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PRICE DISCOVERY IN SINGLE-STOCK FUTURES: EVIDENCE FROM THE WARSAW STOCK EXCHANGE

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Purpose: The aim of the research is to assess the role of single-stock futures in the price discovery process on the Warsaw Stock Exchange**.** The paper seeks to determine whether the futures market contributes significantly to price discovery or if the spot market remains dominant.
Design/methodology/approach: The study employs a two-dimensional vector error correction model (VECM) to describe the dynamics of the relationship between cointegrated spot and futures prices. The analysis is conducted for single stock futures with the highest multiplier (1000) and for underlying stocks. Based on the model, both short-term and long-term causal relationships are analysed and the relative contribution of the spot and futures markets to price discovery is determined for each of the eight pairs of analysed assets separately.
Findings: The findings indicate that, on the WSE, the spot market generally plays a dominant role in the price discovery process, with an average contribution of 72.03%, compared to 27.97% for the single-stock futures market. Short- and long-term Granger causality tests confirmed that, in most cases, stock prices lead futures prices. This suggests that high leverage alone does not guarantee a strong price discovery role of futures.
Research limitations/implications: The research focuses on only eight single-stock futures classes, with the highest contract multiplier, which may not fully represent the broader market. Future research could expand the analysis by incorporating derivatives with lower multipliers as well as making a combined analysis of the prices of stocks, single-stock futures, and index futures.
Practical implications: The research highlights that, on the WSE, the spot market generally dominates the price discovery process. For investors in single-stock futures, this means that relying solely on futures market signals may not be sufficient for forecasting price movements. The study also indicates that high leverage does not guarantee a dominant role of futures in price discovery, which could influence trading strategies and risk management approaches. Economically, these findings can guide market participants in optimizing investment strategies and regulators in assessing the efficiency of the derivatives market.
Originality/value: The paper provides a detailed analysis of the price discovery role of single-stock futures on the WSE, an area with limited prior research. Unlike previous studies, it examines both short- and long-term causal relationships for selected high-multiplier futures contracts, offering new insights into market efficiency. The study is valuable for investors, traders, and regulators by clarifying the dominant role of the spot market and highlighting factors influencing futures market efficiency. It is particularly relevant for financial analysts,

policymakers, and market participants seeking to improve trading strategies and market oversight.
Keywords: price discovery, single-stock futures, Granger causality.
Category of the paper: Research paper.

1. Introduction

Every day, a vast amount of information flows into the stock market, significantly influencing trading behavior of investors and, consequently, the pricing of financial instruments. In a strong-form efficient market, all relevant information should be instantaneously reflected in asset prices (Fama, 1970). However, in markets exhibiting weak or semi-strong efficiency, the full absorption of new information into asset prices—referred to as price discovery—is a process that requires time.

Since financial futures serve as crucial hedging instruments for positions in the spot market, there are strong interdependencies between their prices and the prices of their underlying assets. As a result, the spot and futures markets influence each other. The arrival of new information triggers similar investor reactions in both markets, leading to comparable price movements in the underlying asset and its corresponding derivative. However, in the absence of strong informational efficiency, spot and futures price changes are not perfectly synchronized—one market absorbs new information more quickly than the other. A prior price change in either the underlying asset or its derivative thus signals an imminent adjustment in the other. Such relationships are commonly associated with Granger causality between spot and futures prices.

Examining the relationship between stock prices and their corresponding derivatives provides valuable insights for both investors and regulators overseeing market operations. First, such analyses help assess whether the futures market fulfills its price discovery function, thereby contributing to the efficiency of the spot market. Second, identifying systematic causal relationships between spot and futures prices enables the determination of which market plays a dominant role in the price discovery process. Consequently, observing price movements in the leading market can enhance investors' ability to forecast price changes in the other market, thereby facilitating the construction of more effective investment strategies.

Previous studies on mature, liquid markets indicate that the futures market typically plays a dominant role in price discovery (e.g., Alphonse, 2000; Covrig et al., 2004; Chou, Chung, 2006; Gaul, Theissen, 2008). One key factor contributing to the futures market's advantage in absorbing new information is the leverage effect. In futures contracts linked to large stock portfolios, even small changes in the underlying asset's price can lead to substantial fluctuations in the contract's value. This prompts futures investors to remain highly attentive and react immediately to significant market events. Additional characteristics of mature derivatives markets that reinforce their dominance in price discovery include low transaction costs, the absence of short-sale restrictions and the substantial presence of institutional investors (Bohl et al., 2011).

On most global markets, stock index futures are the most liquid financial derivatives. Consequently, the majority of prior research on price discovery has focused on the relationship between major stock indices and their corresponding futures contracts. Considerably fewer studies have examined the role of single-stock futures (SSF) in the price discovery process. To the best of the author's knowledge, the only study investigating single-stock futures listed on the Warsaw Stock Exchange (WSE) was conducted by Mutlu and Arik (2015). Their analysis, which also covered the Indian, Korean, and Russian markets, provided only general insights into the Polish SSF market. Based on a sample of 20 SSF classes and their corresponding stocks, the authors found that, on average, the Polish SSF market contributed approximately 40% to price discovery, while the spot market accounted for around 60%.

The aim of this article is to conduct a more detailed investigation into the role of single-stock futures in the price discovery process on the Warsaw Stock Exchange. To achieve this, both long-term and short-term causal relationships were analysed for selected stocks and corresponding futures contracts. Based on these findings, the relative contributions of the spot and futures markets to price discovery were determined for each of analysed asset pairs separately. Conducting such an analysis for all available SSF classes (over 40) would require an extensive presentation. Therefore, the study focuses on derivatives with the highest contract multiplier (1,000), as their contribution to price discovery process is expected to be particularly significant (cf. Aggarwal, Thomas, 2011).

2. Literature Review

2.1. Studies from Foreign Markets

There are numerous studies analyzing the price discovery function of financial futures. The majority of these studies focus on index futures. Their findings indicate that in case of mature derivatives markets, significant new information is generally reflected more quickly in index futures prices than in the prices of the corresponding indices. Such conclusions have been drawn, among others, for markets in the United States (e.g., Hasbrouck, 2003; Chou, Chung, 2006), France (Alphonse, 2000), Germany (Gaul, Theissen, 2008), the United Kingdom (Brook et al., 2001) and Japan (Covrig et al., 2004).

For emerging markets, conclusions regarding the extent to which index futures contribute to price discovery are less consistent and vary depending on the market analysed, the research period and the frequency of the data used (e.g., Min, Najand, 1999; Roope, Zurbruegg, 2002; Yang et al., 2012; Fassas, Siriopoulos, 2018; Chen et al., 2019, 2021).

Far fewer studies have examined the price discovery function of single-stock futures (SSF), as these derivatives are considerably less popular than index futures in most global markets. With regard to the Indian market, Kumar and Tse (2009) analysed the role of SSF in price discovery using high-frequency data from 2004. Their findings suggest that transactions in the Indian spot market contributed significantly more to price discovery than SSF transactions, with estimated contributions of 72% and 28%, respectively. Aggarwal and Thomas (2011) also studied the Indian SSF market and found that the role of SSF in price discovery increases with its relative liquidity compared to the spot market. Fung and Tse (2008) examined SSF in Hong Kong from August 2001 to June 2003, estimating the average contribution of SSF to price discovery at approximately 33%. Similar conclusions were reached for the Australian market by Lien and Yang (2003), who attributed the dominance of the spot market in price discovery during their research period (from contract inception to June 1998) to low SSF trading volumes. Furthermore, Lien and Yang (2003) found that switching from cash settlement to physical delivery increased information flow from the spot to the futures market.

On the Thai market, Songyoo (2012) analysed KTB single-stock futures (KTB is the national bank of Thailand) and their role in price discovery. Unlike the previously mentioned studies on Australia, India, and Hong Kong, Songyoo (2012) found that SSFs prices generally led the corresponding prices of KTB stocks. Using 10-minute data from September 12, 2011, to November 14, 2011, the study concluded that analysed SSFs played a dominant role in price discovery during this period.

2.2. Previous Studies on Price Discovery on the Warsaw Stock Exchange

Research on the role of the derivatives market in the price discovery process on the Warsaw Stock Exchange is relatively limited. Bohl et al. (2011) applied a two-dimensional VECM error correction model to analyze the relationship between the WIG20 index closing prices and WIG20 futures prices during the first ten years of the derivatives market's operation (1998-2008). The primary objective of their analysis was to assess the impact of investor structure on the derivatives market's contribution to price discovery. Until 2004, the market was dominated by individual investors—presumably less informed—who accounted for approximately 75-80% of trading volume. The authors checked that, during this period, the derivatives market did not effectively fulfill its price discovery function. Their study found no evidence of information flows from the futures market to the spot market, and the average contribution of WIG20 futures to price discovery was only 16%.

Starting in 2004, regulatory changes allowing investment funds to trade in futures contracts led to a gradual increase in institutional investor participation in futures market. By 2008, institutional investors still remained a minority, accounting for about 47% of total futures market volume. However, this shift in market structure contributed to a rise in the conditional correlation between spot and futures prices and increased the average contribution of the futures market to price discovery to approximately 35%. The VECM estimation results also confirmed the presence of bidirectional causality between the WIG20 index and corresponding futures contracts during 2004-2008, indicating that information was flowing in both directions.

Marcinkiewicz and Kompa (2013) also examined the causal relationship between the WIG20 index and corresponding futures. To identify both short- and long-term causality between spot and futures prices, they employed a vector autoregression (VAR) model and a two-dimensional VECM error correction model, depending on the properties of the analysed time series. Their analysis covered the period from July 1, 2008, to May 31, 2011, using both daily and intraday data (5-, 15-, and 30-minute intervals). Although they did not report full model estimation results, their study indicated that in the short term, Granger causality flowed from the futures market to the spot market, regardless of data frequency. For the highest-frequency data (5-minute intervals) throughout the sample period, as well as for 15-minute data from July 2008 to July 2009, bidirectional causality was observed.

In their discussion of long-term relationships, Marcinkiewicz and Kompa (2013) noted that in all four estimated VECM models, the error correction term was negative and statistically significant in the futures return equation. However, they incorrectly concluded that this implied long-term causality from the futures market to the spot market. In reality, their findings indicate that only futures prices responded to deviations from the long-term equilibrium relationship, meaning that the futures market adjusted to spot prices rather than leading them. This misinterpretation led them to overestimate the role of WIG20 futures in price discovery.

As mentioned earlier, the only study on single-stock futures role in price discovery on the WSE was conducted by Mutlu and Arik (2015). Their study covered four emerging markets—India, Korea, Poland, and Russia—using daily data from contract inception until August 15, 2014, and hourly data from April 1 to August 15, 2015. They modeled cointegrated spot and futures prices using a two-dimensional VECM. For the Polish market, the authors used a sample of 20 stock–futures pairs (stock quotes and quotes of futures on these stocks). Similar to Marcinkiewicz and Kompa (2013), the authors did not present the full estimation results of their models. Instead, based on results obtained for individual markets, they calculated and reported only the average relative shares of the futures and spot markets in price discovery, using formulas proposed by Eun and Sabherwal (2003). For the WSE, the share of the futures market in price discovery was found to be 40.22% for daily data and 38.15% for hourly data. These values indicate that, during the period under study, the spot market played a dominant role in price discovery on the WSE. The shares of the stock futures market in the price discovery process were similar in India and Korea. However, the Russian market exhibited a significantly different pattern, with stock futures accounting for as much as 77.18% of price discovery (based solely on daily data for this market). Mutlu and Arik (2015) attributed this difference to the fact that, among the four analysed markets, Russia was the only one where the trading volume of stock futures exceeded that of the underlying stocks.

To identify the factors significantly influencing the role of the futures market in price discovery, Mutlu and Arik (2015) additionally applied a multiple regression model. Their results confirmed the earlier observation that greater liquidity in the stock futures market relative to the spot market transfer to a higher contribution of futures to price discovery. Furthermore, their parameter estimation revealed a significant negative relationship between the turnover and market capitalization of the underlying stocks and the role of futures in price discovery. The study also confirmed the importance of the "age" of futures contracts: the longer a particular class of contracts had been listed on the market, the better it performed its price discovery function.

3. Data and Research Methodology

3.1. Data

This study utilizes daily closing stock prices of eight companies listed on the Warsaw Stock Exchange and the daily closing prices of corresponding single-stock futures. The list of companies and the characteristics of stocks and futures contracts are presented in Table 1. As mentioned earlier, only derivatives with the highest multiplier were included in the analysis, i.e., those where one contract represents one thousand shares of the company. This means that a 1-grosz change in the contract price translates to a change in its value of 10 PLN. The study covers the period from February 24, 2020, to the end of 2023. The beginning of the research period was set at the outbreak of the COVID-19[1] pandemic, as this marked a significant increase in investments in the derivatives market. The crisis triggered by the pandemic, characterized by sharp fluctuations in stock prices, attracted investors to futures markets as a tool for hedging open positions in the cash market. It is worth noting that in March 2020, the trading volume of single-stock futures on the WSE was nearly three times higher than in March of the previous year. Between 2020 and 2022, the annual trading volume of SSFs exceeded historical levels, only returning to pre-pandemic levels in 2023. Given this, it was assumed that from the onset of the COVID-19 pandemic, the role of SSFs in the price discovery process on the WSE may have increased significantly, making this period an appropriate focus for the study.

In Table 1, in addition to the full name and ticker symbol of each company, information is provided on the average closing price of both the stocks and the futures contracts during the period under study. Mutlu and Arik (2015) identified liquidity ratios of futures market relative

[1] Although the state of epidemic emergency in Poland was officially declared only on March 20, 2020, the impact of the global outbreak of COVID-19 on the Warsaw Stock Exchange became evident nearly a month earlier, on February 24. On that day, the WIG20 index recorded its first sharp decline, dropping by more than four percentage points, and continued its downward trend in the following days. For this reason, February 24, 2020, was chosen as the starting point of the study period.

to stock market and contract age as key factors influencing the role of derivatives in price discovery. Therefore, Table 1 also includes the launch dates of the respective futures contracts and the average relative trading volume, calculated as the ratio of the daily futures trading volume (multiplied by the contract multiplier of 1000) to the daily trading volume of the corresponding stocks. These details will help determine whether the analysed companies exhibit similar dependencies to those identified by Mutlu and Arik (2015).

Table 1.
Characteristics of stocks and futures included in the study (24.02.2020 – 31.12.2023)

Name of the company	Ticker symbol of stocks	Average closing price of stocks (zł)	Ticker symbol of SSFs	Average closing price of SSFs (zł)	Launch date of SSFs	Average relative trading volume (%)
CI Games[2]	CIG	2.24	FCIG	2.26	8.04.2019	1.11
Enea	ENA	7.46	FENA	7.53	3.12.2015	5.89
Bank Millennium	MIL	4.96	FMIL	4.98	3.12.2015	3.04
Orange Polska	OPL	6.99	FOPL	7.03	24.06.2013	4.76
PGE Polska Grupa Energetyczna	PGE	7.56	FPGE	7.55	22.03.2010	6.05
Polimex Mostostal	PXM	3.81	FPXM	3.87	20.03.2017	1.99
Synthaverse	SVE	7.24	FSVE	7.06	5.10.2020	3.17
Tauron Polska Energia	TPE	2.71	FTPE	2.73	20.12.2010	5.76

Source: own elaboration.

Since 2002, the expiration months for single stock futures (as well as index futures) on the WSE have followed a quarterly cycle: the three nearest months from the March cycle (March, June, September, and December). New contract series are introduced into trading nine months before expiration, which falls on the third Friday of the expiration month (or the preceding trading day in case of a public holiday). At any given time, three consecutive series of stock futures of the same class are available on the market, with the most liquid being the one closest to expiration. Consequently, the time series of daily closing prices for the single stock futures used in this study consists of the daily closing prices of the nearest-to-expiry contract series. Data from expiration days were omitted, as previous research by Suliga (2020, 2021, 2023) has shown that stock prices (and consequently, the prices of their corresponding futures contracts) tend to be distorted due to expiration-day effects. To conduct the study, closing prices of stocks S_t and corresponding single-stock futures F_t were logarithmized: $s_t = \ln(S_t), f_t = \ln(F_t)$. Symbols $\Delta s_t = s_t - s_{t-1}$ and $\Delta f_t = f_t - f_{t-1}$ denote daily logarithmic returns of stocks and futures, respectively.

3.2. Methodology

According to financial theory, the fair price of a futures contract should be given by:

$$F_t = S_t e^{(r-d)(T-t)}, \tag{1}$$

[2] As of February 29, 2024, the Management Board of the Warsaw Stock Exchange indefinitely suspended the introduction of new series of futures contracts on CI GAMES stocks into trading.

where r is the risk-free rate, $d$is the dividend yield, and $T - t$ is the time remaining until contract expiration. Arbitrage activity reinforces the relationship between spot and futures prices, ensuring that market prices of futures contracts do not significantly deviate from their theoretical values.

In econometric models, relationship described by equation (1) is often simplified by disregarding dividend yield, time to expiration, and time-varying returns, assuming instead that the time series of natural logarithms of prices f_t and s_t are cointegrated of order (1,1), with the cointegrating relation expressed as:

$$f_t = \beta_0 + \beta_1 s_t + ec_t. \tag{2}$$

This implies that while time series of f_t and s_t are non-stationary, their first differences $\Delta s_t, \Delta f_t$ are stationary, and a stationary linear combination exists ec_t=$f_t - \beta_0 - \beta_1 s_t$, known as the error correction term. The vector $[1, -\beta_0, -\beta_1]$ is referred to as the cointegrating vector.

The dynamics of the relationship between these cointegrated spot and futures prices can be modeled using a bivariate vector error correction model (VECM):

$$\Delta s_t = \mu_s + \alpha_s ec_{t-1} + \sum_{j=1}^{p} \gamma_{ss,j} \Delta s_{t-j} + \sum_{j=1}^{p} \gamma_{sf,j} \Delta f_{t-j} + \varepsilon_{s,t} \tag{3}$$

$$\Delta f_t = \mu_f + \alpha_f ec_{t-1} + \sum_{j=1}^{p} \gamma_{fs,j} \Delta s_{t-j} + \sum_{j=1}^{p} \gamma_{ff,j} \Delta f_{t-j} + \varepsilon_{f,t}. \tag{4}$$

In general, an n-dimensional VECM model can be expressed in matrix form as:

$$\Delta Y_t = \mu + \Pi Y_{t-1} + \sum_{j=1}^{p} \Pi_j \Delta Y_{t-j} + \varepsilon_t, \tag{5}$$

where Π is the error-correction matrix which captures the long-term equilibrium relationships, and Π_j are coefficient matrices capturing short-term dynamics. The Johansen test (Johansen, 1991, 1992) is employed to determine the rank of cointegration (the number of cointegrating relations between n variables). The test is based on two statistics:

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{n} \ln(1 - \lambda_i), \tag{6}$$

$$\lambda_{max}(r) = -T \ln(1 - \lambda_{r+1}), \tag{7}$$

where λ_i are the eigenvalues of Π, ordered in ascending order. The $\lambda_{trace}(r)$ statistic tests the null hypothesis that the number of cointegrating vectors is at most r against the alternative hypothesis that there are more of them. $\lambda_{max}(r)$ statistic tests the null hypothesis that there are exactly r cointegrating vectors against the alternative hypothesis that the number of cointegrating vectors is equal to $r + 1$.

For the bivariate VECM model used in this study, expressed by formulas (3) and (4), at most one cointegrating vector can exist. Thus, conducting the Johansen test aims to confirm whether stock and futures prices are indeed cointegrated of order (1,1).

Applying the VECM model to spot and futures prices enables an examination of both short-term and long-term causal relationships. The error correction terms α_s, α_f in the equations (3) and (4) measure how prices adjust to deviations from the long-run equilibrium described by equation (2). If α_s is significantly different from zero, it indicates that stock prices respond to restore equilibrium, whereas a significant α_f suggests that futures prices adjust instead. If only one of these coefficients is significant, information flows in one direction, implying that, in a long-run aspect, either the spot or futures market leads in price discovery.

Short-term dependencies between stocks and futures prices are analysed using the estimated coefficients $\gamma_{sf,j}$ and $\gamma_{fs,j}$. Finally, $\gamma_{ss,j}$ ($\gamma_{ff,j}$) coefficients indicate the relationship between spot (futures) prices and their past values. The optimal lag order j is determined using the Schwarz Bayesian Information Criterion (BIC).

Based on the estimated parameter values of the VECM model, the Granger causality test between spot and futures prices can be conducted. This causality may be observed in both long-term relationships (measured by coefficients α_s, α_f) and short-term dependencies (expressed by the lagged values of coefficients $\gamma_{sf,j}, \gamma_{fs,j}$). The analysis of Granger causality from spot prices to futures prices requires the verification of the following hypotheses:

$$H_{01}: \alpha_f = 0 \; and \; H_{02}: \gamma_{fs,1} = \gamma_{fs,2} = \cdots = \gamma_{fs,p} = 0. \tag{8}$$

Rejecting at least one of these hypotheses would indicate that spot prices are a Granger cause for futures prices, suggesting that the spot market plays a significant role in price discovery. Similarly, examining causality from futures prices to stock prices involves testing the validity of the following hypotheses:

$$H_{03}: \alpha_s = 0 \; and \; H_{04}: \gamma_{sf,1} = \gamma_{sf,2} = \cdots = \gamma_{sf,p} = 0. \tag{9}$$

Detecting bidirectional causality would signal that both the spot and futures markets contribute significantly to the price discovery process. To test hypotheses H_{01} and H_{03}, it is sufficient to apply the significance t −test for coefficients α_f, α_s . This test can also be used for hypotheses H_{02} and H_{04} if the lag order is $p = 1$. In the case of $p > 1$, these hypotheses can be tested using the Wald restriction test (Witkowska et al., 2008, p. 146).

In addition to conducting the Granger causality test, to determine the average contribution of both markets to the price discovery process, measures based on the values of coefficients α_s, α_f will be calculated. The measures proposed by Schwarz and Szakmary (1994) have been subsequently used in other studies on this topic (e.g., Bohl et al., 2011; Mutlu, Arik, 2015; Fassas, Siriopoulos, 2019):

$$\theta_f = \frac{|\alpha_s|}{|\alpha_s| + |\alpha_f|}, \tag{10}$$

$$\theta_s = 1 - \theta_f = \frac{|\alpha_f|}{|\alpha_s| + |\alpha_f|}. \tag{11}$$

If price discovery occurs exclusively in the spot market, only the futures market would react to disturbances from the long-term equilibrium relationship (2). Out of the two coefficients α_s, α_f, only the latter would be different from zero, leading to a value of $\theta_f = 0$. Conversely, if only α_s was nonzero, then θ_f would be equal to 1. The values of the coefficients defined by equations (10) and (11) thus indicate the average percentage contribution of each market to the price discovery process.

4. Empirical Results

In the first step of the study, the ADF test was used to examine the stationarity of time series for logarithmic stock and futures prices as well as logarithmic returns. The ADF test verifies the null hypothesis of a unit root (non-stationarity) against the alternative that the analysed series is stationary. The obtained test statistics are presented in Table 2. Assuming a significance level of 0.05, it was determined that all considered price series s_t and f_t are non-stationary, whereas logarithmic return series for stocks and indices are stationary. Thus, stock and futures prices are first-order integrated series (I(1)).

To check whether the price series are cointegrated of order (1,1), the Johansen test was conducted at a 0.05 significance level. The test statistics $\lambda_{trace}(r)$ and $\lambda_{max}(r)$ obtained for $r = 0$ i $r = 1$ respectively, as well as cointegrating vectors for each pair of instruments are presented in Table 3. These results confirm significant cointegration for each of the eight examined pairs, justifying the estimation of two-dimensional VECM models defined by equations (3) and (4).

Table 2.
ADF test statistics for logarithmic prices and logarithmic returns of stocks and futures

company	s_t	f_t	Δs_t	Δf_t
CIG	-1.76	-1.74	-31.20***	-31.90***
ENA	-2.18	-2.15	-28.90***	-28.51***
MIL	-1.10	-1.08	-30.10***	-30.00***
OPL	-2.64*	-2.54	-30.10***	-28.90***
PGE	-2.24	-2.02	-29.00***	-29.50***
PXM	-2.09	-2.11	-29.50***	-28.50***
SVE	-2.33	-2.33	-28.50***	-28.50***
TPE	-2.14	-2.12	-28.10***	-27.80***

Note. Symbols: *** and * indicate statistical significance at 0.01 and 0.1 levels, respectively.

Source: own calculations.

Table 3.
Johansen cointegration test results

Company	λ_{trace}		λ_{max}		Coordinates of cointegrating vector $[1, -\beta_0, -\beta_1]$	
	$H_0: r = 0$	$H_0: r \leq 1$	$H_0: r = 0$	$H_0: r = 1$	β_0	β_1
CIG	155,45***	4,22	151,23***	4,22	0,0007	1,0105***
ENA	232,57***	5,82	226,75***	5,82	0,0420***	0,9842***
MIL	345,18***	1,42	343,76***	1,42	0,0149***	0,9932***
OPL	133,78***	7,54*	126,25***	7,54*	0,0103***	0,9981***
PGE	29,91***	4,93	24,98***	4,93	-0,1895***	1,0928***
PXM	269,96***	5,00	264,96***	5,00	0,0281***	0,9913***
SVE	71,59***	7,36	64,23***	7,36	0,0482***	0,9640***
TPE	153,93***	6,64	147,29***	6,64	0,0056***	1,0005***

Note. Symbols: *** and * indicate statistical significance at 0.01 and 0.1 levels, respectively.

Source: own calculations.

The estimated VECM model parameters are presented in Table 4. In each case, the Schwarz Bayesian information criterion indicated the optimal lag order selection $p = 1$.

Table 4.
Estimated VECM model parameters

Company	Estimated values of parametres							
	μ_s	α_s	$\gamma_{ss,1}$	$\gamma_{sf,1}$	μ_f	α_f	$\gamma_{ff,1}$	$\gamma_{fs,1}$
CIG	0.001	0.174***	0.090*	-0.082	0.001	-0.191***	-0.156***	0.185***
ENA	-0.005	0.139	0.037	0.059	0.019***	-0.445***	-0.068	0.170**
MIL	0.002	-0.089	0.144	-0.133	0.013***	-0.846***	-0.084	0.095
OPL	-0.001	0.127	-0.002	0.047	0.002**	-0.226**	-0.193**	0.282***
PGE	0.009**	0.043*	0.070	0.008	-0.001	-0.010	-0.139**	0.204***
PXM	-0.003	0.124*	0.124**	-0.057	0.015***	-0.501***	-0.047	0.189***
SVE	-0.002	0.002	0.012	-0.019	0.007***	-0.180***	-0.204***	0.268***
TPE	0.021	0.001	-0.146	0.258*	-0.385***	0.003**	0.020	0.097

Note. Symbols ***, **, * indicate significance at 0.01, 0.05, and 0.1 levels, respectively.

Source: own calculations.

The obtained values of coefficient $\gamma_{ss,1}$, relating to lagged changes in stock returns, are significantly different from zero (at 0.1 and 0.05 levels, respectively) only for two of the eight analysed companies. The positive values of these coefficients suggest that price trends in the stock quotes of CIG and PXM tend to persist over time. In contrast, the corresponding coefficients in the equations describing futures returns ($\gamma_{ff,1}$), except for one case, are negative, and four of them are significantly different from zero at the 0.05 level. This indicates that, unlike stock prices, at least some of futures prices exhibit a mean-reversion effect.

The analysis of coefficients $\gamma_{sf,1}$ and $\gamma_{fs,1}$allows for determining the nature of short-term dependencies between spot and futures prices. Since in each model, the lag order $p = 1$, verifying hypotheses H_{02} and H_{04} only requires assessing the significance of coefficients $\gamma_{sf,1}, \gamma_{fs,1}$. The values of $\gamma_{sf,1}$, presented in the left part of Table 4 are mostly not significantly different from zero. Only for TPE, a positive and significant coefficient at the 0.1 level was obtained, providing weak evidence that futures prices may be a Granger cause for stock prices in the short term. All estimated values of coefficient $\gamma_{fs,1}$, presented in the last column of Table 4, are positive, and for six of them, significance tests confirm that they are different from zero at the 0.05 level. This indicates that for all companies except MIL and TPE, significant information flow from the spot market to the futures market was observed in the analysed period, meaning stock prices were a Granger cause for futures prices.

Considering the obtained values of coefficient α_s, it should be stated that only in the case of CIG are there strong indications suggesting that significant stock price adjustments occur in response to long-term equilibrium disruptions between stock and futures prices, as described by equation (2). The coefficient α_s is positive, and its significance test confirms that it is different from zero at the 0.01 level. Among the remaining values of this coefficient, only those for PGE and PXM are significantly different from zero, but only at the 0.1 level. These results suggest potential long-term causal relationships from futures prices to stock prices for these two companies as well. For the remaining companies, the obtained values of coefficient α_s do not differ significantly from zero, indicating that their stock prices do not exhibit significant reactions to deviations from their long-term equilibrium with futures prices. This suggests that for ENA, MIL, OPL, SVE, and TPE, no significant long-term information flow from the futures market to the spot market was observed in the analysed period.

The obtained values of coefficient α_f, presented in the right section of Table 4, are mostly negative (with the exception of TPE). Apart from the value obtained for PGE, they are significantly different from zero at the 0.05 or 0.01 level. This indicates that for seven out of the eight analysed companies, there is strong evidence of significant causality from the spot market to the futures market. When a long-term equilibrium disturbance occurs between stock prices and their corresponding futures prices, the price adjustment is primarily observed in the futures market. Generally, stock prices respond more quickly to new market information, while futures prices follow them.

The results described above indicate that long-term causality for most analysed companies flows from spot prices to futures prices. The exceptions in this context are CIG, PGE, and PXM. In the case of CIG and PXM, bidirectional causality is observed. However, for PXM, as previously mentioned, there is only weak evidence supporting the existence of causality from futures prices to spot prices. For PGE, there is no basis for determining causality from stock prices to futures prices; however, a causal relationship in the opposite direction may exist (α_f is not significantly different from zero, while α_s is significantly different from zero only at the 0.1 significance level).

It is also worth noting that, for most companies (7 out of 8), the obtained values of coefficient α_s are greater than zero, whereas coefficients α_f are less than zero. A positive α_s and a negative α_f align with the standard market reaction mechanisms to long-term equilibrium disturbances. A positive ec_t value suggests that the futures price is overvalued relative to the spot price. As noted by Bohl et al. (2011), in such cases, arbitrageurs take short positions in the derivatives market and long positions in the spot market, leading to a decline in futures prices and an increase in stock prices ($\Delta f_t < 0, \Delta s_t > 0$). Conversely, when $ec_t < 0$, meaning that stock prices are overvalued relative to futures prices, arbitrageurs take the opposite positions in both markets, resulting in rising futures prices and declining stock prices ($\Delta f_t > 0, \Delta s_t < 0$). In both cases, there is a negative relationship between futures price changes Δf_t and ec_t ($\alpha_f < 0$), and a positive relationship between stock price changes Δs_t and ec_t ($\alpha_s > 0$).

The detected Granger causal relationships between spot and futures prices are summarized in Table 5. The two columns in the left section of the table list long-term relationships flowing from the spot market to the futures market (column $s_t \dashrightarrow f_t$) and in the opposite direction (column $f_t \dashrightarrow s_t$). Each identified relationship is also marked with its level of significance. Similar information regarding short-term relationships (or their absence) is included in the right section of the table. This summary clearly shows that in both short- and long-term relationships, the spot market dominates the price discovery process, as the vast majority of detected causal relationships flow from spot prices to futures prices.

Table 5.

Detected Granger causal relationships

Company	Long-term causality		Short-term causality	
	$s_t \dashrightarrow f_t$	$f_t \dashrightarrow s_t$	$s_t \dashrightarrow f_t$	$f_t \dashrightarrow s_t$
CIG	CIG ⟶ FCIG***	FCIG ⟶ CIG***	CIG ⟶ FCIG***	none
ENA	ENA ⟶ FENA***	none	ENA ⟶ FENA**	none
MIL	MIL ⟶ FMIL***	none	none	none
OPL	OPL ⟶ FOPL**	none	OPL ⟶ FOPL***	none
PGE	none	FPGE ⟶ PGE*	PGE ⟶ FPGE***	none
PXM	PXM ⟶ FPXM***	FPXM ⟶ PXM*	PXM ⟶ FPXM***	none
SVE	SVE ⟶ FSVE***	none	SVE ⟶ FSVE***	none
TPE	TPE ⟶ FTPE**	none	none	FTPE ⟶ TPE*

Note. Symbols ***, *, and * indicate statistical significance at the 0.01, 0.05, and 0.1 levels, respectively.

Source: own calculations.

The above results are consistent with findings from other emerging markets. Similar conclusions, indicating the dominance of the spot market in the price discovery process, were reached by Lien and Yang (2003) in their analysis of the Australian market, Kumar and Tse (2009) in their study of the Indian market, and Fung and Tse (2008) regarding the Hong Kong market. Lien and Yang (2003) further associate the lack of information flow from the futures market to the spot market with the relatively low trading intensity of futures contracts compared to the stock market. They write that during the period under study daily average trading volume ratio of the individual stock to its futures varies from 150 to 2000 across the companies being analysed. The data presented in the last column of Table 1 indicate slightly higher, yet still very low, investor activity in the Polish SSF market compared to the corresponding stock market. The average relative daily trading volume ranges from 1.11% for CIG to 6.05% for PGE. This means that, on average, the daily trading volume of stocks is several dozen times higher than that of their corresponding single-stock futures, which, according to Mutlu and Arik (2015), may be a key factor contributing to the dominance of the spot market in price discovery. Similar conclusions were also reached by Fung and Tse (2008) regarding the Hong Kong market who write, that it is very likely that SSF market would dominate the price discovery process if comparable trading volumes on both, spot and futures markets were reached. Also Aggarwal and Thomas (2011) in Indian market find that the SSF market dominates price discovery only for the highly liquid securities.

In the final step of the study, to determine the average contribution of the stock and futures markets to the price discovery process, the measures θ_s and θ_f defined by equations (10) and (11) were calculated for each of the eight analysed stock–futures pairs (s_t, f_t). It should be noted that these measures rely solely on the values of α_s, α_f, and therefore reflect the contribution of each market to price discovery only in terms of adjusting deviations from the long-term equilibrium relationship between spot and futures prices. The obtained values of the measures are presented in Table 6.

Table 6.
Contribution of stock and futures market to price discovery

Company	$\boldsymbol{\theta_s}$ (%)	$\boldsymbol{\theta_f}$ (%)
CIG	52,30	47,70
ENA	76,19	23,81
MIL	90,50	9,50
OPL	63,93	36,07
PGE	19,14	80,86
PXM	80,20	19,80
SVE	99,16	0,84
TPE	94,81	5,19
average	72,03	27,97

Source: own calculations.

The highest values of θ_s, exceeding 90%, were obtained for MIL, SVE, and TPE. This indicates that the price discovery process for these stocks and their corresponding futures contracts occurs almost exclusively in the spot market. For the remaining five companies, in four cases values of θ_s exceed 50%, also suggesting that the spot market dominates in price discovery. Therefore, despite all of the analysed derivatives represent one thousand shares of the company, the high leverage effect characterising these futures does not translate into a dominant role of futures market in price discovery.

The only company for which significantly different results were obtained is PGE. The value of the measure θ_s for this stock is only 19.14%, while θ_f is 80.86%. This means that PGE Polska Grupa Energetyczna is the only company for which the futures market plays the dominant role in price discovery. What distinguishes this company from the others? Returning to the data in Table 1, it can be observed that, although the daily trading volume of PGE stocks is, on average, approximately 16.5 times higher than that of its corresponding single-stock futures, PGE still has the highest average daily relative trading volume among all the companies included in the study. As previously mentioned, citing the results of studies conducted on other emerging markets (Lien, Yang, 2003; Fung, Tse, 2008; Aggarwal, Thomas, 2011; Mutlu, Arik, 2015), this may be a key factor influencing the high contribution of the PGE futures market to price discovery.

Moreover, data in Table 1 indicate that PGE had also the highest average closing price of both stocks and futures and that SSFs on PGE stocks are the longest-listed stock futures among the eight analysed. Thus, PGE exhibits the characteristics that Mutlu and Arik (2015) identified as having a significant positive impact on the futures market's price discovery role. Additionally, it is worth noting that PGE was the only analysed company that was continuously included in the WIG20 index throughout the period under study. WIG20 futures are the most liquid instruments on the WSE derivatives market, which increases the chance for a significant participation of the futures market in the price discovery process in case of companies included in this index.

The average values of θ_s and θ_f, presented in the last row of Table 6, suggest that, on average, the spot market played the dominant role in price discovery process for the analysed stocks and futures contracts. This conclusion aligns with the findings of Mutlu and Arik (2015) regarding the Polish market. It is also worth noting that Kumar and Tse (2009) obtained nearly identical values for the relative contribution of both markets to the price discovery process—72% for the stock market and 28% for the futures market—when analyzing the Indian market based on one-minute stock returns and their corresponding single-stock futures (SSF) contracts. A slightly higher contribution of the SSF market to price discovery (37%) was found by Fung and Tse (2008) in the Hong Kong market. These findings suggest that the Polish SSF market does not differ significantly in terms of its role in price discovery from other emerging markets that have been studied in this regard.

5. Summary and conclusions

The study presents the results of an analysis of the price discovery process on the Warsaw Stock Exchange, based on an examination of short- and long-term causal relationships between the stock prices of selected companies and the prices of their corresponding single-stock futures. Among the more than forty classes of SSFs available on the WSE derivatives market, the study included those with the highest multiplier (1000). This selection aimed to determine whether the strong leverage effect translates into a significant contribution of derivatives to price discovery in the market. The starting point of the study period was set at the outbreak of the COVID-19 pandemic. Given that a significant increase in stock futures trading volume was recorded during the pandemic compared to previous years, it was assumed that the outbreak of the pandemic could have led to a substantial increase in the share of the derivatives market in price discovery, thereby strengthening its price discovery function. Contrary to these assumptions, obtained results do not confirm that the stock futures market had a significant contribution to the price discovery process during and after the pandemic

In general, the results are in line with the conclusions formulated for several other SSFs markets (e.g. Lien, Yang, 2003; Fung, Tse, 2008; Kumar, Tse, 2009) and with those phrased for the Polish single-stock futures market by Mutlu and Arik (2015). In both short- and long-term causal relationships, in most cases, spot prices are the Granger cause of futures prices (similar results, but referring to the WIG20 index and futures contracts on this index, were also obtained by Bohl et al. (2011) and Marcinkiewicz and Kompa (2013)). In the case of short-term relationships, a significant information flow from the spot market to the futures market was confirmed for six out of the eight analysed instrument pairs. As for causality in the opposite direction, weak indications suggesting the possible existence of such relationships were found only for the stocks of TPE and the futures contracts on these stocks. Also in long-term causal relationships the spot market was identified as the dominant one in price discovery. For seven out of the eight companies, it was confirmed that in moments of disruption to the long-term equilibrium relationship between stock and futures prices, price adjustments occur in the derivatives market. Only in the case of three companies was causality in the opposite direction also detected.

The calculated values of the measures of markets relative contribution to the price discovery process also indicate that, on average, the spot market plays a dominant role in this process. The share of the stock market amounted to 72.03%, compared to a 27.97% share of the futures market. Thus, in general, it can be stated that despite the strong leverage effect characterising the analysed classes of SSFs, the prices of their corresponding stocks exhibit a faster reaction to new market information, while futures prices follow them. The conducted study allows for the conclusion that a high multiplier does not guarantee that the futures market will take over the price discovery function from the stock market. As shown by Mutlu and Arik (2015), there are other significant factors influencing the extent of the derivatives market's participation in price discovery, whose importance may be much greater.

In the conducted study, the dominance of the futures market in price discovery was found only in the case of PGE, a company that, during the analysed period, was characterized by the highest average closing price of both stocks and futures, the highest average relative trading volume, and the longest-listed futures contracts on the market. All these characteristics were identified by Mutlu and Arik (2015) as factors that positively influence the proper fulfilment of the price discovery function by the futures market. Moreover, throughout the entire period under study, PGE was the only company among those analysed that was included in the WIG20 index. Futures contracts on WIG20 are the most liquid instrument on the Warsaw Stock Exchange derivatives market, thus the company's inclusion in the index may also contribute to an increased share of the derivatives market in the price discovery and, in this context, may be more significant than the strong leverage effect.

The conducted research yields several practical conclusions. Firstly, the findings indicate that, on average, single-stock futures market plays only a minor role in price discovery. This is a crucial insight for regulatory bodies overseeing both the spot and derivatives markets, suggesting that for the SSF market to fulfill its price discovery function effectively, further development is necessary. The dominance of the spot market in price discovery also implies the need for regulators to monitor information absorption asymmetry to identify potential disruptions in this process.

The results of the study also provide valuable insights for investors. In particular, they reveal that the high leverage of SSFs does not confer an informational advantage to the derivatives market over the stock market. Therefore, investors should exercise caution when using SSF prices for predictive purposes, closely tracking price movements in the underlying stocks, which typically react more swiftly to new market information than futures. Furthermore, the detection of bidirectional causality between spot and futures prices for some of the companies under study allows for a broader conclusion: when allocating capital to high-multiplier stock futures or their corresponding equities, investors should closely monitor price changes in both markets. Observing price movements in one market may enhance the accuracy of price forecasts in the other, thereby enabling the construction of more effective investment strategies.

Based on the presented research findings, one should not hastily conclude that the WSE derivatives market fails to fulfill its price discovery function effectively. While, as mentioned in the introduction, previous studies on foreign markets indicate that in mature and liquid markets, the futures market takes over the price discovery function from the spot market, nearly all of these studies focus on stock index futures rather than single-stock futures. During the analysed period of 2020-2023, an average of 90.3% of the annual turnover in the WSE derivatives market was generated by WIG20 index futures, whereas single-stock futures accounted for only 5.2% of total derivatives trading. This suggests that the futures market's role in price discovery may be significantly greater for WIG20 constituent stocks than for stocks outside the index. Although studies conducted by Bohl et al. (2011) and Marcinkiewicz and Kompa (2013) found that the influence of the index market on the futures market is stronger than the reverse causal relationship, the WSE derivatives market has undergone significant development since their research. Consequently, the conclusions they formulated may no longer be valid.

Thus, to determine unequivocally whether, despite the significant development of the index futures and SSFs market on the Warsaw Stock Exchange, the spot market still plays a dominant role in the price discovery process, further research in this area is necessary. First, it would be valuable to expand the study to include more classes of stock futures, incorporating derivatives with a lower multiplier into the analysis. Second, a re-examination of the causal relationships between the WIG20 index and WIG20 futures, focusing on recent years, should also be conducted. Finally, interesting conclusions could be drawn from a combined analysis of the causal relationships between stock prices of the companies listed in the WIG20 index, the prices of SSFs on these stocks, and the price of WIG20 index futures.

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