At the close and in overtime	
	t	$\overline{A\ln(V_{t,1})}$	τ_{grank}	$\overline{A\ln(V_{t,2})}$	τ_{grank}	$\overline{A\ln(V_{t,3})}$	τ_{grank}
Panel A: Subperiod 1	−5	0.024	0.042	−0.052	−0.587	−0.065	−0.017
	−4	−0.066	−0.696	0.054	0.408	−0.002	0.124
	−3	0.076	0.575	0.039	−0.006	0.207	1.243
	−2	0.099	0.982	0.220**	2.078	0.177	1.035
	−1	0.038	0.089	−0.040	−0.807	0.131	0.715
	0	**0.102**	**1.225**	**1.266*** **	**8.338**	**2.494*** **	**6.575**
	1	0.154	−0.141	−0.106	−1.602	−0.045	−0.637
	2	−0.005	−0.412	−0.124	−1.438	0.059	0.024
Panel B: Subperiod 2	−5	0.375	1.888	0.192	0.981	0.258	1.038
	−4	0.177	0.884	0.119	0.641	0.045	0.244
	−3	0.258	1.220	0.164	0.769	0.173	0.569
	−2	0.202	0.947	0.112	0.846	0.075	0.081
	−1	0.148	0.657	0.180	1.054	0.083	0.505
	0	**0.112**	**0.330**	**0.870*** **	**3.683**	**2.344*** **	**5.179**
	1	0.184	0.790	−0.008	−0.129	−0.104	−0.160
	2	0.045	−0.030	−0.134	−0.969	−0.295	−1.237

This table presents results of event study analysis employed to detect abnormal trading volume effect in two subperiods: January 2, 2018, through December 30, 2019 (Subperiod 1, results presented in Panel A, 254 events) and January 2, 2020, through December 30, 2020 (Subperiod 2, results presented in Panel B, 143 events). For both subperiods the analysis was conducted separately in each of the three session intervals: before the last hour of continuous trading phase, in the last hour of continuous trading, at the close and during overtime. For each day in the event window (starting from the 5th day before expiration and ending on the 2nd day after it), average abnormal log-turnover values are presented with corresponding statistic values.

** and *** denote significance at 5% and 1% levels, respectively.

Test statistic values related to averages calculated for expiration days ($t = 0$) indicate that the activity of investors only increase unusually in the last hour of continuous trading as well as at the close and during overtime. The averages are positive and values of τ_{grank} statistic suggest that expected values of abnormal measures are significantly different from zero (at a 1% level). This observation is true for both subperiods and confirms the direct relationship between the time of the occurrence of the anomaly and the procedure for calculating the final settlement prices of futures: trading on underlying stocks is abnormally high during the time when final settlement prices of corresponding derivatives are shaped.

In Panel A, the average abnormal value obtained in reference to the last hour of continuous trading on day $t = -2$ suggest that before the pandemic, trading volume increased abnormally two days before expiration, in the final part of the continuous trading phase. An analogous result was reported in Table 2, when the existence of the volume effect was checked for the whole period under study. We interpreted this as a potential sign of the early increase of investor activity, connected with expiration of futures. However, comparing this observation with results obtained by Gurgul and Suliga (2020) as well as with Suliga and Wójtowicz (2019) we concluded that in the years covered by their research (2012–2017), the volume effect occurred over a longer period (they also discovered clear signals of this anomaly one day before expiration) while in the following years, the time of its occurrence has been shortened. The results in Table 5 additionally support the thesis. In 2020, the volume effect only appeared in the triple witching hour. Has the strength of the anomaly decreased after the outbreak of the pandemic? Comparison of the appropriate abnormal average values ($\overline{A\ln(V_{t,1})}$ and $\overline{A\ln(V_{t,2})}$ for $t = 0$) between Panel A and B may suggest this, as the values related to the latter subperiod are smaller. However, the final answer to this question requires to conduct an appropriate test, what will be done at a later stage of the research.

The results of event study analysis performed for volatility measures in subperiods are presented in Table 6. On the grounds of the data from Panel A, an abnormal volatility effect can be confirmed in the first subperiod only on day $t = 0$ and during the time when final derivatives' prices are being calculated. Averages of the measures obtained on expiration day in the last hour of continuous trading as well as at the close are positive and the corresponding values of τ_{grank} test statistic indicate that expected values of the abnormal variables are significantly positive (at a 1% level). Beyond this short extract of a trading session on expiration day, the volatility effect was not detected in any other part of the event window. In particular, there is no basis for concluding that an unusual increase in the intraday volatility of stock prices occurred at the beginning of the first trading session after the expiration before the pandemic. Such an anomaly was reported on the grounds of the data from Table 3 which contains results of the event study analysis performed for the entire period 2018–2020. However, the outcomes presented in Panel B of Table 6 indicate that this anomaly occurred during the initial phase of the COVID-19 pandemic. In this panel, average abnormal value of the measure $d_{t,1}$ is positive on $t = 1$ and the Kolari–Pynnönen test suggests that expected value of the abnormal variable is significantly positive (at a 5% level). This means that the conclusions which were drawn with regard to the analogous observation from Table 3 only remain valid for the latter of the two considered subperiods. Interestingly, an abnormal volatility effect was only detected on expiration days in 2020 at the close, but its existence cannot be confirmed in the last hour of continuous trading. Mean abnormal value of the measure $|R_0^d|$, although smaller than in the first subperiod, is still significantly positive (at a 1% level) whereas expected value of $Ad_{0,2}$ does not differ significantly from zero. How can such a reduction in anomaly time be explained?

The main source of the expiration day effects is the activity of arbitrageurs and speculators who have open position in expiring futures. Such an activity is undertaken during the time when their transactions on a spot market influence the final prices of expiring derivatives. Thus, anomalies occurring on the WSE in the last hour of continuous trading on expiration day should mainly be identified with the activity of investors who have open positions in index derivatives while effects at the close of the trading session – with the activity of holders of stock futures. Efforts of speculators who try to control final settlement prices of futures, or even deliberately manipulate their prices, may be successful inasmuch as they constitute a significant group operating on the spot market at a given time. However, if the market is dominated by investors using contracts in hedging strategies, the occurrence of significant price anomalies is much less likely. Their activity compensates for the activity of speculators and limits the possibility of rapid changes in share prices (and ipso facto in prices of expiring derivatives).

As highlighted in subsection 3.1, market risk increased significantly with the outbreak of the pandemic and the prices of the stocks of many companies included in the most important indices listed on the WSE declined sharply. At the same time, there was a clear increase in the turnover of the futures market, which can be read as a signal that the crisis caused by the pandemic prompted investors to look for tools to hedge against the increasing risk of investing in shares. In the period March–December 2020, the trading volume of index futures was approximately 65% higher than in the corresponding period in 2019 (see Czech et al., 2020b).

This sharp increase in turnover should be identified (if not in its entirety, then at least in a major part) with an increase in hedging positions on the futures market, and thus with a decrease in the importance (impact on prices) of actions undertaken by arbitrageurs and speculators.

How to explain the occurrence of abnormal volatility effect at the close on expiration days in 2020 in this context? A comparison of relevant averages from Panel A and B in Table 6 suggests that the effect was probably weaker during the pandemic than before it (it will be tested later in the study), but it was still visible. The difference in the procedure for calculating final settlement prices of stock and index futures seems to be crucial. Such a single value of stock is much easier to influence than the average value of the index. Thus, thoughtful transactions made by speculators on the shares of a particular company at the very end of the trading session on expiration day (for example, placing appropriate closing orders) may cause an unusually large change in this share's closing price, reflected in increased volatility at the close. This is possible even during a crisis, when many investors use derivatives as hedging tools.

The results presented in Panel B of Table 6 suggest, however, that such disturbances in the level of stock prices are only temporary – the increase in volatility detected at the beginning of the first trading session after expiration might be a sign of a fast return of prices to a "normal" level, what will be further investigated by the measures of the price reversal and price shock effects.

Table 6

The effect of abnormal volatility of 5-min returns in subperiods

		From opening to the last hour of continuous trading		In the last hour of continuous trading		At the close	
	t	$\overline{Ad_{t,1}}$ [%]	τ_{grank}	$\overline{Ad_{t,2}}$ [%]	τ_{grank}	$\overline{A\,\|R_t^d\|}$	τ_{grank}
Panel A: Subperiod 1	−5	0.006	0.484	0.000	0.234	0.027	0.716
	−4	−0.001	−0.316	−0.007	−0.420	−0.038	−1.438
	−3	−0.003	−0.027	−0.012	−1.213	−0.050	−1.459
	−2	0.001	0.064	0.000	−0.299	−0.007	−0.685
	−1	−0.006	−0.774	−0.014	−1.115	−0.033	−0.695
	0	**−0.001**	**0.034**	**0.059*****	**3.586**	**0.437*****	**7.546**
	1	0.013	1.356	−0.007	−0.329	−0.037	−0.694
	2	0.003	0.331	0.011	0.751	0.030	0.621

Table 6 cont.

	t	From opening to the last hour of continuous trading		In the last hour of continuous trading		At the close	
	t	$\overline{Ad_{t,1}}$ [%]	τ_{grank}	$\overline{Ad_{t,2}}$ [%]	τ_{grank}	$\overline{A\,\lvert R_t^d \rvert}$	τ_{grank}
Panel B: Subperiod 2	−5	0.108	1.481	0.039	0.960	0.095	1.192
	−4	0.097	1.195	0.098	1.094	0.009	−0.234
	−3	0.083	0.805	0.048	0.277	0.085	1.526
	−2	0.083	0.532	0.033	0.240	−0.048	−1.036
	−1	0.059	1.406	0.034	0.897	−0.025	−0.467
	0	**0.051**	**1.045**	**0.036**	**1.304**	**0.288*****	**4.617**
	1	0.080**	2.432	0.033	1.053	0.052	1.071
	2	0.024	0.748	0.004	0.424	−0.031	−0.772

This table presents results of event study analysis employed to detect abnormal volatility effect in two subperiods: January 2, 2018, through December 30, 2019 (Subperiod 1, results presented in Panel A, 254 events) and January 2, 2020, through December 30, 2020 (Subperiod 2, results presented in Panel B, 143 events). In both subperiods the measures of intraday volatility of stock prices are: mean deviation of 5-min returns from before the last hour of continuous trading, mean deviation of 5-min returns during the last hour of continuous trading, as well as absolute values of returns at the close. For each day in the event window (starting from the 5th day before expiration and ending on the 2nd day after it) average abnormal values of these measures are presented with corresponding statistic values. ** and *** denote significance at the 5% and 1% levels, respectively.

Table 7 presents the results of the analysis of the price reversal and price shock effects in subperiods. In Panel A, average abnormal values of both measures of price reversal are positive on expiration days. This means that, on average and before the COVID-19 pandemic, after futures expiration the direction of the changes in stock prices was opposite to the direction at the end of expiration day. However, the Kolari–Pynnönen test statistic indicates that the expected value of the abnormal variable $AREV_t^1$ does not differ significantly from zero while the expected value of the second variable $AREV_t^2$ can be considered as significantly positive on day $t = 0$ only if 0,1 significance level is assumed. These results do not give a clear confirmation of the occurrence of price reversal effect in the first subperiod. However, the results presented in the right part of panel A indicate the occurrence of a significant price shock effect. The averages of both price shock measures are positive on day $t = 0$ and the test confirms that expected values of abnormal measures APS_t^1 and APS_t^2 are positive (at a 1% level). It means that differences between the return from the last hour of trading session on expiration day and appropriate return from the beginning of the next trading session (the return at the opening or the return from the first hour of continuous trading) are unusually high compared to the average of analogous differences observed in pre-event widow.

The results in Panel B, relating to the initial phase of the pandemic, do not differ widely from those discussed above. This time, however, there are no indications of the price reversal effect. The averages of abnormal measures are both negative – not only on expiration day but also on day $t = -1$. It means that, on average, on these days stock prices at the beginning of trading session tend to continue the trend from the last hour of a previous session. As in the Kolari–Pynnönen test, a one-sided alternative hypothesis was employed (see eq. (6b)) the test obviously suggests that none of the expected values of abnormal variables of price reversal are significantly higher than zero. As in the first subperiod, price shock effect is detected on expiration day by both measures. Based on the test statistic values it can be concluded that expected values of abnormal variables APS_t^1 and APS_t^2 are significantly positive on day $t = 0$ while they are not higher than zero one day before the expiration. Average values of the measures are higher than in Panel A which may suggest the intensification of price shocks in the COVID-19 pandemic. However, it relates to the increase in volatility of prices which is a typical phenomenon during a crisis. Thus, to be done properly, the comparison of the strength of the anomaly before and during the pandemic should be carried out with the use of standardized, abnormal values of the measures, given by equation (7).

Comparing the results described above with the results from Table 4, related to the study performed for the entire period 2018–2020, it can be concluded that they are consistent. In particular, the data from Table 7 confirm that price shock effect, detected at an earlier stage of the research, occurred both before and in the initial phase of the pandemic. The division of the research period into two parts did not provide valuable, additional information on the occurrence of price reversal effect, while giving some indications of this anomaly before the outbreak of the pandemic. It is possible that it only occurred in the prices of some of the stocks under study (as Suliga, 2020) showed in the study related to the period 2012–2017) and that research conducted to each of the companies separately would give more information on this point.

To sum up the analysis of the expiration day effects conducted in the subperiods, it was confirmed that expiration day effects occurred on the WSE both before and in the initial phase of COVID-19 pandemic. On expiration days, during the last hour of continuous trading as well as at the close and during overtime activity of investors on a spot market intensified, as reflected in the increased trading volume of underlying stocks. This statement is true for both researched subperiods.

Moreover, the results suggest that before the pandemic trading volume increased abnormally two days before expiration (in the last hour of continuous trading) but in 2020 the volume effect only occurred during the triple witching hour.

Table 7

The effects of price reversal and price shock in subperiods

	Price reversal measures				Price shock measures			
t	$\overline{AREV_t^1}$ [%]	τ_{grank}	$\overline{AREV_t^2}$ [%]	τ_{grank}	$\overline{APS_t^1}$ [%]	τ_{grank}	$\overline{APS_t^2}$ [%]	τ_{grank}
Panel A: Subperiod 1								
−1	−0.075	−0.230	0.026	0.220	−0.167	−0.857	−0.147	−1.392
0	0.205	1.182	0.108*	1.592	0.466***	3.621	0.394***	3.649
Panel B: Subperiod 2								
−1	−0.529	−0.207	−0.614	−1.606	0.199	0.536	0.195	0.484
0	−0.155	−0.905	−0.205	−0.742	0.793**	2.390	0.693***	2.616

This table presents results of event study analysis employed to detect price reversal and price shock effect in two subperiods: January 2, 2018, through December 30, 2019 (Subperiod 1, results presented in Panel A, 254 events) and January 2, 2020, through December 30, 2020 (Subperiod 2, results presented in Panel B, 143 events). For both subperiods average abnormal values of measures given by equations (3a), (3b), (4a) and (4b) are presented with corresponding statistic values for expiration day ($t = 0$) and for the previous day ($t = -1$).
*, **, *** denote significance at the 10%, 5%, and 1% levels, respectively.

The result suggests that the time of the occurrence of the volatility effect on expiration day shortened after the outbreak of COVID-19: in 2018–2019 it was detected, as with the volume effect, during the time when stock and index futures final settlement prices are being calculated. In 2020 abnormal growth in intraday volatility of stock prices only occurred on expiration days at the close but, additionally, it also appeared at the beginning of the next trading session.

As expected, the research confirmed that price reversal is not a phenomenon that constantly accompanies the expiration of stock and index futures on the WSE. Only in the first subperiod and in the case of one of the two measures of the anomaly some indication of the existence of abnormally strong price reversal was obtained. In the initial period of the pandemic this anomaly did not occur on the WSE. However, the analysis of price shock confirmed Vipul's (2020) statement that price reversal measures are insufficient to express all potential perturbations in the price formation process after futures expiration. The existence of a significant price shock was detected in both subperiods by both of the measures employed.

4.3. Comparison of the strength of the expiration day effects between the subperiods

The results obtained for the two subperiods described in the previous subsection are insufficient to verify the validity of the hypothesis 7, which states that futures expiration effects weakened after the outbreak of the pandemic. Admittedly, they indicate a shortening of the duration of the volume (no anomaly before the expiration day) and volatility effect (no effect in the last hour of continuous trading) in the initial phase of the pandemic compared to the period before its outbreak. They also give some indication of price reversal in the first subperiod but give any basis for concluding that this effect occurred after expiration days in 2020. However, in case of the anomalies whose occurrence was confirmed in a given time interval before both the pandemic and in its initial phase, foregoing results do not provide sufficient grounds to conclude whether the strength of these anomalies differs significantly between the compared subperiods. To verify this, a Mann–Whitney *U* test was conducted (see Mann, Whitney, 1947). This non-parametric test allows to check if two independent data samples come from the same distribution. The test was applied to the abnormal, standardized values of only these measures, which confirmed the occurrence of a given expiration day effect in both of the two analyzed subperiods.

Table 8 presents the results of the conducted Mann–Whitney *U* test. It contains means and medians of the standardized, abnormal values of the measures calculated in two subperiods separately (2018–2019 and 2020). In the rightmost part of the table *p*-values of the *U* test, comparing the distributions of the measures, are presented.

The volume effect was confirmed on expiration days in both subperiods during the last hour of continuous trading as well as at the close. Thus, the *U* test was employed to abnormal, standardized values of measures $\ln(V_{0,2})$ and $\ln(V_{0,3})$. *P*-values of the test, which are close to zero, suggest that compared distributions differ significantly (at a 1% level). Means and medians are greater in the first sample, related to the period before the pandemic, indicating that this anomaly really weakened after the outbreak of COVID-19. Similar results were obtained in reference to the volatility effect at the close on expiration day. Mean and median of the standardized, abnormal measure $SA|R_0^d|$ are lower in the second subperiod and the test confirms a significant difference between the distributions of the two compared samples.

In the case of the effect of price shock, the conducted Mann–Whitney *U* test does not give grounds to conclude that the strength of this effect changed significantly after the outbreak of the pandemic. The means and medians of both employed measures are slightly greater in the second sample, related to the data from 2020, but *p*-values of the test indicate that there are no differences between the compared distributions. Thus, it should be concluded that the strength of the price shock effect, occurring at the beginning of the session following expiration days, was comparable during the pandemic to its strength in previous years.

Table 8

Comparison of the strength of the expiration day effects between the period before the outbreak of the COVID-19 pandemic (2018–2019) and the initial phase of the pandemic (2020). The results of Mann–Whitney ***U*** test applied to abnormal, standardized measures of the effects

Measure	Subperiod 1		Subperiod 2		*p*-value
	mean	median	mean	median	
$SA\ln(V_{0,2})$	2.046	2.058	1.339	1.272	**0.000**
$SA\ln(V_{0,3})$	2.943	2.794	2.498	2.494	**0.005**
$SA\|R_0^d\|$	1.529	1.118	0.774	0.338	**0.000**
$SAPS_0^1[\%]$	0.463	0.056	0.554	0.172	0.305
$SAPS_0^2[\%]$	0.478	0.209	0.617	0.225	0.626

This table presents values of means and medians of abnormal, standardized measures of expiration day effects in two subperiods: January 2, 2018, through December 30, 2019 (Subperiod 1, results presented in the left part of the table) and January 2, 2020, through December 30, 2020 (Subperiod 2, results presented in the right part of the table). Only these measures which confirmed the occurrence of a given anomaly in both of the two analyzed subperiods were included in the table. Distributions of these measures' values were compared between the two subperiods with the use of nonparametric Mann–Whitney *U* test. *P*-values of the test are presented in the most-right column of the table. *P*-values smaller than 0.01 are in bold indicating that the compared distributions differ significantly at 1% level.

Concluding the results from the previous subsection and those from Table 8, hypothesis 7 should be regarded as partially true. It can only be unambiguously confirmed that the effects had weakened for the volume and volatility effects occurring on expiration day after the outbreak of the COVID-19 pandemic.

5. Summary and conclusions

In this study, the existence of expiration day effects of stock and index futures on the spot market of the Warsaw Stock Exchange was examined. Four types of anomalies, namely abnormal growth of trading volume of underlying stocks, significant increase in volatility of their prices, price reversal and price shock, were analyzed. To detect the effects and precisely determine the time of their occurrence, event study analysis was employed to high-frequency data.

According to the authors' knowledge, this study is the first to check the occurrence of expiration day effects on the Polish market in the period 2018–2020, as earlier studies in this area covered periods ending before or at most in 2017. As they confirmed the occurrence of the anomalies on the WSE, one of the important goals of this study was to check if the effects have been visible in recent years. Since the Polish stock market was classified by the FTSE Russell agency as a developed one in 2018, anomalies, which hit mostly developing markets, should disappear or at least weaken. As the research period covered the initial phase of the COVID-19 pandemic, the authors also checked if its outbreak in March 2020 had significantly influenced the strength of the detected expiration day effects. With this end in view, the research period was divided into two parts (January 2018 – December 2019, January 2020 – December 2020) and the Mann–Whitney *U* test was employed to compare distributions of the measures of anomalies between the two subperiods.

The results confirmed most of the hypotheses formulated in section 3.3. In the period 2018–2020 expiration day effects of futures still occurred on the spot market of the WSE. On expiration days, the trading volume of the underlying stocks increased unusually. This increase only occurred, however, during the time when final settlement prices of expiring derivatives were being formed, that is in the last hour of continuous trading as well as at the close and during overtime. Before the outbreak of the COVID-19 pandemic, an abnormal growth of trading volume was also detected two days before the expiration. This can be a sign of early unwinding arbitrage positions. Analogous results, indicating the existence of the volume effect on days directly before expiration were obtained by Suliga and Wójtowicz (2019) as well as by Gurgul and Suliga (2020) in reference to the period 2012–2017. However, in 2020, the volume effect was only detected on expiration days in the final part of trading session. The results suggest that with the development of the market, the time of the occurrence of this anomaly was shortened and narrowed to the time of the formation of derivatives' final prices.

The research also confirmed that the intraday volatility of stock prices is abnormally high on expiration days. The division of the research period into two parts allowed us to discover that before 2020 this anomaly, just as trading volume effect, appeared on expiration days during the last hours of continuous trading and at the close. However, in the initial period of the COVID-19 pandemic, the intraday volatility of underlying stocks was significantly higher than normally on expiration days only at the close and, additionally, at the beginning of the next trading session. Considering the difference in the procedure of calculating final prices of stock and index derivatives on WSE, it can be assumed that the increase in price volatility in 2020 resulting from the expiration of stock futures continued to occur on expiration days, while the effect of the increase in volatility associated with the expiration of index futures disappeared. This may stem from both the development of the WSE futures market and from the outbreak of the pandemic. In March 2020, when the risk of investing in leading stocks skyrocketed, futures market turnover (in particular, turnover of WIG20 future, the most popular derivative instrument on the WSE) increased significantly. This growth of hedging positions on the derivative market certainly reduced the importance of actions undertaken on expiration days by arbitrageurs and speculators with open positions in expiring index derivatives.

The research of price reversal confirmed that this effect is not a phenomenon which appears constantly after futures expiration. One of the two applied measures suggest the existence of this anomaly in the period 2018–2019 but there were no grounds to conclude this effect still occurred in the initial phase of the pandemic. However, the existence of price shock, understood as an abnormal difference between stock returns from expiration day and from the next day, was confirmed for the whole period under study, indicating that on expiration days stock prices are distorted but this distortion is very short-lived and they come back to their normal levels, reflecting intrinsic values, just at the beginning of the next trading session.

Comparison of the strength of the expiration day effects between the subperiods revealed that volume effect in the triple witching hour, as well as the volatility effect at the close on expiration days, weakened after the outbreak of the pandemic. However, they were still visible in 2020. Moreover, the Mann–Whitney *U* test conducted suggests that the strength of the price shock effect had not changed after the outbreak of COVID-19 pandemic.

To sum up, the study confirmed the occurrence of expiration day effects on the WSE. Although over the years and with the development of the market, some anomalies have weakened and their duration have been shortened, significant price distortion at the close of the trading session on expiration day have been still visible. Even during COVID-19 pandemic, when the importance of the activity hedgers in the futures market certainly increased, expiration of stock futures was associated with abnormal increase in volatility of underlying assets' prices. Many studies related to various foreign markets confirmed that if the final price of a derivative depends on a single value of underlying stock, expiration day effects are highly probable (see e.g. Hsieh, Ma, 2009; Xu, 2014). However, if this price is calculated as an average of many values, the anomalies are the weaker the longer is the time of price formation (see e.g. Kan, 2001; Chow et al., 2003; Fung, Yung, 2009). Would such a change in the procedure of calculating final settlement prices of stock futures on the WSE be desirable? This is a question that only the Polish

Financial Supervision Authority can answer. However, this research, as well as previous research on the expiration day effects on the Polish market, allows us to suppose that as long as the method of calculating final settlement prices of stock futures does not change, expiration effects will occur.

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Summary

This paper examines the existence of expiration day effects of stock and index derivatives on the Warsaw Stock Exchange. Event study analysis is employed to high-frequency data to check the occurrence of four types of anomalies: abnormal increase in trading volume and in intraday volatility of underlying stocks, price reversal and price shock. The study confirms that on expiration days trading volume of underlying stocks increase unusually during the time when final settlement prices of expiring futures are being calculated. Intraday volatility of stock prices is also abnormally high on expiration days. However, before 2020 this price effect occurred on expiration days during triple withing hour, while in the initial phase of COVID-19 pandemic it has been visible on expiration days only at the close and additionally at the beginning of the next trading session. The analysis of price reversal and price shock effects revealed that only the second anomaly is a phenomenon which constantly appears after futures expiration, indicating the distortion of stock prices on expiration days and their return to normal levels at the beginning of the next trading session. Division of the research period (2018-2020) into two parts allow to find out that after the outbreak of the pandemic, when the importance of hedgers' activity on the futures market have increased, some of the analyzed anomalies have weakened and their duration have been shortened. However, distortions of underlying stock prices have been still visible at the close of the trading session on expiration days. This suggests that as long as the final settlement prices of stock future are equal to closing prices of underlying stocks, expiration day effects will occur on the WSE.

JEL codes: C14, C32

Keywords: *COVID-19, event study, expiration day effects, futures market, high-frequency data, stock market, Warsaw Stock Exchange*