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ORIGINAL ARTICLE

Prudential supervisory disclosure (PSD) with supervisory technology (SupTech): lessons from a FinTech crisis

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Abstract

The U.S. financial markets faced an unprecedented rapid decline and recovery on May 6, 2010, known as the May 6 flash crash. Roughly one trillion $ market value in less than thirty minutes vanished with the biggest one-day point decline in the history of the DJIA at the time. Since the market events took place in electronic markets, and algorithmic trading and high-frequency trading, parts of FinTech, played significant roles, we handle the May 6 flash crash from the FinTech, SupTech, and financial supervision perspectives. With the flashback method, we analyzed the reactions of market participants, media, and two financial supervisors, the SEC, and the CFTC, to the market crash. We find that the technological imbalance between financial markets or institutions and their supervisors drove the markets in uncertainty, hence in a fear and panic environment. Since the imbalance has not diminished yet, the same risks still exist. As a remedy, we introduce a new concept and model with a well-functioning SupTech system to cope with the May 6 type FinTech crises.

Keywords Supervisory technology · SupTech · FinTech · RegTech · Financial supervision · Financial system · Prudential supervisory disclosure · Financial authority · Digital finance · May 6 flash crash · FinTech crises · Financial crises · Financial stability · Informational efficiency · Systemically important data · Systemically important markets · Know-your-data · Know-your-technology · Know-your-markets · Inform-your-markets

JEL Classification D47 · D53 · G18 · G01 · G28 · H11 · K22 · K23 · L15 · O31 · O32

Abbreviations

AI	Artificial Intelligence
AT	Algorithmic Trading
BaFin	German Federal Financial Supervisory Authority
BCBS	Basel Committee on Banking Supervision
BIS	Bank for International Settlements
CAT	Consolidated Audit Trail
CMB	Capital Markets Board of Turkey
CFTC	U.S. Commodity Futures Trading Commission
CME	Chicago Mercantile Exchange
CQS	Consolidated Quotation System
CTS	Consolidated Tape System
DJIA	Dow Jones Industrial Average
EBA	European Banking Authority
EC	European Commission
ECB	European Central Bank
EDGAR	U.S. Electronic Data Gathering, Analysis, and Retrieval System
EFIF	European Forum for Innovation Facilitators
EIOPA	European Insurance and Occupational Pensions Authority
E-Mini	S&P 500 Futures Contracts
ESMA	European Securities and Markets Authority
ETF	Exchange Traded Fund
EU	European Union
EWS	Early Warning System
FED	U.S. Federal Reserve System
FDIC	Federal Deposit Insurance Corporation

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FINRA	U.S. Financial Industry Regulatory Authority
FinTech	Financial Technology
FSB	Financial Stability Board
FSP	Financial Services Provider
HFT	High-frequency Trading
HFTs	High-frequency Traders
IMF	International Monetary Fund
LRPs	Liquidity Replenishment Points
MIDAS	Market Information Data Analytics System
NBBO	National Best Bid and Offer
NLP	Natural Language Processing
NMS	National Market System
NYSE	New York Stock Exchange
OCC	Office of the Comptroller of the Currency
PSD	Prudential Supervisory Disclosure
RegTech	Regulatory Technology
SEC	U.S. Securities and Exchange Commission
SPY	S&P 500 SPDR Exchange Traded Fund (SPDR: Standard and Poor's Depository Receipt)
SRO	Self-Regulatory Organization
SSM	Single Supervisory Mechanism
SupTech	Supervisory Technology
TECHs in Finance	FinTech, RegTech, SupTech, and other "Tech" areas in Finance and at Financial Sectors.
U.S.	United States of America
VIX	Volatility Index
VPIN	Volume-Synchronized Probability of Informed Trading

Introduction

Technological imbalance or asymmetric technology between financial markets or institutions and their supervisors is more dangerous than cyber-attack risks since cyberattacks are well-known risk types; hence, there is considerable vigilance to develop shields against them. However, the lack of a well-functioning supervisory technology (SupTech) leaves many doors wide-open for detrimental technological transactions and their ensuing effects on an economy's financial stability. In other words, asymmetric technology between financial markets and the relevant supervisors is one of the most significant risks today. Therefore, having a digital financial supervisory system with a well-functioning SupTech is one of the best risk management strategies in this regard.

Since the October 1987 crash originated at the U.S. markets, the financial market structure has evolved as technological advancements that have enabled participants to trade using algorithms with little or no human intervention (Kirilenko et al. 2018). Today, digital finance and the FinTech world have a lot of tools and technologies, including high-frequency trading (HFT) and algorithmic trading (AT). HFT and AT were intensively debated due to the May 6, 2010, flash crash and received close attention by the public and regulators (Gomber et al. 2017). This debate also triggered intensive academic research on the impact of high-frequency trading and algorithmic trading on market quality, especially market stability and integrity (Gomber et al. 2017). However, the roles of supervisors in the digital financial world have not been discussed enough to develop new instruments to answer new risks arising from new technological tools, market speed, and big data. The May 6 flash crash is a convenient case to analyze the roles and possible responding technologies and policies against FinTech-related risks.

The market events of May 6, 2010, shook the confidence of market participants and raised questions about the market structure of electronic markets (Kirilenko et al. 2017). Considering the regulatory and supervisory responsibilities, it also raised questions about possible responses with SupTech. Most academic papers and discussions about the May 6 flash crash have focused on the market microstructure. However, supervisory agencies' roles are not less important than that. We believe that the May 6 case has more issues and implications than the concerns about the market structure. For example, the May 6 case addresses a market disorder that nurtures fear and panic and feeds market-made detrimental stories about the crash, which might fuel further crashes and vicious circles, ultimately crises.

One of the concerns about the May 6 case was uncertainty during the market crash. With a flashback perspective, we collected information about responses of market participants and media to the crash. No one, including the supervisors, did know what happened during the day, even after the day until the supervisory agencies revealed a joint report with convincing findings, approximately five months later, on September 30, 2010.

The SEC's chairperson announced with a written statement on May 20, 2010, that: "*On the Monday following the events of May 6, I met here in Washington with the leaders of six markets—New York Stock Exchange, NASDAQ Stock Market, BATS Exchange, Direct Edge ECN, International Securities Exchange, and Chicago Board Options Exchange—and FINRA, to discuss the causes of market events of May 6, the potential contributing factors, and possible market reforms. The meeting was productive and collaborative, and there was a strong consensus that the type of aberrational volatility experienced on May 6 is wholly*

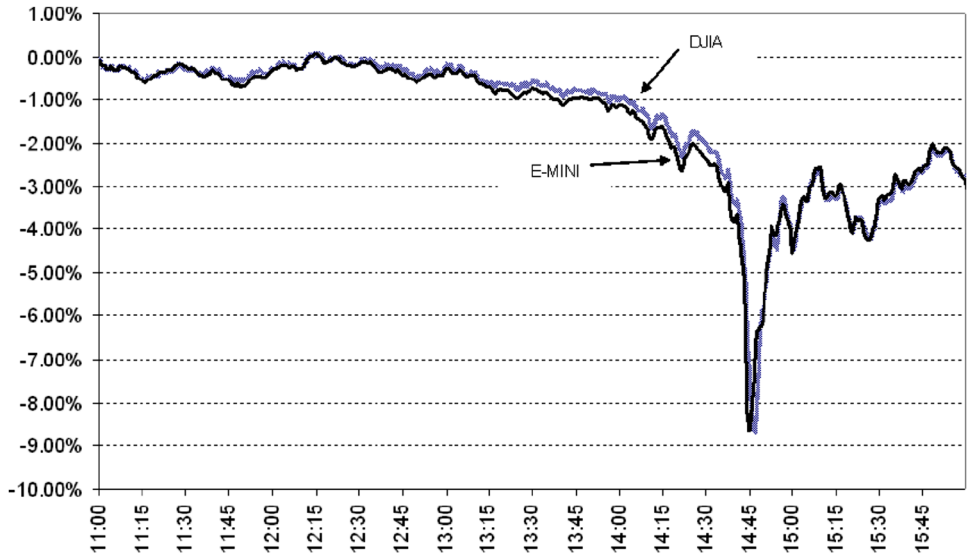

Fig. 1 Decline of E-Mini and DJIA Based on 11:00 AM Levels. Source: Schapiro (2010); Bloomberg

unacceptable in our markets." The May 6 case has forced the U.S. financial supervisors to reform their infrastructure.

Analyzing the May 6 case and examining the reform efforts, we have realized that financial supervisors need entirely new instruments to monitor and supervise today's markets. This paper mainly focuses on prudential supervisory disclosure and the reasoning behind it with a real and stunning case, the May 6 flash crash.

Prudential supervisory disclosure is the set of disclosure rules for supervisors to inform the market participants timely about market-wide harmful conditions and activities to preserve market integrity and protect markets from detrimental rumors, orders and transactions by using their SupTech capacity. This paper's concept is much more related to the biggest economies, such as the U.S. and the EU, since their state-based or member-based economic areas are more conducive to the PSD model.

This paper consists of two sections. In the first section of this paper, we analyze the May 6 market crash from the supervisory technology perspective and the media and market participants' reactions. The second section explains the general framework of the new concept, prudential supervisory disclosure, and its implications for banking and capital markets sectors. The conclusion gives a summary of our findings, views, and highlights.

Analysis of the May 6 market crash and aftermaths

Chronological order of the May 6 market crash

On May 6, 2010, the negative sentiment, unsettling political and economic news from overseas concerning the European debt crisis, led to growing uncertainty in the financial markets (CFTC and SEC 2010). This negative sentiment-driven sell pressure and flight to quality transactions accelerated the overall decline in the financial markets suddenly beginning shortly after 2:30 PM (CFTC and SEC 2010).

The following graph indicates the path and the timing of the E-Mini and the DJIA movements on May 6, based on 11:00 AM levels (Fig. 1).

As shown by the graph, the market crash deepened in 30 min, but market indicators came back in one hour, with around 2% decline based on 11:00 AM levels.

The following table is the flashback of the events of May 6 (Table 1).

On May 6, in the four-and-one-half minutes (from 2:41 p.m. through 2:45:27 PM), prices of the E-Mini had fallen by more than 5%, and prices of the SPY suffered a decline of over 6% (SEC and CFTC 2010). Internal stabilizers or circuit breakers carried out an important function to prevent further liquidity and price collapses. For example, at 2:45:28 PM, trading on the E-Mini was paused for five seconds when the Chicago Mercantile Exchange (CME) Stop Logic Functionality[1] was triggered; hence, the sell-side pressure in the E-Mini was partly alleviated, and the buy-side interest increased, and when trading resumed at 2:45:33 PM, prices stabilized and shortly after that, the E-Mini began to recover, followed by the SPY[2] (SEC and CFTC 2010). We

[1] Stop Logic Functionality pauses trading when the trading engine recognizes that it has a series of resting stop orders that could lead to a cascade and move the market up or down beyond a specified amount (SEC and CFTC 2010).

[2] In contrast to the fact that the Chicago Mercantile Exchange (CME) Stop Logic Functionality was triggered and functioned, the SEC and the CFTC (2010) reported that the staffs of the CFTC and SEC were working together with the markets to consider recalibrating the exist-

Table 1 The May 6 Market Crash Timeline

Phases	Time	Event	Effects and Results
Phase I	1:00 PM	Due to the news from overseas concerning the European debt crisis, broadly negative market sentiment was affecting an increase in the price volatility of some individual securities	The number of volatility pauses, also known as Liquidity Replenishment Points (LRPs), triggered on the New York Stock Exchange (NYSE) in individual equities listed and traded on that exchange began to substantially increase above average levels
	2:30 PM	The S&P 500 volatility index (VIX) was up 22.5 percent from the opening level	Yields of ten-year Treasuries fell as investors engaged in a "flight to quality," and selling pressure had pushed the Dow Jones Industrial Average (DJIA) down about 2.5%
	During the first phase, from the open through about 2:32 PM, prices were broadly declining across markets, with stock market index products sustaining losses of about 3%		
Phase II	2:32 PM	A large fundamental trader (a mutual fund complex) initiated a sell program to sell a total of 75,000 E-Mini contracts (valued at approximately $4.1 billion) as a hedge to an existing equity position via an automated execution algorithm and executed the sell program by only targeting trading volume, and neither price nor time, extremely rapidly in just 20 min	Sell pressure was initially absorbed by: high-frequency traders (HFTs) and other intermediaries in the futures market, fundamental buyers in the futures market, and cross-market arbitrageurs who transferred this sell pressure to the equities markets by opportunistically buying E-Mini contracts and simultaneously selling products like SPY or selling individual equities in the S&P 500 Index As a result, HFTs accumulated a net long position of about 3,300 contracts
	From about 2:32 PM through about 2:41 PM, the broad markets began to lose more ground		
Phase III	2:41 PM- 2:44 PM	HFTs aggressively sold about 2,000 E-Mini contracts to reduce their temporary long positions. At the same time, HFTs traded nearly 140,000 E-Mini contracts or over 33% of the total trading volume	Two liquidity crises – one at the broad index level in the E-Mini, the other with respect to individual stocks
	2:45:28 PM	Trading on the E-Mini was paused for five seconds when the Chicago Mercantile Exchange Stop Logic Functionality was triggered to prevent a cascade of further price declines	Sell-side pressure in the E-Mini was partly alleviated and buy-side interest increased
	Volume spiked upwards and the broad markets plummeted a further 5–6% to reach intra-day lows of 9–10%		
Phase IV	2:45:33 PM-3:00 PM	Trading resumed	Prices stabilized and shortly thereafter, the E-Mini began to recover, followed by the SPY
	Broad market indices recovered while at the same time many individual securities and ETFs experienced extreme price fluctuations and traded in a disorderly fashion		
Phase V	3:00 PM -Closings	Most securities had reverted to trading at prices reflecting true consensus values	After the market closed, the exchanges and FINRA met and jointly agreed to cancel (or break) all such trades under their respective "clearly erroneous" trade rules
	Prices of most individual securities significantly recovered, and trading resumed in a more orderly fashion		

Source CFTC and SEC (May 2010) and SEC and CFTC (2010); outlined by the Authors

*Within the NYSE's hybrid floor/electronic trading model, on May 6, the NYSE implemented price-bands known as "liquidity replenishment points.", or LRPs. LRPs are intended to act as a "speed bump" and to dampen volatility in a given stock by temporarily converting from an automated market to a manual auction market when a price movement of sufficient size is reached SEC and CFTC (2010)

In the course of the day, VIX, a measure of the expected volatility of the S&P 500 Index, increased by 31.7 percent, which was the fourth largest single day increase in VIX SEC and CFTC (2010)

It was realized that especially in times of significant volatility, high trading volume is not necessarily a reliable indicator of market liquidity SEC and CFTC (2010)

contemplate that the circuit breakers played an important role in alleviating the crash stress and adverse effects. Even though the circuit breakers at different markets function with different parameters and protect the markets from broader and higher price and liquidity collapses, they are mainly not for public disclosure and an information source against market rumors and uncertainty. Circuit breakers might be a window for fresh air and an opportunity to gain some time for making a prudential supervisory disclosure, but they

Footnote 2 (continued)

ing market-wide circuit breakers—none of which were triggered on May 6—that apply across all equity trading venues and the futures markets.

cannot carry out any supervisory disclosure role. Even, circuit breakers might signal unintended messages to markets and market participants. Moreover, there is no guarantee that circuit breakers work properly or work at all in every case. During the U.S. Treasury "Flash Rally", on October 15, 2014, market safeguards could not prevent large price movements[3] (Bouveret et al. 2015).

Cross-market propagation issues were also in the center of the May 6 market crash. Since many products and markets are connected to each other, a market crash may trigger another one, multiple exchanges and trading platforms might be affected without knowing the real causes of the crashes they face at their markets. For example, a stock market crash at an exchange might trigger other crashes at derivatives exchanges due to the underlying stocks or stock indices. In this case, the derivatives exchange members or managers cannot know the real causes of the market crash at derivatives markets. However, a supervisory agency that has a real-time data collection capacity from all markets, either stock markets or derivatives markets, can capture the causes of a market crash or intervene with before a crash comes out by applying advanced data analytics. Thus, the May 6 type FinTech crises only can be managed by a real-time market-wide data collection capacity, which is one of the essential features of a well-functioning SupTech system. Moreover, we should point out that the supervisory model of the U.S. financial markets is still not functional, since considering the case above, the SEC and the CFTC have different market responsibilities. Without perfect coordination and collaboration, which is not a case in many times among national financial supervisors, cross-market propagation issues cannot be managed, even with the real-time data collection capacity.

The May 6 market crash indicated that during the crash, not only media and individual investors but also institutional investors did not know about the real causes of the crash since they were not able to see the whole picture of the markets. Considering asymmetric information environment during the market crash, based on their respective individual risk assessments, some market makers and other liquidity providers widened their quote spreads, others reduced offered liquidity, and a significant number withdrew completely from the markets (SEC and CFTC 2010). Not only did some withdraw, but arguably they became liquidity consumers by dumping their inventories, thus exacerbating the crash (Easley et al. 2011). The flash crash might have been avoided, or at least tempered, had liquidity providers remained in the marketplace[4] (Easley et al. 2011).

Our idea is that only exchanges or SROs like FINRA and financial supervisors, such as the SEC and the CFTC, could help protect the markets by making a statement from further deterioration. Uncertainty and the fear about the causes of the May 6 crash harmed the market integrity and market quality. The harm could be less with the supervisors' immediate disclosure statement in the sense of prudential supervisory disclosure. However, at the time, neither the CFTC nor the SEC had the capacity to inform the markets with the facts about the crash.

One of the observations is that many (though not all) firms significantly curtailed or completely halted their trading activities at some point during the afternoon of May 6 (SEC and CFTC 2010). Data integrity issues were their number one concern. This also addresses the prudential supervisory disclosure. With the real-time data collection capacity from multiple data centers and having data integrity control capacity, during the cases like the May 6 market crash, the supervisors can inform the markets and eliminate potential concerns or clarify the situation for better market quality.

Data-integrity pauses were the reality of markets at the time. There were some other concerns about this unusual market behaviors. For example, at the time, it could be hypothesized that these delays were due to a manipulative practice called "quote stuffing" in which high volumes of quotes were purposely sent to exchanges in order to create data delays that would afford the firm sending these quotes a trading advantage (SEC and CFTC 2010).

Even though neither FinTech nor SupTech was a part of financial terminology at the time, the SEC and the CFTC's report (September 2010) addresses FinTech, RegTech, and SupTech concepts (TECHs in Finance) many times without using these terms. The following paragraph is one of the key statements indicating agencies' concerns in this regard:

"*The events of May 6 clearly demonstrate the importance of data in today's world of fully-automated trading strategies and systems. The SEC staff will therefore be working closely with the market centers to help ensure the integrity and reliability of their data processes, especially those that involve the publication of trades and quotes to the consolidated tape. In addition, the SEC staff will be working with the market centers in exploring their members' trading practices to identify any unintentional or potentially abusive or manipulative conduct that may cause such system delays that*

[3] Even though the market safeguards, circuit breakers, were not triggered on October 15, 2014, they were triggered previously (Bouveret et al. 2015).

[4] The paper of Easley et al. (2011) suggests the Volume-Synchronized Probability of Informed Trading (VPIN) as a solution. The VPIN might capture the increasing toxicity of the order flow in the hours and days prior. The VPIN contract might be used with prudential supervisory disclosure to monitor and manage similar risks dynamically.

inhibit the ability of market participants to engage in a fair and orderly process of price discovery."

Being supervisors of the foremost capital markets in the world, the SEC and the CFTC have been aware of the importance of technology. However, digital transformation with a cutting edge SupTech system and a country-wide market reform requires political leadership and strong financial support, which have been not entirely in the hands of the agencies. The same bottleneck holds for almost all financial regulators and supervisors.

Reactions of the market participants and the media

The reactions of market participants during the day on May 6 have been analyzed by both financial agencies and academics. The SEC and CFTC reports tried to capture the behaviors of different market actors. In response to the increased risk perceptions, some market makers and other liquidity providers widened their quote spreads, others reduced offered liquidity, and a significant number withdrew completely from the markets (SEC and CFTC 2010). The investigations of the staffs of the SEC and the CFTC revealed that the largest and most erratic price moves observed on May 6 were caused by withdrawals of liquidity and the subsequent execution of trades at stub quotes.

Academic papers also analyzed the market structure and reached some results for the FinTech world. For example, the papers of Kirilenko, Kyle, Samadi, & Tuzun, *The Flash Crash: High-Frequency Trading in an Electronic Market* (2017) and *Automation, Intermediation and the Flash Crash* (2018) assert that HFTs behave differently than traditional market makers; their behavior is empirically more consistent with quote sniping than traditional market-making.

The final report of the May 6 case was published on September 30, 2010, and it has more robust evidence about the causes of the events. However, with the preliminary report, the CFTC and SEC's staffs were considering some working hypotheses. There were no clear and definite findings even though the agencies delivered 150-page preliminary reports on May 18, 2010, twelve days later.

For the informational efficiency and market integrity concerns, market participants should be informed by the responsible authorities in critical times and should not be left in the hands of rumor feeds. We also believe that market participants should be well informed to reduce adverse selection risks and other outcomes of the inefficient informational environment.

Some financial news sources were mentioning about a "fat finger" issue as the triggering source of the crash. The preliminary report's response to these rumors and news was as follows (CFTC and SEC 2010): "*We have found no evidence that these events were triggered by "fat finger" errors, computer hacking, or terrorist activity, although we cannot completely rule out these possibilities.*" This statement and the preliminary report's general findings suggest that both agencies did not have enough evidence to rule out rumors and detrimental news feeds. The SEC's chairperson also touched on the "fat finger" rumors as follows (Schapiro, Testimony Concerning the Severe Market Disruption on May 6, 2010, 11 May 2010): "*There have been reports in the press about a "fat-finger" error where, it is hypothesized, an order of billions of shares was entered, rather than an intended order of millions of shares. While we cannot yet definitely rule that possibility out, neither our review nor reviews by the relevant exchanges and market participants have uncovered such an error.*"

The May 6 market crash also attracted the attention of the media. Economic and financial media are important sources of information for financial consumers. Peress (2014) demonstrates that the media influence the stock market by increasing the speed with which information diffuses across investors and is impounded into stock prices.

Borch (2017) evaluates the experimental impact (the Flash Crash's effect on market participants), the real economic impact (the actual economic effects) and the potential systemic impact (the systemic risk involved in algorithmic trading, as illustrated in the crash), and subsequently argues that each impact is contestable.

Borch (2017), inter alia, discusses the following three aspects of the May 6 flash crash for today's financial markets: (a) as an event that significantly changed how market participants perceive markets; (b) as an event that generated a massive loss of value, and hence had or could have had considerable economic effects; and/or (c) as an event that is symptomatic of a novel set of systemic risks associated with algorithmic finance.

We took snapshots of some available news feeds about the flash crash to conceptualize the effects of the uninformed media risk (Table 2).

The executive vice president and head of operations at the NYSE Euronext's New York Stock Exchange commented on the May 6 crash that "*This highlights the risks of electronic trading. When you have low volatility, electronic trading works very well. But there are risks. It highlights the need for human-based intervention.*" (Lauricella and McKay 2010).

Four years later, a news portal commented on the case as follows (CNBC 2014):

> The Dow Jones Industrial Average slumped nearly 1000 points in a matter of minutes in the flash crash of 2010, sending traders into a panic and inciting scrutiny of the U.S. equities markets that's still being felt four years later.
> The May 6, 2010, crash was initially blamed on a "fat-finger" error made at Citigroup-a theory that was later shot down and ultimately attributed to investment firm

Table 2 Economic and Financial Media Comments on the Market Events of May 6, 2010

News source	Date	Comment
Reuters	6 May 2010	"The Dow suffered its biggest ever intraday point drop —998.5 points. The market's fall may have been exacerbated by erroneous trades that showed some shares briefly fell to nearly zero The situation remained unclear long after the closing bell as the Nasdaq Stock Market and others said they would cancel multiple erroneous trades. Other exchanges scrambled to examine orders." (Krudy 2010)
Forbes.com	6 May 2010	"Why the market plunged so much and so fast in the middle of the afternoon isn't entirely clear. Some blame an erroneous quote on Procter & Gamble (PG), saying it caused panic selling across the board. Others say the selloff was caused by a trading error on the Nasdaq. This so-called fat-finger error occurred when a trader accidentally entered an order to sell a billion shares rather than a million shares. Still others blame the rioting in Greece for the selloff. That rioting was widely broadcast on trading floors." (Janjigian, 2010)
CNBC.com (TV)	6 May 2010	A commentator on TV: "…machines broke down…", "…the system obviously broke down…" "…it broke down, machines broke down…" A speaker on TV: "…there should be an investigation…" A speaker asks a question about the P&G prices: "…with P&G is there any rational way that you could describe P&G being three percent down and then 25 within what was in 90 s to three minutes?…" A P&G analyst answers: "…no as machines that to be broken I mean there is no fundamental reason for Procter to be down more than two percent today…" (CNBC 2010)
Wall Street Journal	7 May 2010	"A bad day in the financial markets was made worse by an apparent trading glitch, leaving traders and investors nervous and scratching their heads over how a mistake could send the Dow Jones Industrial Average into a 1,000-point tailspin." "Traders theorized that an initial trading error triggered a piling-on effect from computerized trading programs designed to sell when the market moves lower. At the same time, pre-set orders from individual traders and investors to sell on declines during market downturns were likely triggered." "The move highlighted how fragile U.S. markets have become and how the various fragmented markets have deficiencies in the way they buffer volatility." (Lauricella and McKay 2010)
Marketwatch.com	11 May 2010	"Two top financial regulators said Tuesday they aren't sure yet what caused the stock market's dizzying May 6 plunge and partial recovery, but they don't believe any one event created it At issue is the Dow Jones Industrial Average drop of nearly 1,000 points last Thursday—a fall of roughly $1 trillion in market value—much of it in a matter of minutes, before recovering to a 348-point loss for the session Both Mary Schapiro, Securities and Exchange Commission chairwoman, and Gary Gensler, Commodity Futures Trading Commission chairman, refuted speculation that a trader might have made a so-called "fat finger" error that contributed to the stock market plunge." (Orol 2010)
Financial Times	14 May 2010	"Just over a week later the cause of the "flash crash", where in the space of those 20 min stocks plunged and rebounded, still remains a mystery. Talk, however, circulates that an algorithm, or "algo" computer program that dominates trading these days, may have exploited an already nervous market by sinking the shares and then buying them back at much cheaper prices." (Mackenzie 2010)

Source References and the Authors

> Waddell & Reed. But in addition to that trading error, a number of possible reasons for the crash has since come to light. One of those supposed causes was high-frequency trading, according to a report from the Securities and Exchange Commission that year.

As another comment made in the fourth anniversary of the flash crash has been raised an idea that the causes are still not fully agreed (Krantz 2014):

> Even four years after the crash that wiped out $1 trillion in wealth in the blink of an eye, investors and academics still haven't agreed on what caused one of the most vicious and inexplicable short circuiting of market to occur.

On May 6, the market participants were in a panic situation, and neither market participants nor market surveillance units did have a data-driven explanation about the market turmoil. On May 6, traders were also stunned by the sudden sharp moves (Lauricella and McKay 2010).

Risk and uncertainty are entirely different concepts. Uncertainty leaves risk management techniques ineffective. For financial markets, uncertainty also fuels rumors and home-made stories about market events, as the markets experienced during and after the May 6 market crash. The best strategy in these cases is getting rid of uncertainty. In this regard, financial supervisors should have an automated and real-time data collection capacity with advanced data analytics tools as well as prudential supervisory disclosure capacity to keep the markets running without uncertainty.

Supervisory technological capacity of the U.S. financial authorities

The May 6 market crash also an indicative market event in terms of the technological capacity of the U.S. financial authorities in 2010. There were and still are two main regulatory and supervisory agencies for the U. S. capital markets: The Securities and Exchange Commission, the SEC, and the Commodity Futures Trading Commission, the CFTC. Two agencies established a Joint CFTC-SEC Advisory Committee on Emerging Regulatory Issues. The Committee's establishment was one of twenty recommendations included in the agencies' joint harmonization report issued in October 2009 (CFTC and SEC 2010). The joint committee published the "Preliminary Findings Regarding the Market Events of May 6, 2010," on May 18, 2010, twelve days after the case. The report's content draws a general picture about the initial findings of the May 6 market crash. The same report also gives the framework of the U.S. financial markets as well as the supervisory technology at the time. The following statement with the CFTC and the SEC (2010) report is a summary of the SupTech capacity of the U.S. financial supervisors at the time:

> It is important to emphasize that the review of the events of May 6 is in its preliminary stages and is ongoing. The reconstruction of even a few hours of trading during an extremely active trading day in markets as broad and complex as ours— involving thousands of products, millions of trades and hundreds of millions of data points—is an enormous undertaking. Although trading now occurs in microseconds,[5] the framework and processes for creating, formatting, and collecting data across various types of market participants, products and trading venues is neither standardized nor fully automated. Once collected, this data must be carefully validated and analyzed. Such further data and analysis may substantially alter the preliminary findings presented in this report. The staffs of the Commissions therefore expect to supplement this report with further additional findings and analyses.

In summary, the U.S. financial authorities, the SEC and the CFTC, in 2010, did not have.

- real-time data collection capacity,
- cross-market surveillance capacity,
- consolidated transaction data collection capacity,
- consolidated order tracking system,
- standardized data,
- fully automated data collection system (CFTC and SEC 2010).

On the other hand, there was no evidence that both agencies deployed advanced data analytics technologies such as artificial intelligence, machine learning, natural language processing. The above picture was as of May 2010. However, Broeders and Prenio (2018) mentions data analytics tools that the SEC either uses or projects to use as of 2018.

In response to the situation realized after the May 6 flash crash, the SEC announced a project that may eliminate legacy systems, let the agency collect real-time basis data, and deploy advanced data analytics. We will handle the policy response of the U.S. financial supervisors in the following chapters. However, the May 6 case clearly indicated that the U.S. financial supervisors, namely the SEC and the CFTC did not have good enough SupTech capacity at the time, even though the U.S. is one of the leading technology innovating countries in the world.

Since the October 1987 crash, the market structure has evolved as technological advancements have enabled participants to trade using algorithms with little or no human intervention (Kirilenko et al. 2018). The requirements of supervisory technology for the U.S. markets have been signaled since the 1980s; however, the pace of the technology adoption has been significantly different between the markets and their supervisors. We observe here another fact that it is not about having available technology; it is about organizing, designing, and having a well-functioning SupTech and supervisory system at large. On the other hand, as we pointed out in different sections, having a full-fledged SupTech system is not entirely tied to financial supervisors. It requires additional funds and political support as well as leadership.

Since the U.S. capital markets have more than one supervisor, authorities shared the workload of analyzing the data considering their responsibility areas. In this regard, for example, the SEC has sourced and analyzed price, time, and volume data on over 19 billion shares executed on May 6, and quote data representing the best bid and best offer for over 7,800 securities, for each exchange, for each millisecond during the trading day, and the CFTC has analyzed transaction and order book data on stock index futures, including the E-Mini S&P 500 futures contract (CFTC and SEC 2010). Data collection, consolidation, and data analytics from two different channels by two different supervisors in the same jurisdiction for the same case are not effective supervisory strategies in the FinTech world.

After the May 6 case, the SEC emphasized the importance of having a consolidated order tracking system or consolidated audit trail system. If adopted, this rule proposal should result in a continuous reporting mechanism for market participants to capture the data needed for effective

[5] One million microseconds are equal to one second ($1\ \mu s = 10^{-6}$ s).

Table 3 Overall quality check of the dimensions of the U.S. financial supervisory system as of May 2010

Feature	Status
Organizational Structure	Fragmented
Supervisory Model	Not for the FinTech World
Real-Time Data Collection	NA
Automated Data Collection	Partly
Digital Identification	NA
Early Warning System	NA
Regulatory and Industry Sandboxes	NA
Data Analytics	Partly
Prudential Supervisory Disclosure	NA

Source The Authors

The exchanges report the daily positions and transactions of each clearing member to the CFTC and the data are transmitted electronically during the morning after the "as of" date SEC and CFTC (2010). The CFTC also collects trade data on a daily, transaction date + 1 ("T + 1"), basis from all U.S. futures exchanges through Trade Capture Reports SEC and CFTC (2010)

For the CFTC, all transactional data is received overnight, loaded in the CFTC's databases, and processed by specialized software applications that detect patterns of potentially abusive trades and alerts SEC and CFTC (2010)

cross-market surveillance (CFTC and SEC 2010). Cross-market surveillance was not in play on May 6. Therefore, it was impossible to capture the big picture of the U.S. capital markets. Together with other lessons, the May 6 crash was an important reminder of the inter-connectedness of derivatives and securities markets, particularly with respect to index products (SEC and CFTC 2010).

As specified with the paper (Zeranski and Sancak 2020), one of the most critical features of a financial supervisory system is the real-time data collection. For example, the exchanges report daily to the CFCT, and the agency conducts daily surveillance with them. Daily surveillance seems to be a close look at the market; however, it is not enough in the FinTech environment.

Considering the main features of a digital financial system set forth by the paper Zeranski and Sancak (2020), we evaluate the overall quality of the dimensions of the U.S. financial supervisory system with the following table (Table 3).

Beyond the table above, the U.S. financial markets have two structural weaknesses from the supervisory perspective. First, the U.S. markets are fragmented.[6] However, it is hard to change this picture in a free market economy. Second, the supervisory structure is fragmented, and this also poses a significant risk for the markets. The May 6 case forced to bring the CFTC and the SEC together on a project basis. However, later, the flash events in the U.S. Treasury markets of 15 October 2014 led to a bigger coordination requirement: the U.S. Department of the Treasury, the FED, the Federal Reserve Bank of New York, the SEC and the CFTC. Restructuring economic and financial agencies is a national economic area, and it is in the hands of the governments and politicians. It is a strategic risk management area. Thus, it is a real challenge but still possible.

Supervisors' technological, administrative, and policy responses

The CFTC and SEC's initial report, Preliminary Findings Regarding the Market Events of May 6, 2010, was partially relieving work to eliminate some rumors and cascading effects of the crash; however, it was not a clear answer at the time. The report stated the lack of.

- real-time,
- standardized,
- automated data collection features.

These features are the main pillars of digital financial systems in the FinTech world (Zeranski and Sancak 2020). The content of the initial report and some statements, such as "*It is important to emphasize that the review of the events of May 6 is in its preliminary stages and is ongoing."* and *"Much work is needed to determine all of the causes of the market disruption on May 6.*", were not so helpful to manage the fear of the markets. The report's main message was not signaling a strong perception of the technology-oriented supervision of the markets. Instead, it was signaling that there was a considerable gap between the technology that markets used and the supervisors' technology. In other words, asymmetric technology was the case. What makes the case worse, the U.S. financial markets faced an undefined situation, and the supervisors were not in the capacity to spot the causes of the crash until the final report came out on September 30, 2010. The reform efforts and official statements also signaled a long way to close the gap.

Knowing the root causes of a market crash enables supervisors to respond to the drivers of the crash timely and adequately. The May 6 case indicates that supervisors did not have SupTech tools to respond to the drivers or decide whether any additional supervisory measures should be taken on May 6 or in the aftermath. In other words, at the time, neither financial supervisors nor market participants did know what happened and why it happened exactly. Probably the large trader who gave momentum to the market

[6] Although fragmented markets may have many implications, in the context of the May 6 crash, Albert J. Menkveld and Bart Zhou Yueshen's research, *The Flash Crash: A Cautionary Tale about Highly Fragmented Markets*, suggests that liquidity supply in severely fragmented markets might become vulnerable when liquidity is demanded.

crash with its algorithmic trading also did not know what happened and why it happened.[7]

The May 6 case raised another question at the time: Who was responsible for the supervision of the May 6 market crash? The SEC or the CFTC? Since the causes of the market crash were not known during the day, the responsible supervisor could be one of them or both of them could be. Or, the worst-case scenario; none of the agencies assumes responsibility to act immediately. This question also points out another fact: The organizational model of the U.S. financial markets per se a source of risk in the sense that there was an ambiguity about the responsible supervisory authority to respond to the market crash. The responsible supervisor might be the CFTC or the SEC.[8] Since there was no solid information about the causes of the flash crash, it was also unclear that which of them would act against the market crash. Thus, the supervisory model of the U.S. financial system has been improper for the FinTech world. The country's model has been under discussion after the global financial crisis of 2008. Today, the fast-developing FinTech sector addresses the need of reform requirements again.

It can be said that coordination is the answer. However, coordination between two different independent supervisory organizations is both an intricate issue and time-consuming in practice. In the FinTech world, market crashes require prompt response and reaction. There is no time to develop new formal working groups from different organizations for taking prompt actions during market crashes like the May 6 crash. Thus, cumbersome, and difficult-to-update systems, like the U.S. financial supervisory system, are relatively riskier than the easy-to-update financial systems.[9]

Unless financial supervisors have multi-market and multi-asset supervision capacity, having successful supervisory infrastructure at one part of the markets is not enough for protecting market integrity. The U.S. financial supervisors have been aware of this fact and their report (2010) put it in this way:

> An important lesson from the events of May 6 is the need to better understand cross-market linkages between trading venues for exchange-traded funds, equity index futures, and equity index options—instruments used by investors to manage their exposures in the face of broad market movements.

We agree the idea stated with the CFTC and the SEC report (2010) that a uniform circuit breaker rule, which would briefly pause trading across the securities markets when the price of a security has rapidly declined over a short time, should make a recurrence of a severe market disruption, like the one that occurred on May 6, much less likely. However, circuit breakers neither inform financial supervisors nor market participants about exactly what happened at the market. Moreover, circuit breakers may not function in every case.

Designing a well-functioning circuit breaker system is a significant step to relieve extraordinary market movements. However, it does not give a picture of abusive market transactions. If we assume that a circuit breaker system works very well, but the supervisors do not have real-time data collection capacity, in this case, supervisors still may not know what happened at the market. As stated within the second report (2010), market participants might interpret a triggered circuit breaker with their own story and might attribute greater importance to the circuit breakers or market pauses. Thus, we infer that particularly for fragmented and relatively bigger financial markets, precisely for the U.S. capital markets, a centralized responsible authority should inform the markets about the nature of the extraordinary market events. We name this kind of announcements or disclosure policy as "prudential supervisory disclosure". As we explain it in a separate section, an important feature of disclosure policy is that announcements are not discretionary. Thus, market participants know that there will be an announcement, and they will know what is happening exactly.

To sum up, whatever was the root cause of the flash crash, market participants and the public should have been informed about that. Unless an authority, which has a capacity to capture the picture of the market, announces the facts about unusual market events, market participants and media will produce their stories. In this regard, financial supervisors should have a SupTech capacity such that they can capture all market activities, namely orders and transactions in a real-time basis, and in certain situations, public disclosure should be mandatory but not discretionary for financial supervisors so as not to let media and market participants use their news production vision about probable causes of a market event.

On the other hand, both the SEC and the CFTC took lessons from the May 6 case and started new projects against similar crises.

In order to increase the timeliness and efficiency of account identification, the CFTC was considering possible rules to enhance the CFTC's surveillance capabilities by

[7] We assume that none of the traders has an intention to cause the market crash at the time. Since no one, including financial supervisors, has the capacity to see all the data at all markets, we assume that a single trader also cannot know the causes of the May 6 crash during the day.

[8] In fact, it was turned out that both the equity and the derivatives markets experienced severe declines and disorders on May 6. Thus, the May 6 case was about both the securities market and the derivatives market. That means the case was both in the SEC and in the CFTC's areas of responsibility.

[9] There is a misconception that developed countries have always advantage in terms of technological reforms. In fact, this is not the case for every developed country.

deploying automation of the statement of reporting traders in the large trader reporting system and obtaining account ownership and control information in the exchange trade registers (CFTC and SEC 2010).

On May 20, the SEC's chairperson stated that (Schapiro, Examining the Causes and Lessons of the May 6th Market Plunge, 20 May 2010);

> During a 20-min period during the afternoon of May 6, the U.S. financial markets failed to live up to their essential price discovery function. That period of gyrating prices directly harmed those investors who traded based on flawed price discovery signals, and it undermined the confidence of investors in the integrity of the markets. We are committed to taking all necessary steps to identify causes and contributing factors and are already working to reduce the likelihood of a recurrence of that day.

Some of the SEC's proposals were about the market structure of the U.S. capital markets. Since the market structure is not the main theme of this paper, we focus on other proposals, mainly ones about the supervisory capacity of the agency.

One of the critical steps on the way of development of a well-functioning SupTech system has been the Consolidated Audit Trail (CAT) project. In this regard, the SEC's chairperson stated that (Schapiro, Examining the Causes and Lessons of the May 6th Market Plunge 2010);

> One of the challenges we face in recreating the events of May 6 is the reality that the technologies used for market oversight and surveillance have not kept pace with the technology and trading patterns of the rapidly evolving and expanding securities markets."
> "Today's fast, electronic, and interconnected markets demand a robust consolidated audit trail and execution tracking system.

The SEC staff started in 2009 to work, in consultation with SROs and others, on a rule proposal that would require the SROs to jointly develop, implement and maintain a consolidated order tracking system, or consolidated audit trail (Schapiro, Examining the Causes and Lessons of the May 6th Market Plunge 2010). The expectations with the CAT project were mainly to increase the ability to access in real-time the majority of the data needed to reconstruct the type of the May 6 market disruption, to enhance the ability to detect and monitor aberrant and illegal activity across multiple markets.[10]

The CAT will track orders throughout their life cycle and identify the broker-dealers handling them, thus allowing regulators to more efficiently track activity in Eligible Securities throughout the U.S. markets (FINRA 2020). Through the CAT, regulators in the U.S. expect to have more timely access to a comprehensive set of trading data, enabling authorities to more efficiently and effectively conduct research, reconstruct market events, monitor market behavior, and identify and investigate misconduct (SEC 2019). The SEC estimates that the system will cost 2.4 billion USD initially and then 1.7 billion USD a year to run (Bullock and Stafford 2019). The CAT project works are still ongoing, and the project has not been in play yet.

On the way of having a well-function SupTech system, the SEC has outsourced the Market Information Data Analytics System (MIDAS). The history of MIDAS began with the need to more efficiently collect and analyze order book data for equities and futures (SEC 2013). According to the SEC, MIDAS has many applications at the SEC, and it can help the agency monitor and understand mini-flash crashes, reconstruct market events, and develop a better understanding of long-term trends. However, there are some concerns about the success of the system (Podkul 2020).

The agencies' preliminary report stated that "*Although the coordinated circuit breakers between futures and equities were not triggered, the events of May 6 reinforce the importance of having communication links between futures and equity markets so that there is meaningful and appropriate coordination of trading pauses and halts.*"

The SEC and the CFTC's circuit breaker project might be a good fit for the prudential supervisory disclosure system. As stated by the agencies within their September 2010 report, pausing a market might be an effective way of providing a window for market participants to reassess their strategies, for algorithms to reset their parameters, and for an orderly market to be re-established. In this regard, the CME's Stop Logic Functionality helped prevent a possibly bigger and more detrimental market crash by triggering a halt in E-Mini trading.

On May 31, 2012, the SEC approved a "Limit Up-Limit Down" mechanism to address market volatility by preventing trades in listed equity securities when triggered by large, sudden price moves in an individual stock (SEC 2012). In July 2012, the SEC also announced that the securities and futures exchanges have procedures for coordinated cross-market trading halts if a severe market price decline reaches levels that may exhaust market liquidity (SEC 2012). These market-wide circuit breakers may halt trading temporarily or, under extreme circumstances, close the markets before the normal close of the trading session.

During the crashes, some trades might be carried out with erroneous prices and later might be broken or canceled. However, market participants cannot exactly know which of

[10] For a summary of the SEC's proposals against the May 6 type market crashes, please see Schapiro (2010).

their trades will be canceled, and this uncertainty may cause further trading problems and produce additional risks. For example, market participants might not provide liquidity in such a case. As seen this an important lesson taken from the May 6 case, to provide market participants more certainty as to which trades will be broken and allow them to better manage their risks, the SEC staff worked with the exchanges and FINRA to clarify the process for breaking erroneous trades using more objective standards[11] (SEC and CFTC 2010). By using real-time data infrastructure, it can be much faster to spot erroneous data and manage the broken and erroneous trades.

On the other hand, in January 2020, the SEC announced that the agency would modernize the national market system. The SEC's Chairman stated that "*The Commission has received extensive public input on issues relating to equity market structure and access to market data, as well as suggestions for how that structure should be updated to ensure that our markets continue to best serve the interests of investors. Today's proposed order is designed to address issues regarding the dissemination of market data that affect the efficiency and fairness of our markets. In particular, we welcome public input on the specific proposed governance provisions.*" (SEC 2020a, b). This academic paper might be a supportive work to help increase the efficiency and fairness of the U.S. markets. However, PSD is also conducive to other markets, particularly complex markets with multiple trading venues. In this regard, the European Commission should also think about PSD implementation, considering the member states' markets.

Prudential supervisory disclosure for the digital financial world

Terminology: "Prudential", "Supervisory Disclosure", and "Prudential supervisory disclosure"

Information disclosure, public disclosure, and supervisory disclosure are well-known concepts in finance and the financial sector. Information disclosure helps contractual parties to know about all relevant information and facts of a transaction or a contract. For example, a bank informs its clients when the clients would like to buy products. If one party does not inform the other party fully and causes asymmetric information between parties, multiple risks might arise. For example, if a party does not have the full information about a contract, as the uninformed party, runs the adverse selection risk. Therefore, information disclosure is a fundamental ingredient of contracts and transactions. Public disclosure has a similar function. In a public disclosure case, one of the parties informs the unknown people, makes announcements to the public to maintain a level playing field. There are specially designated disclosure platforms to operate public disclosure activities in financial markets. For example, EDGAR is the web-based public disclosure platform for the U.S. capital markets.[12] An Internet-based platform enables all parties to reach the publicized information and help collect data. Public disclosure is one of the main features of capital markets, particularly stock markets—public statements and filings flood markets with other market information. For example, the EDGAR's system processes about 3,000 filings per day, serves up 3,000 terabytes of data to the public annually and accommodates 40,000 new filers per year on average (SEC 2020a, b). Therefore, data visualization, AI, NLP, and other technology tools are now required to benefit from available data and information.

Capital markets produce in every business day, on the one side, massive amounts of publicized information that are available at the public disclosure platforms, like EDGAR, on the other side, generate order and transaction data in markets. Data vendors sell these data to their clients. Therefore, not everybody has all the data outreach capacity. On the other hand, many financial institutions submit data to the supervisors under supervisory disclosure requirements. In this world, only several organizations can legally see all data in the financial sector. Those are financial supervisors.

Financial supervisors have macro-prudential responsibilities. "Prudential" is literally in the meaning of "*involving or showing care and forethought, especially in business*" (Lexico 2020). "Prudence" is another word for caution involving forethought, and prudential policies relate to actions that promote sound practices and limit risk-taking (European Central Bank 2017). Prudential requirements aim at making the financial sector and economy sounder and more stable. For example, the EU rules on prudential requirements mainly concern the amount of capital and liquidity of banks (European Commission June 2020). For the banking sector, the goal of these rules is to strengthen the EU banking sector's resilience so that it can better absorb economic shocks while ensuring that banks continue to finance economic activity and growth (European Commission 2020).

[11] As stated by the SEC and CFTC's report (2010), on September 10, the SEC approved the new trade break procedures, which like the circuit breaker program, is in effect on a pilot basis through December 10, 2010.

[12] EDGAR is the Electronic Data Gathering, Analysis, and Retrieval system used at the SE (SEC 2020a, b). Containing millions of company and individual filings, EDGAR benefits investors, corporations, and the U.S. economy overall by increasing the efficiency, transparency, and fairness of the securities markets (SEC 2020a, b).

Mishkin (2000) broadly defines prudential supervision as "*government regulation and monitoring of the banking system to ensure its safety and soundness*". The forms of prudential supervision might be.

- restrictions on asset holdings and activities,
- separation of banking and other financial industries like securities, insurance, or real estate,
- restrictions on competition,
- capital requirements,
- risk-based deposit insurance premiums,
- disclosure requirements,
- bank chartering,
- bank examination,
- supervisory versus regulatory approach (Mishkin 2000).

Mishkin's approach to prudential supervision is mainly related to the banking sector. However, his approach does not consider the speed and big data factors that markets face today. Two decades later, we have today completely different financial technology. Hence, prudential supervision can be used for many more areas and may have a broader mission if we enter other avenues of the financial sector.

Wall (2016) addresses advanced analytics and the importance of data by stating that the availability of more granular information, combined with new tools to analyze them, may provide supervisors with a variety of opportunities to evaluate the risk of financial systems better. The development of machine learning using deep learning techniques raises the possibility that supervisors will be able to use granular data to better understand the risks in the financial system (Wall 2016).

Sound prudential supervision policies should take into account the potential for investment firms and their clients to engage in excessive risk-taking and the different degrees of risk assumed and posed by investment firms (European Parliament 2018). With the PSD model, we also raise the idea that not only financial institutions but also markets should also be the realm of prudential supervision for the financial regulators and supervisors. According to a report of the European Parliament (2018), differences in the application of the existing framework in different member states of the EU threaten the level playing field for investment firms within the Union, hampering investors' access to new opportunities and better ways of managing their risks. This also holds for technology and the market data or prudential supervisory disclosure.

Since there might be differences in prudential supervisory capacities among the EU member states, creating a mechanism of cooperation and exchange of information among the financial authorities to ensure harmonized prudential supervision of investment firms across the Union seems to be essential (European Parliament 2018). In the FinTech world, the EU should consider the PSD model for the Union-wide risk management mechanism against market-driven risks in addition to the investment firms-based prudential supervision.

The European Banking Authority (EBA) could play a leading role in networking to help initiate a well-functioning SupTech system across the Single Market (EBA 2020). The EBA considers that the European Forum for Innovation Facilitators (EFIF) provides a good means for supervisors to share experiences on a cross-sectoral basis, aiding the identification of innovation trends, regulatory and supervisory issues that require a cross-sectoral position and to monitor interconnectedness on a multi-disciplinary basis (EBA 2020).

There are supporting views of the banking sector of the EU that FinTech activities give rise to not only operational risks but also financial risks, especially of a systemic nature (EBA 2018). And, a potential 'FinTech bubble' was raised as another issue of concern with the risk of reducing the effectiveness of monetary policy noted as another potential threat (EBA 2018). Thus, the PSD model should be considered in response to FinTech risks.

Prudential supervision can be classified into micro- and macro-prudential supervision. The prefix "macro" indicates that the policies or actions relate to the whole or significant parts of the financial system rather than individual financial institutions (European Central Bank 2017). Supervisory or regulatory policies for individual financial institutions, by contrast, are known as micro-prudential policies (European Central Bank 2017). While macro-prudential policies consider the soundness of the whole financial system, soundness and informational efficiency of markets should also be in this scope. However, today's macro-prudential policies do not focus on financial market-driven informational imbalances, particularly FinTech environment data production, usage, and the speed factors at the electronic markets.

In other words, the FinTech world brings new responsibilities to financial regulators and supervisors, as financial institutions have the responsibility of Know-Your-Customer, financial supervisors should also have "Know-Your-Markets", "Know-Your-Technology", "Know-Your-Data", and "Inform-Your-Markets" responsibilities. The truly transformative potential of regulatory technology addresses a Know-Your-Customer mindset transformation into a Know-Your-Data approach (Arner et al. 2016). FinTech crises are a new source of systemic risks and the market data are systemically important in the FinTech world. In this regard, all market data should be considered as a new area for macro-prudential supervision.

Markets produce massive amounts of data every day, and data analytics tools should be deployed at supervisory agencies. Without data analytics tools and a well-designed SupTech system, big data might be a black hole for financial

supervisors. By knowing the market data and conducting data analytics, financial supervisors can utilize big data and even stay ahead of markets. The PSD model requires a well-designed SupTech system. The PSD model has both a systemic risk management capacity and implications for transparency requirements.

The growing FinTech world addresses new business models for private sector firms and new supervision models for financial supervisors. In this regard, based on the prudential supervisory disclosure (PSD), we introduce the PSD model.

The scope, design, and functions of prudential supervisory disclosure[13]

Supervisory disclosure or public disclosure are well-known concepts in the financial industry or academic world. These are regulatory requirements for market participants but not for supervisors or financial authorities.

Financial services providers are required to disclose some information either to supervisors or to the public. On the other hand, public disclosure is one of the main responsibilities of publicly held companies. There are strict rules for publicly held companies to reveal proper information timely for related parties; shareholders, investors, and others. In all modern financial markets, public disclosure is one of the main features and regulated areas. For example, the Transparency Directive (2004/1009/EC) requires issuers of securities traded on regulated markets within the EU to make their activities transparent, by regularly publicizing certain information (European Commission 2020). In this regard, the information to be publicized includes (European Commission 2020):

- yearly and half-yearly financial reports
- major changes in the holding of voting rights
- ad hoc inside information, which could affect the price of securities.

On the other hand, as part of the supervisory disclosure requirements in the EU, according to the Directive 2013/36/EU (Capital Requirements Directive—CRD IV), all EU member states are required to present information regarding the laws, regulations, administrative rules and general guidance in the field of prudential regulation and supervision (BaFin&Deutsche Bundesbank 2020).

Publicly held companies and financial services providers, even real person investors in some cases, are under the requirement of public disclosure or supervisory disclosure, but supervisors do not have specific disclosure requirements regarding market events. For example, Turkey's main supervisor for capital markets, the CMB, is not under a responsibility to inform the markets publicly under a written disclosure policy. There are some obscure and general requirements, but there is not a specific requirement and a policy document or a guide to inform related parties at the Turkish capital market. Therefore, market participants do not exactly know when the CMB will inform them or whether the CMB will make any announcement or not.[14]

In the FinTech world, supervisors should react promptly to market events. Any delayed reaction might cause inevitable losses and market crashes. The May 6 market crash is the case indicating the timing concern in the FinTech world. On May 6, when markets were already under stress, a sell algorithm[15] chosen by a large trader to only target trading volume, and neither price nor time, executed the sell program extremely rapidly in just 20 min (SEC and CFTC 2010). During the May 6 market crash in the U.S., there were many unknowns and fears of unknowns about probable roots of the crash, and supervisory agencies were under stress to act against the drivers of the crash. They could not reveal useful information to the public timely. Six days after the crash, the CFTC and the SEC published a report about the market events. However, the report did not exactly answer the questions. Twenty days later, on May 26, 2010, the chairperson of the SEC made a statement and pointed out that the SEC, at the time, could not track data across multiple markets, products, and participants in a real-time basis. Later, to fill the gap, the SEC introduced a Consolidated Audit Trail project or CAT in short. The following statement of the chairperson of the SEC on May 26, 2010, inter alia, addresses the prudential supervisory disclosure requirement:

"*If adopted, this consolidated audit trail would, for the first time ever, allow the SEC and other market regulators to track trade data across multiple markets, products, and participants in real-time,*"

"*It would allow us to rapidly reconstruct trading activity and quickly analyze both suspicious trading behavior and unusual market events.*" (SEC 2010a, b).

About the addressed May 6, 2010 crash, the SEC, together with the CFTC, revealed the full report approximately five months later, which was an extremely late action in the FinTech world. On May 6, 2010, the U.S. markets suffered not only from an improper algorithm fueled the market crash

[13] The term "Prudential Supervisory Disclosure", or PSD, was first coined by Zeranski and Sancak (2020). This section mostly depends on their papers.

[14] To analyze the announcement policies of financial supervisors, we can check the official web sites since supervisors use mainly their web sites to make announcements. Periodic bulletins, press releases, and annual reports are not in the focus of these discussions.

[15] Algorithmic trading and high-frequency trading are in the domain of FinTech.

but also rumors and detrimental speculations about the drivers of the market crash at the time. Prudential supervisory disclosure could save the market from huge material losses and loss of confidence at the time.

It might be less detrimental if some announcements were made immediately, and some supervisory actions were taken during the day. However, many supervisory agencies are not under the obligation of revealing timely information about the roots of similar market crashes or events to the public to calm down market participants, and markets at large. They do this only within their discretion. As in the May 6 case, some supervisors had not been in that capacity, too. Therefore, we see this situation as a new risk for financial markets in our high-speed FinTech world.

Public disclosure is mainly a pillar of market discipline and transparency issues. The BCBS touches on supervisory disclosure from the banking sector perspective in the report, *Enhancing Bank Transparency: Public Disclosure and Supervisory Information that Promote Safety and Soundness in Banking Systems* (BIS 1998):

"*Market discipline, however, can only work if market participants have access to timely and reliable information which enables them to assess a bank's activities and the risks inherent in those activities. Improved public disclosure strengthens market participants' ability to encourage safe and sound banking practices.*"

We believe that there are multiple drivers for prudential supervisory disclosure. For example, the global financial crisis (2007–2009) has called into question the role of financial policy in general, especially in banking, revealing major shortcomings in market discipline, regulation, and supervision (The World Bank 2020). Additionally, in the FinTech world, supervisors may have more technological opportunities and potentially strong tools available to carry out their duties. The FinTech world also brings new responsibilities of more active market surveillance and more promptly response to the market crashes and abusive market transactions or news. Moreover, supervisors may have a bigger capacity to contribute to financial stability. From the market quality perspective, supervisors can contribute more to the informational efficiency of the markets.

The structuring a prudential supervisory model is not a complicated work, but it requires a new supervision perspective. In the private sector, financial services providers have been changing their business models in the FinTech world. Their supervisors should also update their business models, or, their supervision perspectives accordingly.

The following figure shows an interaction between two parties in terms of the prudential supervisory model (Fig. 2).

In this regard, each supervisory authority should have a predetermined and written prudential supervisory disclosure policy. Under this policy, market participants know that the markets have all the required information or will have it timely.

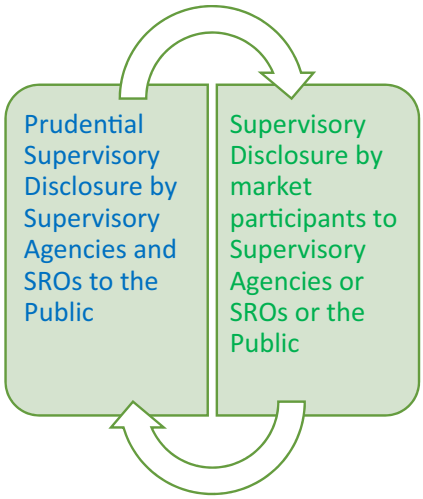

Fig. 2 Prudential supervisory disclosure

The following concerns address the requirement of prudential supervisory disclosure:

(1) Timing Concern: FinTech has the potential to bring a more radical change within the financial industry and become a core constituent of its infrastructure and processes, hence boosting the speed and the agility of financial services (Kashyap and Weber 2018). In the FinTech world, transactions take place in microseconds.[16] Any late response to the markets might cause severe crashes, FinTech crises and financial crises.

(2) Scope Concern: Publicly held companies and FSPs have limited scope, not a market-wide scope. In some cases, there might be material information that only supervisors have with their vast information outreach capacity from multiple data sources. In many regulatory frameworks, banks, FSPs at large, transmit to supervisory authorities, based on a relationship covered by professional secrecy laws and rules, a larger amount of accounting data and other information than they are legally required to make public (e.g., annual reports) or that they publish voluntarily (e.g., in the press) and supervisory authorities can use this important stock of information not only to perform the tasks entrusted to them by law but also to enrich the information available to the public (BIS 1998). As stated with the same BIS report, confidentiality will not be breached if the information is released in aggregate forms.

[16] One million microseconds are equal to one second ($1\ \mu s = 10^{-6}$ s).

(3) Technology Concern: Supervisors potentially have more technological tools and solutions to carry out their duties. SupTech gives supervisors both more technological tools and new responsibilities. Computers can exceed the abilities of human experts in some cases (BaFin 2018).

4) Transparency Concern: Market participants should know under a regulation that supervisors are under the obligation of revealing all market-sensitive information, and supervisors will reveal all relevant information to the public. Transparency concern also addresses the informational efficiency.

5) Mandate Concern: Each financial supervisory authority has designated mandates and is responsible for successfully fulfilling the mandates. SupTech applications can turn risk and compliance monitoring from a backward-looking into a predictive and proactive process (Broeders and Prenio 2018). Solutions that use advanced data analytics and technologies could lead to more timely, dynamic, and even predictive supervision, which enables supervisors to extract knowledge from data that would be otherwise inaccessible (Dias 2017). Having higher data collection capacity and data analytics tools forces supervisors to deliver more useful products and services in a timely fashion.

(6) Accountability Concern: Supervisors should be accountable for their poor disclosure policies to protect market integrity and financial consumers as well as financial stability.

Twenty years ago, the regulatory sandbox idea was not a vision in the supervisory landscape. However, it is well accepted today. Prudential supervisory disclosure is only another concept that we may face soon to handle FinTech related issues properly.

To sum up, a SupTech system enables supervisors to collect much better information timely. And, by having market-wide information, supervisors should reveal information as part of a prudential supervisory disclosure policy to calm down markets, especially in stressful times, increase informational efficiency, cope with market-wide rumors and increase confidence in the markets.

We assume that the initial concern about the PSD model might be the operational responsibility. It is an acceptable concept that regulators and supervisors should not act as if they are a market actor. They might not be a market actor, but they are also not outside of the markets. Regulators and supervisors and central banks are not entirely outside of the daily market operations. They interfere with markets for the sake of market integrity and financial stability. On the other hand, staying technological-neutral, with the PSD model, financial supervisors do not affect the market directions, but contribute to the informational efficiency of the markets,

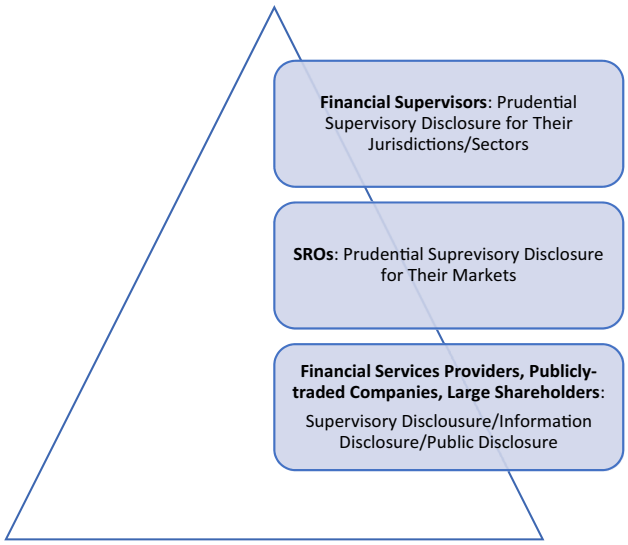

Fig. 3 Laddering PSD

enable a level playing field for all market participants, and eliminate technology-related asymmetric information risks.

The responsibility of prudential supervisory disclosure might be delegated to SROs when the prudential information is only in the hand of an SRO. The following figure indicates a possible delegation model (Fig. 3).

Under the current setup, some supervisors already share their supervisory responsibilities with SROs, such as FINRA and exchanges in the U.S. Therefore, a centralized SRO might be assigned as the PSD agency in this regard.

A partly similar rule to PSD has already been in practice at the U.S. markets. The Rule 603(b) of Regulation National Market System (NMS) requires equity exchanges and FINRA to act jointly to disseminate consolidated information, including a National Best Bid and Offer (NBBO), on quotations for and transactions in NMS stocks (SEC and CFTC 2010). The rule is mainly for fair trading practices. In this regard, the consolidated information is disseminated through securities information processors that collect, process and prepare to publish such information, including the price, size, and symbol of quotations and executions (SEC and CFTC 2010).

The SEC rules require that the exchanges and FINRA provide timely and accurate data to the Consolidated Tape System (CTS) and Consolidated Quotation System (CQS) to inform all participants of the trading and quoting activities occurring in the market place (SEC and CFTC 2010). According to the SEC and the CFTC's report (September 2010), at the time, there was considerable attention in the public media regarding the data delays, and the staff agreed that this was an important topic that should be addressed. PSD is a broader concept and requires informed market participants not only for orders and transactions at one exchange

or trading center but also for capital market-wide material information that only the supervisory agencies have by their mandate.

Prudential supervisory disclosure is the name of public disclosure for supervisors in the FinTech world. It is a technical requirement with SupTech today. A PSD model might be the idea of flying cars for today, but it seems a reality for the future. A statistic says that ninety percent of the data in the world was created in the previous two years alone (IBM 2016). Therefore, we should not extrapolate the past too far into the future for technological developments.

Implications of prudential supervisory disclosure for banking and capital market sectors

The global financial crisis (2007–2009) has called into question the role of financial policy in general, especially in banking, revealing major shortcomings in market discipline, regulation, and supervision (The World Bank 2020). FinTech also increases the importance of totally new financial policies. The pace of technology, as well as some FinTech crashes, addresses the urgency of supervisory reforms. The May 6 market crash has many lessons for both capital markets and banking sector supervisors.

Our analyses mainly focus on the May 6 market events, which are about the capital market sector. We prove that the lack of a well-designed SupTech system leaves the capital markets unprotected in the FinTech world. Many economies still run the same risks today.

On the other hand, the PSD model also has many implications for the banking sector. The decade following the global financial crisis was characterized by intense regulation of banking sectors worldwide, especially in advanced countries (The World Bank 2020). A decade after the global financial crisis, intense regulation seems to be not enough to keep the financial sector safe and sound, since technological developments have been disrupting the sector and transcending the regulatory issues.

The PSD model may be more conducive to the banking sector since public disclosure rules and regulations are not similar to the publicly traded companies, which are in the realm of the capital market sector. In other words, banks have more regulatory rules to submit information to supervisors than to financial consumers about their capital requirements, operations, organizations, and financial soundness. Therefore, financial supervisors collect colossal information from the banking sector, much of them are not available for financial sector participants. Moreover, after the global financial crisis, bank regulations became more complex, potentially reducing transparency, increasing regulatory arbitrage, and taxing supervisory resources and capacity (The World Bank 2020). However, financial supervisors are not obliged to inform financial consumers with all available information about banks and banking sector.[17]

After the global financial crisis, bank supervision became stricter and more complex, and supervisory capacity did not improve proportionally to match the greater complexity of bank regulations (The World Bank 2020). On top of that, the SupTech capacity of many financial supervisors could not catch up with the FinTech developments.

As one of the drivers of the global financial crisis, the risk was transferred in nontransparent ways owing to the rapidly increasing trade in complex, structured financial products (The World Bank 2012). Today, some risks might be within the big data, and unless data analytics tools capture these risks and timely published by the relevant parties to the public, uncertainty might fuel some other FinTech crises. Therefore, Know-Your-Data and PSD are crucial for financial stability.

Using data on publicly traded banks in 61 countries, Anginer et al. (2018) examined how the institutional environment affects the relationship between bank capital and system-wide fragility. Their research concludes that bank capital is associated with a reduction in the systemic risk contribution of individual banks and this effect is more pronounced for banks located in countries with less efficient public and private monitoring of financial institutions and in countries with lower levels of information availability (Anginer et al. 2018).

The study of Demirgüç-Kunt et al. (2008) finds a significant and positive relationship between compliance with the Core Principles for Effective Banking Supervision related to information provision and bank soundness. Countries[18] that require their banks to regularly and accurately report their financial data to regulators and market participants have more highly-rated banks, as timely disclosure of high-quality information strengthens monitoring by regulators and markets alike (Demirgüç-Kunt et al. 2008). Their results suggest that countries aiming to upgrade banking regulation and supervision should consider giving priority to information provision over other elements of the core principles.

Challenges for financial supervisors

In today's world, in addition to the low pace of digital transformation of supervision with SupTech, one of the main challenges is the fragmentation of financial supervision. Supervision is divided among the FED, the FDIC, the OCC, the SEC, FINRA, the CFTC, and state regulators in the U.S., centralized bodies such as the ECB, the SSM, the ESMA, the EIOPA, and the EBA share a stage with national

[17] We still reserve the privacy issues of banks.

[18] A sample of 39 countries.

competent authorities in the EU, and regulation is developed at a national level, and regional coordination is limited in Asia (Frisell et al. 2018). Regulatory and institutional frameworks will need to be revised in light of new and evolving risks and industry landscapes (Frisell et al. 2018). In other words, as pointed out with a recent paper, *Digitalization of Financial Supervision with Supervisory Technology*, before the digital transformation, a check-up for the whole financial system and adjustments for the financial structure are the prerequisites of having a modern and functional supervisory system.

The regulatory and supervisory framework in the EU does not directly address the RegTech or SupTech paradigms, and the approach taken by firms and supervisors to pilot and adopt RegTech and SupTech frameworks is currently ad-hoc and uncoordinated (European Commission 2019). This was seen as an important issue and handled by a report, *Expert Group on Regulatory Obstacles to Financial Innovation (ROFIEG):30 Recommendations on Regulation, Innovation and Finance -Final Report to the European Commission.* The Group recommends that the EU develops and implements a comprehensive and ambitious agenda for the establishment of advanced RegTech and SupTech capabilities, in coordination with relevant authorities in and beyond the EU and international standard setters.

It is estimated that finance goes real-time, and periodic reporting no longer drives operations and decisions in the near future (Deloitte 2020). And, speed has always been of the essence in financial markets (Ait-Sahalia and Saglam 2013). Therefore, supervisors also should equip with high-speed technological tools to respond to market crashes and FinTech crises properly.

FinTech players often fall outside the applicable regulatory and supervisory framework both for prudential and customer protection supervisions, which is a challenge that regulators or supervisors with capacity constraints may be ill-equipped to address (Berg et al. 2020). The U.S. financial markets are the most complex markets from supervisory perspectives. The magnitude of transactions, fragmented but interconnected markets, the variety of financial instruments coupled with the fragmented and intricate design of the financial regulatory and supervisory structure make the markets incredibly difficult to monitor, manage FinTech related risks, and cope with financial frauds.

Even though financial supervisors are independent in their responsibility areas, their budgets are tied to political decisions. In many countries, budget allocations to independent financial agencies take place only once a year. Since the financial sector of the U.S. is extraordinarily complex, modernization and updating works require not millions but billions of U.S. dollars. If an agency cannot get a budget increase for technology investments or reform requirements for a fiscal year, then the agency has the chance to get it only in the next fiscal year. Assuming success in the second fiscal year, two years delay without technology investment makes supervisory agencies old-fashioned in the FinTech world. This picture leaves supervisory agencies unarmed against the fast-growing FinTech world.

What makes the case worse is that operating in a technologically leading country does not help the U.S. financial supervisors carry out their responsibilities successfully, but the technology stirs mostly financial markets and institutions, namely the private sector. This legacy political structure is per se a source of risk for financial stability. As we observe that the major financial reforms have been followed mostly by crises or scandals, unless politicians do not get pressure from lobbying channels, they are not inclined to increase the budget for financial supervisors. This situation also seems a kind of vicious circle or dilemma for the stability of the financial industry and the global economy at large.

Conclusion

Financial supervisors collect vast amounts of data and information about market institutions and activities, but they are not obliged to reveal information under a specific disclosure policy. They inform the public within their discretion but not under a predetermined disclosure policy. This should not be the case anymore in the FinTech world with a SupTech capacity. As financial institutions have the responsibility of Know-Your-Customer, financial supervisors should also have "Know-Your-Markets", "Know-Your-Technology", "Know-Your-Data", and "Inform-Your-Markets" responsibilities. With the PSD model, from the market quality and micro-structure perspectives, supervisors can contribute more to the informational efficiency of the markets.

The U.S. financial markets faced an unprecedented rapid decline and recovery on May 6, 2010, known as the May 6 flash crash. Roughly one trillion $ market value in less than thirty minutes vanished with the biggest one-day point decline in the history of the DJIA at the time. Since the market events took place in electronic markets, and algorithmic trading (AT) and high-frequency trading (HFT), parts of FinTech, played significant roles, we handle the May 6 flash crash from the FinTech, SupTech, and financial supervision perspectives. Our research is unique because we analyzed the May 6, 2010 flash crash first time from FinTech and SupTech, or "TECHs in Finance" perspectives. We flashbacked the events and analyzed the responses of the economic and financial media and two U.S. financial supervisors, the SEC and the CFTC, to the market events. The case has many lessons and takeaways for the governments, economic policymakers, and regulatory and supervisory authorities, and academic communities. Our analyses are

more conducive to the U.S. and the EU because their fragmented financial systems are in the urgent need of TECHs in Finance reforms.

Analyzing the May 6 flash crash, we find that the technological imbalance between financial markets or institutions and their supervisors drove the markets in uncertainty, hence in a fear and panic environment. Since the imbalance has not diminished yet, the same risks still exist. As a remedy, we introduce a new concept, prudential supervisory disclosure (PSD), and a model, the PSD model, with a well-functioning SupTech system, to cope with the May 6 type FinTech crises. Even though the U.S. has been one of the leading technology innovating countries in the world, the May 6 case indicated that the U.S. financial supervisors, namely the SEC and CFTC did not have good enough SupTech capacity at the time. We are convinced that it is not about having available technology; it is about organizing, designing, and having a well-functioning SupTech and supervisory system at large. Moreover, having a full-fledged SupTech system is not wholly tied to financial supervisors. It requires additional funds and hence political support as well as leadership.

Risk management policies were developed mostly after a crisis comes out in the financial sector. However, we do not have such a comfortable reform approach any more against FinTech crises. Due to the nature of such crises, markets and institutions can be wiped out in hours, if not in minutes. The May 6 market crash depleted market liquidity in twenty minutes, collapsed prices, and caused a massive panic at the U.S. financial markets.

PSD is the name of public disclosure for supervisors in the FinTech world. It is a technical requirement with SupTech today. The PSD model helps protect market integrity by revealing useful information timely about market functions and against improper market activities or rumors. A PSD model might be the concept of flying cars for today, but it seems a reality for the future. Taking seriously a statistic about 2017 trends saying that ninety percent of the data in the world was created in the previous two years alone, we do not extrapolate the past too far into the future for technological developments. Thus, we expect the PSD model or a version of the model as the next normal of the financial sector.

FinTech crises might cause bank runs and destroy the baking sector as well as capital markets. One of the initial considerations for the May 6 market crash was about fat finger speculations for a bank. This makes the case more important; banks are vulnerable to rumors which might trigger bank runs. In this regard, the PSD model is crucially important to protect banks from FinTech crises and bank runs. We contemplate that the May 6 case could have been more detrimentally and driven the banks into collapse under the supervisory setup at the time. And, it could have been less detrimental under a PSD model. Currently, without a PSD capacity, the EU Member States, the U.S., and many other countries run similar risks.

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Compliance with ethical standards

Conflict of interest The authors certify that they are not affiliated with or involved in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

References

Ait-Sahalia, Y., and M. Saglam. 2013. *High Frequency Traders: Taking Advantage of Speed*. Cambridge: National Bureau of Economic Research.

Anginer, D., A. Demirgüç-Kunt, and S.D. Mare. 2018. Bank capital, institutional environment and systemic stability. *Journal of Financial Stability*, pp. 97–106.

Arner, D.W., J. Barberis, and R.P. Buckley. 2016. The emergence of RegTech 2.0: from know your customer to know your Data. *Journal of Financial Transformation*, pp. 79–86.

BaFin, F. 2018. *Big Data Meets Artificial Intelligence: Challenges and Implications for the Supervision and Regulation of Financial Services*. Bonn: BaFin.

B.D. Bundesbank. 2020. *Supervisory Disclosure*. Retrieved from Supervisory Disclosure: https://www.supervisory-disclosure.de/supervisory-en/

Berg, G., M. Guadamillas, H. Natarajan, and A. Sarkar. 2020. *Fintech in Europe and Central Asia: Maximizing Benefits and Managing Risks*. Washington, DC.: The World Bank Group.

BIS. 1998. *Enhancing Bank Transparency: Public Disclosure and Supervisory Information that Promote Safety and Soundness in Banking Systems*. Basle: Bank for International Settlements-Basle Committee on Banking Supervision.

Borch, C. 2017. High-frequency trading, algorithmic finance, and the flash crash: reflections on eventalization. *Economy and Society*, pp. 350–378.

Bouveret, A., P. Breuer, Y. Chen, D. Jones, and T. Sasaki. 2015. *Fragilities in the U.S. Treasury Market: Lessons from the "Flash Rally" of October 15, 2014*. Washington. D.C.: International Monetary Fund.

Broeders, D., and J. Prenio. 2018. *Innovative Technology in Financial Supervision (Suptech)-the Experience of Early Users*. Basel: Bank for International Settlements-Financial Stability Institute.

Bullock, N., and P. Stafford. 2019. *SEC Approves Vast Surveillance System for Stock Market.* Retrieved from Financial Times: https://www.ft.com/content/2a428156-ab1e-11e6-9cb3-bb8207902122.

CFTC and SEC. (2010). *Preliminary Findings Regarding the Market Events of May 6, 2010.* washington, D.C.: CFTC and SEC.

CNBC. (2010). *FLASH CRASH May 6, 2010 (Part 6 of 6) CNBC.* Retrieved from Youtube: https://www.youtube.com/watch?v=7UhKOs3dYk4.

CNBC. 2014. *The Lasting Impact of the 2010 Flash Crash*. Retrieved from CNBC: https://www.cnbc.com/2014/05/06/the-lasting-impact-of-the-2010-flash-crash.html.

Deloitte, J.A. 2020. *Digital Finance Series: Finance 2025*. London: Deloitte.

Demirgüç-Kunt, A., E. Detragiache, and T. Tressel. 2008. Banking on the principles: compliance with Basel core principles and bank soundness. *Journal of Financial Intermediation*, pp. 511–542.

Dias, D. 2017. *FinTech, RegTech and SupTech: What They Mean for Financial Supervision*. Toronto: Toronto Centre.

Easley, D., M. Lopez de Prado, and M. O'Hara. 2011. The microstructure of the 'Flash Crash': flow toxicity, liquidity crashes and the probability of informed trading. *The Journal of Portfolio Management*, pp. 118–128.

EBA. 2018. *The EBA's FinTech Roadmap: Concluions from the Consultation on the EBA's Approach to Financial Technology (FinTech).* Paris: EBA.

EBA. 2020. *EBA Response: EC consultation on the Digital Finance Strategy/Action Plan*. Paris: EBA.

European Central Bank. 2017. *A Quick Guide to Macroprudential Policies.* Retrieved from European Central Bank: https://www.ecb.europa.eu/explainers/tell-me-more/html/macroprudentialpolicies.en.html.

European Commission. 2020. *Prudential Requirements*. Retrieved from European Commission: https://ec.europa.eu/info/business-economy-euro/banking-and-finance/financial-supervision-and-risk-management/managing-risks-banks-and-financial-institutions/prudential-requirements_en.

European Commission. 2019. *Expert Group on Regulatory Obstacles to Financial Innovation (ROFIEG):30 Recommendations on Regulation, Innovation and Finance -Final Report to the European Commission—December 2019.* Brussel: European Commission.

European Commission. 2020. *Transparency Requirements for Listed Companies*. Retrieved from European Commission: https://ec.europa.eu/info/business-economy-euro/company-reporting-and-auditing/company-reporting/transparency-requirements-listed-companies_en.

European Parliament. 2018. *Report on the proposal for a directive of the European Parliament and of the Council on the prudential supervision of investment firms and amending Directives 2013/36/EU and 2014/65/EU.* Retrieved from https://www.europarl.europa.eu/: https://www.europarl.europa.eu/doceo/document/A-8-2018-0295_EN.pdf.

FINRA. 2020. *catnmsplan*. Retrieved from FINRA CAT: https://www.catnmsplan.com/.

Frisell, L., M.J. Fernandes, L. Quest, E. Rennick, S. Roy, and D. Treeck. 2018. *Supervising Tomorrow*. New York: Oliver Wyman.

Gomber, P., J.A. Koch, and M. Siering. 2017. Digital finance and FinTech: current research and future research directions. *Journal of Business Economics*, pp. 537–580.

IBM. 2016. *10 Key Marketing Trends for 2017*. New York: IBM.

Janjigian, V. 2010. *Fat Fingers Cause Panics*. Retrieved from Forbes.com: https://www.forbes.com/sites/greatspeculations/2010/05/06/fat-fingers-cause-panics/#180adfe160e9.

Kashyap, K., and M.G. Weber. 2018. How Emerging Technologies will Change Financial Services. In *The FinTech Book*, ed. S. Chisti and J. Barberis, 228. Cornwall: Wiley.

Kirilenko, A.A., A.S. Kyle, M. Samadi, and T. Tuzun. 2017. The flash crash: high-frequency trading in an electronic market. *Journal of Finance*, pp. 967–998.

Kirilenko, A.A., A.S. Kyle, M. Samadi, and T. Tuzun. 2018. Automation, intermediation and the flash crash. *Journal of Investment Management*, pp. 29–46.

Krantz, M. (2014). Four-year flash crash anniversary haunts markets. Retrieved from CNBC: https://www.cnbc.com/2014/05/05/four-year-flash-crash-anniversary-haunts-markets.html.

Krudy, E. (2010). *Stocks plunge as trading glitch suspected*. Retrieved from Reuters.com: https://www.reuters.com/article/us-markets-stocks/stocks-plunge-as-trading-glitch-suspected-idUSTRE6341EA20100506.

Lauricella, T., and P.A. McKay. 2010. *Dow Takes a Harrowing 1,010.14-Point Trip; Biggest Point Fall, Before a Snapback; Glitch Makes Thing Worse.* Retrieved from WSJ: https://www.wsj.com/articles/SB10001424052748704370704575227754131412596.

Lexico. 2020. *Definition of prudential in English*. Retrieved from Lexico: https://www.lexico.com/en/definition/prudential.

Mackenzie, M. 2010. *Vital lessons of the 'flash crash'*. Retrieved from ft.com/: https://www.ft.com/content/2e1a96ee-5f7e-11df-a670-00144feab49a.

Menkveld, A. J., and B.Z. Yueshen. 2018. The flash crash: a cautionary tale about highly fragmented markets. *Management Science*, pp. 4470–4488.

Mishkin, F. S. 2000. Prudential Supervision: What Works and What Doesn't? *NBER Conference-Working Paper 7926* (pp. 1–36). Florida: National Bureau of Economic Research.

Orol, R.D. 2010. *SEC: No evidence that one event caused market plunge*. Retrieved from Marketwatch.com: https://www.marketwatch.com/story/no-evidence-of-fat-finger-error-in-may-6-plunge-2010-05-11.

Peress, J. 2014. The Media and the Diffusion of Information şn Financial Markets: evidence from Newspaper Strikes. *The Journal of Finance*, pp. 2007–2043.

Podkul, C. 2020. *When Volatility Surges, SEC's Trade-Monitoring System Has Struggled*. Retrieved from WSJ: https://www.wsj.com/articles/when-volatility-surges-secs-trade-monitoring-system-has-struggled-11585796442?mod=searchresults&page=1&pos=5.

Schapiro, M. L. 2010. *Testimony Concerning the Severe Market Disruption on May 6, 2010.* Retrieved from SEC: https://www.sec.gov/news/testimony/2010/ts051110mls.htm.

Schapiro, M.L. 2010. *Examining the Causes and Lessons of the May 6th Market Plunge.* Washington, D.C.: U.S. Securities and Exchange Commission.

SEC. 2010. *SEC Proposes Consolidated Audit Trail System to Better Track Market Trades.* Retrieved from SEC: https://www.sec.gov/news/press/2010/2010-86.htm.

SEC. 2012. *Investor Bulletin: Measures to Address Market Volatility.* Retrieved from SEC: https://www.sec.gov/oiea/investor-alerts-bulletins/investor-alerts-circuitbreakersbulletinhtm.html.

SEC. 2013. *MIDAS-Market Information Data Analytics System*. Retrieved from SEC: https://www.sec.gov/marketstructure/midas.html#.XoTYl4hKg_E?mod=article_inline.

SEC. 2019. *SEC Approves Plan to Create Consolidated Audit Trail.* Retrieved from U.S. Securities and Exchange Commission: https://www.sec.gov/news/pressrelease/2016-240.html.

SEC. 2020. *About EDGAR*. Retrieved from SEC: https://www.sec.gov/edgar/about.

SEC. 2020. *SEC Proposes Improvements to Governance of Market Data Plans.* Retrieved from SEC: https://www.sec.gov/news/press-release/2020-5.

SEC and CFTC. 2010. *Findings Regarding the Market Events of May 6, 2010: Report of the Staffs of the CFTC and SEC to the Joint Advisory Committee on Emerging Regulatory Issues*. Washington, D.C.: SEC and CFTC.

SEC. 2010. *Concept Release: Concept Release on Equity Market Structure; Proposed Rule.* Retrieved from SEC: https://www.sec.gov/rules/concept/2010/34-61358fr.pdf.

The World Bank. 2012. *Rethinking the Role of the State in Finance: Global Financial Development Report 2013*. Washington, D.C.: The World Bank.

The World Bank. 2020. *Bank Regulation and Supervision a Decade after the Global Financial Crisis: Global Financial Development Report 2019–2020*. Washington, D.C.: The World Bank.

Wall, L.D. 2016. *Prudential Regulation, Big Data, and Machine Learning.* Retrieved from Federal Reserve Bank of Atlanta: https://www.frbatlanta.org/cenfis/publications/notesfromthevault/11-prudential-regulation-bigdata-and-machine-learning-2016-11-21.

Zeranski, S., and I.E. Sancak. 2020. Digitalisation of Financial Supervision with Supervisory Technology (SupTech). *Journal of International Banking Law and Regulation*, pp. 309–330.