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FROM PAPER-BASED TO ELECTRONIC SECURITIES POST-TRADING: FINANCIAL AUTOMATION AND THE CASE OF CREST

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From paper-based to electronic securities post-trading: Financial automation and the case of CREST

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Abstract

Over recent decades, securities post-trading has seen a radical change from paper-based to electronic procedures. Technological advances have facilitated digitisation as a global trend. While in the investment industry technology has also been a key driver for financial automation since the late 1950s, a range of additional driving forces can be identified. In the 1980s, deregulation in the finance sector and privatisation led to millions of new shareholders and increasing transaction numbers in securities trading. The subsequent settlement crisis called for new solutions to transform centuries old business practices in the investment industry.

This study focuses on CREST, a leading settlement infrastructure that facilitated the leap from paper-based to electronic post-trading in London. In 1993 it started as a project of the Bank of England, and today, CREST is operated by Euroclear United Kingdom & Ireland (EUI).

Research objectives of this study are to investigate the industry context, how the CREST project was managed and introduced at a time of crisis, how the technology was designed, and its impact on financial markets and today's UK and European infrastructure. Twenty individual interviews and one group interview with key actors were conducted, complemented by document analysis and secondary data. The study has generated rich data and confirms that CREST achieved the dematerialisation of securities settlement through a joint industry effort effectively reducing settlement time, risk and cost. A framework to study different perspectives on CREST is presented, and suggestions for a programme for future research are given.

Key words: Securities post-trading, CREST, CRESTCo, settlement and clearing, financial automation, dematerialisation, European financial infrastructure, T2S, financial technology

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Contents

Executive Summary

2016 marks the 20th anniversary of the launch of CREST, which went live on 15 of July 1996. This working paper is an outcome of the first phase of the CRESTCo Research programme. It presents first findings, lays the groundwork for future research, and suggests conceptual frameworks and layers of investigation to analyse different aspects of CREST.

- This paper argues that to understand CREST, it is important to look at the industry context at the time it was initiated and launched. The financial "Big Bang" in 1986 involved reforms of the London Stock Exchange (LSE) and the underlying legal framework, but did not change the paper-based processes. Privatisation had led to millions of new private investors. When stock markets crashed in 1987, the securities industry was being crippled by a "paper blizzard" of certificates as private investors wanted to sell their shares (the so called 'settlement crisis'). Diagrams with settlement times and fees from the early 1990s enable context analysis.
- This paper demonstrates that CREST enabled the step change from paper-based procedures to electronic techniques (i.e. dematerialisation) in securities settlement in London. CREST's functionality was enabling the accurate processing of much higher volumes at increased speed, and its unprecedented resilience was ultimately solving the settlement crisis leading to a "back office revolution". This paper argues that the concept of market friction is an adequate tool to explain the settlement crisis and the processes leading to the introduction of CREST and the resulting automation of post-trading.
- This paper discusses and provides historical details about CREST's origin as a spin-off of the Bank of England initiated in 1993 and launched in 1996. The project was delivered on time, on budget and meeting the requirements set by the Task Force. This was achieved by strong leadership and the commitment by the Bank of England and the CREST team. CREST was acquired by Euroclear in 2002, and is still in operation today.
- CREST is often seen as a consequence of an earlier endeavour by the LSE called TAURUSTAURUS, that had attempted to resolve the settlement crisis but had to be suspended in a much publicised failure. When the chairman of the LSE, John Rawlins, informed the Governor of the Bank of England, Eddie George, about the suspension, a Task Force was appointed and called in immediately developing an analysis, and providing the blue print for CREST. However, this paper argues that CREST's success should be seen against the backdrop of providing a solution to the settlement crisis and as an enabler of digitalisation of post-trading rather than being just a replacement for TAURUS.
- This paper suggests several topics which are outside the scope of this particular paper as future research. For example, the design of CREST as a technology has impacted on the operations of financial markets and today's UK and European infrastructure. Some of

its core functionality was also used as a blueprint for the new Target2-Securities (T2S) system of the Eurozone and the ECB.

1. Research background

1.1 Research problem

In the 1980s and 1990s, the systems of securities trade execution and post-trading used in the UK and European capital markets went through a radical transformation. This study focuses on CREST, an electronic settlement system, which was designed, built and implemented in London between 1993 and 1996. Initially a spin-off of the Bank of England, it became an independent company as CRESTCo, and was in 2002 acquired by Euroclear where it is operated today by Euroclear United Kingdom & Ireland (EUI).

1.1.1 Trading and post-trading in financial markets

Financial markets involve a complex ecosystem of market participants, service providers and market observers. With a daily turnover reaching trillions of pounds Sterling, the investment industry as a financial system, embracing "global capital and commodity markets, as well as foreign exchange markets" (Knorr Cetina and Bruegger, 2002:905), performs the basic functions of finance (Levine, 1997:691) as it:

- mobilises savings;
- facilitates the trading, hedging, diversifying, and pooling of risk;
- monitors investments by monitoring managers and exerting corporate control; and
- facilitates the exchange of financial instruments and other financial services.

Typically, investors buy and sell financial instruments (e.g. securities such as shares and bonds) through a stockbroker or a bank. When the trading parties, i.e. a buyer and a seller, have completed the trade agreement process, a settlement instruction is sent to a settlement agent with orders to make or accept delivery of a financial instrument in exchange for receiving payment of funds by the counterparty.

The importance of post-trading (i.e. clearing and settlement of securities transactions) for a modern securities market is highlighted by Schaefer (in Pagano and Roell, 1990:110):

> "A modern securities market (even this term is not broad enough since we should include the increasingly wide range of instruments, e.g. swaps, which are traded 'over the counter') is defined by aspects such as the set of agents to whom information is disseminated, the clearing and settlement mechanism, the regulatory structure and the set of instruments being traded."

In the following analysis, this study focuses on the clearing and settlement mechanism as a key defining element of modern securities markets.

1.1.2 Competition and fragmentation in the European securities industry

With regards to the competition between the six large stock exchanges in Europe, Benos and Crouhy (1996) point out that financial institutions had to make strategic decisions to gain market power. In particular, this involved the acquisition or development of information technology infrastructures.

The following table (Pagano and Roell, 1990:74) maps the local turnover of each of the eight largest European stock exchanges against the total of equity turnover of the European Communities (EC).

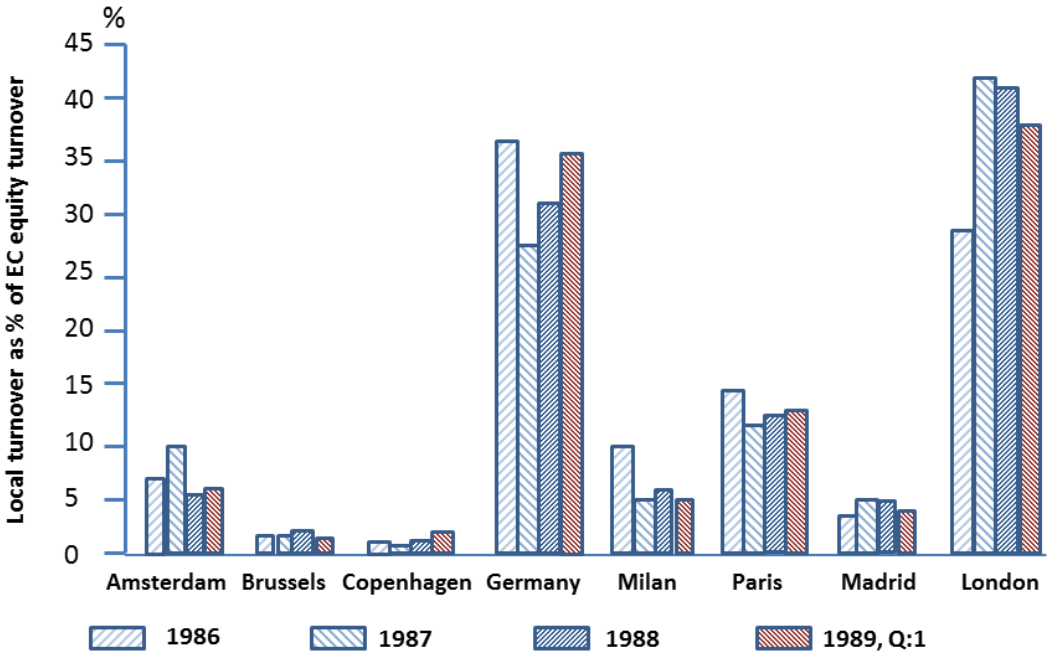

Figure 1: Relative shares of EC equity turnover
Source: Pagano and Roell (1990:74)

As can be seen in the above diagram, London was leading the field of European stock exchanges in the four years following the financial Big Bang. While its relative share of EC equity turnover had been in 1986 less than 30%, London strengthened its pole position by taking away more than 10% from other stock exchanges, having

> "gained a first-mover advantage and being able to keep on gaining ground or at least to maintain its leadership unless the others are markedly better or more efficient" (Danthine, in: Pagano and Roell, 1990:107).

During the 1980s, London was the top financial location in Europe and among the top three in the world. London had maintained its initial pre-eminence

> "relative to Continental exchanges, exploiting its first- mover advantage in the process of liberalization: the 'Big Bang' and the creation of SEAQ International have been its main assets. However, there are some signs that Frankfurt and Paris are starting to recover some of the lost ground." (Pagano and Roell, 1990:76)

At the beginning of the 1990s, London was perceived to have a "gravitational pull" as it was expected to be able to "exploit more extensively the economies of scale in brokerage, handling and settlement systems" (Pagano and Roell, 1990:101). However, competition was ongoing, and "several continental exchanges are trying to recover lost ground, or at least to avoid further losses, by reducing transaction costs and improving the liquidity and immediacy offered by their markets." (Pagano and Roell, 1990:102). Settlement time is also a performance indicator for the efficiency of the settlement infrastructure of the respective country.

> "Nevertheless, the approximate ranking in the table [see above Figure 1] is probably correct - with Germany outdistancing all other EC exchanges for its settlement efficiency, Italy lagging behind the rest of the pack, and other exchanges somewhere in the middle between these two extremes." (Pagano and Roell, 1990:79)

Overall, settlement was a critical component in the competition between the financial hubs of London and Frankfurt. The only real European competitor for London at the time was Frankfurt which had "the most efficient and the safest settlement system in the world." (Pagano and Roell, 1990:71)

1.1.3 Securities settlement and the critical relevance of settlement time

Securities settlement is determined by several primary concerns (Donald, 2013:557) which must be addressed when launching a new settlement system such as CREST:

(1) the legal framework;
(2) the safety of the settlement process;
(3) the efficiency and cost effectiveness so that the market it serves can compete internationally; and
(4) Settlement should preserve the nature of the transferred securities so that security holders can exercise their rights against the issuer.

Pagano and Roell (1990) add an additional factor, tradition, as it influences investor's behaviour.

> "Three main factors attract business to a financial market: lower transaction costs, higher market liquidity and simply tradition which so often permeates the behaviour of international investors." (Pagano and Roell, 1990:76) "While the importance of tradition obviously cannot be quantified at all, one can attempt to quantify transaction costs and some aspects of liquidity." (Pagano and Roell, 1990:77)

Liquidity is defined as "the ease and speed with which agents can convert assets into purchasing power at agreed prices" (Levine, 1997:692). Regarding speed or immediacy,

> "Immediacy is another important factor: especially for large institutional investors, getting quotes over the phone from a London dealer and striking deals in a matter of seconds may be preferable to securing a slightly tighter spread on the Paris Bourse at the cost of waiting for a counterparty." (Pagano and Roell, 1990:92)

The costs for securities transactions are a key factor for the attractiveness of a financial market. With regards to transaction costs, Pagano and Roell (1990:77) mention settlement time as an implicit component.

> "Transaction costs indicate the explicit costs that are paid in brokerage commissions and taxes to carry out a transaction plus the implicit costs of the time required for its settlement."

Settlement time is the delay between agreeing and completing a transaction including payment and transfer of ownership of the traded securities, and it has a cost both in terms of capital and risk allocation. In 1988, settlement time varied at the different financial centres as can be seen in the following table:

Settlement times for major European markets						
	Italy	**France**	**Germany**	**UK**	**Spain**	**Netherlands**
Settlement time	End of subsequent month	End of subsequent month or immediate for a 1% commission	2 days	10 business days	Friday of week of trade	10 business days

Table 1: *Settlement times for major European markets*
Source: Adapted from Pagano and Roell (1990).

As can be seen in the above table, London was at a disadvantage in terms of settlement time with 2 days for Frankfurt as compared to 10 business days for London. Moreover, these time estimates were often exceeded in practice:

> "In practice, settlement times often exceed the official figures by a wide margin, especially when there are large unforeseen increases in turnover. This happened, for instance, in Milan during the stock price rally of early 1986 and in London during the crash of 1987." (Pagano and Roell, 1990:79)

Longer settlement time will increase risks, costs, and slows down follow-up transactions, and is therefore an important component of overall transaction cost. Danthine (in Pagano and Roell, 1990:107) cautions that "the shorter settlement time of Frankfurt relative to London (by a difference of eight days) cannot make up for the explicit transaction cost difference between the two exchanges."

> "The difference amounts to 0.4% for large transactions made by foreign investors, according to the 'Quality of Markets Report'; it is larger than 1% for most transactions, according to published sources […] and it is even higher for the deals settled without commission on SEAQ international. One may hypothesize that as is

> the case in many other industries, the Germans (and probably the Swiss as well) are concentrating on selling a higher quality, higher price service. But then the notion of 'competing on transaction costs' becomes quite misleading." Danthine (in Pagano and Roell, 1990:107)

Pagano acknowledges that the time required for settlement (see above Table 1) "did not […] refer to the completion of all paperwork, including the delivery of property claims. This matters because an asset cannot be transacted again until the appropriate property claim has been delivered. […] the puzzle of London's supremacy could be partly explained by a more efficient handling of paperwork." (Pagano and Roell, 1990:112)

Paper-based processes significantly slowed down any transactions and the following settlement which led to increased transaction costs. A race to digitise securities trading was on.

1.2 Background of the investment industry 1986 to 1993

The following sections focus on the broader technical, political, organisational and institutional environment of the investment industry in the years between the financial "Big Bang" in London in October 1986 and the start of the CREST project in 1993. These years were characterised by several developments that caused radical structural changes for UK and European financial markets. The underlying and interwoven developments can be summarised as follows:

1.2.1 Technical backdrop and the digitisation of information

Since the late 1950s, the financial industry used mainframe systems for reliable heavy duty financial transaction processing. The availability of personal computers (PCs), increased computing power, database technology, the global interconnection of local computer networks, and the commercialisation of the internet created a new technical landscape in the late 1980s. In many offices of financial institutions, terminals used to interact with mainframe computers were gradually replaced by PCs. New operating systems (e.g. Windows in 1985, Linux in 1991) and graphical user interfaces (since 1981, popularised by Apple and Microsoft Windows 95) enabled the development of a new generation of software.

While traditionally securities were traded as paper certificates for centuries, the above technological advances facilitated digitisation. While 'digitisation' and 'digitalisation' are two concepts "that are closely associated" and the terms are "often used interchangeably in a broad range of literatures, Brennen and Kreiss (2014) argue that there is "analytical value in explicitly making a clear distinction". They define the terms as follows:

- *Digitisation* is the material process of converting individual analogue streams of information into digital bits.
- *Digitalisation* is the way in which many domains of social life are restructured around digital communication and media infrastructures.

Accordingly, in this study the term digitisation is referring to the technical conversion process of converting information on paper into digital information.

Digitised information offers great advantages over paper as it can be easily, cheaply, and accurately controlled, stored and transferred between points. The unique characteristics of digitised information have been described in the following way:

- it can be easily stored and transferred, permitting the 'easy manipulation and display of these data' (Verhulst, 2002: 433);
- it has 'close to zero marginal cost of reproduction' (Brynosofisson and McAfee, 2014), and permits cheap, faithful, and widespread copies of digitised content; and
- it allows 'lossless' transmission, giving rise to 'less faults and replication of mistakes and more opportunities for exact processing and calculation' (van Dijk, 2005: 44).

Given these advantages of digitised information, i.e. the ease of handling, cost, and control, a global trend emerged using computer technology for the digitisation of information which has revolutionised whole industries.

At the time when the CREST project was initiated in 1993, Merton and Bodie (1995) report that 'financial markets and intermediaries […] [were] globally linked through a vast international telecommunications network, so that the trading of securities and the transfer of payments go on virtually around the clock' (1995:3). In securities trading, electronic digital systems were first introduced in the front office where e.g. corporate investment bankers, securities traders and stock brokers worked on trading and sales. This was a business driven choice as the front office generates most of the revenues of a financial services firm, and accordingly, new software applications focused first on trading systems. The role of the back office was to support the activities of the front office, e.g. through clearing and settlement as post-trading activities.

However, post-trading in London was mostly using paper-based techniques where paper certificates had to be handled manually. This changed only in 1996 with the launch of CREST when back office operations were computerised.

1.2.2 Political developments

Deregulation has been "a dominant theme in economic policy discussions" since the 1970s (Stiglitz *et al.*, 1993:19). The fall of communist governments in Europe after 1989, and the ongoing "progressive liberalization of European economies" through deregulation and privatisation programmes "stimulated the revival of sleeping stock exchanges and the establishment of new ones" (Benos and Crouhy, 1996:37).

The Single European Act signed in 1986 added another layer of supranational complexity by introducing a European Single Market. At the beginning of the 1990s, it was discussed how a new currency, the Euro, could complement the European Single Market by creating a monetary union and later a Single European Capital Market (Giddy *et al.*, 1996).

> "With the advent of the European Monetary Union (EMU), the creation of a unique currency will make many actively traded instruments (mainly those traded on the floors of derivative markets) obsolete, among them, currency options and futures on local bonds." (Benos and Crouhy, 1996:37)

To conclude, political developments were a driving force conducive to increased competition and larger economies of scale in financial markets. However, the "urgent need for well-functioning, efficient capital markets" to support privatisation, resulted in fragmentation of "35 stock exchanges and 23 futures and options exchanges all around Europe" (Benos and Crouhy, 1996:38), and 46 clearing and settlement institutions (Li and Marinc, 2016) in 23 countries.

1.2.3 Financial industry context

"Big Bang"

The financial "Big Bang" involved two legal events (Hablutzel, 1992:365): first, on 27 October 1986 a package of reforms resulted in a major restructuring in the operation of the London Stock Exchange (LSE); and, secondly, a new legal framework for the investment industry was applicable when the Financial Services Act 1986 (Chapter 60) came into force on 7 November 1986. Considering the specific industry context (Messner, 2016) is important because technology cannot be understood 'by focusing only on the technical characteristics' (2016:103), but also the industry context in which it operates.

These reforms are seen as "one of the most significant revisions in market organization by a major international stock exchange" (Masulis and Ng, 1995:365). Under "Big Bang" in London, a new electronic trading system, the Stock Exchange Automated Quote (SEAQ), was launched. Screen-based trading and the new market organisation after "Big Bang" meant that market "participants [...] [were] connected electronically through the SEAQ quote and transaction display system, which "is similar to the NASDAQ market". (Masulis and Ng, 1996:366).

> "Actual order execution takes place by telephone or, for small trades, electronically through the SEAQ Automated Execution Facility. Larger trades are negotiated over the phone" (Masulis and Ng, 1996:366).

The far-reaching changes which the reforms set in train meant "banks, brokers and jobbers merged; trading moved off the market floor; and new measures were brought in to oversee a thoroughly modernised industry" (Snyder, in: Centre for Policy Studies, 2006:1), and it also involved the loss of low skilled jobs.

> "After substantial resistance from many members of the exchange, the 'Big Bang' of October 1986 eventually swept away the traditional roles of jobbers and brokers, opened dealership to competition by banks and other financial institutions, liberalized commission charges, and at the same time introduced the extensive use of computerized systems in price quoting and order placement procedures […]. This

> led to a substantial gain in the competitiveness of the London Stock Exchange: partly as the result of these changes and partly because of the concomitant reduction by 50% of the stamp duty, transaction costs fell substantially on the London market (by almost 3 on large transactions)." (Pagano and Roell, 1990:67)

The following table shows the effect of the financial "Big Bang" on transaction costs. As a result, a securities transaction of £ 1 million had become £ 8,800 cheaper. This cost reduction led to increased competitiveness of London as a financial centre.

[% of £500,000]	Before 'Big Bang'	After 'Big Bang'
Stamp Duty	1.00	0.50
Commission	0.31	0.25
Average touch	1.56	1.24
Total	**2.87**	**1.99**

Table 2: London: total cost of a round-trip transaction of £500,000 (%)
Source: Pagano and Roell (1990:68)
Notes: The figures for commission are drawn from […] the Quality of Markets, Second Report, March 1987; the figures for the average touch are touches at maximum size for Alpha, Beta and Gamma stocks, weighted by turnover, Quality of Markets Quarterly 1987.

From a perspective of twenty years later, former Chancellor of the Exchequer, Nigel Lawson, judged the importance of "Big Bang" as a genuine reform that was critical for London to remain a world-class financial centre modernising its securities business because the financial industry is not only the "fastest growing [industry] on the planet", but "it is also one of the most mobile" (Centre for Policy Studies, 2006:v). While "the reforms triumphantly succeeded in achieving their objective", there were also "setbacks along the way". The first setback was about ensuring "a fair number of substantial British-owned players in the new London marketplace". The Bank of England "went to great lengths to encourage mergers between brokers, jobbers, UK investment banks and commercial banks", but ultimately these efforts "did not prove particularly successful, and Wimbledonisation has ensued" (2006:iii) with domestic and international large banks gaining a dominant presence in London by acquiring smaller stock exchange member firms.

The second setback concerns regulation. After a long period of self-regulation of the London Stock Exchange (Hennessy, 2001; Kynaston, 2001), a "statutory regulatory framework, covering all aspects of the savings and investment industry" (Centre for Policy Studies, 2006:v) was required. Influenced by the Gower Report, the Financial Services Act 1986 (Chapter 60) was the second legal event of "Big Bang", an important component of the deregulation policies introduced by the Thatcher-Government giving a certain degree of self-regulation to the financial industry by setting up a number of agencies under the Act. "Paradoxically, the involvement of practitioners in the regulatory process" led to a regulatory system that "was far more cumbersome and bureaucratic" than envisaged. "Changes since 1986 – not least in the regulatory personnel – have improved the system, but in a number of areas regulation remains excessive, and in some it is arguably getting worse" (Lawson, in: Centre for Policy Studies, 2006:iv) with additional U.S. and EU regulation.

Overall, the role of government in financial markets "has been mixed", and government interventions need to "be well designed" (Stiglitz *et al.*, 1993:19) to be effective.

Settlement crisis

Before CREST, the settlement process relied on the exchange of paper certificates, and traditionally the ownership exchange of the security happened at the registrar long after payment was executed. Paperwork was handled largely manually by back-office support staff. Change of securities ownership meant that paper certificates had to be physically transported across London between the settlement agents of the counterparties of a trade.

Regarding the changes introduced by "Big Bang", Masulis and Ng (1995) state that "these changes can alter the way brokers and dealers do their business and can alter the speed at which trades are executed and quotes and transactions are disseminated to the public" (Masulis and Ng, 1995:365). Although, the London Stock Exchange (LSE) had designed and implemented in 1979 the Talisman settlement and accounting system (Talisman stood for Transfer Accounting and Lodgement for Investors, Stock MANagement for Jobbers; Norman, 2007:40 Fn 21), which partly eliminated paper from the settlement process by electronically matching transactions (or "bargains" as they were known at the time), paper-based procedures produced a bottleneck creating risks and costs.

> "Long lines of trades remaining unsettled and snail-mail postal services did not allow a fast enough turnaround for buy and sell transactions. This resulted in people selling shares that had not been legally registered into their name, not once, but many times. Inevitably firms and people began to own illiquid assets and by the time of the crash in 87, paper losses were beginning to be reflected in bank accounts, which occasioned defaults. Consequently, settlement risk became an issue of concern." (B.I.S.S. Industry Report, 2016:13)

The settlement crisis evolved because paper-based processes were too slow and operations could not cope with increasing transaction volumes after the reforms introduced by "Big Bang", and figuratively it was dubbed "paper crunch", "paper blizzard", and "back office crisis" (Donald, 2013). Settlement time of more than two weeks created a range of risks: a broker or their clients could default within the time period until trade settlement, and therefore any of the coutnerparites could be without cash, without securities, or without control of the assets. If any of these risks occured, it had to be resolved legally. The settlement crisis had almost become a normal operational procedure, and, for example, stockbrokers adapted by closing for half days to their clients to deal with the follow-up of trades and chasing the related paper certificates. The question was whether settlement operating under crisis conditions could cope if there was to be a stock market crisis.

The stock market crash of October 1987

Monday, 19 October 1987, is remembered in financial markets as 'Black Monday'. Following the sharp decline in the stock market in Hong Kong, European stock markets were affected, and finally the U.S. Dow Jones industrial index fell by 22.61% (Browning, 2007). The stock market crash was accompanied by rumours "about possible clearinghouse failures" adding to "the sense of panic in the markets, especially on October 20" (Bernanke, 1990:134). The fall in stock prices was at a similar scale to the crash in October 1929 when share prices were "falling 23% over two days" (Browning, 2007). The large increase in sales orders created problems for the trading and settlement systems, in particular during the week commencing 19 October 1987 (Bernanke, 1990:133).

While a "bull market [had] been running for five years and [was] looking somewhat tired" and the "[U.S.] dollar was under attack in 1987" (Browning, 2007), an "identifiable external cause" could not be identified which "motivated an intense examination of the mechanics of the markets themselves" (Bernanke, 1990:133). "Although the clearing and settlement system did survive the critical days intact, there were undeniably severe stresses and strains" (Bernanke, 1990:134). Securities clearing and settlement, "long ignored by most financial economists and even market participants as an institutional detail", received "a good share of this attention and criticism" (Bernanke, 1990:133-134).

Settlement "became an issue for public policy after the stock market crash of 1987" and "cross-border settlement moved rapidly up the European policy agenda" (Norman, 2007:9). Recommendations for reforming the clearance and settlement system(s), "including controversial proposals for unified settlement among different markets, were prominent features of the Brady Report (1988) and several of the other reports on the crash." (Bernanke, 1990:134)

In summary, the need for a new electronic settlement system enabling digitisation of post-trading, and the decision to start the CREST project was caused, first, by a range of historic developments such as the settlement crisis which was aggravated by the stock market crash of October 1987 and the suspension of work on TAURUS by the London Stock Exchange on 11 March 1993 (Drummond, 1996 and 1999; Keil and Montealegre, 2000; Head, 2001). Secondly, the need for a new electronic settlement system has to be seen on the backdrop of the competitive position of London to remain a world-leading financial centre with a modern securities industry, and calls for the settlement cycle to be shortened based on the recommendations of the Group of Thirty and others.

1.3 What is CREST and what does it do?

CREST is an electronic settlement system through which equity (UK and Irish shares), fixed income (UK government bonds, so-called 'gilts'; Mann, 1998), and money market financial instruments (MMIs) are settled. Irish bonds are settled by Euroclear Bank.

CREST is a clearing house (but not a Central Counterparty, (CCP)) and a Central Securities Depositary (CSD) that acts as a major settlement service provider organising the transfer of ownership of securities from the seller to the buyer. CREST is also the national CSD for the

UK. Initially, it was regulated directly by the Financial Services Authority (FSA), and today by the Bank of England.

The following diagram shows how securities were settled through the CREST system from its launch in 1996 until summer 2016.

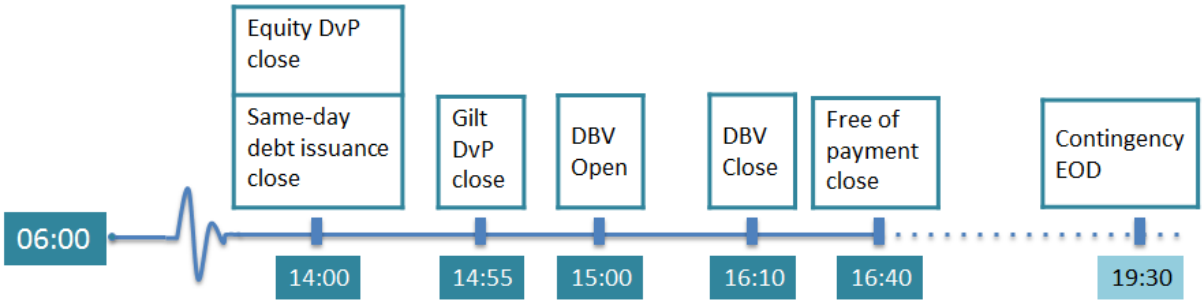

Figure 2: CREST Settlement Day
Source: Bank of England (2015)

On 20 June 2016, the settlement day was extended to 18:00, and it is expected to create three main benefits (Bank of England, 2015): First, enhancing risk management by enabling market participants to make CHAPS payments later in the day to fulfil sterling cash obligations; secondly, providing increased flexibility in balance sheet management by enabling end-users (e.g. corporates and investment managers) to undertake some funding and investment decisions later in their typical business day; and, thirdly, allowing end-users to make high-value transactions later in their typical business day.

1.4 Timeline

After the suspension of TAURUS on 11 March 1993 work on CREST started in July 1993. It took three years to design, build and implement CREST. It was launched in July 1996 on time and on budget, and is still in operation today. Initially a project of the Bank of England, CREST is today a key component of European post-trading infrastructure for settling UK and Irish securities and is operated by Euroclear United Kingdom & Ireland (EUI). CREST had completely replaced the Talisman system(which was founded in 1979) by April 1997 (Norman, 2007:134). The below diagram presents a time line to illustrate some relevant events and developments in London from 1979 to 1997.

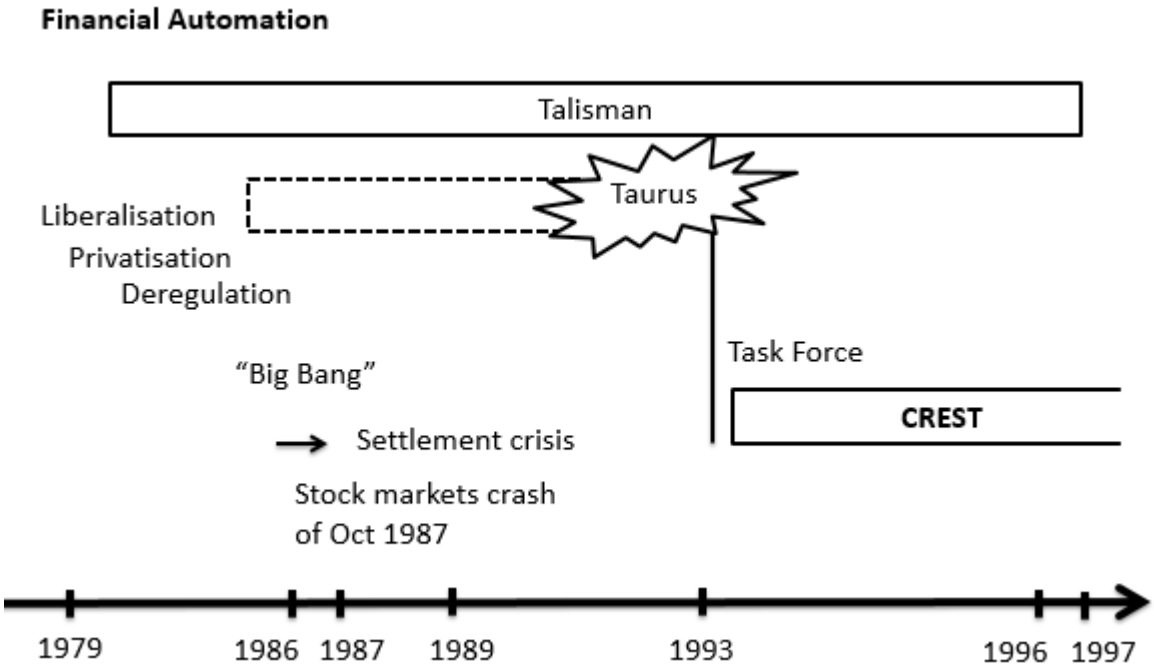

Figure 3: The timeline of CREST
Source: By the authors (2016)

1.5 Research objectives

This study investigates CREST as the centrepiece of the radical transformation of post-trading in the 1990s.

The research objectives of this study are to investigate the industry context and the step change towards financial automation of post-trading, how the CREST project transformed settlement and clearing and the related back office operations in financial institutions, how the technology was designed, and its impact on financial markets and today's UK and European infrastructure.

A key objective of this working paper is also to set the groundwork for further research on CREST, and to identify and suggest themes for future research (see Chapter 5).

2. Research Design and Methodology

2.1 Case study design

This investigation is an empirical enquiry based on a case study approach (Yin, 2013). It focuses on CREST within its real-life context of financial markets, and the related technical, business and legal background. A realist-informed research design is selected because such an approach is "guided by theoretically derived conjectures about the social mechanisms at

work in the world, and considers, through data collection and investigation, the extent through which theoretical ideas explain chosen outcomes." (Ackroyd, 2011:533)

This working paper investigates the mechanism of CREST and its role in financial automation while taking into account that it is embedded in specific conditions of its financial markets environment and industry context (Messner, 2016). It is therefore focusing only on one unique case study, and given its specific embeddedness, it is not designed as a comparative study.

2.2 Methodology

Investigations that 'explicitly discuss industry contexts are exceptions rather than the rule' (Messner, 2016:104). In the context of the investment industry, the topic of post-trading has been addressed from different theoretical perspectives, e.g. Sociology of Finance, Institutional theory, and Practice theory. From a sociology of finance viewpoint, prior research was done by Knorr Cetina and Preda (2012); MacKenzie (2007), Pardo-Guerra (2012), Panourgias (2015), and Frame and White (2015), to explain different aspects of financial markets and the concept of dematerialisation. The aim for this working paper was to deploy a research methodology which allows for triangulation of sources, including peer-review by actors involved in the original project.

Functional approach

The functional approach creates insight in the dynamics and possible patterns of technological change (Merton and Bodie (1995:4). Taking a functional perspective, Hekkert *et al.* (2007) explains the use of functions as heuristic:

> 'Notwithstanding its cumbersome history, we think that the notion of "function" is useful, provided we stress its heuristic value instead of its positivistic value: it helps to identify, understand, and compare the crucial activities in technology specific innovation systems and it creates insight in the dynamics and possible patterns of technological change and related innovation processes. By doing so, it offers policy makers and other actors involved in innovation processes important insights that may guide and support their actions.' (Hekkert *et al.*, 2007:429)

Similarly, this study focuses on CREST as a technology and the radical change it enabled.

2.3 Multiple layers of investigation

When the researchers started to investigate CREST, it became clear from the data collected that there are many of aspects to consider in order to analyse the mechanism, impact and context of CREST.

Different layers of investigation have been identified:

Layer of investigation	*Examples*	*Theoretical perspective*
People & Decisions	The CREST project was led by Pen Kent as Chairman and Iain Saville as Project Manager and the CEO of CRESTCo.	Leadership theory Strategic management Decision making
Project	Project team Project culture Project communications	Project Management theory Innovation theory
Organisation	CREST as a spin-off of the Bank of England; Foundation of CRESTCo; Acquisition of CRESTCo by Euroclear	Organisational and Institutional theory
Business Process	Dematerialisation Electronic settlement Back Office Operations	Sociology of Finance Process perspective Operations perspective
Industry	London as a financial ecosystem, and the joint industry effort by the investment industry to implement a new settlement system	Business History Institutional theory Functional theory
Financial Markets	UK and European Post-trading infrastructure; Financial technology	Finance theory Information systems theory

Table 3: Multiple layers of investigation
Source: By the authors (2016)

This study takes two perspectives: first, from a business process perspective it is discussed how dematerialisation was achieved by CREST, and how back office operations were transformed; and, secondly, it is analysed how the technology design of CREST impacted on financial markets.

First, dematerialisation of securities settlement is not yet sufficiently investigated. Methodologically, the literature on dematerialisation is based on a holistic view of industry considering the entire system. For example, industrial ecology explores the assumption that "the industrial system can be seen as a certain kind of ecosystem" (Erkman, 1997). This study is informed by the field of research on dematerialisation and the resulting capability of virtual trading.

Secondly, with regards to the study of financial markets and financial technology, Messner (2016) supports deploying a multi-level research design because “many […] studies are conducted on the organizational (rather than industry) level, they do allow for some insight into the particular sector or industry more generally.” (2016:104)

Such research on the industry context allows better understanding of the dynamics, rivalry and collaboration between corporate actors at industry level. In the case of CREST this is advantageous because a settlement system like CREST could be introduced only as a joint industry effort of telecommunication service providers, legal experts and lawmakers, software vendors, industry associations and leaders of global and domestic corporate actors. This research allows insights into the resulting interaction (e.g. user groups, engagement with industry, legal framework, and industry training).

3. Data collection

The first phase of the data collection for this research started in June 2015 and ended in December 2015.

Type of data collection	*Description*	*Details*
Interviews	Face-to-face (n=17) and telephone interviews (n=3); One group interview	N=20 (individual interviews); N=3 (group interview)
Document analysis	57 business newspaper articles, e.g. Financial Times	ProQuest Business database was screened
Secondary data	Data on trading systems at six European stock exchanges at the end of the 1980s; Effect on settlement prices of the financial Big Bang	Secondary data from a study by Pagano and Roell (1990)

Table 4: Types of data collection
Source: By the authors (2016)

The interviews were held in three rounds. The first round of interviews was conducted during three days, from 24 -26 June 2015. Apart from one interview, all took place at the Moorgate campus of London Metropolitan University. The second round was held as telephone interviews on 22 September, and again as face-to-face interviews at London Metropolitan University one day later, and also on 25 September. Additionally, on 25 September an interview was held at the London office of Euroclear. In a third round, a group interview was conducted on 15 October 2015 at the premises of Travers Smith, a London law firm, with three of their lawyers.

Overall, 20 single interviews and one group interview were conducted with a total of 23 interviewees. Most of the interviews were face to face, and three telephone interviews. The interviews were conducted by an international team of researchers from three different universities supported by a research assistant.

> "It was a great experience to be in dialogue with busy, first-rate industry experts who gave their time and effort to conduct interviews generating a wealth of rich data."

As the data generated from the interviews was extraordinarily rich, and more requests from the industry were received to be interviewed, it was decided to conduct more interviews in a second phase of data collection which will start later in 2016.

3.1 Sampling of interviewees

The interviewees for the CREST research were referred by contacts that were provided through B.I.S.S. Research in London, providing network access to key players in the industry, which enabled stronger and faster rapport to be established with them (Yin, 2013).

Interviewees were selected in several different ways to cover direct and indirect involvement with CREST. For example, interviewees included members of the original CREST team, a chairman of CREST and the project manager who became the CEO of CRESTCo.

Interviewees were drawn from different market sectors such as buy side firms (i.e. investment firms such as stock brokers and asset managers), sell side firms (banks, market makers), market structure organisations (such as registrars, stock exchange, regulators), ancillary services (vendors, network services providers, SWIFT, legal services), and government.

3.2 Document analysis

The researchers were given access to some internal documents of CREST. The two documents used for this working paper are a report to the then chairman of CRESTCo, Scott Dobbie, by a London consultancy, Roffey Park Management Institute (1998). Also, the report to the Governor of the Bank of England by the Task Force on Securities Settlement from June 1993 ("The Golden Book") was made available for this research.

Additionally, newspaper articles were used, covering a decade of CREST's development and operations, dating back to the initiation of the project in 1993 and up to 2002, when it was acquired by Euroclear to become Euroclear UK & Ireland and the following year 2003 while the settlement system adjusted to changes in leadership, culture, structure, etc.

ProQuest Business database was screened to identify and introduce 57 relevant articles from reliable sources, such as the Financial Times.

These documents helped to contextualise the development of the settlement system and add another dimension to the findings.

3.3 Secondary data

This study uses data from a study by Pagano and Roell (1990) on trading systems at six European stock exchanges. In particular, performance data are used to compare the competitive position, and the effect of the financial Big Bang in London on settlement prices.

4. Findings and discussion

In the following sections, first findings of the CRESTCo Research are presented. Findings include (4.1) details about the origin of the CREST project and (4.2) the innovation it facilitated for financial automation and dematerialisation revolutionising back office operations. (4.3) Furthermore, a framework is presented to analyse the interaction of financial markets and technology design.

4.1 Business history perspective on CREST

4.1.1 The origin of CREST as a spin-off of the Bank of England

CREST was first mentioned in a report to the Governor of the Bank of England (BoE) by an industry Task Force on Securities Settlement (1993) that Pen Kent initiated. Work on TAURUS was suspended by the London Stock Exchange (LSE) on 11 March 1993, and the Bank of England had been informed two days earlier before it was publicly announced. On behalf of the BoE and in coordination with HM Treasury, Pen Kent had asked leading industry figures to meet and discuss how the crisis situation could be solved. On 11 March 1993, the Governor of the BoE established the Task Force.After frequent breakfast meetings at the Bank and 16 weeks later a 37-page short report was submitted to the BoE in June 1993, 16 weeks later, with copies being sent to the Chancellor of the Exchequer, the president of the Board of Trade, the chairman of the LSE, and the chairman of the Securities and Investment Board (SIB). The report was signed by Pen Kent and the other nine members of the Task Force. In an appendix it is stated that in total 291 written submissions were received contributing to the decision-making process. The high number of contributing organisations and individuals show how important solving the settlement crisis was to the industry.

The report (Task Force on Securities Settlement, 1993) reviewed the role of settlement, and made five high-level suggestions. Decision-making included a response to the question whether the LSE Talisman system could be adapted or “to opt for a new build” (1993:6). In the model preferred by the Task Force, “the stock is held within the system in separate participants’ accounts and legal ownership remains with the account holders. Transfers within the system must be subsequently registered. We recommend this option be called ‘CREST’” (1993:6). For the time required to design, build and implement CREST, "interim

changes to Talisman to provide a 10-day rolling settlement from mid-1994, and a 5-day cycle from 1995" (1993:1) were recommended.

> "I have to say I studied the Golden Book carefully when I took post [having been appointed in July 1993 and starting officially on 2 August 1993 on the CREST project], but 3 months later it was obsolete - not wrong, but accepted as the right basis, so not referred to." (Iain Saville)

The approach used by the BoE to implement CREST was through putting together a project team of BoE employees supported by external software specialists. In the literature, such an approach is conceptualised as a spin-off (Carayannis *et al.*, 1998:1) if a new company is formed (1) by individuals who were former employees of a parent organization, and (2) around a core technology that originated at a parent organization and (3) that was then transferred to the new company.

In the case of CREST, (1) the individuals who formed the core team were indeed BoE employees at the time when the CREST project was initiated in 1993. When the CREST project was initiated in 1993, no one from the failed TAURUS project team was recruited. (2) The core technology was based on approaches adopted by the BoE, and was developed by programmers from a supplier of the Bank, Admiral. The hardware basis was Tandem computers, and they were selected because the BoE had long experience in operating that resilient hardware successfully. (3) CRESTCo later became independent, and was founded as a new company; however, at the launch of CREST the BoE held 100% of voting shares.

> "A spin-off is a mechanism of technology transfer because it is usually formed in order to commercialize a technology which originated in a government R&D laboratory, a university, or a private company." (Carayannis *et al.*, 1998:2)

After the crisis caused by the failure of TAURUS, the Bank of England was determined to ensure a solution was delivered. Iain Saville sent out a very clear message that the project must be completed on time and on budget. Concerning the technical solution, a key test set by the Task Force was "technical feasibility without venturing beyond tested technology" (1993:3). Using the organisational form of a spin-off also met the recommendation by the Task Force of "a phased approach to cost-effective improvement of UK equity settlement" (1993:1), although internally it was not called a spin-off (Iain Saville).

4.1.2 The acquisition of CRESTCo by Euroclear

CRESTCo was acquired in 2002 by Euroclear where it is operated today by Euroclear United Kingdom & Ireland (EUI).

4.2 Business process perspective on CREST

4.2.1 The concept of dematerialisation

There is a body of research on dematerialisation at the level of the economy from an industrial ecology perspective (e.g. Vellinga *et al.*, 1998), but it is not well understood how dematerialisation is an underlying concept for the digitalisation of financial markets. In particular, case studies explaining empirically how the transformation from paper-based operations to a state where trading and settlement based on digital processes and electronic systems is achieved are scarce.

One of the few empirical studies in the field of financial markets is the seminal study of MacKenzie (2007) focusing on derivatives markets from a Sociology of Finance viewpoint. He confirms this gap of empirical studies with regards to financial derivatives trading stating 'in the existing literature, the "virtual" nature of financial derivatives is often commented upon, but how these products are brought into being has seldom been examined in any depth" (2007:355). Another empirical study was presented by Panourgias (2015) investigating the Single Settlement Engine (SSE) which was developed by Euroclear.

Dematerialisation "occurs when the physical securities or documents of title that represent ownership of securities are eliminated so that the securities exist only as accounting records" (Norman, 2007:11). Regarding settlement, CREST can be understood as a type of accounting technology where book-entry transactions are "processed without the movement of physical certificates, being effected instead by means of credit and debit entries" (ECB, 2009). CREST was providing a central database, acting as a settlement hub for the recording of data and the execution of transactions. It enabled Delivery versus Payment (commonly known as DvP), the simultaneous, irrevocable, and risk free exchange of securities and money between seller and buyer or their custodians (Simmons and Dalgleish, 2006). The following section discusses how CREST has affected on post-trading operations.

4.2.2 CREST – the "back office" project

In London, the introduction of CREST led to structural changes in back office operations. In the contemporary depository model, the 'front office' is the unit where brokers and dealers execute and match orders, while the post trade settlement function of the 'back office' fulfils the legal requirements for securities ownership transfer in a safe, efficient and cost-effective way preserving the nature of the transferred securities (Donald, 2013). The idea behind CREST "was really to bring the technology of the back office or the transaction side of the things, up to the level seen in the front", as Scott Dobbie, the chairman of CRESTCo, explained.

Traditionally, the back office was "never seen as absolutely crucial to an industry until it goes wrong" (Scott Dobbie). Previously, an army of back office personnel processed paper (Iain Saville) when front office processes started to go digital, accelerating the trading, the volumes exploded, creating challenges for back office systems, which managed the "all important" BoE settlement risk (David Wyatt). Clearing and settlement, amongst other

things, could not cope with the paper-based system (Jon Vyse) making a huge numbers of errors (Alistair Reed), leading to the settlement crisis.

The CREST team, despite contrary advice, "put the people who were doing the design work in front of the people that were going to use it" (David Wyatt). This enabled discussion of business and IT processes and any pressing issues with the specialists who were directly designing the technology solution. Furthermore, the CREST team engaged the relevant domain experts from the financial industry, the "back office people", "the real nuts and bolts people", "the ones that KNOW", who, once persuaded, were the ones best placed to go with the new CREST design and try it out (David Wyatt). This wide range of cooperation efforts involving the CREST team can be understood as micro processes facilitating strategic knowledge management. Applied to the work of the CREST team as "frontline workers" doing "strategy work", i.e. being involved in strategizing practices (Balogun *et al.*, 2015) discussing and solving strategically relevant issues, e.g. using the Whiteboard technique and with user groups.

> "Strategy work of frontline workers" (Balogun *et al.* 2015): CREST team members interacting with financial community (e.g. stockbrokers, investment bankers, registrars, lawyers) and software developers.

Overall, CREST intrinsically changed the settlement process, shifting the back office paradigm, who were not used to "big hardware boxes with lots of processes in it" (Fiona Hamilton). It "changed how a lot of market infrastructures are implemented in that the model is seen to have worked extremely well in this market so people don't want to re-invent the wheel" (Fiona Hamilton).

However, when CREST was launched in 1996, back office operations were not at the centre of media attention: "When the system went live and worked, it was plumbing and it was back office, and it was not relevant any more" (Charlotte Black). This lack of coverage by the media about a successful technology has contributed to CREST not being widely known despite its importance as a critical component of UK post-trading.

The long-term impact of the digitisation of post-trading information is that the back office function today also includes information technology (IT) departments, and technical support. Due to focus on reducing settlement times, more complex and increased risk management, and a greater technological role that algorithms have gained in trading, the technical side of the back office has become more prominent in the daily functions of financial services companies.

In summary, CREST achieved dematerialisation of securities trading though a joint industry effort by building a value chain for settlement: the CREST computerised electronic settlement engine eliminated huge volumes of paper and reduced settlement time drastically. Over time, rolling settlement reduced the settlement time from three weeks to three days (T+3). It is now two days for equities and less for bonds and money market financial instruments (MMIs). As well as near real-time settlement, CREST offered periodic optimisations ("circles") designed to improve settlement efficiency and thus reduce the costs and risks of settlement failures.

4.3 Financial markets and technology design

Clearing and settlement in financial markets is often organised by clearing houses. Along with the exchanges, clearing houses are financial intermediaries which are "responsible for the clearing and settlement process" (Bernanke, 1990:134). The following section presents a framework to study the innovation of CREST for financial markets as a settlement system achieving a step change through financial automation and dematerialisation of securities post-trading (see 4.2).

4.3.1 The settlement crisis as a market friction

In the following analysis, a five-phase framework presented by Levine (1997) is used to analyse whether the settlement crisis was a market friction that financial markets had to overcome through technical innovation and capital investment.

Levine (1997) has suggested the following framework to analyse 'how specific market frictions motivate the emergence of financial contracts, markets, and intermediaries': first, market frictions cause increased information and transaction costs; secondly, financial markets and intermediaries are affected; thirdly, the financial functions of the investment industry are impaired; fourthly, new channels to growth are sought; and finally, a phase of new growth is achieved.

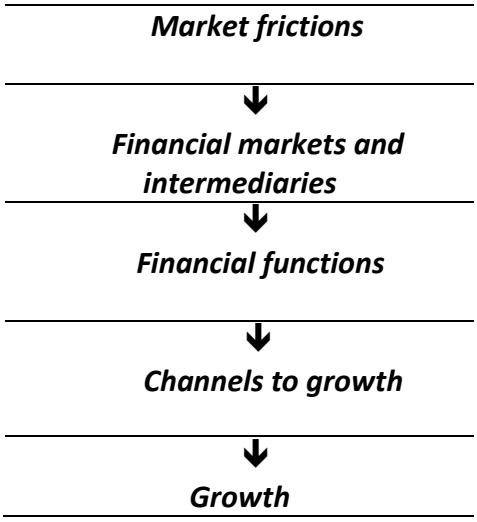

Table 5: *Framework to analyse finance and growth.*
Source: Levine (1997:691)

4.3.2 Financial automation and technical Innovation

For thinking about "the operations of the clearinghouse both in normal times and under stress as well as for examining the potential role of government policy", Bernanke suggests an elementary analogy: clearing houses "function in ways analogous to other more familiar

intermediaries. In particular, in some of its operations a clearinghouse is like a bank; in others, it is like an insurance company." (1990:134)

As it unfolded in 1993-94, the design of CREST became a radical departure from the existing central Stock Exchange market processing. It extended the central market to include settlement banks actively providing (secured) credit and payment services for CREST users, to reduce risk by ensuring an adequate standard of simultaneous delivery versus payment. In the below table, the columns to the left and right give specifics about the case of CREST:

Settlement crises in London (and New York)	***Market frictions*** - information costs - transaction costs	Affected were registrars, stock brokers, traders, and private investors
	↓	
1987 stock market crash; Liquidity crisis	***Financial markets and intermediaries***	LSE Private and corporate investors
	↓	
Risk: T + 3 weeks Time had to be spent on clearing instead of trading	***Financial functions*** - mobilise savings - allocate resources - exert corporate control - facilitate risk management - ease trading goods, services, contracts	Call for reforms by Group of Thirty Pressure on LSE (TAURUS) and then Bank of England (CREST)
	↓	
Dematerialisation Financial automation	***Channels to growth*** - capital accumulation - technological innovation	CREST as electronic settlement system
	↓	
Increased number of transactions; Electronic settlement allowed large rights issues (e.g. BT), M&As (e.g. AstraZeneca merger), and the demutualisation of UK mortgage houses	***Growth***	Acquisition of CRESTCo by Euroclear in 2002.

Table 6: *Framework to analyse finance and growth.*
Source: Levine (1997:691)

Stiglitz notes “that financial markets are markedly different from other markets; that market failures are likely to be more pervasive in these markets; and that there exist forms of government intervention that will not only make these markets function better but will also improve the performance of the economy.” (Stiglitz *et al.*, 1993) While the collapse of TAURUS was not a market failure, it was a failed effort to introduce a financial technology to solve the ongoing settlement crisis that affected the functioning of financial markets.

The CREST design required reconciliation between registrars, the CREST system and all users. Hence it required not only connectivity between issuers, the market and institutional investors via the registrars, but also with agents and retail investors via the brokers. The technology design obliged share registrars to interact electronically with CREST to confirm within a maximum delay of 2 hours that ownership of securities had been legally transferred. The risk that ownership could not be fully transferred was mitigated by other legal measures, but not fully eliminated until new law came into force, in 2001 which meant that legal title transferred in CREST. There was no incidence of loss in the interim period. (Iain Saville)

CREST was also designed to reduce the risk and costs associated with handling share certificates and paper instruments of transfer. CREST functionality provided much cheaper, timelier and safer processes for the holding and transfer of shares, and the team expected that use of non-electronic methods would quickly decline – but not disappear. Additionally, increased transparency of (post) trading activity “can alter the impact and persistence of return shocks on volatility” (Masulis and Ng, 1995:366), and it is notable that the UK post-trading infrastructure and CREST showed sufficient resilience during the financial crises of 2007-2008. The following are key features of CREST’s design:

- CREST enabled payment banks to monitor in quasi real-time the use of credit by CREST market user clients.
- CREST provided a facility by which a bank could offer a client both an unsecured credit limit and a secured limit driven by a bank-specified haircut on the securities held in the client’s own account. This enabled banks to manage and monitor market and credit risk, and improved settlement performance through efficient use of cash.
- CREST placed no restrictions on membership of CREST, except technical competence, reducing effectively barriers to competition.
- Collateral for bank or stock loans was standardised as CREST enabled securities houses/market makers to fund their overnight equity positions by delivering a basket of varied securities of a specified type in exchange for cash borrowed from a cash rich entity such as an insurance company, the delivery to be reversed at the start of the following day.
- CREST provided functionality for processing corporate actions ranging from simple dividends to complex optional events.
- CREST led the European move to standardise messages and processes to enable clients of one CSD to access securities issued in another CSD, to help development of

the single securities market. It introduced CDIs (CREST Depositary Interests) to simplify cross-border hodlings and increase the investment options available to CREST clients.

In summary, the launch of CREST in 1996 solved successfully the settlement crisis in the UK through radically changing post-trading operations and eliminating the market frictions felt by market participants. The new settlement capabilities provided by CREST facilitated a new era of growth for London as a world-leading financial centre and the financial markets served by CREST.

5. Summary

5.1 Conclusions

This study has investigated the radical transformation of post-trading in the 1990s. It has focused on CREST as the key component of the step change from paper-based to electronic processes in post-trading of securities. The following conclusions have emerged from the analyses:

First, the industry context at the time when CREST was launched is described using secondary data from earlier studies on the financial "Big Bang", the 1987 stock market crash and the situation of post-trading in the early 1990s. It was found that an increase in the number of securities transactions following the privatisation of large UK companies and the efficiencies created by the reforms of the financial "Big Bang" in combination with the stock exchange crash of 1987 led to the settlement crisis. Paper-based operations could not cope with the increased transaction volume creating market friction and affecting the performance of the securities industry. These problems had become so severe that the industry called for a solution. The automation and digitisation of securities post-trading enabled by CREST ultimately solved the settlement crisis. To conclude, the successful launch of CRESTin 1996, initiated by the Bank of England and facilitated through a wide ranging industry effort, is linked to a range of specific factors and circumstances where the pressure caused by the failure of TAURUS is only one factor.

Secondly, the step change towards financial automation of post-trading is seen as the key achievement of CREST. It transformed settlement and clearing and the related back office operations in financial institutions in a so-called "back office revolution". CREST fundamentally changed the settlement process, shifting the back office paradigm from paper-based processes to more sophisticated computer-based processes requiring fewer people but higher qualifications.

Thirdly, CREST's impact on financial markets is that it enabled much higher transaction volumes in UK and Irish securities allowing the market to create new financial products and reductions in both cost and time through more efficient post-trading.

5.2 Limitations

With regards to the settlement crisis, this study focuses only on post-trading in Europe and the UK. Simultaneously, a settlement crisis occurred in the United States, but it is not the focus of this paper.
This paper covers the time period from the launch of the CREST project in 1993 until 1997 when CREST replaced Talisman.

In terms of content, this study had not covered details about the legal and regulatory activities which supported and enabled the introduction of CREST as a major component of UK and European post-trading infrastructure. More details about these specific topics can be found in the B.I.S.S. Industry Report (2016).

5.3 Future research

It is good academic practice to outline suggestions for future research activities based on the experiences during the current research. It is suggested, that the following open questions be addressed in further research.

Legal framework: Central securities depositories regulation (CSDR) introduced by the EU
The clearing and settlement industry is "heavily regulated, arguably even more in countries where there is only one clearing and settlement service provider." (Li and Marinc, 2016) In order to improve efficiency further, CREST pioneered a “settlement discipline” regime, based on league tables of performance, and introduced fines for failure to meet set performance standards. Some 18 years later,a form of settlement discipline will become mandatory across the EU. Further work is needed on this subject.

Target2-Securities system
Target2-securities (T2S) is the Eurosystem’s central settlement engine launched in 2016 for the settlement of almost all bonds and equities that are traded in Europe against euro central bank money. While some of the features of CREST have been adopted by other CSDs, the system that most closely resembles CREST is T2S (Iain Saville). It is independent of trading platforms, belonging to the central banks of the Eurozone; it is not for profit, like CREST; and it seeks to be accountable to its users as CREST did (and still does) (Iain Saville).

> “If you look at the Target 2 functional specification, if you have ever read a CREST functional specification, you can kind of see the terminology is different, but how it works in cycles and stuff like that and the status messages, and the pull versus push kind of technology, you can see the same things happening now” (Fiona Hamilton).

While Target2-Securities (T2S) was launched only in 2016, its development began almost ten years earlier. The future of post-trading infrastructure is a highly interesting area for future research including the question whether centralised or distributed systems (e.g. based on distributed ledgers and blockchain technology) will be more successful.

CREST and competition

Looking at CREST from a competition policy perspective (Kauko, 2007; Li and Marinc, 2016), there are a number of aspects which deserve to be analysed in more depth.

CREST is the only UK national settlement system and is not administrationally connected to the LSE whereas in other European countries CSDs are linked to the stock exchanges (Li and Marinc, 2016). CREST "provided settlement services for the London Stock Exchange, Irish Stock Exchange, virt-x and a range of ECNs." (CRESTCo, 2001) An ECN, which is short for Electronic Communication Network, runs an electronic order book aiming for high trading volume. This is a link between smaller market participants and major banks (so called tier-1 liquidity providers). An ECN broker obtains liquidity from a major bank, and makes it available to clients. Also, an ECN broker delivers clients' orders to banks for execution earning a commission fee per transaction. That CREST was providing services to ECNs on the same terms as the LSE trading platform was creating some anxiety for the LSE (Norman, 2007:134) However, this was a "well considered policy choice" (Iain Savillein: Norman, 2007:134) based on discussions between the BoE, HM Treasury and market participants. More recently CREST has settled for other trading platforms including multilateral trading facilities (MTFs).

Competition was also introduced at the level of network access and the offering of telecommunication service providers, BT (Syntegra) and SWIFT.

Regarding settlement infrastructure at a European level, Li and Marinc (2016) confirm that competition between clearing and settlement institutions is limited, and Europe is disadvantaged with regards to transaction costs in comparison to the U.S. The reasons for this are discussed by Giovannini (Giovannini, 2003).

5.4 Impact and legacy

The investment industry is fast paced. Preserving the memory of the social and technical changes that happened over the last decades is a massive challenge. The legacy of the industry is in telling and documenting the stories of the people involved and the projects they were working on, documenting the changes in business processes and data workflow, changes in organisations and at the level of financial markets, and also how it affected the whole industry in terms of job profiles, education and international connections.

Several interviewees shared that some private archives have already been dissolved and historic material has been lost. On the other hand, the readiness and support from all participants in this research was overwhelming. Therefore, a second phase is planned with another round of data collection with more interviews, and a systematic effort to digitise existing documents for future research. There is an effort amongst several industry figures with the aim to preserve the industry legacy, and possibly creating a Museum of Finance in London. This research attempts to contribute to these efforts by adding an academic dimension and inviting other scholars and researchers to participate.

2016 marks the 20th anniversary of the launch of CREST. This working paper is an outcome of the first phase of the CRESTCo research programme. We look to bring you more research on CREST in 2017.

Appendix

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