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Review

Market Manipulation in Stock and Power Markets: A Study of Indicator-Based Monitoring and Regulatory Challenges

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Abstract: In recent years, algorithmic-based market manipulation in stock and power markets has considerably increased, and it is difficult to identify all such manipulation cases. This causes serious challenges for market regulators. This work highlights and lists various aspects of the monitoring of stock and power markets, using as test cases the regulatory agencies and regulatory policies in diverse regions, including Hong Kong, the United Kingdom, the United States and the European Union. Reported cases of market manipulations in the regions are examined. In order to help establish a relevant digital regulatory system, this work reviews and categorizes the indicators used to monitor the stock and power markets, and provides an in-depth analysis of the relationship between the indicators and market manipulation. This study specifically compiles a set of 10 indicators for detecting manipulation in the stock market, utilizing the perspectives of return rate, liquidity, volatility, market sentiment, closing price and firm governance. Additionally, 15 indicators are identified for detecting manipulation in the power market, utilizing the perspectives of market power (also known as pricing power or market structure), market conduct and market performance. Finally, the study elaborates on the current challenges in the regulation of stock and power markets in terms of parameter performance, data availability and technical requirements.

Keywords: market manipulation; stock markets; power markets; market monitoring; indicators; market power

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1. Introduction

1.1. Reasons and Importance of Monitoring the Stock and Power Markets

The stock and power markets, as global markets with significant annual trading volumes, represent two major pillars in the market structure worldwide. Electricity is one of the most versatile sources of energy in the world, and thus, it plays an essential role in the progress and development of human society. According to a survey analysis by Statista [1], the global electricity trading volume in 2018 was 2339 billion kWh, with an increase of 2.6% compared to 2013. Fair cost allocation among users and peer-to-peer trading can help incentivize coordination between the owners of large-scale and small-scale power resources at different levels of power systems [2,3]. Meanwhile, another survey analysis by Statista [4] showed that, in the first quarter of 2021, global equity trading totaled USD 40.3 trillion, an increase of 101.6% over the same period in 2017. It should be noted that the stock market is one of the most fundamental financial markets and has been active for a long time [5–8]. Thus, as these markets deal with such a large amount of money and people, it is important to ensure that they are fairly and properly operated.

However, the open and liberalized nature of markets make it possible to face unethical attempts to gain unfair benefits through market manipulation. For this reason, any country hosting large-volume markets has its dedicated regulator institution, which is responsible for market regulation (in Section 2) and allows the markets to operate properly in a fair, orderly and reliable environment.

Recent years have encountered an increasing use of APIs (Application Programming Interfaces) acting on the market (both the stock market and the power market). APIs are application interfaces created to meet the increasingly large scale of software in recent years and are also a convention for the interface of different components of the software system. APIs allow different software applications to be linked together in a lightweight way, allowing quick access to data from other platforms, and also allowing third-party openers to build on top of existing products and services. According to [9], the use of APIs reached 52% of the volume on the Nord Pool power exchange's intraday markets in July 2019, compared to only 13% of total transactions using APIs in the same month in 2018. Nord Pool [10] is one of the largest electricity trading markets in the world, operating in numerous countries, such as Sweden, Norway, Finland, the UK and Estonia. More than 90% of the total electricity consumption in the Nordic region is traded through Nord Pool. Similarly, APIs occupy a high position in the stock market. According to [11], a large number of APIs are active in the stock market permanently. There is large consensus among experts that, with the rapid progress of Artificial Intelligence (AI), machine learning-based APIs may soon have a massive impact on orderly running markets and may even potentially pose a threat to equity and order in the stock and power markets. Aliabadi et al. [12] and Liang et al. [13] show that advanced pricing algorithms may, even unintentionally, create collusion cases for power-generating companies. Mizuta [14] pointed out that if an AI replaces a human as a market trader, its behavior would affect the market price and, due to its strong learning capability, it may learn how to manipulate the market.

Indeed, it seems that the development of algorithmic manipulation is already 'stimulating' the growth of market manipulation [15–17]. Cases of algorithmic manipulation derived by APIs use have been frequently reported in the stock and power markets [18]. Algorithmic trading is the pre-programming of code based on rules or developer's tendencies, which immediately execute a buy or sell object to complete a market operation when current market conditions meet pre-defined conditions [19,20]. In recent years, nearly 70% of the total trading volume in developed stock markets comes from algorithmic trading based on learning algorithms [18], such as Q-learning [21], Genetic algorithms (GA) [22] and Long Short Term Memory (LSTM) [23]. In the US, algorithmic trading accounted for approximately 60–73% of the total equity trading in 2018 [19]. According to [24], the total algorithmic trading market is expected to reach USD 18.8 billion by 2024. The advantages of algorithmic trading include accuracy in determining the current state of the market, automatic order processing, high-speed order processing [25], high-speed data retrieval and decision making, and, most importantly, the ability of trading algorithms to process orders without being influenced by human emotions, ultimately increasing profitability [24]. The advent of algorithmic trading has led to the development of High-Frequency Trading (HFT) [26]. Unfortunately, the emergence of algorithmic trading has provided powerful technical support for market manipulation [27]. There are reported case, such as in the flash crash in the eastern United States in 2010, where companies used algorithmic trading to manipulate stock market prices. Filling or cancelling large orders quickly caused stock market prices to fall sharply in a short period of time, resulting in market disruption, as well as serious financial losses (Section 3) [6].

Thus, these algorithmic trades already have a tremendous impact on today's stock and power markets, and they make market regulators face big challenges. Indeed, the complexity of market trading makes it difficult to detect different forms of manipulation, leading to distorted market trading going undetected for a long time and affecting the efficient guidance of the market for optimal resource allocation [28].

1.2. What Are the Indicators to Evaluate These Markets?

1.2.1. Stock Market

Several indicators have been proposed to measure the state of the stock market. This paper recalls and collects 10 indicators, which have been proposed to assist in monitoring the possibility of stock market manipulation over a certain period from the perspective of return rate, liquidity, volatility, market sentiment, closing price and firm governance by considering different scenarios. These indicators, which will be described in detail in Section 4.1, can help market regulators detect market participants while they attempt to manipulate the stock market and also provide evidence for judicial conviction in market manipulation cases.

1.2.2. Power Market

Similarly, several indicators have been proposed to measure the state of the power market. The monitoring of the power market can be divided into three aspects: the implementation of market rules, the identification and correction of manipulation behaviors (behaviors not stipulated by market rules), and the improvement of market rules or scheduling procedures [29]. In industrial economics, the criterion for determining effective competition is the structural-conduct-performance (SCP) analytical framework [30]. Therefore, market structure monitoring (also known as market power monitoring), market conduct monitoring and market performance monitoring are investigated to determine whether the market is manipulated. This paper summarizes 16 parameters from the 3 perspectives of market power, market conduct and market performance described in Section 4.2.

1.3. What Are the Similarities between These Two Markets?

The power market and the stock market have many aspects in common, as they both follow similar concepts. Firstly, in terms of trading venues: trading in the stock market usually takes place on a stock exchange, while trading in the power market takes place on a power exchange with similar functions to a stock exchange. Secondly, in terms of participation: in the power market, participants (e.g., generators) have a right to power into and back from the grid through the transmission network, in a similar way as investors in the stock market are free to buy and sell shares in companies. Finally, in terms of influence: the power market and the stock market are both highly liquid, and both have a significant impact on the economy. This makes it necessary for both stock and power markets to be regulated by a third-party body to avoid the damaging effects of market manipulation.

1.4. Contribution of This Work

This study conducts a literature review to compile a set of 10 indicators for detecting manipulation in the stock market and 15 indicators for detecting manipulation in the power market. The primary contribution of this research is the compilation of these indicators for use in monitoring manipulation in these markets. In collecting these indicators, a multi-faceted approach is adopted. For the stock market, various perspectives are considered, including the return rate, liquidity, volatility, market sentiment, closing price and firm governance. Similarly, for the power market, multiple perspectives are taken into account, including market power (also known as pricing power or market structure), market conduct and market performance. This paper provides detailed information on the values of each indicator that may indicate potential manipulation, as well as an analysis of the strengths and limitations of each indicator. To the best of our knowledge, there is a lack of literature that offers a comprehensive examination of the regulatory landscape across multiple countries or regions for both stock and power markets, as well as a comprehensive list of indicators for monitoring manipulation, complete with an evaluation of their advantages and disadvantages.

This study is organized as follows. Section 2 provides definitions for surveillance and manipulation in the stock and power markets. It also presents an overview of the regulatory institutions that oversee these markets in different regions, including a summary of the regulatory strategies and functions in each region. Section 3 presents an analysis of reported cases of manipulation in recent years in the stock and power markets. Section 4 presents a thorough literature review of existing indicators for detecting manipulation in the stock and power markets. Section 5 examines the current challenges and limitations in data acquisition, parametric performance and technical requirements in these two markets. Finally, in Section 6, the study concludes by highlighting the current state of market surveillance and manipulation detection in the stock and power markets.

2. Surveillance in the Stock and Power Markets

This section details the definitions of market manipulation and market surveillance. As each country has a specific authority to regulate the market to prevent market manipulations, we consider the regulatory authorities in four exemplifying regions, namely, Hong Kong, the United Kingdom, the United States and the European Union. We consider both stock and power markets.

2.1. Surveillance in the Stock Market

According to [31,32], manipulation in the stock market is defined as "intentional or willful conduct designed to deceive or defraud investors by controlling or artificially affecting the price of securities, or intentional interference with the free forces of supply and demand, ultimately causing stock prices to fluctuate up and down, disrupting the order and function of the market and affecting the free and fair functioning of the stock market". Correspondingly, surveillance in stock markets refers to the use of computer algorithms or other tools that can detect market manipulation in various forms of transactions, allowing regulators to more effectively monitor market trading activities [33].

2.1.1. Hong Kong Stock Market Regulator

In Hong Kong, since the enactment of the Securities and Futures Ordinance (SFO) in 2003, the Securities and Futures Commission (SFC) [34] has become the principal authority for the regulation of the stock market in Hong Kong. Specifically, the SFC in Hong Kong is responsible for monitoring changes in the stock market daily. Once abnormal circumstances are identified, an investigation occurs on, for example, the source of the purchase or the sale of the stocks involved, which refers to the reports submitted by the securities institutions to see the background information of the investors. If any suspicion is found, a case is closely monitored and examined for more action. As an example, when faced with the outcome of market manipulation, it can be dealt with by administrative and criminal rulings, with administrative rulings made by the Market Misconduct Tribunal and criminal sanctions decided by the Hong Kong courts.

2.1.2. United Kingdom Stock Market Regulator

In the United Kingdom, the market manipulation legislation adopted the Market Abuse Regulation (MAR) No596/2014 in 2016 to prevent market manipulation. Market manipulation cases occur mainly through the Fraud Act 2006 (FA) and the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT) to adjudication. The UK stock market regulator consists of the Financial Conduct Authority (FCA) [35] and the Serious Fraud Office (SFO) [36]. Between these, the FCA is the leading financial services regulator, and it was established in April 2013 to take over the responsibilities for conduct and related Prudential Regulatory Authority (PRA) affairs from the Financial Services Authority (FSA) [35]. The three main objectives of its activities are: (1) to secure a degree of protection for consumers to protect consumers, (2) to protect and strengthen the integrity of the UK financial system and (3) to promote fair, effective and reasonable competition in the interests of protecting consumers [35]. The FCA is an independent organization, monitored and controlled by the Treasury and Parliament in the UK, and financially serviced by companies and other institutions authorized by the FCA [37]. In addition, the FCA is empowered with rule making and investigative and enforcement powers [37]. Once the

FCA regulates a market, it first investigates whether a company meets the minimum standards and then authorizes the company to enter the market. After the FCA has granted authorization, it continuously monitors whether the company meets the requirements. When the FCA finds that the company may harm the market and the interests of consumers, it requests relevant materials from the company for review [34,35]. As a legal enforcement agency, the FCA can penalize firms by stopping them from selling specific services and products, removing firms from the regulated industry, fining or prosecuting individuals, etc. [38,39]. The Serious Fraud Office (SFO) [32,36] is another UK regulatory body, but it is non-governmental. The SFO [40] investigates only the most serious economic crimes, such as suspected new types of fraud and situations where there is a very important public interest element, and conducts criminal proceedings for these complex economic crimes.

2.1.3. United States Stock Market Regulator

In the United States, the Securities and Exchange Commission (SEC) [41] is an independent, federal government, regulatory agency with primary responsibility for protecting all market participants and maintaining the fair and orderly functioning of the securities markets, based on the Securities Exchange Act of 1934 (SEA) and the Commodity Exchange Act (CEA) [41]. The SEC ensures that market participants are able to complete transactions in the securities market fairly and equitably, primarily by ensuring that companies make truthful representations about their business [38,39]. The SEC measures market manipulation mainly through Intent-Based Approaches, Fischel /Ross/Easterbrook Approaches, Intent and Unlawful Conduct/Harm Approaches or a combination of these approaches [42,43].

2.1.4. European Union Stock Market Regulator

In the EU, the European Securities and Markets Authority (ESMA) [44] is an independent EU body. It focuses on three main objectives that follow the Market Abuse Regulation (596/2014/EU) (MAR), namely, investor protection, orderly markets and financial stability. In order to achieve these objectives, ESMA sets market entry thresholds, regularly publishes lists of non-compliance for disciplinary purposes and adopts a risk-based approach to regulation. Once manipulation behavior is detected in the market, penalties are determined in accordance with Article 36a of the Credit Rating Agencies (CRA) Regulation and Article 25j and Article 65 of the European Market Infrastructure Regulation (EMIR) Regulation, and administrative sanctions are imposed under MAR [43–45]. Table 1 summarizes the regulatory responsibilities and penalties of the above four regional or national regulators.

Table 1. Regulatory measures of manipulative behavior in the stock market for Hong Kong, the United Kingdom, the United States and the European Union.

Country/ Region	Regulator	Main Basis	Principles of Fines/Penalties	Regulatory Approach
Hong Kong	Securities and Futures Commission (SFC) [34]	Securities and Futures Ordinance (SFO)	Administrative and criminal rulings (fines and fixed term of imprisonment).	Set market access principles, and continuously examine all companies for unusual behavior. Conduct targeted investigations if unreasonable conditions are identified.
United Kingdom	Financial Conduct Authority (FCA) [37] and Serious Fraud Office (SFO) [36]	Market Abuse Regulation (No596/2014) (MAR)	Remove firms from the regulated industry, fine or prosecute individuals, for example.	
United States	Securities and Exchange Commission (SEC) [41]	Securities Exchange Act of 1934 (SEA) and the Commodity Exchange Act (CEA)	Fines and the fixed term [41] of imprisonment.	
European Union	European Securities and Markets Authority (ESMA) [44]	Market Abuse Regulation (596/2014/EU) (MAR)	Fines and fixed terms of imprisonment.	Adopted a risk-based approach to its supervision.

2.1.5. Summary

Surveillance analysis through the stock market of these countries or regions is summarized in Table 1. It also demonstrates their regulatory responsibilities and the penalties of them.

2.2. Surveillance in the Power Market

According to Klei [28], power market manipulation is defined as "profiting by changing the price of financial assets", which means power market manipulators use various means to create an "artificial price". Moreover, according to [11,43–47], surveillance in the power market means supervising and managing the power market in accordance with national regulatory regulations, prohibiting market manipulation and any potential for insider trading, modifying imperfect market rules to prevent market manipulation, maintaining and promoting a fair and limited market, and safeguarding the rights and interests of all market participants and consumers. In the face of any breach of regulatory regulations, it is taken into account by the relevant legal requirements.

2.2.1. Hong Kong Power Market Regulator

Electricity in Hong Kong is supplied by two separate companies, the Hong Kong and China Light and Power Company Limited (CLP) and the Hongkong Electric Holdings Limited (HK Electric), depending on the geographical location. In order to strengthen the regulation of electricity, the Hong Kong Government has entered into a Scheme of Control Agreements (SCAs) [48] with each of these two companies. The SCAs set out the responsibilities of the power companies and the powers of the Hong Kong Government to regulate them. The Hong Kong Government can control the price of electricity through the Development Plans submitted by the power companies and the annual tariff reviews and audits. This is precisely conducted by the power companies, together with the maximum rates of return set for the power companies in the SCAs. Energy control in Hong Kong is mainly a responsibility of the Environment Bureau and the Electrical and Mechanical Services Department. The Environment Bureau formulates energy policies, plans energy development and regulates the economic situation of the energy market. The Electrical and Mechanical Services Department is responsible for safety matters and provides some technical support to the Environment Bureau in economic regulation.

2.2.2. United Kingdom Power Market Regulator

In the UK, the electricity regulators are the Department for Business, Energy and Industrial Strategy, the Gas and Power markets Authority, the Office of Gas and Power markets (Ofgem) and the Competition and Markets Authority [49]. Among these, Ofgem is the main one to regulate the UK electricity sector, including electricity trading [49] and market manipulation. Ofgem's key responsibilities include strict enforcement of government policy and monitoring of the power market [49], a strict crackdown on energy market manipulation [50], and imposing severe penalties on companies or individuals who manipulate the market [50]. Ofgem analyzes the presence of manipulation in the power market by testing several indicators, such as market share and concentration. The Regulation on Energy Market Integrity and Transparency (REMIT) guarantees Ofgem the right to collect information, monitor transactions and take action when Ofgem identifies a suspicious company or suspects manipulation or insider trading [51].

2.2.3. United States Power Market Regulator

In the United States, there are three institutions responsible for monitoring the electricity system, namely, the Market Monitoring Units (MMU), the ISO/RTOs and the Federal Energy Regulatory Commission (FERC) [52].

The MMU reviews market performance, assesses market efficiency and competitiveness, investigates the exercise of market power and implements mitigation measures as appropriate [52]. The MMU also monitors market anomalies, modifies and improves market rules, etc. [52]. In short, the MMU conducts regular analysis, for example, hourly or daily, depending on the market, to ensure that no company is interfering with the efficiency of the market while profiting from anti-competitive behavior. While the MMU finds any fraud throughout the power market, it co-operates with FERC and other jurisdictions to negotiate to fix the market rules [52].

In most states, the FERC has ultimate regulatory authority over the ISO/RTO and wholesale markets [52]. FERC concentrates on regulating the transmission and wholesale sale of electricity in commerce between continents, monitoring and investigating the energy markets, as well as using civil penalties and other sanctions against energy organizations and individuals who violate FERC rules in energy markets [53]. Currently, the FERC requires all participants in the power market and entities subject to regulation to provide real-time enhanced data to better monitor the market [54].

2.2.4. European Union Power Market Regulator

There is a two-tier regulatory system in the EU, i.e., the National Regulatory Authority (NRA) [55] and the European Union Agency for the Cooperation of Energy Regulators (ACER) [56]. Between them, the NRA investigates suspected cases of market abuse and enforces the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT) and Fraud Act 2006 (FA) as a penalty within their national legal framework. As an EU Regulation, REMIT is directly effective in all EU Member States. Specific enforcement and sanctions are carried out by the NRA, while ACER's main responsibilities are: to participate in the creation of European network rules, to advise on energy-related issues in Europe, and to monitor and report on the development of the European energy market in terms of the integrity and transparency of the wholesale energy market regulations.

2.2.5. Summary

Surveillance analysis through the power market of these countries or regions is summarized in Table 2. It also demonstrates their regulatory responsibilities and penalties of them.

Table 2. Regulatory measures of manipulative behavior in the power market for Hong Kong, the United Kingdom, the United States and the European Union.

Country or Region	Regulator	Main Basis	Principles of Fines/Penalties	Regulatory Approach
Hong Kong	Environment Bureau	Scheme of Control Agreements (SCAs)	No	In addition to fines, take measures to regulate the behavior of market members so that they comply with the relevant laws and regulations
United Kingdom	The Office of Gas and Power markets(Ofgem)	Regulation on Wholesale Energy Market Integrity and Transparency (REMIT)	Fines and criminal prosecution [57]	
United States	Federal Energy Regulatory Commission (FERC)	Regulations of the FERC Anti-Manipulation Act and its related acts	Impose fines of up to USD 1 million per day for each violation by a market member (note: this maximum fine is adjusted for annual inflation)	
European Union	The European Union Agency for the Cooperation of Energy Regulators (ACER); National regulatory authorities (NRA)	Fraud Act 2006 (FA) and Regulation on Wholesale Energy Market Integrity and Transparency (REMIT)	No cap on fines	

3. Stock Market and Power Market Manipulations

The stock and power markets have always been subject to manipulation by various means and factors. This section presents some well-known cases of stock and power market manipulations.

3.1. Stock Market Manipulation Cases, Examples

In Hong Kong, during the period 4 September 2007–17 January 2008, 3 accounts were used to complete 128 transactions in VST Holdings Limited shares [58]. Upon investigation, these transactions did not result in a change in share ownership, but invariably inflated the share price. Following an investigation into these transactions, the SEC determined that it was price manipulation using three indicators—volume, trading interval and price reflection [58]—and fined the responsible team USD 240,000 [59].

On May 2010 during Easter, a 36-minute-long lightning crash (or flash crash) occurred in the US stock market [56,59]. The flash crash had an effect on financial markets over a period of around 10 minutes, followed by a return to normal prices [60–63]. In April 2015, after a five-year investigation, the US Department of Justice filed 22 criminal charges against a British financial trader, including market manipulation [64]. Specifically, the trader placed thousands of orders for futures contracts from 2009 and then manipulated the market by modifying the code of trading software to quickly and automatically cancel these orders [65]. Back then, the major market indexes fell more than nine percent before rebounding [66], and in an instant, a trillion dollars of market value disappeared [66]. According to the investigation, the trader made more than USD 40 million profits from illegal trading between 2009 and 2015 [66]. This flash crash undermined public confidence that financial markets could operate safely [65].

In another case, in December 2020, the Securities and Exchange Commission (SEC) filed a complaint against Barton S. Ross alleging that Barton S. Ross manipulated the stock market by spreading false information across major media outlets and other platforms, resulting in an artificially inflated price of his company's stock [67]. Investigation revealed that Barton S. Ross created and disseminated false information at least 49 times over nearly 2 years, between February 2018 and January 2020, and made an illegal profit of USD 36,000 [68]. There are many other cases of market manipulation through the dissemination of false news. For example, Mark Melnick disrupted the normal functioning of the stock market in August 2021 by using his position as a live webcast host of stock trading to spread false news and was charged by the US SEC [69]. An investigation revealed that Melnick created and spread more than 100 false rumors for no apparent reason, causing the price of the subject company's stock to rise for a short period of time and making an illegal profit of USD 374,000 [69]. Ultimately, Melnick was enjoined from violating the fraud provisions of the federal securities laws and paid prejudgment interest and civil penalties in addition to the amount of his unlawful gains [70].

3.2. Power Market Manipulation Cases, Examples

The Federal Energy Regulatory Commission (FERC) received reports in 2007 of possible manipulative trading by Barclays Bank in the Western United States power market [71]. In a subsequent investigation, the FERC determined that Barclays Bank illegally manipulated the FERC-regulated electricity spot market for 655 days between November 2006 and December 2008 at the 4 most liquid trading points in the Western United States. The manipulated trading centers involved the US states of Washington, Arizona and California [28]. The manipulation roiled the power market in the Western United States by affecting not only the wholesale price of electricity in the West [72], but the final retail price for tens of millions of consumers in the Western United States. The main allegation was "index manipulation", meaning that the units were fined for trading with the knowledge that they would lose money in order to help Barclays Bank make a profit on its positions. Specifically, Barclays' traders took large monthly positions in physical electricity and then bought or sold to close them out in the open market at a fixed price, forcing the electricity price index to rise or fall in favor of the financial swap product, making a risk-free profit [24,68]. The Petition alleged that the defendants' daily trades lost an average of USD 117,404 per month during the months they were manipulated, with a total net loss from dailies trading in those months exceeding USD 4 million. Taking into account the financial position that benefited, FERC enforcement initially estimated that Barclays unfairly profited by at least

USD 34.9 million and caused at least USD 139.3 million in economic losses to other market participants [72]. In 2012, the FERC required Barclays Bank Master to pay USD 435 million in civil penalties, and a total of USD 18 million in fines was imposed on 4 staff members who were primarily involved in this manipulation. Ultimately, in July 2017, the FERC and Barclays reached an agreement for Barclays to pay a USD 105 million fine [73].

Similarly, there have been instances of manipulation of the power market in the UK. In 2016, Ofgem's investigation found that InterGen had manipulated the power market by sending false "physical information" to the National Grid electricity system operator (ESO) on four days (31st October, 7th November, 8th November and 15th November 2016), resulting in InterGen manipulating the power market and profiting from it [74]. Specifically, InterGen sent "physical notices" stating that they could not produce during peak hours in order to induce ESOs to pay them for additional production and to expend the paid generation hours during the day, ultimately making a substantial amount of ill-gotten gains in the balancing mechanism [74]. The investigation found that InterGen made GBP 12.8 million in illegal profits from market manipulation [75].

According to official reports [72], Ofgem monitoring found that between March 2019 and September 2020, ESB Independent Generation Trading Limited and Carrington Power Limited manipulated market prices by submitting inaccurate amounts of minimum energy available for supply to the National Grid Electricity System Operator (NGESO), allowing the NGESO to buy more energy than was needed for the balance between supply and demand, ultimately leading to an increase in the cost of electricity purchased by consumers, to the detriment of the consumer. Subsequently, ESB Independent Generation Trading Limited and Carrington Power Limited admitted that they had inadvertently manipulated the market and took timely steps to rectify the errors. Finally, they were penalized to pay GBP 6 million to the energy redress fund to support consumers [76,77].

4. Surveillance in the Stock and Power Markets

To enable a more quantitative measure of the performance of the stock and power markets, this section details the indicators used to measure the situation of these two markets and analyzes the relationship between these indicators and market manipulation.

4.1. Indicators to Evaluate the Stock Market

Stock price manipulation can be classified as action-based manipulation, information-based manipulation or trade-based manipulation [28,78]. Among these, action-based manipulation is market manipulation accomplished by "changing the actual or perceived value of the assets" [79]; information-based manipulation is used to manipulate the stock market by creating and disseminating false information to mislead stockholders [78], and the heart of information-based manipulation is that exploiting information asymmetry can lead to different asset returns [80]; and trade-based manipulation is where a trader manipulates stocks by buying high and selling low in a way that does not meet the general profitability requirements [78]. While trade-based manipulation is the most common type of manipulation, it is also the most difficult to detect [81].

1. Rate of Return (ROR) [82]

Return is the percentage of capital gains made in the stock market over a period of time. This indicator reflects the general trend of the share price during the period. Its formula is as follows:

$$ROR = \frac{Share\ Price\ t_1 - Share\ Price\ t_0}{Share\ t_0} * 100\% \quad (1)$$

Market manipulation increases the value of ROR [83]. Aggarwal and Wu [84] proved that stock prices rise during the manipulation and fall sharply after the manipulation ends. So, the ROR increases significantly during the stock manipulation phase and exceeds 100 percent; but after the stock is manipulated, the value of the ROR will drop sharply to a negative value. It can be argued that the ROR is a good supporting indicator for determining whether a stock market is being manipulated. However, the ROR indicator only considers the fluctuation of stock prices from a quantitative perspective and does not take into account other dynamic factors, such as inflation.

2. Liquidity

The liquidity of a stock market is the ease and efficiency with which shares can be bought and sold without significant impact on their price. Foucault [85] provided a theoretical account of the effect of manipulation on liquidity in 1999, noting that when stock markets are manipulated, market volatility increases and order non-execution risk decreases, which leads to conservative investment quoting strategies and ultimately wider spreads, making trading costs higher. In short, market liquidity rises significantly at the time of the manipulation, but falls significantly afterwards. On the contrary, very liquid stocks are less susceptible to manipulation. Li et al. [86] and Akinmade et al. [87] also demonstrated that the emergence of manipulative behavior (after manipulation) makes stock market transactions more expensive and less liquid.

There are a number of indicators currently used to detect stock liquidity, such as Bid-ask spread, Turnover ratio, etc. The following are detailed.

- Bid-ask spread (BAS)

The bid-ask spread [82] measures the difference between the close of the trade asking price and the bid price. It has been identified as an important measure of information asymmetry [84], liquidity and efficiency, and it is also one of the common indicators of market liquidity [86]. According to Akinmade et al. [87], there is a negative correlation between bid-ask spread and market sales. The bid-ask spread's equation is as follows:

$$BAS_{i,t}^{k} = \frac{A_{i,t}^{k} - B_{i,t}^{k}}{Midquote_{i,t}^{k}}, \tag{2}$$

where $Midquote_{i,t}^{k} = \frac{A_{i,t}^{k}+B_{i,t}^{k}}{2}$, $A_{i,t}^{k}$ and $B_{i,t}^{k}$ denote the best ask price and the best bid price of k-th transaction for stock i on day t.

When there is information asymmetry in the market, the BAS value increases. As highlighted by Gerace et al. [82] and Aggarwal and Wu [84], market manipulation expands the value of BAS, allowing trades to take place in a context of information asymmetry. The higher the value of BAS, the less liquid the market is. However, bid-ask spreads are not sensitive to the size of transactions and do not reflect the ability of market prices to change in market volume without disruption.

- Amihud illiquid measure

The Amihud illiquid measure was proposed by Amihud [88] to measure the sensitivity of share prices to trading volume. The indicator of Amihud is the ratio of stock returns to trading volume over a period of time. Its formula is as follows:

$$Amihud_{i,y} = \frac{1}{D_{i,y}} \sum\nolimits_{t=1}^{D_{i,y}} \frac{\left|R_{i,d,y}\right|}{VK_{i,d,y}}, \tag{3}$$

where $R_{i,d,t}$ denotes the return on stock i on day d of year y, $VK_{i,d,y}$ represents daily volume, and $D_{i,y}$ denotes the number of days for which data are available for stock i in year y.

If a change in stock trading volume brings about violent fluctuations in the share price (sharp rises and falls), the larger the Amihud indicator, the less liquid the stock; conversely, if the change in trading volume has less impact on the change in share price, the more liquid the stock is. The advantage of this indicator is that the data required for this indicator are readily available, and it can also be used to construct a long, illiquid time series for continuous observation [88].

- Turnover ratio

The turnover rate is the frequency with which a stock changes hands in the market over a given period of time. It is also an indication of the liquidity of a stock. Its specific formula is as follows:

$$Turnover_{iy} = \frac{1}{D_{iy}} \sum\nolimits_{t=1}^{D_{iy}} \frac{Volume_{iy,t}}{Share_{iy,t}}, \tag{4}$$

where $Volume_{iy,t}$ explains the number of shares traded in stock i on day t of period y, and $Share_{iy,t}$ shows the corresponding number of outstanding shares.

The Average Daily Exceptional Turnover Rate [89] is an indicator constructed on top of the turnover rate and is used to warn whether a stock market is being manipulated. The average daily exceptional turnover of shares for the $(t_2 - t_1)$ days prior to the beginning of the manipulation was:

$$V[t_1, t_2] = \frac{1}{t_2 - t_1} \sum\nolimits_{t=t_1}^{t_2} \left(Turnover_t - \frac{1}{t_2 - t_1} \sum\nolimits_{p=t_2+t_1}^{t_2} Turnover_p\right), \tag{5}$$

Based on a China securities market share price manipulation case, Chen and Hu [89] concluded that if a stock has a certain period of time and the average daily exceptional turnover rate suddenly increases significantly compared to the previous period without corresponding positive (or negative) news in the market, then the stock is likely to be suspected of being manipulated. This index has the best timely warning function.

The turnover rate also has some disadvantages [90]. Firstly, the turnover ratio does not take into account changes in the price of the stock, as liquidity decreases when the price of a stock continues to rise. Further, the turnover rate does not take into account other conditions of the market, such as high speculation rates. Moreover, it has been realized that using the turnover ratio alone to measure market liquidity is incomplete [90,91].

- Volume

Volume [84,90] is the number of shares changing hands at a given time. Volume is an increasing function of liquidity, and as trading volume becomes larger, liquidity must also increase. A spike in trading volume over a certain period of time and a decrease after that time is a likely sign that the stock is being manipulated. The advantage of this indicator is that it is easy and straightforward to measure.

3. Volatility

Volatility [92], also called risk, is the rate at which the price of a stock increases or decreases over a period of time. It reflects the degree of uncertainty in the value of the stock. Usually, stock market traders and analysts rely on different indicators to track fluctuations in order to determine the best time to buy or sell a stock. Similarly, volatility is an important indicator of whether a stock market is being manipulated. Aggarwal and Wu [84] used US market data as a case study to figure out and demonstrate that the occurrence of manipulation increases the volatility of stocks. A stock is highly volatile if its price rises sharply or falls sharply over a certain period of time. Further, sharp fluctuations in the price of a stock over a short period of time are, to some extent, an indication that the stock is at risk of being manipulated. According to Akinmade et al. [87], volatility and bid-ask spreads are positively correlated. For each stock, its volatility is considered to be equal to the logarithm of the proportion of daily high and low share prices, namely:

$$Volatility = Log\frac{P_{max}}{P_{min}}, \tag{6}$$

where P_{max} and P_{min} represent the maximum and minimum stock prices, respectively. There are a number of indicators currently used to detect stock volatility, such as the Beta coefficient, detailed as follows.

- Beta coefficient

The Beta coefficient is a risk index that measures the price volatility of a stock relative to the overall market and is a tool used to assess the systematic risk of a stock. Its specific formula is as follows:

$$\beta = \frac{Covariance(R_e,\ R_m)}{Variance(R_m)}, \quad (7)$$

where R_e denotes the return on an individual stock, and R_m denotes the return on the overall market.

If $\beta > 0$, it indicates that the stock price is positively correlated with the overall market price: as the overall market price rises, the price of the stock also rises. Conversely, if $\beta < 0$, it indicates that the stock price is negatively correlated with the overall market price: as the overall market price rises, the price of the stock falls. Normal stocks have a Beta coefficient of around 1 and are positively correlated with the market. However, when a stock is manipulated, the Beta coefficient becomes smaller or even negative, indicating that the stock price becomes less positively correlated with the market index. Lu and Chen [93] found that the Beta coefficient was significantly lower only during the period of manipulation, while the difference in Beta coefficients at pre- and post-manipulation and for non-manipulated stocks was not significant. Thus, the Beta coefficient can provide some reference in terms of stock market monitoring. However, since the Beta coefficients are calculated using historical data, they cannot help with real-time monitoring.

4. Closing-price manipulation index

The closing-price manipulation index was proposed by Comerton-Forde and Tālis J.Putniņš [94]. The coefficient takes into account the characteristics of returns, spreads, trading frequencies and return reversals, which can distinguish manipulated closing prices from those that occur in normal trading. It is formulated as follows:

$$I_{manip} = \frac{1}{1 + e^{-(a + b\Delta^{sign}_{return} + c\Delta^{sign}_{reversal} + d\Delta^{sign}_{frequency} + e\Delta^{sign}_{spread} + \varepsilon)}}, \quad (8)$$

where the coefficient indicators $(a,\ b,\ c,\ d,\ e, \varepsilon)$ can be obtained from a binary logistic regression of manipulated and non-manipulated stock days using a regression model. Where Δ^{sign}_i denotes the difference-in-variables. It is formulated as follows:

$$\Delta^{sign}_i = S_i - med_s(S_i), \quad (9)$$

where the variable i may include return, reversal, frequency and spread; S_i denotes the sign statistic for variable i on a particular stock day; and $med_s(S_i)$ denotes the median sign statistic for all other stocks.

The Closing Price Manipulation Index takes a value between 0 and 1 and represents the probability of the closing price being manipulated. It tends to increase in response to anomalies in day-end returns, trading frequencies, returns reversals and spreads. This is because abnormal day-end returns and returns reversals reflect the extent to which prices deviate from their normal levels; an increase in trading frequency can indicate that manipulation has increased trading volume. The regulator can, therefore, give priority to investigating the instances with the highest data for this index.

5. Market sentiment

The relationship between shareholder tendency and stock market performance has been carefully investigated [95–99].Market pressure can also be expressed on the side of news containing negative sentiment [100]. The analysis of past market manipulation shows that market manipulators can twist the sentiment of individual investors by manipulating public opinion [101]. Therefore, the sentiment of individual investors and the market is also an indicator to predict whether the stock market is manipulated. The following indicators can be taken into account and used while measuring market sentiment.

- Analysis

The analysis mainly refers to the evaluation of the manipulated stock by securities analysts. The normal stock evaluation is the number of positive evaluations minus the number of negative evaluations of a given stock by all securities analysts over a certain period of time. The main pillar of the analysis is whether the current share price is reasonable. The higher the number of analysts' evaluations, the less likely the stock is manipulated [15]. As a case study, applying this indicator and the indicator of the number of negative outside impacts on a stock to the Chinese stock market from 2014–2016 and using the China Securities Regulatory Commission penalty cases as a reference, Liu et al. [15] found that introducing market sentiment can be a significant marginal increment to the model, and the accuracy of a stock in the market can be improved. However, various terms play an important role in this object, for instance, misled data.

- Sentiment score

The sentiment score was proposed in [102] to analyze the interplay between social media news and stock returns. Its formula is as follows:

$$Sent_d = \frac{N_d(pos) - N_d(neg)}{N_d(pos) + N_d(neut) + N_d(neg) + 3}, \tag{10}$$

where $N_d(neg)$, $N_d(neut)$ and $N_d(pos)$ denote the daily number of negative, neutral and positive news, respectively. $N_d(neg)$, $N_d(neut)$ and $N_d(pos)$ take the values -1, 0 and 1, respectively. The constant 3 in the denominator is Laplace corrected. Deveikyte et al. [95] demonstrated experimentally that with an increase in positive sentiment, the sentiment score increases, market volatility decreases and the market is less likely to be manipulated. However, due to the high number of social networking software, there can be incomplete data collection or false data, leading to the invalidation of this indicator.

6. Firm Governance

In terms of corporate governance, the higher the concentration of a company, the higher the probability that the stock can be manipulated. Therefore, stock market conditions can also be measured by concentration.

Concentration refers to the percentage of shares held by the top largest shareholders. Insider information trading is an important way for information to manipulate prices. The concentration of shareholding increases the likelihood of trading manipulation. The more concentrated shareholding, the greater the incentive for controlling shareholders to manipulate prices in real-time through various means.

Based on the above analysis, Table 3 summarizes the advantages and disadvantages of the above stock market monitoring system indicators.

4.2. Indicators to Evaluate the Power Market

This section summarizes the parameters of power market monitoring from three perspectives: market power, market performance and market conduct [103].

4.2.1. Market Power

Market power [104–107], which is also known as pricing power or market structure, is the ability of a company to ultimately raise prices above the competitive level, by exploiting its unique position in the industry or by using a particular method, and to profit from this. Thus, large values of market power may raise concerns of market manipulation. Identifying or measuring the size of a company's market power can be defined by indices.

Table 3. Summary of power market monitoring indices.

Indicator	Category	Data Required	Concern of Manipulation When the Indicator	Strengths	Weaknesses
Rate of Return (ROR)	Ex-post	Share price at different times	Rises significantly (beyond 100%)	A good supporting indicator	No consideration is given to the effect of other factors on stock prices
Liquidity					
Bid-ask spread (BAS)	Ex-post	The best ask price and the best bid price of k-th transaction for stock i on day t	Rises significantly	Information asymmetry is taken into account	Not sensitive to the size of transactions and does not reflect the ability of market prices to change in market volume without disruption.
Amihud illiquid measure	Ex-post	Return on stock i on day d of year y, daily volume and number of days for which data are available for stock i in year y.	Falls significantly	Can also be used to construct a long, illiquid time seriesfor continuous observation	N.A.
Turnover Ratio	Ex-post, close to real-time, Ex ante	The number of shares traded in stock i on day t of period y, the corresponding number of outstanding shares	Rises significantly (beyond average)	Best timely warning effect	Does not take into account changes in the price of the stock and other conditions of the market, such as high speculation rates.
Volume	Ex-post, close to real-time, Ex ante	The number of shares changing hands at a given time	Rises significantly or falls significantly	Easy to count, simple and straightforward	Does not take into account other conditions of the market, such as high speculation rates.
Volatility					
Beta Coefficient	Ex-post	Individual stock and return on the overall market	Falls below average (or even negative)	Provides some reference in terms of the stock market monitoring	Cannot help with real-time monitoring
Closing-price Manipulation Index	Ex-post	Return, reversal, frequency and spread	Close to 1	Takes into account manipulation for which prosecution data are not readily available and provides options for more effective regulation of the market	N.A.
Market Sentiment					
Analysis	Ex-post, close to real-time, Ex ante	The number of the evaluation of the manipulated stockfrom securities analysts	Falls significantly	Simple and intuitive	There are instances where some securities analysts are also involved in manipulation, which can make these data misleading.
Sentiment Score	Ex-post, close to real-time, Ex ante	The daily number of negative, neutral and positive news	Falls significantly	Simple and intuitive	Due to the high number of social networking software, there can be incomplete data collection or false data, leading to the invalidation of this indicator.
Firm Governance					
Concentration	Ex-post, close to real-time, Ex ante	The percentage of shares held by the top i largest shareholders	Rises significantly	Simple and intuitive	N.A.

1. Herfindahl–Hirschman Index (HHI)

The Herfindahl–Hirschman Index [108] is a commonly used indicator to measure market concentration. It is expressed as the sum of the squares of the market shares of all firms in a power market. It is formulated as follows:

$$\mathrm{HHI} = \sum_{i}^{N} (S_i)^2, \quad (11)$$

where S_i is the market share percentage of firm i. HHI is typically in the range of 0 to 10,000. The FERC gives specific evaluation criteria [109], with an HHI of less than 1000 indicating a competitive market; an HHI between 1000 and 1800 indicating a moderately concentrated market; and an HHI greater than or equal to 1800 indicating a highly concentrated market. Although HHI requires few parameters and is simple to calculate, it does not respond dynamically to market changes and does not include certain aspects of power supply and bidding strategies [103].

2. Market Share Index (MSI)

The Market Share Index (MSI) is the percentage of a company in the overall market share. It is presented as:

$$\mathrm{MSI} = \frac{q_i}{Q}, \quad (12)$$

where q_i is the quantity supplied by a company, and Q denotes the total volume of the market. Market share can be used for long-range studies or for near real-time screening [110]. Similar to HHI, MSI is intuitive and simple to calculate, but does not dynamically reflect market changes.

The market share index and HHI are the two commonly used concentration indices, which represent the percentage of a company's share of the overall market. The logic behind it is that the more concentrated the market, the greater the likelihood that participants exercise market power [110]. However, in the power market, a generator with a small market share may have significant market power within a local area due to blockages. Therefore, market share can hardly be used as a basis for measuring the degree of market power in the power market [111].

3. Pivotal Supplier Index (PSI)

The Pivotal Supplier Index (PSI) shows whether the residual supply is sufficient to meet market demand. It is a binary index calculated as

$$\mathrm{PSI} = \begin{cases} 0, \mid & \left(\sum_{i=1}^{N} AIC_i - AC_j - \sum_{i=1}^{N} hG_i\right) \geq 0 \\ 1, \mid & \left(\sum_{i=1}^{N} AIC_i - AC_j - \sum_{i=1}^{N} hG_i\right) < 0 \end{cases}, \quad (13)$$

where AIC_i is the available installed capacity, AC_j is the available capacity, and hG_i denotes the hourly generation of supplier i. This indicator is used as a measure of how critical the target generator is [112]. When the PSI is 1, it indicates that the corresponding generator is very important in the market and has the potential to use market power. PSI is able to capture market dynamics; however, it ignores the correlation between the behavior of market participants, such as collusive behavior [103].

4. Residual Supply Index (RSI)

The Residual Supply Index (RSI) [113] is a parameter that shows the ratio of residual supply to demand. The Residual Supply Index is a measure of the extent to which a generator's capacity meets demand, after taking into account the capacity of other generators [110]. It reflects the incentive for firms to exercise market power by retaining capacity. It is defined as follows:

$$\mathrm{RSI} = \frac{TC - CRC}{TD}, \tag{14}$$

where TC denotes Total Capacity, CRC denotes the Company's Relevant Capacity, and TD denotes Total Demand. When the RSI for company i in a given time period is greater than or equal to 100%, it indicates that other suppliers have the ability to meet the market demand, which indicates that company i does not have market power and only has a little influence on the market price. On the contrary, when RSI is less than 100%, other suppliers cannot meet the market demand without company i, so company i has a certain market power and influence on the market clearing price [110,114]. While this parameter does not represent the potential of a company to withhold capacity, the Return on Withholding Capacity index was presented to compensate for the shortcomings of RSI [115]. Compared to HHI and MSI, RSI can capture dynamic market parameters [103]. The two parameters, RSI and PSI, are similar, but RSI is more refined.

The RSI has had an important influence, for example, as the predictor of the power market [112,113], when it was first used by FERC as an assessment indicator to determine the market power of suppliers in the electricity market [115].

5. Return on Withholding Capacity (RWC) Index

Withholding is one of the core methods of exercising market power. In terms of withholding, there are two ways for companies to exercise market power [58–61]. The first way is through reserved capacity; by reducing the supply of energy, power generators make changes in supply and demand, which leads to higher electricity prices. This strategic retention of a portion of the capacity to produce electricity leads to an increase in profits, which can also be called Physical or Quantity Withholding. The second way is through financial withholding, i.e., increasing the supplier's bid price above the marginal cost of the generator set. This strategy is risky, as there is no guarantee of market acceptance [114]. Both of these strategies have an impact on costs and prices. RWC [115] represents the possibility of capacity withholding by the supplier. It is defined as follows:

$$RWC_{i,t} = \frac{\Delta p * (running\ capacity_{i,t} - 1)}{market\ price\ _t}, \tag{15}$$

where Δp denotes the estimated value for the price premium expected by the supplier i for withholding one MWh capacity at time t. When $RWC \geq 1$, supplier i has a high probability of withholding capacity. However, when $RWC < 1$, the interpretation of RWC as an indicator is limited.

6. Residual Demand Elasticity (RDE)

Residual Demand Elasticity (RDE) measures a firm's ability to raise prices by reducing output after taking into account the demand response of buyers and the supply response of competitors [116]. It is also a method for measuring whether a company has applied market power by testing the demand curve it faces [116]. The residual demand curve is usually constructed ex-post and is calculated by subtracting from the total demand curve all the offer curves bid into the market by other participants [110]. RDE is inversely proportional to market power [116]. The smaller the value of RDE, the greater the likelihood that the corresponding company has exercised market power, and vice versa.

7. Lerner Index (Bid-Cost Margins)

The Lerner Index (LI) is also known as Bid-Cost Margins. It is used to measure the proportional deviation of the price at the firms' profit-maximizing output from a firm's marginal cost at that output [117–122]. The Lerner Index formula for firm i is

$$LI_i = \frac{p_i - MC}{p_i}, \tag{16}$$

where p_i and MC denote the price and marginal cost, respectively, at the firm's profit-maximizing output. The LI index is the higher deviation from the marginal cost.

Moreover, it is hard for LI to determine the appropriate reference level, and it is susceptible to factors other than market power [103]. The index also does not effectively reflect the response of prices to demand [122]. Although the LI is an indicator of market power, it cannot be used as a common screening tool for market monitoring due to the lack of sufficient cost data in its calculation [114].

8. Must-Run Rate (MRR)

Must-Run Rate (MRR) [123] is the ratio of the generator's Must-Run Power to its usable capacity. Its specific formula is as follows:

$$MMR_i = Max\left(\frac{D - \sum_{j=1,i=1}^{N} q_j}{C_i}, 0\right), \tag{17}$$

where D indicates the overall market demand, q_j presents the successfully declared electric quantity by generator j, and C_i denotes the generating capacity of power companies. MRR takes values from 0 to 1. When MRR is zero, it indicates that the firm has a high probability of being substituted and has no influence on market prices. When MRR is greater than 0 and less than 1, it indicates that the company has some influence in the market. However, most companies in the market have an MMR greater than 0. Even if a company has the largest MMR after ranking, there is insufficient evidence to suggest that it has engaged in market manipulation.

4.2.2. Market Performance Monitoring

Market performance monitoring is primarily designed to monitor market inefficiencies and the potential for market abuse [103]. Market performance monitoring shares some of the same methods and indicators, such as market power monitoring and behavioral monitoring, so the different indicators and methods of market performance monitoring are highlighted here.

1. Degree of market competition

According to Dale L and William L [124], the level of market competition can be divided into four categories, which are perfect competition, monopolistic competition, oligopoly and monopoly. The degree of market competition is formulated as follows:

$$CD = \frac{P_C - MC}{P_C} * 100\%, \tag{18}$$

where P_C and MC denote the upper limit of the market price and the marginal price of the market, respectively. The more competitive the market, the less likely it is to be manipulated.

2. Output Gap

This index [111] was pioneered by Potomac, the independent monitoring agency for New York State. The Output Gap index captures the difference between the economic generation and actual output at current market prices for single, multiple or all generators. Its formula is as follows:

$$OG = EO_i - AO_i, \tag{19}$$

where EO_i and AO_i denote the Estimated Output (or estimated power generation) and Actual Output of firm i. The output gap can identify the capacity-holding behavior of generators. However, the method also has drawbacks; for example, the estimation of costs, power system coupling and unit mix in the model may differ from the actual situation.

3. Bid Sufficiency Index

The Bid Sufficiency Index [119,121] is based on previous data to measure the winning bid rate of a company. It is formulated as

$$BS_i = \frac{S_i}{S_a}, \tag{20}$$

where S_i denotes the ratio of the declared electric quantity to the transacted electric quantity of the power generation company i, and S_a indicates the ratio of the average declared electric quantity to the transacted electric quantity across the market. This parameter provides an intuitive way of detecting the winning rate of a company over a period of time. In a free market, the higher value, the more likely it is that the company in question is involved in or dominates market manipulation.

4.2.3. Market Conduct Monitoring

Market behavior is the strategy adopted by a company to achieve higher profits and market share. The market strategy consists mainly of a price strategy and a supply strategy for generators. Due to its characteristics, conduct monitoring has the same monitoring indicators as market power monitoring and market performance monitoring, such as HHI, PSI and RSI. However, some indicators are peculiar for conduct monitoring, which are presented in the following.

1. Highest market price index

The highest market price index [112] is the ratio of the electricity amount when the generation company's offer was closest to the maximum price to all declared electricity amounts over a period of time. Its formulation is:

$$CP_i = \frac{q_{ai}}{Q_a}, \tag{21}$$

where q_{ai} denotes the amount of electricity that corresponds the closest to the highest price quoted by generation company i, and Q_a is the amount of all declared electricity. The purpose of market manipulation is to gain more profit. Therefore, the index can be used as an auxiliary discriminator when judging whether a company is involved in market manipulation. The index is derived and ranked for all companies involved in the bidding process. The higher the value and the higher the ranking of the company surveyed, the more likely it is that the company has engaged in market manipulation.

2. Maximum price winning rate

Maximum price winning rate [108,122,125] refers to the probability of a successful bid at the highest price. Its formula is as follows:

$$CR = \frac{T_{hi}}{T_b}, \tag{22}$$

where T_{hi} represents the number of cycles where the market clearing price is equal to the maximum price, and T_b denotes the total amount of bidding time cycles. The larger the value, the more likely it is that manipulation is involved. Therefore, the index can be used as an auxiliary discriminator when judging whether a company is involved in market manipulation.

3. Price markup index

The price markup index [112,126] is an index primarily used for measuring the difference between the bid price and the marginal cost. The formula is as follows:

$$PA_i = \frac{p_{mi} - MC_i}{MC_i}, \tag{23}$$

where p_{mi} and MC_i represent the bid price and marginal cost of generator i, respectively. The PA index responds to market profitability. This index indicates the bid characteristics or strategy of the power generator. When this indicator has a high value after ranking with other companies, it is an offensive bid strategy; when this value is less than zero, it indicates that the company would rather lose money than complete the bid. This index can be used as an auxiliary indicator to study whether a company is involved in a manipulation case. However, this parameter faces the problem that the estimated marginal costs are not always very accurate, which leads to doubts about the accuracy of the results of the price markup index [111].

4. The bid price of cleared energy monitoring index

This index was invented by Kasperowicz et al. [123] for the specific situation of the data available in the Spanish electricity system. It shows the relationship between the weighted average price of clean energy at a certain time for a particular technology and the weighted average price at the same time for all technologies. It is calculated as follows:

$$BPceM = \frac{wPcE_{i,t} - wPcE_t}{wPcE_t}, \tag{24}$$

where $wPcE_{i,t}$ represents the weighted average price of firm i at time t, and $wPcE_{j,t}$ represents the weighted average price of all firms at time t. When the value of the index is greater than zero, the corresponding firm may have triggered an increase in the final price. Conversely, if the value of the index is less than zero, the surveyed firm may have caused a decrease in the final price. Once the value is almost zero, it means that the firm's bid price has almost no impact on the overall market price. This index can be used to detect relationships between those generators that have a large impact on the final price and all generators. This indicator helps to quickly locate companies that cause changes in energy prices.

Based on the above analysis, Table 4 summarizes the advantages and disadvantages of the above power market monitoring system indicators.

Table 4. Summary of power market monitoring indices [110].

Indicator	Category	Data Required	Concern of Manipulation When the Indicator	Strengths	Weaknesses
			Market power		
Herfindahl Hirschman Index (HHI)	Usually ex-ante	- Total volume of market - Quantity supplied by a company	Rises significantly (beyond 1800)	- Small amount of data required for the calculation - Simple to understand	- Does not respond dynamically to market changes - Does not include certain aspects of power supply and bidding strategies
Market Share Index (MSI)	Usually ex-ante	- Quantity supplied by a company - Total volume of the market	Rises significantly	- Small amount of data required for the calculation - Simple to understand	- Does not respond dynamically to market changes - Does not include certain aspects of power supply and bidding strategies
Pivotal SupplierIndex (PSI)	Ex-ante, close to real-time, ex-post	- Available installed capacity - Available capacity - Hourly generation of supplier i	Close to 1	- Can track dynamically changing markets.	- Ignores elasticities and market contestability factors.
Residual Supply Index (RSI)	Ex-ante, close to real-time, ex-post	- Total Capacity - Company *i*'s Relevant Capacity - Total Demand	Falls significantly below 100%	- Can track dynamically changing markets. - Widely used	- Ignores elasticities and market contestability factors.
Return on Withholding Capacity (RWC)	Ex-ante, ex-post	- Running capacity - Market price	Rises significantly beyond 1	- Can capture dynamic market parameters	N.A.
Residual Demand Elasticity (RDE)	Ex-post	- Total demand - Other participants' bid	Very small	- Consider other participants' bids and market needs	- Requires bid data
Lerner Index (Bid Cost Margins)	Ex ante, close to real time, ex-post	Price and marginal cost at the firm profit-maximizing output	Rises significantly (but could be due to factors other than market power)	- Difficulties in determining costs or appropriate competitive 'reference' levels	- Does not effectively reflect the response of prices to demand - The lack of sufficient cost data in its calculation
Must-Run Rate (MRR)	Ex-post	- Overall market demand, - Successfully declared electric quantity by generator j - The generating capacity of power companies	Rises close to 1	- Intuitively	- Results are not convincing

Table 4. *Cont.*

Indicator	Category	Data Required	Concern of Manipulation When the Indicator	Strengths	Weaknesses
		Market performance monitoring			
Degree of market competition	Ex-ante, ex-post	- Upper limit of market price - Marginal price of a market	Falls significantly	- Intuitively	N.A.
Output Gap	Ex-ante	- Estimated power generation - Actual output of firm i	Value rises significantly (but could be due to other factors)	- If calculated accurately, can identify the capacity-holding behavior of generators	- If the data used in the calculation are inaccurate, the result is not credible either
Bid Sufficiency Index	Ex-post	- Ratio of declared electric quantity to transacted electric quantity of the power generation company I - Ratio of average declared electric quantity to transacted electric quantity across the market	Rises significantly	- Intuitively	N.A.
		Market Conduct Monitoring			
Highest market price index	Ex-post	- the amount of electricity that corresponds the closest to the highest price quoted by generation company *i* - the amount of all declared electricity	High value and high ranking	- Can assist in determining whether a company is involved in market manipulation	N.A.
Maximum price winning rate	Ex-post	- The number of cycles where the market clearing price is equal to the maximum price - Total amount of bidding time cycles	Value rises significantly	- Can assist in determining whether a company is involved in market manipulation	N.A.
Price markup index	Ex-post	- Bid price - Marginal cost	High value and high ranking (but could be due to other factors)	- Can assist in determining whether a company is involved in market manipulation	An inaccurate estimate of marginal costs would make the results of this parameter infeasible
Bid price of cleared energy monitoring index	Ex-post	- Weighted average price of a firm - Weighted average price of all firms	Large positive values or large negative values	- Data available (in the Spanish market) - Help to quickly locate companies that cause changes in energy prices	N.A.

5. Existing Barriers to Stock Market Surveillance and Power Market Surveillance

Many pressing issues still need to be resolved in the stock and power markets, and this section focuses on the barriers encountered in both markets.

5.1. Barriers to Stock Market Surveillance

First, the primary challenge related to technological developments is the issue of data collection. Different stock exchanges differ in the time they capture information, the breadth of information they receive, and even the extent to which they capture such information. However, all stock exchanges share the challenge that the speed of trading on all exchanges has increased significantly, requiring regulators to adapt quickly to market developments, steadily increasing their ability to collect and process the increased volume of trading data. In the face of a complex market environment and advanced technological challenges, the ability to collect complete data and information in an accurate and timely manner is the biggest challenge for regulators [127].

Second, another challenge is to extract key and true information from the vast amount of data and information available [127,128]. The increasing amount of "trading noise" due to the advent of HFT and fully automated trading programs makes it a challenge to distinguish between real orders and trading and manipulative activity [125,126]. Algorithmic trading is bound to leave a trail, as long as it exists (e.g., executed trades, program code, etc.), so it is relatively easy to detect algorithm-based market manipulation [129]. However, when the market becomes an algorithm-driven market, it becomes difficult to accurately detect algorithm-based market manipulation. This is because interpreting the data and deducing the problematic orders from the vast amount of data available takes a lot of time and money, and requires sophisticated technology and skilled personnel. This creates a huge hurdle for regulators [129]. In addition, some companies have inefficient disclosure, which can be lagging or inconsistent, and in some cases, even evasive. This leads to the need for regulators to not only extract key information from the vast amount of information available, but also to identify unusual or false information [15].

Third, most indicators are biased to some extent, which can be also a challenge. Although most trading platforms around the world have automated monitoring systems that take into account multiple measurement factors, essentially all indicators (such as those mentioned in Section 4.1) can be somewhat biased because the indicator itself has some shortcomings that can affect the accuracy of the monitoring system to some extent. This is a barrier that needs to be addressed by regulators.

Fourth, as known from experience, most manipulation cases do not involve an isolated transaction, but usually involve one or more market participants and a series of market behaviors over a long period of time. These participants and these abnormal market behaviors ultimately lead to the manipulation of the market. This requires the regulator to look beyond a single isolated transaction and to take a broader view and a larger time horizon, integrating market information while focusing on the timing and sequence of market transactions. Accurate analysis of data and keen market monitoring skills are also challenging for agencies and their policies.

Finally, keeping up with market changes promptly is a constant challenge for market regulators. With the development of the stock market, the manipulation techniques and manipulation tools in the stock market have been upgraded, so the relevant policies and regulatory tools also need to be improved and strengthened in line with the development of the market, so as to respond to the gaps in market regulation in a timely manner.

5.2. Barriers to Power Market Surveillance

Firstly, the primary barrier to power market surveillance, as with the stock market, is the issue of timely data collection. The public release of data submitted to the system (e.g., bids, output levels, etc.) and generated in the system can increase the transparency of wholesale power markets to some extent [130]. However, this is not always the case; for example, in the US, there is a six-month delay in the release of relevant information, and the identity of market participants is kept anonymous. This creates a significant barrier to effective market regulation, as the availability of complete and timely information and data is a prerequisite for efficient and timely regulation by the regulator and provides a good environment for effective monitoring by other market participants.

Second, data accessibility can be a challenge for regulators. For the generation side, assessment of the market power of generators is often difficult. Often, indirect parameters are needed to measure a firm's market power (Section 4.2.1 for details), but the parameters are usually obtained with the help of other parameters, and the values of these parameters are usually obtained with delays or inaccurately, or are even not accessible, which leads directly to an inaccurate assessment of market power. For example, generation withholding capacity can influence market power, but obtaining generation withholding capacity is complicated [131].

Third, after systematically analyzing the economic parameters of the power market, Kasperowicz et al. [103] stated in 2016 that the lack of available source data makes the innovation of new monitoring indices and methods a fundamental challenge and an objective of power system monitoring. Similar to the indicators for the stock market, the indicators for the power market (Section 4.2) are also biased and depend on other values to be obtained when solving for them, and these values are often slow to update or even have spurious values. Errors in indicator data can mislead the regulator's analytical results. This also creates barriers to effective market surveillance.

Fourth, as with the stock market, another obstacle to monitoring the power market is extracting anomalies from the vast amount of data and using this information as a clue to uncover and verify whether a company or companies are involved in market manipulation. The extensive use of APIs in the power market, while facilitating, for example, bidding by generating companies, also creates a barrier for regulators to identify potential anomalies from the vast amount of normal quotes and orders.

Fifth, as with the stock markets, past manipulation cases have shown that the power market can be manipulated in a variety of ways, also involving multiple companies and over multiple time periods. This requires the regulator to be able to spot the manipulator's purpose hidden behind the transactions from the complexity of the transactions and to identify anomalies keenly with a macro view and senior experience.

Finally, the ability of regulators to consistently and steadily keep pace with the market is an enduring test for regulators. In total, 24% of people at the 2019 Navigating Change—Regulation and Tomorrow's Grid seminar in Brisbane felt that in the energy sector, regulation has failed to keep pace with the market [132].

According to the abovementioned literature analysis, it can be summarized that both markets are facing almost the same barriers, which can be itemized as:

1. how to collect and complete data and information in an accurate and timely manner,
2. how to extract true and key information from vast data,
3. how to find better indicators or overcome the shortcomings of biased indicators (how to match barriers to an aimed market),
4. how to accurately analyze data and improve the accuracy of algorithms, and
5. how to ensure that the algorithm is capable of continuous learning so that it can respond to changes in the market and upgrades in manipulation techniques.

6. Conclusions

Both stock and power markets play major roles in trading worldwide. The nature of these markets allows market manipulation and unfair strategies. It requires careful monitoring and assessment of markets to prevent any manipulations.

According to a literature review, this paper studied, reviewed and listed the existing stock and power market indicators to monitor markets and detect false signals. At present, there are visible challenges to monitoring both the stock and power markets. Based on the comprehensive investigation, it is vital to develop clearer and more oriented data collection mechanisms and a monitoring system that can incorporate expert mechanisms and automatic learning.

This paper introduced the regulatory authorities and their responsibilities for overseeing market manipulation cases in the stock and power markets in Hong Kong, the United Kingdom, the United States and the European Union, and elaborated on six high-impact market manipulation cases. It is found that manipulation cases are generally characterized by high concealment, a large number of manipulators, a high number of manipulations and a long investigation time. Although all of these regions have set up special regulators to prevent market manipulation and have established tougher penalties based on policies, it is clear that manipulation is still common.

In order to better establish a relevant digital regulatory system, we categorize and list the indicators used to monitor the stock and power markets, and provide an in-depth analysis of the relationship between all the indicators involved and market manipulation. Through an extensive and in-depth literature reading, the framework based on market power, market performance and market behavior presented in this paper could be very important for the construction of a completely new monitoring system in the electricity market. In addition, the existing indicators for monitoring electricity markets generally have some shortcomings. A better index may also be needed for the ever-changing power market. At present, there are many challenges in monitoring both the stock and power markets, and there is still an urgent need to develop better data collection mechanisms and a monitoring system that can incorporate expert mechanisms and automatic learning to free staff from cumbersome and time-consuming tasks.

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