POLITECNICO DI MILANO

School of Industrial and Information Engineering
Master of Science in Management Engineering

Economic Geography & Econometric Analysis of the impact of Brexit on the main European Financial Hubs

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Academic Year 2020 - 2021

ABSTRACT – *English version*

In this work we focus on the tangible impact the Brexit event has had on the European financial markets, trying to understand if the recognized leadership of London as financial center has been affected in the last years. To do so, a literature review has been conducted, analyzing the immediate impact of Brexit on financial services firms that must comply two independent regulatory regimes after the UK departure from the single market. Relying on the economic geography framework literature, the importance of geographical agglomeration in the development of financial hubs was analyzed, to later understand the determining factors for the success of the financial centers.

Initially, an event study, following the event study methodology (ESM) was performed, in order to assess the relevance of six major events during the Brexit process over a set of financial variables. The results confirmed that the date of the announcement of the Brexit referendum can be considered as the strongest event. Insightful results were found by analyzing the changes in the behavior of the time series of trade volumes at the main financial hubs in Europe. Frankfurt and London have been consolidated as main financial hubs where a large volume of contracts and instruments are traded. In general, there was a migration of total trade volumes from Paris and Milan to Germany, whilst London volumes kept on increasing, especially for UK and RoW instruments. Despite the consolidation of Frankfurt as the main European financial hub, the trade volumes hosted in London were twenty times larger in 2020. Evidence suggests that after the Brexit announcement in 2016, the European financial markets re-structured, firms moved or duplicated their presence to keep strategic access to the main financial hubs. The number of MFIs in London increased, likely due to its privileged position as a global financial hub, in contraposition to the macro trend of market consolidation and therefore reduction of the total number of MFIs seen in Europe.

Keywords: *Brexit, Financial hubs, Financial markets, Economic Geography, London, European markets, Agglomeration economies, Event Study,*

ABSTRACT – *Italian version*

In questa tesi ci focalizziamo sull'impatto tangibile che l'evento Brexit ha avuto sui mercati finanziari europei, cercando di capire se la leadership di Londra come centro finanziario sia stata, in qualche modo, impattata negli ultimi anni. Per fare ciò, è stata condotta una revisione della letteratura, in cui è stato analizzato l'impatto immediato che Brexit ha avuto sulle imprese di servizi finanziari, che, dopo l'uscita del Regno Unito dall' Unione Europea hanno dovuto adeguarsi a regimi normativi indipendenti. È stata analizzata, inoltre, l'importanza dell'agglomerazione geografica nello sviluppo dei centri finanziari, basandosi sulla letteratura esistente capendo quali sono i fattori che determinano il successo di un centro finanziario. È stato condotto inizialmente un "Event study", seguendo la metodologia ESM, per poter valutare la rilevanza di sei eventi avvenuti durante il periodo che ha portato alla firma dell'accordo finale. Tale lavoro ha confermato che la data in cui sono stati annunciati i risultati del referendum, può essere considerato l'evento più rilevante. Risultati rilevanti sono stati rilevati analizzando i cambiamenti nelle serie temporali delle variabili finanziarie e non finanziarie, dei diversi centri finanziari presi in considerazione: Londra e Francoforte sembrano essersi consolidati come maggiori centri finanziari europei dove vengono scambiati grandi volumi di contratti e strumenti finanziari. In generale è possibile notare una migrazione di attività di compravendita di strumenti finanziari da Parigi e Milano, verso la Germania, mentre i volumi Londinesi hanno continuato ad aumentare, soprattutto per quanto riguarda strumenti provenienti dai mercati extra UE e dalla Gran Bretagna stessa. Nonostante Francoforte si stia affermando come centro principale dell'Eurozona, la quantità di strumenti scambiati sul mercato tedesco sono di circa 20 volte inferiori ai volumi di Londra. Infine, è probabile che il processo brexit, dopo l'annuncio del risultato del referendum nel 2016, ha determinato una ristrutturazione dell'equilibrio dei centri finanziari europei: molte imprese sembrano aver spostato da Londra o duplicato la propria sede in altri centri europei. Londra, contrariamente al resto d' Europa, ha visto un aumento in MFI, suggerendo una maggiore abilità di attrarre più imprese grazie alla sua presenza come centro finanziario globale.

Parole chiave*: Brexit, Centro Finanziario, Mercati Finanziari, Geografia Economica, Mercati Europei, Londra, Economie di Agglomerazione, Event Study*

ACKNOWLEDGEMENTS

We would first like to thank our supervisor, Professor Miriam Judit Manchin, whose expertise was fundamental for formulating the research questions and establishing a methodology. We would like to thank Politecnico di Milano for being our second home during these years, for providing us invaluable experiences, knowledge, opportunities, and for witnessing our personal and professional growth.

~ Diego Alejandro S. Rodriguez & Giacomo Donelli

I would like to thank my father *Stefano* who always supported my decisions and my sister *Emily* whom I can always rely on for help and advice. The continuous caring support and advice have been of immense value during these years.

I would also like to thank my grandparents and all my relatives who have always shown interest in my studies and offered help when needed. Big thanks go to my friends for sharing both the long studying hours and the happy distractions. I truly believe that all those who have crossed my path, be it for years or short moments, have had a lasting impact on me and my work.

Finally, I wish to thank my mum, to whom I will always be grateful for teaching me the values I will always follow and who would have loved nothing more but to see me through my journey.

~ Giacomo Donelli

I would like to thank to my grandparents, *Tata & Abu,* for their unconditional support and their warm love that has been key to succeed in every new endeavor undertaken. To my mother *Feney*, my father *Enrique* and my brother *Julian,* a huge thank you, for everything, you are a constant source of energy and inspiration. I also thank my whole family; I have not enough words to express my gratitude for your support all along these years and end to end.

My intensely beloved and wonderful *Sol,* you have more than anyone been by my side and made every success in these years be possible. There will be not enough time in my life to give back to you half of the love and beautiful vibes that you have given me during these years. To you and to my dearest unconditional companions *Michin, Bianca and Didi:* I love you all very much, across time and space.

To my dear friends, the *Viejos Soles*, to *Rubén, Anita y los pollos espaciales*, to *Tea* and *Mattia*, to *Simseok*, to *Anica*, to *Nata*, to *Andrés* and to all of you around the world a huge thank you for all the love and support. My most sincere gratitude to all my professors, particularly *Rubén Godoy, Hermes Rangel, Yoon Yeo* .

~ Diego Alejandro Sánchez Rodríguez

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INTRODUCTION

The idea that geographical concentration drives economic growth has been studied and developed since the late 19th century, when Alfred Marshall suggested a framework for industrial districts, leading to the concept of agglomeration economies in his "Principles of Economics". His idea was that industries, by concentrating in a confined geographical area, could grow, reduce unitary costs, and ultimately become more successful. The growth in the economic activity of the geographical location is fueled and in turn fuels the growth of the individual firms which thrive in a developing industry. Cities make the interactions between firms and people more efficient facilitating a higher quality matching between jobs and workers, higher availability of qualified human capital, and knowledge. Such idea has since been investigated and the agglomeration forces, the factors driving the economic development in specific locations, have also been studied in detail. The process of urbanization has greatly contributed to the development of industries, turning cities into the engine of the world's economy. Whilst urbanization accentuated an already existing trend, globalization gave cities the means to specialize and emerge as global suppliers and this is also the case for the financial industry. Although Marshall didn't focus his research on the financial industry, the same principles have been identified with cities becoming providers of financial services on a global or national scale. As in other industries, highly specialized services are delivered more efficiently at central places in urban space, and less complex services with a more dispersed pattern. The spatial proximity of financial services firms has reportedly helped the growth of the single firms operating in the industry, allowing a cost reduction and increased ease of delivering the service to the selected market. There are many reasons why this may happen, namely the financial industry agglomerations forces which increase the competitiveness of a city, turning into a financial hub. Availability of skilled personnel, a favorable regulatory environment, tax regime, availability of infrastructure, and cultural factors all seem to have a big impact on the success and the growth of the financial sector of a city. The concentration of such factors in a limited geographical area gives the city the ability to supply financial services to a whole region, country, or even international area in the case of global financial centers.

This is the case of the City of London, which has enjoyed a favorable position as a global financial hub for centuries, emerging as the capital of the British Empire where the wealth coming from the colonies around the globe converged. Although in different forms, London has kept its image as a global financial center, passing through changes in the regulatory environment which helped attract foreign investors and financial institutions. This is certainly the case for European firms which turn to London for the supply of financial services. European companies and individuals rely on the international reach of London in order to look for investors, secure fundings, and trade financial instruments. Most global financial companies have their European headquarter based in London and rely on the competitiveness factors of the City to grow and successfully serve their clients. In the City of London, we find large banks, insurance firms, and law firms driving the agglomeration in which physical proximity to related firms and institutions enabling face-to-face contact and relationship-building is of fundamental importance. But London is not the only European financial hub: many cities in the continent have set up a sound infrastructure and developed the competitiveness factors that determine the success of financial centers.

Many have now raised the question if Brexit has changed the status quo; is London still the main center for European financial markets? Has Brexit, in any way, affected the competitiveness factors of the City?

The process of the UK abandoning the EU, commonly known as Brexit, has definitely disrupted the economic and political equilibrium of the European continent, with consequences for the years to come which can hardly be estimated. Starting from the referendum carried out in 2016 in which the citizens of the UK were asked "*Should the United Kingdom remain a member of the European Union or leave the European Union?*", the financial markets started reacting to the different announcements. When the referendum was announced some concerns rose among the financial industry, international firms like investment banks and hedge funds contributed to the "remain" campaigns, while most local European firms remained neutral to avoid a negative influence over the "remain" option due to the sector's negative public perception. The results of the Brexit referendum represented a turning point for the whole of Europe's financial ecosystem, giving us measurable data throughout the last five years, which has been studied in this work.

In chapter 1 a literature review was conducted, aimed at understanding the functioning of European financial markets, the agglomeration theory behind financial centers, and all the different aspects of Brexit, focusing on those that influence the financial industry. In chapters 2 and 3 we define, the data and the methodology used to carry out the work, hence the parameters used in the Event Study and the time series regression. In chapter 4 an in-depth analysis of the Event study is carried out, presenting the results of all the different time series taken into consideration, including the regression of market volumes and financial hub factors. Finally, we discuss the conclusions of the work in chapter 5, highlighting the main results, findings and the limitations of the thesis.

1. LITERATURE REVIEW

1.1 Financial Markets in Europe

The financial system is composed of financial markets, financial institutions, and financial market infrastructure (Frank J. Fabozzi, 2019). There are several financial assets and instruments that facilitate the economic resources allocation and risk hedging within the current financial system. After the financial crisis of 2007-2008, there has been a broader concern for ensuring greater stability and safeness (Lagarde, 2019; Pesendorfer, 2020; Rebbeca Christie, 2020; Schiereck, Kiesel, & Kolaric, 2016). Some of the most relevant types of financial instruments to recognize, and their associated markets, are equity, debt, mortgages & secured loans, currency, and derivatives.

The different instruments are traded among market participants of different sizes, with different objectives and each serving a different purpose within the economy while also maximizing their objective function. It is possible to classify the actors as institutional and individual investors. Among the largest institutional actors in the financial markets there are commercial and investment banks, investment and hedge funds, private equity firms, governments, and central banks, insurance, and re-insurance firms, and pension funds. These actors trade different securities for different purposes and thus with different risk appetites, for which some trades are carried out on standardized and closely monitored markets such as the exchanges, or on less-standardized and less-surveilled markets as the OTC markets or even the financial instruments are privately arranged with increased customizability. The supervisory authorities are entitled by the legislation of every nation to set and enforce the compliance of the rulebook under which the different actors can operate as well as the conditions for them to be granted the permission to operate, even more, when the entity is from a foreign country with different legislation and has a headquarter regulated and supervised by another authority. At this point, there is a tight integration among finance, politics, and law. However, not only the general architecture, flow structure, and major regulatory guidelines need to be defined for the financial markets to properly function, the fine details need to be regulated and adjusted as well and all these are part of the financial market infrastructure, which are made possible thanks to fundamentally important, yet more quiet, actors of the financial system such as clearinghouses, brokers, exchange holders or market makers, among others (Hohlmeier & Fahrholz, 2018).

There is a need for coordination and common understanding of the rules, as well as effective protocols, recognized legitimacy, and legality for the protocols and communications that enable the regulatory authorities to enforce the compliance of the legislature set by policymakers. When it comes to international integration of the markets, the European Union is a particular case of an attempt to bring closer and yet having not fully integrated the financial markets of different countries, with a common legislature for the markets, thus a single policy-making organism and general supervisory and regulatory agency acting over different local regulators that oversee local segments of the European financial market. The integration of the capital market in the European Union (EU) is yet to be attained (Rebbeca Christie, 2020), if ever is going to happen at all, however, the barriers are multiple and not as easy to overcome as many would like to. The multiple barriers are found in a wide range of political, social, legal, and ideological aspects. These aspects take a particular connotation and are presented to diverse environments for almost every country in the union. Nevertheless, so far, the EU agencies and political bodies have been able to integrate the different markets of the member countries under a clear regulation that facilitates the trades and flows across nations, leading to what is known as the single market, to which any actor from a member country can enjoy access once it has been authorized (Hohlmeier & Fahrholz, 2018). That is, for 2021, seamless access to the national markets of 27 countries and just one single rulebook to follow, broadly speaking (Hohlmeier & Fahrholz, 2018). The scenario posed by Brexit implies the exit of one of the major economies from the block and the segregation of an important market in terms of goods and factors as is the one from the United Kingdom (UK). In fact, the relevance of the city of London to the global financial markets is of common understanding and obeys a historical evolution and consolidation (A. Baker & Wigan, 2017; F, 1979; G, 1984; Howarth & Quaglia, 2017; James, Kassim, & Warren, 2021; Talani, 2012). Consequently, Brexit has great implications for the financial industry and the future of London as a financial hub (James et al.; Rebbeca Christie, 2020).

There are several laws in place, made by the European Parliament, that regulate the different sectors of the financial markets and design regulatory and supervisory functions for different agencies and institutions. The banking services in the EU are primarily regulated by the CRD-IV and CRR-II (Hohlmeier & Fahrholz, 2018). The capital market companies and their related services over securities and derivatives are regulated by MiFID II and MiFIR, which regulate at an EU-wide level the permits for data provision and trading venues (Hohlmeier & Fahrholz, 2018). The insurance business is subject to and mainly regulated by the SOLVENCY II directive, which determines the requirements for insurers and reinsurers to operate in the EU (Hohlmeier & Fahrholz, 2018). While regulation of financial market infrastructure is provided by the EMIR, the trading and clearing of derivatives are among the most critical activities here regulated, along with the MiFID II and MiFIR (Hohlmeier & Fahrholz, 2018).

1.2 History of Brexit

The process of the UK abandoning the EU, commonly regarded as *Brexit,* was a process originated by the referendum carried out in 2016 in which the citizens of the UK were asked "*Should the United Kingdom remain a member of the European Union or leave the European Union?*". When the referendum was announced some concerns rose among the financial industry, international firms like investment banks and hedge funds contributed to the "remain" campaigns, while most local European firms remained neutral to avoid a negative influence over the "remain" option due to the sector's negative public perception (James et al., 2021). The result of the referendum, to the surprise of many (Doyle, 2016; Schiereck et al., 2016), both in the UK and around the world, came to be "*Leave the European Union*", with 51.9%. Some authors had said that Brexit as a historic defeat derives from the regulatory clashes and conflicts following the 2007-2008 financial crisis, the Euro-zone crisis, and a disruption of the traditional political approach of the UK towards the EU (Thompson, 2017). The results of the referendum were announced on the 24th of June of 2016, and despite the referendum being legally non-binding and the government of that moment not being euro-skeptic, the withdrawal process went on and formally started on the 29th of March of 2017 (Hohlmeier & Fahrholz, 2018). The process lasted four years, after multiple extensions for the negotiation period, one deal rejection by the British parliament, two general elections in

2017 and 2019 as well as two changes of Prime Ministers, both from the conservative party. The UK formally left the EU at the end of the 31st of January of 2020, during the government of Boris Johnson as Prime Minister. There was a transition period, allowing the UK to participate in the E.U. Customs Union and the E.U. Single Market, extending until 31st of December of 2020 (Hohlmeier & Fahrholz, 2018; Rebbeca Christie, 2020). The negotiations for a trade deal agreement extended until few days before the expiration of the transition deal, which was agreed on 24th of December of 2020, and subsequently ratified by the UK parliament on the 30th of December of 2020 and provisionally approved for appliance by the EU the 31st of December of 2020, amid the on-going COVID-19 pandemic.

The turbulent process faced several unexpected twists due to an expected difficult political landscape. The Brexit process originated during the David Cameron government, who later resigned as Prime Minister of the UK, and was later succeeded by Theresa May in the role of Prime Minister. Under the Theresa May government, a withdrawal agreement was negotiated and agreed upon by November of 2018. This first agreement was repeatedly rejected by the British parliament between January and March of 2019, hence forcing the UK government to ask for a delay of the exit date, which was initially set for March of 2019, until June and later once again needed to be pushed back to October of 2019. Theresa May resigned as Prime Minister after the deal negotiated under her government was rejected, she was succeeded by Boris Johnson, her former foreign secretary and former mayor of London (James et al., 2021). Boris Johnson assumed office in July of 2019 and initially vowed to leave by October of the same year, but after agreeing over a revised withdrawal agreement on October 17th of 2019 which was partially accepted by parliament, it was refused to be passed into law by October 31st, thus leaving the government with no choice but asking for a third delay of the exit date. After general elections held on 12th December 2019, it was possible to break the deadlock with a conservative party majority in the parliament, and the withdrawal agreement was ratified by the UK on 23rd January and later by the EU, making it possible for the UK to leave the EU at the end of the 31st of January of 2020. Despite the road to that point being long and tortuous, the transition period starting the 1st of February 2020 and ending the 31st of December 2020 was as much as the initial negotiation phase.

During the transition period travel, trade, and freedom of movement remained largely unchanged, however, the trade and cooperation agreement (TCA) regulating the future of the relationship between the UK and the EU still needed to be negotiated and approved.

There had been an expectation during the negotiation process for the financial industry to lobby the UK government into seeking to retain access to the EU single market (James et al., 2021). As a matter of fact, during 2016 some financial groups lobbied in favor of a deal that granted access to the single market also referred to as passporting rights (James et al., 2021). However, the power and influence of banks had been constrained by an enhanced estate capacity, a more politized regulatory environment (Bell & Hindmoor, 2014, 2015), and a wave of increasing public anger (James, 2018; Ziegler & Woolley, 2016), which would be pointed out as a mistake during the Brexit negotiations lobby enforced by the banking sector and which the insurance sector preferred to avoid (James & Quaglia, 2019). There is, in fact, and opposed to popular say, a limit for financial power (James et al., 2021).

Even through the whole length of 2020, as the transition period was coming to an end, (Rebbeca Christie, 2020) the hopes for a contractual outcome rather than a cliff-edge exit were low [20], and just like the withdrawal agreement the TCA was approved only a few days before the end of the transition period. In fact, through the whole process, some politicians from the UK side argued that a no-deal Brexit would be much better than a "bad deal" Brexit (Hohlmeier & Fahrholz, 2018). On both sides, EU and UK governments warned at different points during the process that they might need to start preparing for a hard Brexit if things were to keep their course. Due to the previously mentioned prevalent uncertainty atmosphere, the general expectation for most players was to brace for the worst scenario (Breinlich, Leromain, Novy, Sampson, & Usman, 2018; Caporale, Gil-Alana, & Trani, 2018; Hohlmeier & Fahrholz, 2018; Philippon, 2016; Reynolds, 2017), that was a no-deal or hard Brexit since companies need to make economic decisions based on expected future circumstances and resulting policy environment (Brogaard & Detzel, 2015). There was plenty of time for actors to think about what to do in order to avoid being disrupted by Brexit once it happened due to the exit date being repeatedly pushed back, initially it was planned for March 2019 and finally took place in January 2020, with almost a year more of the transition period. Thus, as time went by, a free-trade agreement was perceived as less likely since further adjustments would be senseless under the light of preemptive commitments already undertaken and associated higher costs for reversal (Hohlmeier & Fahrholz, 2018). Many preemptive and mitigation actions, restructuring processes, and decisions were made by several economic actors in order to adapt to the new scenario by the time the UK formally left the EU (Commission, 2019; ECB, 2020; Eichengreen, 2019; Hohlmeier & Fahrholz, 2018; Rebbeca Christie, 2020; Talani, 2019).

1.3 Theoretical aspects of financial centers

1.3.1 Financial hubs

Mainly relying on the work of Kindleberger (Kindleberger, 1973), recent empirical literature defines financial centers, also called financial hubs, as geographical locations, and narrowly defined regions where banks, subsidiaries, funds, and other financial intermediaries are based. Usually, it is a large city where a number and variety of financial services institutions are headquartered. Financial services firms tend to conglomerate in a small number of areas, carrying out their services to clients in a specific geographical region or with similar characteristics or needs met by the financial center.

We must distinguish between financial centers and global financial centers: A global financial center is an intense concentration of a wide variety of international financial businesses and transactions in one location (Mark Yeandle & Mainelli, 2005) as opposed to a concentration of regional financial transactions in financial centers. Examples of global financial centers are certainly London and New York, which have been considered as the two only real global financial centers by many (Mark Yeandle & Mainelli, 2005) whilst financial centers which influence smaller geographical areas are Tokyo, Shanghai, Singapore, Hong Kong, Frankfurt, Zurich, Milan, Sidney, Paris and many others (Michael Mainelli, 2021).

1.3.2 The economic geography approach

The reason for the existence of financial centers has always been the object of study for many economists who have tried to explain how the industry thrives within geographical conglomerations.

The same concept has been applied to industries outside of finance, starting with Alfred Marshall who started analyzing the phenomenon of “industrial districts”, geographical industry concentrations that cannot be explained by the presence of natural resources (Marshall, 1890). He also focused on external economies of scale, which exist when economies of scale apply at an industry level rather than at an individual firm level (Krugman, Obstfeld, & Melitz). Marshall studied the presence of external economies of scale in the cluster of cutlery manufacturers in Sheffield and the cluster of hosiery firms in Northampton, realizing how production efficiency increased in presence of an industrial district: unitary production cost of producing cutlery and hosiery was much smaller but not in presence of bigger firms, as we would notice with internal economies of scale, but within the industrial district which had formed. Marshall argued that there are three main reasons why a cluster of firms may be more efficient than an individual firm in isolation: i) the ability of a cluster to support specialized suppliers, ii) the way that a geographically concentrated industry allows labor market pooling and iii) the way that a geographically concentrated industry helps foster knowledge spillovers.

Concerning the presence of specialized suppliers, we should notice how, in many industries, the production of goods and services must be supported by a consistent supply chain, which may only be applicable in presence of a conspicuous customer base, meaning a large number of firms: an individual company does not provide a large enough market for these services to keep the suppliers in business. A localized industrial cluster can solve this problem by bringing together many firms that collectively provide a large enough market to support a wide range of specialized suppliers.

Labor market pooling, moreover, can represent an important factor in the formation of external economies of scale as the presence of a high number of firms in the same industry, operating in the same region can create a pooled market for workers with highly specialized skills. Such a pooled market is to the advantage of both the producers and the workers, as the producers are less likely to suffer from labor shortages and the workers are less likely to become unemployed. Finally, the presence of industrial districts can help knowledge spillovers, meaning that the informal exchange of information and ideas that takes place at a personal level and often seem to take place most effectively when an industry is concentrated in a fairly small area so that employees of different companies mix socially and talk freely about technical issues.

More recent studies tend to focus more on the importance of reduced transaction costs deriving from urban clustering, meaning that the resulting balance between localized increasing returns to scale and spatial distance transactions costs can provide an explanation of the development of the types of hierarchical spatial industrial patterns typically observed (Fujita & Mori, 1997; Krugman & Fujita, 1995). The existence of localized increasing returns to scale explains industrial clustering, as firms tend to congregate taking advantage of increased factor rewards which are only exhibited over a limited spatial domain, where such clustering takes place (Fujita & Mori, 1997; Krugman & Fujita, 1995).

Strong external economies of scale can be found in many different industries, both modern and less recent. In the United States, examples include the semiconductor industry, in California’s Silicon Valley (Langlois, 1992), or the entertainment industry, concentrated in Hollywood (Scott, 2006). The small city of Qiaotou in China makes up more than 60% of the world's production of buttons (Krugman, 2009) and the textile industry in certain areas of northern Italy also represents an important example (Ottati, 2009).

Such studies are carried out within the field of Economic Geography, which studies interregional and international trade, the rise of cities and their interaction across space, initially focusing on industrial location and the use of quantitative methods, following the line of Weber (Weber & Friedrich, 1929) and later developing into the so-called “New Economic Geography”. In the latter approach, more importance is given to historical, social, cultural, and institutional factors in the spatial economy. The new work indicates how historical accidents can shape economic geography, and how gradual changes in underlying parameters can produce a discontinuous change in spatial structure (Krugman, 1998).

The traditional economic geography approach tends to rely on the three main reasons proposed by Marshall (see above), identifying dispersion forces that tend to encourage firms to disperse geographically (including rents, land prices, cost of non-traded services, level of competition) and agglomeration forces which lead the industry to cluster geographically (including spillovers, labor market pooling, demand linkages and supply/cost linkages).

In this work we decided to adopt a more traditional economic geography approach, analyzing the development of the agglomeration forces for financial hubs under a quantitative approach. Nevertheless, the relevance of the historical events that led to the establishment of London as the main financial hub for Europe, has not been neglected and has been reviewed in chapter 1.4.

1.3.3 Financial hub agglomeration factors

Examples of industrial districts can also be found in finance, where the geography of finance, a branch of economic geography, studies, amongst other topics, the formation and development of financial centers around the world. Agglomeration forces have been found to be particularly important in the financial sector: evidence is found by Kindleberger (Kindleberger, 1973) and evidence of the three agglomeration forces proposed by Marshall is found in the finance industry by Krugman (Krugman, 1991). In the City of London, we find large banks, insurance firms, and law firms driving the agglomeration in which physical proximity to related firms and institutions enabling face-to-face contact and relationship-building is of fundamental importance (Cook, Pandit, Beaverstock, Taylor, & Pain, 2007). Moreover, the building of relationships between firms is considered to be crucial and this is definitely aided by geographical proximity (Cook et al., 2007).

Although some authors believe we are facing “The end of geography” referring to a state of economic development where geographical location no longer matters in finance, (O'Brien, 1991) many authors believe “there will be no end of geography” as international financial centers are crucial in satisfying essential communication needs (Thrift, 1994). In the banking industry transaction costs, in the form of transportation and information costs, seem to be reduced in presence of geographical proximity (Elliehausen & Wolken, 1990)leading us to believe that distance continues to matter in banking, especially for small financial services companies (Kenneth P. Brevoort, 2008). The factors driving such agglomeration and consequently increasing the competitiveness of the financial sector, are many and have been analyzed in this paper. The Global Financial Center Index (GFCI) clusters the instrumental factors into five main areas of competitiveness, which are then broken down into more specific factors which add up the calculation of the final index score. The areas taken into consideration are the Business Environment, Human Capital, Infrastructure, Financial Sector Development, and Reputation.(Michael Mainelli, 2021). The Corporation of London drafted a table ranking the different factors of competitiveness of financial centers (Mark Yeandle & Mainelli, 2005).

Table 1 Competitiveness factors of Financial Centers ranked by the Corporation of London (Mark Yeandle & Mainelli, 2005).

Factor of Competitiveness	Rank	Average Score
Availability of Skilled Personnel	1	537
Regulatory Environment	2	516
Access to International Financial Markets	3	508
Availability of Business Infrastructure	4	501
Access to Customers	5	490
A Fair and Just Business Environment	6	467
Government Responsiveness	7	461
Corporate Tax Regime	8	447
Operational Costs	9	438
Access to Suppliers of Professional Services	10	433
Quality of Life	11	430
Cultural & Language	12	428
Quality / Availability of Commercial Property	13	404
Personal Tax Regime	14	389

In this work, we decided to use a set of factors that best fit the needs of the research, including the main agglomeration forces used by the different sources and in line with the theoretical economic geography approach. Therefore, the factors used as agglomeration forces, called *Financial Factors*, and the corresponding representative variables used in the research are shown below.

Table 2 Representative variables for the current work corresponding to the agglomeration forces (Financial Factors).

Financial Factor	Some representative variables
Human Capital	*Availability of Higher Education Training*
	Availability of skilled personnel
Business and Regulatory Environment	*Political Stability and Rule of Law*
	Institutional and Regulatory Environment
	Freedom to Trade Internationally
Financial Sector Development	*Availability of Capital*
	Number and Size of Financial Institutions
	Market Liquidity
	Infrastructure: Transport, ICT, and Built infrastructure
Tax Regime	*Average Tax rate amongst financial companies*

1.4 London as Financial Center

The city of London has had a long history as a financial center (James et al., 2021; Rebbeca Christie, 2020), however, its modern dynamics were originated after the "Big-Bang" opening or deregulation of the industry in the '80s (James et al.). This event opened the gates for major foreign firms and changed the relationship and ideation of the city's largest firms with the economic and financial regulatory institutions in the country (A. Baker, 1999; James et al., 2021; M. Moran, 1991; Michael Moran, 2009). This change implied a transformation of the financial industry from being driven by institutional trade associations to be driven by products and markets, it also implied that foreign firms would enter to push for their own interests while local firms saw a reduction in their influence ability (David Lascelles, 2002; James et al., 2021)

The city consolidated its role as a global financial hub after the conformation of the EU when it adopted the position of the main European financial center (Galán-Gutiérrez & Martín-García, 2021; Howarth & Quaglia, 2017; James et al., 2021; Rebbeca Christie, 2020). The concentration of firms, human resources, technology, and institutions led London to be a strategic position for many financial firms (A. Baker & Wigan, 2017; F, 1979; G, 1984; James et al., 2021; Talani, 2012). The main attractiveness of the city has been the light regulatory approach for the financial system, which sparkled after the 1986 deregulation that followed the governmental initiative to relax some of the restrictions of the London Stock Exchange obeying the lobby of the financial industry, and which was later internalized as a pro-liberalization discourse (James et al., 2021; M. Moran, 1991). The light regulatory approach was later institutionalized by governmental policies and regulatory re-structuring (James et al., 2021) and became a competitive advantage for the city of London, its attractiveness was accentuated after the financial crisis of 2007-2008 when financial firms saw a refuge for the increasing regulatory pressure coming from Brussels (Bell & Hindmoor, 2014, 2015; Howarth & James, 2019). The shock of the financial crisis brought an increasing regulatory environment, politicized discussion on the matter, and public anger due to the bailouts during the crisis (James et al., 2021), that were "mostly" aimed to preserve the stability of the financial system. As a consequence, the strategic discourse changed, aiming at emphasizing the contribution of financial services to the real economy and the need to defend the city's competitiveness by distancing from the increasing regulatory burden (James et al., 2021). The city of London became, therefore, a "refuge" that enabled financial firms to maintain the passporting rights that provide access to the European single market (Hohlmeier & Fahrholz, 2018; James et al.; Rebbeca Christie, 2020), thus making London a strategic place for locating their European headquarters (James et al., 2021; Schiereck et al., 2016). The financial products and services also enjoy passporting rights, which enable them to be offered in the countries of the single market with just one license application (Hohlmeier & Fahrholz, 2018). However, as exposed by James et al. (James et al., 2021)**,** the ideation of the City as well as the discursive strategy of the financial industry towards what the future of the city should look like and how the policymakers should be influenced changed after Brexit. It is argued that before Brexit, structural and instrumental power was in place and facilitated to the industry, as a whole, the exercise of a certain influence on the decisions of the UK and the city in terms of regulation for the sector (James et al., 2021). It is also said that the strategy once protecting the industry in London from the EU parliament and EU commission regulations, lost coherence and had to change once Brexit was announced (James et al., 2021). The firms and actors of the industry were forced to react and re-organize for the best of their interest, leading to a division and segregation within the financial industry in terms of what the post-Brexit agreement should look like and what was the most important aspect to preserve or root for (James et al., 2021).

The relevance of discourse is explained by James et al. (James et al., 2021), who state that it allows disparate actors to rethink, restate and align their interests through a common problem, the redefinition of a policy approach, or the promotion of shared base values and a common identity. As Brexit proceeded, the landscape within the financial industry was fragmented, the lobby preferences were ambiguous and fluid so that were not too rigid when re-interpreted in the future, and the discursive strategy divided in two, those pushing for a mutual recognition framework in the post-Brexit scenario and those ideating the city as a hyper-globalized financial hub which implied a complete break-up and distancing from EU regulatory framework (James et al., 2021). On the one hand, the mutual recognition strategy aimed at reconciling the interests of two groups, in first instance the global banks (both commercial and investment) which were prone to maintaining a close UK-EU relationship and regulatory alignment, since Brexit would imply compliance with two different regulatory frameworks, yet it would be a manageable inconvenience. The second group was formed by the UK banks, investment funds, and insurance firms which aimed at minimizing disruption for their local customers yet preferred being regulated by London rather than by Brussels (James et al., 2021). Nevertheless, tensions, during the negotiation phase, within the financial lobby emerged as smaller firms argued there was an over-representation of banks and their issues were sidelined, global banks complained about not being included in meetings with the government bodies and US investment banks were lobbying the government on their own through the EFSCAC without seeking and industry-wide consensus (James et al., 2021). On the other hand, a pro-Brexit coalition formed in between the financial industry which added sympathizers which amounted up to one-third of firms in the sector

(James et al., 2021). The pro-Brexit coalition was more prone to re-orientate London as a super-globalized financial center (James et al., 2021; Kalaitzake, 2020; Talani, 2019), resembling the approach of Singapore, for which exiting the EU and diverging from the EU regulatory framework would work completely fine (Britain, 2019; James et al., 2021; Shanker Singham, 2018). This coalition attracted mainly non-banking actors in the industry, such as private equity, hedge and investment funds, venture capitalists, and the financial legal profession (James et al., 2021), which saw Brexit as an opportunity to roll back the regulatory constraints imposed by the EU in the preceding years and to be able to more easily adapt to access the opportunities from emerging markets mainly in Asia (Britain, 2019; James et al., 2021). Amid the heat of the debate, the EU based firms tended to remain on the sidelines, fearing possible retaliations from their home government (James et al., 2021; Lavery, McDaniel, & Schmid, 2019), however, their interest leaned toward a closer regulatory framework and an arms-wide relationship so that keeping their operations in the UK would be easier. Nevertheless, there was evidence of a weakened financial lobby as the city of London had a reduced ability to influence over Brexit, maintaining the old discursive strategy and harmony among the financial institutions (Howarth & Quaglia, 2018; James et al., 2021; James & Quaglia, 2019; Lavery et al., 2019). James and Quaglia (James & Quaglia, 2019) argue that the reduction of the EU market's relevance perception showed how London as a financial hub has had an impaired influence which in turn has derived from several factors like domestic political environment (Rebbeca Christie, 2020), institutional barriers and, a weakened and disorganized financial industry. The weakened transnational financial lobbying was also a consequence of the battle among the countries competing to lure financial firms away from London (Eivind Friis Hamre, 2019; Howarth & Quaglia, 2018; James et al., 2021; Lavery et al., 2019; Rebbeca Christie, 2020; Reynolds, 2017), such an approach made the negotiating parties lose the focus on the economic consequences (Rebbeca Christie, 2020).

The magnitude and relevance of the UK-EU relationship can be pictured through some relevant figures in terms of the size of commercial trade, volume and number of financial services, and concentration of financial actors in the city of London (Hohlmeier & Fahrholz, 2018; James et al., 2021). The relevance of the UK-EU commercial relationship is reflected in the size of the imports from the EU to the UK (₤ 373.5 billion by 2019 (Ward, 2020)) and exports from the UK to the EU (₤ 294.3 billion, by 2019 (Ward, 2020)). In 2018, from the total foreign direct investment (FDI) stock in the UK, 30% corresponds to FDI in the financial services sector (Paul J.J. Welfens, 2018).

As mentioned before, London had become the default financial center for Europe (James et al., 2021; Rebbeca Christie, 2020), and both the EU and the UK relied on that fact (Galán-Gutiérrez & Martín-García, 2021) for tracing their strategies and organization. The financial market of the city of London was home to 90% of the EUR denominated interest rate swaps (IRS) of euro-area banks, 75% of all foreign exchange transactions, 50% of bank lending, and 50% of European securities transactions by 2017 (Couré, 2017; Donnery, 2017). In 2019 exports to EU of financial services were about 20.5% of total services exports to the EU, the latter being in turn about 42.6% of the total British exports to the EU, therefore the financial services exports represented a total of 26 billion, the second-largest category among service exports (Ward, 2020). As of 2016, about 8000 financial firms from the EU used the passporting rights for their activities in the UK, and just under 23,500 services and products enjoyed the same rights (Hohlmeier & Fahrholz, 2018). Conversely, about 5,500 British companies benefited from passporting to operate in the EU, and about 335,000 passports were in place for their financial services and products (Hohlmeier & Fahrholz, 2018). Hohlmeier and Fahrholz (Hohlmeier & Fahrholz, 2018) provide some figures sizing the relevance of the derivatives trading in the Brexit context, they report that the nominal value of OTC derivatives worldwide was about USD 532 trillion by 2017 and a gross market value of USD 11 trillion. The interest rate (IR) derivatives amounted to USD 427 trillion (around 80% of nominal value), of which 29% were EUR-denominated, that is about USD 122 trillion in nominal value. About USD 320 trillion (75% of the IR derivatives) were cleared through central clearing counterparties (CCPs), the share is slightly smaller for EUR-denominated derivatives for which 72% go through CCPs. The London Clearing House (LCH) clears about 95% of all OTC IR-derivatives globally, of which 29% are EUR denominated, that is about 96% (USD 117.6 trillion) of all the EUR-denominated IR-derivatives. This figure presents the magnitude and paramount relevance of the London financial market for Europe and the world. EU-based firms account for 25% of the EUR-denominated IR-derivatives cleared globally, and up to almost 14% for all the IR-derivatives.

1.5 Brexit General Implications and General Economic Impact

The impact of Brexit on the UK and EU economies will be large, some authors have highlighted how the event will hinder the economic growth for both parties, and substantially reduce the mutual trade (Ansgar Belke, 2016; Bekaert, Harvey, & Lundblad, 2005; Boulanger & Philippidis, 2015; Bulmer S., 2018; Dhingra et al., 2017; Dhingra, Ottaviano, Rappoport, Sampson, & Thomas, 2018; Francesco Papadia, 2018; Gudgin, 2018; Henökl, 2018; McCann, 2018; Ziv et al., 2018). The impact and cost of Brexit were expected to be significant amounting to 1.5% of GDP in the third quarter of 2017 and projected, to sum up to 60 Bn of GBP by end of 2018 (Born, Müller, Schularick, & Sedlacek, 2017). The full effect over the financial markets is still unknown and projections cover a wide range of scenarios, yet it has been constantly repeated that the actual final outcome would in fact depend on the trade agreement between the UK and the EU (Eichengreen, 2019; Hohlmeier & Fahrholz, 2018; Philippon, 2016; Rebbeca Christie, 2020). The scenario for when the UK formally left the EU and by the end of the transition period was that of similar legislations that allowed for equivalence regimes to be applied. In spite of similar legislation and regulatory framework for when Brexit effectively came in force (Rebbeca Christie, 2020), no business activity could keep on at the levels of pre-Brexit (Hohlmeier & Fahrholz, 2018). In fact, as it had been said by British politicians "Brexit is Brexit" (Hohlmeier & Fahrholz, 2018; Rebbeca Christie, 2020).

An immediate effect was the loss of passporting rights for financial institutions established in London (James et al., 2021; Rebbeca Christie, 2020), which no longer were able to trade currencies and securities for their European customers directly from the UK-based offices. These institutions would be required to have a separated subsidiary compliant with local capitalization requirements, which would at first contribute to a reduced return on equity as aggregation benefits are lost, as for example in terms of risk diversification, limited netting, and increased margin requirements (Eichengreen, 2019;

Hohlmeier & Fahrholz, 2018; James et al., 2021). In the absence of passporting, the third country regulation and equivalence regime, which, at least for some time during the Brexit negotiation, some actors hoped to be able to rely on, appeared too narrow and too specific to sustain the pre-Brexit level of relations in trade and services (Group, 2017; Hohlmeier & Fahrholz, 2018; Klaus, 2019; Rebbeca Christie, 2020). Broad equivalence was initially promoted as a possible solution (CMS, 2017; Panagiotis Asimakopoulos, 2020) and an idea around which financial institutions tried to converge, but it was ruled out in 2017 (James et al., 2021). The equivalence regime offers equal treatment for third country-based firms and EEA-based firms as long as recognition of equivalence for the legislative, regulatory, and supervisory regimes are provided by the European authorities. It would require the cooperation of supervisory authorities, however, a framework like this had been classified as insufficient and too insecure to base large and significant trade and service relations on (Hohlmeier & Fahrholz, 2018). The two main reasons why equivalence would not be sufficient are the limited applicability of equivalence, which tends to be niche- or case-specific within an industry (Group, 2017; Hohlmeier & Fahrholz, 2018), and the fact that recognition of equivalence is a lengthy process and could be withdrawn in the short notice (Rebbeca Christie, 2020). In absence of a third-country regulatory regime, the remaining areas would be governed by WTO rules mainly (Hohlmeier & Fahrholz, 2018).

The directives regulating the different actors in the financial market did not offer homogeneous equivalence regimes for all areas of activity. The CRD-IV and CRR-II, which regulate the banking services within the EU, specify no third country regime (Hohlmeier & Fahrholz, 2018). Therefore, banks needed to re-organize their European business units, relocating to a subsidiary in the EU (Rebbeca Christie, 2020), transfer capital for regulatory compliance, transferring staff or seeking new hires and set up the required infrastructure, and in some cases re-applying for licenses (Hohlmeier & Fahrholz, 2018). The MiFID II and MiFIR, which regulate the activities of capital market companies and the related services, offer third country regulations allowing equivalence recognition, yet it is limited to some particular areas like investment services to professional clients (Hohlmeier & Fahrholz, 2018). This constitutes one example of the limitations of equivalence as an unsuitable way to substitute the stability, freedom, and advantages of passporting rights. The SOLVENCY II directive regulates the insurance business, including insurers and re-insurers, it offers a third country regulation in the form of equivalence as well. However, it is limited to re-insurers only, and even in this case it stipulates home-country authorization and control, consequently, EU firms would be required to comply with UK legislation for operations to be maintained, while no primary insurance services could be offered across borders (Hohlmeier & Fahrholz, 2018). The EMIR provides a third-country equivalence regime for CCP yet, given the 2017 European commission revision of the regulatory framework, systemically relevant non-European CCPs must be supervised by the ESMA. Thus requiring that ESMA and the competent home-country central banks (CB) conclude the feasibility of enforcing regulatory measures (Hohlmeier & Fahrholz, 2018).

Some authors argued that the future of London as an international financial center would depend on the passporting rights and whether European authorities would require EU-based companies to clear the derivatives within the euro-area or not (Eichengreen, 2019), while others argue that the position of London as a global financial hub will change but is by no means threatened, only changed (James et al., 2021; Rebbeca Christie, 2020; Reynolds, 2017). Passporting was not possible for financial institutions due to political grounds (Eichengreen, 2019; James et al., 2021; Rebbeca Christie, 2020) and incompatibility of cooperation between the supervisory bodies, since BoE would have needed to give up its autonomy and maintain a certain subordination to ECB and ESMA (Hohlmeier & Fahrholz, 2018; Klaus, 2019), which is contrary to the motivations of Brexit itself. Similarly, the sought of access to the single market was ruled out during the negotiations held under the government of Theresa May (James et al., 2021).

The need for European subsidiaries of UK based banks to operate, and conversely of UK subsidiaries of EU based banks, remained unresolved due to different regulatory regimes, while the EU has pushed for more strict regulations to guarantee the stability of the financial system (Bell & Hindmoor, 2014, 2015), London has pushed for less restrictive regime towards being a global financial center (Kalaitzake, 2020; Talani, 2019). The previous would lead to a fragmentation of the market and the need to set up new regional offices for many financial institutions, meaning there would be duplicated resources and processes due to fragmented market, leading to higher cost structures (Eichengreen, 2019; Hohlmeier & Fahrholz, 2018; Rebbeca Christie, 2020) and more expensive capital (higher cost of capital) (Hohlmeier & Fahrholz, 2018; James et al., 2021); such costs were estimated on a pan-industry study, known as project Oak, between ₤ 12 and 15 billion (Treanor, 2011). Other actors such as investment and hedge funds had found themselves in the position of needing to apply for special permission or re-structure their organization so that EU portfolios can be managed from London or to maintain the service level for existing clients. Additionally, in order to ensure the stability of the financial market the EU agencies, like the ESMA, could require EU firms to clear EUR denominated derivative transactions within a domestic market (Hohlmeier & Fahrholz, 2018; Rebbeca Christie, 2020) or even overall securities trade (Eichengreen, 2019); as of 2018 the MiFID II, MiFIR and EMIR introduced the requirement for all EU financial counterparties and non-financial counterparties with large traded volumes, excluding risk hedging, to settle the contracts through a CCP (Hohlmeier & Fahrholz, 2018). Clearing houses for EUR-denominated securities would need to be provided with liquidity to ensure such stability, yet it would not be possible for the ECB to provide it for foreign CCP without the European authority being able to enforce regulatory and supervisory oversight (Eichengreen, 2019). The previous scenario leads to the question of whether the number of transactions that will move out of London will be that of the EU firms or will it also drag foreign firms' related contracts, which are almost 75% of the EUR-clearing market and could in principle keep clearing through UK based CCPs (Eichengreen, 2019). It has been projected that a significant portion of firms would move after Brexit was voted for (Hohlmeier & Fahrholz, 2018; Tata, 2018).

EU clients are roughly 20% of the total UK banking revenue (Rebbeca Christie, 2020) which suggests that up to 20% of assets would require to be relocated (Silvia Caló, 2019). Shortly before, Sapir et al. (André Sapir, 2017), suggested that roughly USD $ 2 trillion in assets could leave the UK due to Brexit, that figure accounts for about 17% of UK banking assets between 2017 and 2019, as the UK hosted nearly € 11 trillion in banking assets (Rebbeca Christie, 2020). Based on a report by the firm Oliver Wyman from 2017 (Wyman, 2017), the wholesale banking industry would require raising about € 30 to 50 billion, were they to keep the relationship with the European customers after Brexit.

Christie and Wright (Rebbeca Christie, 2020) estimate that Brexit could lead to the relocation of as much as 40% of the turnover of IR derivatives and 14% of other intermediary assets. The shifts would imply an increase of the fragmentation risks yet a relief from the concentration risks across the industry (Silvia Caló, 2019).

As by the effective day of the exit of the UK from the EU, the ESMA was required to withdraw the recognition of UK-based agencies, yet the necessary bypass had already been implemented (Rebbeca Christie, 2020). The UK has implemented two transition periods for financial services starting from the end of the transition period for the EU based firms planning to down-scale (and exit) their British business, providing already signed contracts coverage for maturities varying between 5 to 15 years depending on the kind of contract, and for the firms willing to keep their business in the UK, the provision of temporary permissions while applying for permanent permissions (Rebbeca Christie, 2020). The fact that London had hosted non-bank financing channels for the EU which the EU long relied on, forces the post-Brexit EU to re-consider what it takes for its financial sector to look as projected, especially since the EU is already experiencing dependency on bank financing with too many banks and not enough capital market options (Pagano Marco, 2014)**.**

1.6 Financial Impact and Consequences of Brexit

The reaction of financial markets to policy changes, trade uncertainty, and political uncertainty has been documented and studied from various perspectives, following different econometric approaches and analyzing aspects like market efficiency, correlation, and persistence among instruments and indices, and volatility spill-overs, in equity, debt and derivative markets (Ansgar Belke, 2016; Aristeidis & Elias, 2018; Baele, 2003; Bashir et al., 2019; Bekaert et al., 2005; Boutchkova, Doshi, Durnev, & Molchanov, 2012; Breinlich et al., 2018; Brogaard & Detzel, 2015; Caporale et al., 2018; Dao, McGroarty, & Urquhart, 2019; Eichengreen, 2019; Foerster S.R., 1997; Galán-Gutiérrez & Martín-García, 2021; Guedes, Ferreira, Dionísio, & Zebende, 2019; Korkeamäki, 2011; Lee & Rui, 2002; Muchal Gregus Mária Bohdalová, 2017; Oehler, Horn, & Wendt, 2017; Pantzalis, Stangeland, & Turtle, 2000; PÁSTOR & VERONESI, 2012; Schiereck et al., 2016; Škrinjarić, 2019). The stock and foreign exchange markets play an utterly important role in determining the progress of the countries' economies (Bashir et al., 2019), and are tightly related (Breinlich et al., 2018) as the expectations on the relative currency affect the value of firms' assets as explained by the uncovered interest rate parity theory (Bashir et al., 2019), the tight relation is also present in the traditional flow approach for exchange rate (Dornbushc R., 1980) and the portfolio based approach (Frankel, 1992) and had been previously studied (Koulakiotis, Kiohos, & Babalos, 2015; Nieh & Lee, 2001; Pan, Fok, & Liu, 2007; Peter Franck, 1972; Raj, 1981; Ratner, 1993); however, for the first, the stock market reacts to the movements of the foreign exchange market while the second suggests the causation is in the opposite direction. In this section, we present a summary of the impact the Brexit process has had so far on the stocks market, the currencies market, their volatilities, and some observations about the impact on the derivatives market.

Stock prices' drop is associated with policy changes particularly for environments with high uncertainty (Ansgar Belke, 2016; S. R. Baker, Bloom, & Davis, 2016; Boutchkova et al., 2012; Caporale et al., 2018; PÁSTOR & VERONESI, 2012; Škrinjarić, 2019), but also currencies can see a significant level of depreciation upon political uncertainty (Scott Baker, 2016). At the same time, the uncertainty is associated with a decrease in market returns, and increased instability of financial markets, and negative implications for the real economy (Ansgar Belke, 2016; Bekaert et al., 2005; Boutchkova et al., 2012; Caporale et al., 2018; Francesco Papadia, 2018; Korkeamäki, 2011; PÁSTOR & VERONESI, 2012), in particular effects of elections have been studied by Pantzalis (Pantzalis et al., 2000) and Foerster (Foerster S.R., 1997). Notwithstanding, typically, once the uncertainty has disappeared the stocks' prices tend to recover (Brogaard & Detzel, 2015; Pantzalis et al., 2000), it has been observed how after the Brexit referendum results the increased uncertainty had disappeared after few days (Aristeidis & Elias, 2018; Caporale et al., 2018; Škrinjarić, 2019).

Several major stock markets worldwide responded to Brexit referendum results (Burdekin R.C., 2018; Oehler et al., 2017; Schiereck et al., 2016; Škrinjarić, 2019; Sultonov & Jehan, 2018), with many indices sinking and particularly stocks of the banking industry (Caporale et al., 2018; Oehler et al., 2017; Ramiah, Pham, & Moosa, 2017; Schiereck et al., 2016; Shaikh, 2018). The effect of Brexit was seen most noticeable over the volatilities (Aristeidis & Elias, 2018; Caporale et al., 2018; Rafal Kierzenkowski, 2016; Shaikh, 2018), while returns were in general ambiguous (Ansgar Belke, 2016; Caporale et al., 2018; Mindaugas Dadurkevicius, 2017; Škrinjarić, 2019). In fact, volatility, and in particular implied volatility indices such as the implied volatility index (IVI) of FTSE 100 or the VIX index for the Chicago stock market, can be seen as investors' fear gauges (Whaley, 2000). While Bohdalová (Muchal Gregus Mária Bohdalová, 2017) studied 3 market indices and suggested to rule out any association between Brexit and FTSE100 volatility, Caporale (Caporale et al., 2018), found an increase in the level of persistence for the implied volatility index of the FTSE100 and the implied volatility for the GBP against other currencies. It was noticed, as well, that Brexit produced less volatility increase than expected (Rebbeca Christie, 2020), especially when compared to similar events (Schiereck et al., 2016). Effects, however, varied on a sector and firm's characteristic basis (Dao et al., 2019; Gu & Hibbert, 2021; Oehler et al., 2017; Ramiah et al., 2017). It had been warned, well in advance, the possible effect on the FDIs in the case the UK were to leave the EU (Pain & Young, 2004), yet it has been observed that effects could vary from sector to sector (Ramiah et al., 2017). Caporale (Caporale et al., 2018; Guglielmo Maria Caporale, 2017) found evidence suggesting that Brexit may have a more pronounced and long-lasting impact on the foreign exchange market when compared to the stock market.

The relevance of the status and health of the EU-UK relationship has outreaching relevance around the world, since both the EUR and the GBP are amongst the main foreign currencies (Caporale et al., 2018; Dao et al., 2019), according to the IMF for the second quarter of 2018 the EUR accounted for 20.2% and GBP for 4.5% of the global foreign currency reserves (Eichengreen, 2019). By 2017, HM Treasury (Treasury, 2017) reported that about 40% of the unhedged reserves net of gold were in EUR which amounted to about 40 billion EUR.

The foreign exchange market is reportedly the largest market (by transaction volume) in the world (Dao et al., 2019; Settlements, 2016). The relevance of a certain currency in the foreign exchange market and as part of the reserve currencies is related to the performance of the home-country economy (of most reserve currencies), it is particularly affected by the inflation rate, the participation of the nation's economy in the global GDP and the pair-wise international trade relations. Eichengreen et al. (Eichengreen, Mehl, & Chitu, 2017) have shown that the influence of the role of a country's currency as international reserve currency depends upon three channels: i) the macroeconomic that encompasses the weight on global GDP and local inflation rate ii) the trade channel iii) the geopolitics and military alliances, which has an even larger impact than that of the trade channel. The persistence of a currency as a foreign reserve has been observed to have a relatively long-term persistence, with half-lives of about 7 years (Eichengreen, 2019; Eichengreen, Chi, x, U, & Mehl, 2016). Therefore, it has been said that the international status of the involved currencies would, if any, suffer slow changes (Eichengreen, 2019). A higher risk premium derived from Brexit has depreciated the GBP with respect to other major currencies (Caporale et al., 2018; Dao et al., 2019; Scott Baker, 2016)**.** Dao et al. (Dao et al., 2019) observed on an intra-day basis a flight to quality in the trade of the major currencies at a global level following the Brexit referendum results announcement. In terms of the cross-border bank flows, it has been highlighted that the stability of the exchange rate between GBP and EUR will play a major role, as well as similar inflation targets by the central banks, in reducing the severity of the Brexit impact (Eichengreen, 2019; Kalemli-Ozcan, Papaioannou, & Peydro, 2010). However, trade flows affect the exchange rate as well, depending on their volumes and composition, for which instability can lead to negative effects over the bank-intermediated flows. There has been a warning about the risk of the UK and the EU battling in terms of taxation and regulations over the financial system to attract the most FDIs (Eichengreen, 2019; Pain & Young, 2004).

The financial stability of G20 is also threatened by Brexit, leading to attempts to move standardized derivatives settlement to central clearing houses (Hohlmeier & Fahrholz, 2018), which could be incentivized through an increase of requirements in terms of capital in the form of larger margins for non-centrally cleared contracts (Eichengreen, 2019; Hohlmeier & Fahrholz, 2018). In fact, the primary impact of Brexit over the clearing activities has been an increase in capital requirements (James et al., 2021) derived from capital charges from the capital requirement regulation (CRR) and an inevitable increase of the risk-weighted assets (RWA). The RWA was estimated to potentially increase 16 times (Astieninstitut, 2018) as the counterparty increases its risk classification being a third country based CCP, as in the case of LCH, not to mention the additional restrictions that the regulatory frameworks like the EMIR could imply (Hohlmeier & Fahrholz, 2018). Major issues and early concerns were represented by the already subscribed instruments and derivatives (Rebbeca Christie, 2020) for which a grace period has been offered or a permit extension while working out the re-papering process for moving the contracts to a European CCP in order to comply with the regulation (Hohlmeier & Fahrholz, 2018). The new contracts would just need to use the clearing activities of a European CCP (Hohlmeier & Fahrholz, 2018). This split in the derivatives market, has been said, would lead to an increase of costs mainly due to the decrease in liquidity associated with the market fragmentation and the potential increase in margin requirements associated with the increased risk (ISDA, 2017), yet others have an opinion pointing towards a decrease of costs (Investment, 2017); Hohlmeier and Fahrholz (Hohlmeier & Fahrholz, 2018) explain that the difference in appreciations is likely due to the portfolios and business structures of the market participants considered. Alternatives for CCP where to concentrate the clearing activities in EU like Eurex (Hohlmeier & Fahrholz, 2018) have emerged, with IRSs daily clearing by 2017 up to € 71 billion and outstanding contracts for about $ 7 trillion USD (Hohlmeier & Fahrholz, 2018). Non-financial firms would be less severely affected as EMIR only imposes regulatory clearing obligations to some limited number of cases that do not include most risk hedging, yet should overall costs increase, these firms could suffer from a costs-spill over reflected in more expensive or fewer offered financial services (Hohlmeier & Fahrholz, 2018). It has been argued based on recent events regarding the regulation of activities for relevant actors in the financial industry from Switzerland, Brazil, Argentina, Canada, Australia and Singapore, that many of the expected barriers expected due to the change in regulation could actually be overcome with additional paperwork and some extra expenditures for the firms and clients (Michael Baltensperger, 2019; Rebbeca Christie, 2020).

Brexit implies a change of the status quo in several aspects like the strategic organization of firms and their strategic resource management, the geopolitical weights within the international organizations, and the internal dynamics of governance and politics in the EU and the UK.

It was widely stated that Brexit would rip off some jobs from London and spread them over the EU, Tata (Tata, 2018) projected that about 20 and 30% of UK-based corporations and investment banking would migrate to the EEA after the vote. Hamre and Wright in an analysis published on the think tank "New Financial" (Eivind Friis Hamre, 2019), identified that by 2019, 332 firms had re-located at least partially their financial business away from London, among the main destinations are: Dublin, Frankfurt, Amsterdam, and Luxemburg. Should as many firms as expected (Hohlmeier & Fahrholz, 2018; Tata, 2018) move out of the UK post-Brexit, the economies of concentration and scope in the hub would be lost, as no clear destination for these resources has consolidated in the form of a new European financial hub (Eivind Friis Hamre, 2019; James et al., 2021; Rebbeca Christie, 2020). Many firms have relocated partly to different cities such as Amsterdam, Paris, Frankfurt among others. Caló and Herzberg (Silvia Caló, 2019) highlight that these shifts will have a larger impact on the receiving cities than in London. While the financial industry loses the advantages from the concentration of human resources it would become more reliant on the communication and travel infrastructure (Silvia Caló, 2019), yet the COVID pandemic may have allowed these firms to gain expertise in the management of dispersed HR since freedom of movement will not be granted anymore (Rebbeca Christie, 2020). A parallel industry affected by Brexit would be that of complementary and related services (Hohlmeier & Fahrholz, 2018) that do not belong directly to the financial industry but are closely tied to it, like the accounting and legal services (Rebbeca Christie, 2020) and for which little lobby and few considerations were made while negotiating.

Brexit presents an opportunity for the EU to increase its influence in the so-called "Bretton woods institutions", that is the International Monetary Fund (IMF) and the World Bank (WB), and to have a stronger and better-articulated position as Euro-Area in the matters discussed (Eichengreen, 2019). Analyses of the impact of Brexit from a geostrategic perspective can be found in (Armour, 2017; Hall, 2018; Howarth & Quaglia, 2017; Lavery, McDaniel, & Schmid, 2018; Moloney, 2019; S & Pompeo, 2018). The EU would need some reforms to its financial system in order to make the EUR more reliable and attractive internationally, such efforts could be oriented to a unified financial market (Eichengreen, 2019; Rebbeca Christie, 2020) which could lead to increased size, stability, and liquidity and therefore rendering the currency more attractive (Barry Eichengreen, 2017). Other complementary efforts that have been mentioned include banking union, fiscal union, and political union, which could appear more feasible as the euro-skeptic UK leaves the union, yet it is unlikely (Eichengreen, 2019) for them to promptly happen as national interest of different governments and institutions have historically resisted to the integration of power in the EU for the sake of homogenization. The need to ensure more solid market stability and increased efficiency, features that could derive from a unified financial market, are also related to the need of tackling three main issues that are currently threatening the development of the European economies, these are: *i)* climate change *ii)* the sustainability of the pension funds *iii)* the COVID-19 recovery (Rebbeca Christie, 2020).

1.7 The Agreement Today

Christie and Wiesen (Rebbeca Christie, 2020) expressed amid the uncertainty of 2020 that an actual cliff-edge exit would be not likely, despite the political statements and pointed that initially an equivalence regime would be possible to implement (Panagiotis Asimakopoulos, 2020), owing to close regulatory frameworks at the starting point, as long as regulatory these frameworks were dully recognized and mechanisms for granting and reviewing such status were properly defined in order to ensure stability. They also emphasize the unavoidable divergence in regulatory terms that will occur as time goes by, it is also estimated a horizon of between three and five years for a new equilibrium in the sector to be fully reached. They pointed the need for the new TCA to ensure an efficient and prompt arbitration process (Rebbeca Christie, 2020). On 30 December 2020, the UK and EU signed the EU-UK Trade and Cooperation Agreement (TCA) which sets out preferential arrangements in areas such as trade in goods and in services, digital trade, intellectual property, public procurement, aviation and road transport, energy, fisheries, social security coordination, law enforcement, and judicial cooperation in criminal matters, thematic cooperation and participation in Union programs

(Commission, 2021; "TRADE AND COOPERATION AGREEMENT between the European Union and the European Atomic Energy Community, of the one part, and the United Kingdom of Great Britain and Northern Ireland, of the other part," 2021). Although the level of economic integration between the UK and EU will by no means match the pre-Brexit level, the TCA has been built based on principles that go beyond usual free trade agreements. The EU-UK Trade and Cooperation Agreement, in fact, consists of i) a Free Trade agreement, ii) a close partnership on citizen's security and iii) an overarching governance framework.

At the same time, many crucial topics have been left out of the TCA: the UK refused to include foreign policy, external security, and defense cooperation in the agreement. Decisions relating to equivalences for financial services and passporting rights, the adequacy of the UK data protection regime, or the assessment of the UK's sanitary and phytosanitary regime for the purpose of listing it as a third country allowed to export food products to the EU, have also been left out, leaving the EU as the unilateral decision-maker in such subjects (Commission, 2021; "TRADE AND COOPERATION AGREEMENT between the European Union and the European Atomic Energy Community, of the one part, and the United Kingdom of Great Britain and Northern Ireland, of the other part," 2021). As previously mentioned, by leaving the EU and EEA the UK's status has become that of a third country meaning that UK firms have no longer access to the passporting regime, hence financial services companies located there will need to establish a subsidiary within an EEA country in order to regain those passporting rights.

In the absence of a bespoke arrangement in the TCA, UK firms must, as has been repeatedly emphasized by the Commission, construct other access routes to the EU's heavily regulated financial services market.

i. The first route is to relocate business to the EU by establishing a subsidiary.

ii. Second, a UK firm that does not have an EU subsidiary from which to operate in the EU must be authorized to provide services in each Member State in which it seeks to operate (whether through branches or services supply).

iii. Third, a precarious access route is available through the 'reverse solicitation' process. Under EU law, where a financial service is exclusively initiated by an EU client (the firm cannot market to clients or solicit clients to request services) and provided by a third country firm, it is not deemed to be provided within the territory of the EU.38.

iv. Finally, for those sectors for which an equivalence regime is in place, and where the UK regime is found to be equivalent, the firm in question has passport-like access to the EU.41 The equivalence regime is scattered across sectoral EU financial services legislation and across over 40 legislative measures. (Finance, 2021).

The TCA is unusual in the sense that it is an agreement that raises barriers to trade compared to previous existing agreements (Yohannes Ayele, 2021), nevertheless, there is complete elimination of tariffs and quotas, in line with expectations between two political entities which have such a close trade relationship. The elimination of tariffs and quotas is offered to those firms which can prove their goods satisfy the rules of origins requirements and providing no measures are introduced for other reasons such as "rebalancing" measures or trade defense.

Rules of origin represent another key point of the FTA and are more complex compared to other EU agreements in terms of detail and distribution. In order to obtain tariff-free access to the EU market, a UK firm must prove that the good was produced or 'originated' in the UK (and vice versa) so both in terms of administrative requirements and ease of obtaining preferential access, the trade conditions are worsened compared to previous status quo (Yohannes Ayele, 2021). Also, important to note that mutual recognition of conformity assessment (to standards), has not been assessed in the TCA although there are some minor elements of mutual recognition, for example, concerning automobiles and self-certification for the least sensitive product, which will lead to an increase of the bureaucratic complexity and costs of exporting to the EU.

Fisheries have also been an important negotiation topic, and while fishing is a negligible part of the two economies, it is an important point of national pride for coastal and island nations and has a massive impact on politics. (Casert, 2020). Under the deal, Britain agreed to an adjustment period, when fishing rights for the bloc's fleet in British waters will gradually be reduced over five years. From 2026, there will be annual talks to set the terms of access. (Elizabeth Piper, 2021). There are additional non-tariff barriers that raise the costs of accessing the EU market, such as catch certificates and export health documents that will have to be completed, and customs processes to clear.

1.8 The Research up to Today

Here we present some of the studies that have been carried out on how Brexit has impacted several aspects of the financial markets. The studies range from a short-term analysis made in the vicinity of the referendum results announcement to a more wide-spanned analysis focusing on the systemic changes and structural changes after Brexit. The financial markets under analysis include the stocks market, currency market, derivatives (futures and credit default swaps) markets, exports, and the volatility of these series. The studies include efficiency analysis, changes in the degree of persistence, spillovers, cointegration, and regressions that evidence the various effects of Brexit. Table 1 summarizes the author, title, central topic, results, statistic methodology used for the study, and database from which time series were retrieved for these research papers. We classified these studies into three categories: **E**, **C**, and **R**. The first one **(E)** stands for the methodologies used to analyze the impact of Brexit in terms of a significant change of a single time series on the returns of volatilities, including ESM or SUR methodologies. The second **(C)** groups the studies focus on the relationship among different time series for which correlation and cointegration methodologies are employed. In these studies, there are analyses of the degree of persistence through the assessment of the autocorrelation of each time series. Finally, the third category **(R)** includes other types of studies that use time-series regressions for which models like ARIMA, MGARCH (Sultonov & Jehan, 2018), or VAR are implemented to analyze non-stationary series or test the suitability of proposed deterministic models. Oehler et al. (Oehler et al., 2017) studied the reaction of the stock market after the Brexit voting results were announced, finding that the level of internationalization could explain the differences in terms of abnormal returns, less severe abnormal negative returns were found for stocks of companies with a higher level of internationalization after the announcement. This study also provided evidence towards a high efficiency of the market due to the quick adjustment reflecting that explanatory variable.

Skrinjaric (Škrinjarić, 2019) analyzed the effect of the Brexit referendum on the Central and Eastern European (CEE) and South and Eastern European (SEE) stock markets following an event study methodology (ESM). No clear significant results were found for the return series (yet negative cumulative returns are present), however, greater volatilities were found for the short-term following the referendum results announcement.

Schiereck et al. (Schiereck et al., 2016) analyzed the reaction of the stocks and CDS spreads to the Brexit referendum announcement and compared it to the Lehman Brothers bankruptcy announcement. It was found that the drop in the stock prices for European (UK-based included) banks after the Brexit announcement was larger compared to the one that occurred to Lehman Brothers. There was also an increase in the CDS spread for European banks (Caporale et al., 2018), however, it was less pronounced when compared to the increase seen after the Lehman Brothers bankruptcy. As for the non-European banks, no significant effect over the stocks' prices nor CDS spread was observed. The author concludes that efforts to increase the resilience of financial markets have been effective and can, therefore, better tolerate uncertainty nowadays.

The event study methodology (ESM) has been used by (Alkhatib & Harasheh, 2018; Amewu, Jones, Odei-Mensah, & Alagidede, 2016; Mindaugas Dadurkevicius, 2017; Škrinjarić, 2019), based on (Binder, 1998; S. Brown & Warner, 1980; S. J. Brown & Warner, 1985; MacKinlay, 1997; Strong, 1992), and also detailed by Kothari (Kothari &

Warner, 2007). However, it is argued that ESM mainly orientates to single-series analysis and suits better short-term analysis as it is less reliable of long-time horizons (Kothari & Warner, 2007); it also focuses on the behavior of each time series rather than the relationship it could have with other (Dao et al., 2019). Nevertheless, Dao et al. (Dao et al., 2019) suggest that similar results in their study would have been found in case of implementing an ESM approach instead of employing DCC and VAR models for studying the correlation and volatility spillover.

Bashir et al. (Bashir et al., 2019), studied the dynamic linkage between stock prices and the exchange rate for the UK and four countries in the EU, to further investigate the relationship and analyze the existence of co-movements among EU financial markets. They found that most EU financial markets tend to be negatively correlated in the long term after the Brexit referendum. This study focused on long-term effects while others (Adesina, 2017; Alkhatib & Harasheh, 2018; Amewu et al., 2016; Ansgar Belke, 2016; Bouoiyour Jamal, 2016; Burdekin R.C., 2018; Caporale et al., 2018; Michal Greguš Mária Bohdalová, 2017; Mindaugas Dadurkevicius, 2017; Oehler et al., 2017; Petar & Filip, 2018; Quaye, Mu, Abudu, & Agyare, 2016; Schiereck et al., 2016; Škrinjarić, 2019; Sultonov & Jehan, 2018) have focused on the short-term plunges that followed the Brexit referendum results announcement (Bashir et al., 2019). No significant trend for the returns of the EU market indices after the Brexit referendum in the mid-term was found, yet an anti-persistent behavior for the stock market and a persistent behavior for the foreign exchange market after the Brexit referendum were observed. At the same time, a negative correlation among the financial markets in the study was found (Bashir et al., 2019), implying a reduced need for hedging (Galán-Gutiérrez & Martín-García, 2021).

Guedes et al. (Guedes et al., 2019) analyzed the autocorrelation of the British and European markets' indices as well as the cross-correlation between the UK stock market with other European markets through DFA and DCCA methodologies. No evidence was found of changes in the general levels of autocorrelation or efficiency for the markets which were exhibiting behaviors compatible with the weak form of the efficient market hypothesis (EMH) (Eugene, 1991; Fama, 1970). Regarding the level of correlation, it was found that the British stock market had a positive correlation with most of the European markets, however, it decreased after Brexit suggesting a lower level of integration among the markets; which, is highlighted by the authors, could prevent greater welfare in countries (Bekaert et al., 2005; Guedes et al., 2019).

Galán-Gutierrez et al. (Galán-Gutiérrez & Martín-García, 2021), analyzed the cointegration between the structure of copper futures, that is the difference of spot and 3-month future contracts' prices, and Brexit through the BKHI50P index, which includes the 50 companies from the CBOE-UK100 index with the largest market capitalization deriving the highest portions of their revenues from the UK, and has been used to represent the impact of Brexit on such stocks. A cointegration of the Brexit effects on local companies with the future structure of copper was found and the existence of a detrimental effect of weakening economy Brexit-related news for the future structure of copper was highlighted.

Volatility studies are used to determine the level of integration between markets (Dao et al., 2019) but also as a topic of utmost importance for risk management and hedging (Galán-Gutiérrez & Martín-García, 2021). Some authors (Bashir et al., 2019; Caporale et al., 2018; Dao et al., 2019; Sultonov & Jehan, 2018) have focused on the impact of Brexit on the foreign exchange market, as it is related to other financial markets, and also bridges them with activities from the real economy like cross-border trade. Dao et al. (Dao et al., 2019) studied the impact of the Brexit referendum on high-frequency correlation and volatility spillover in the foreign exchange market for major currencies. An increase in the correlation of currencies not directly affected by Brexit and which are regarded as safe-havens, particularly the Japanese Yen, the Swiss Franc (Caporale et al., 2018; De Bock & de Carvalho Filho, 2015; Fatum & Yamamoto, 2016; Grisse & Nitschka, 2015; Ranaldo & Söderlind, 2010) and gold (Baur & Lucey, 2010; Baur & McDermott, 2010; Bredin, Conlon, & Potì, 2015; Dao et al., 2019)**,** was found, while the correlation of the former with the involved currencies (EUR and GBP) decreased. The authors also point to the fact that overall the levels of volatility spillover have increased among all currencies suggesting a greater market integration, however, the volatility transmission between the involved currencies (EUR and GBP) decreased after the results were announced, which is in coherence with the findings of other authors regarding a decreased market integration post-referendum. Overall, the evidence suggests a flight to quality following the announcement. Caporale et al. (Caporale et al., 2018) used long-memory techniques to examine the effect of Brexit over the degree of persistence of the FTSE100 implied volatility index (IVI) and of GBP implied volatility (IV) vis-à-vis the main currencies traded in the foreign exchange market (EUR, USD, YEN). An increase of the volatility indices and in the level of persistence for implied volatilities confirming the effect of Brexit referendum results announcement over the uncertainty in the market, however, for the stock market it appears to have decreased soon after.

Dadurkevicius 2017 (Mindaugas Dadurkevicius, 2017) modeled the variance of the FTSE100 index based on political uncertainty variable, binary variables, and Google search results for the word “Brexit” following an ESM approach. Overall an increase of volatility before the event was found (Caporale et al., 2018; Mindaugas Dadurkevicius, 2017; Rafal Kierzenkowski, 2016) while the effect on returns appeared to be sector-specific. Similarly, Gu and Hibbert (Gu & Hibbert, 2021) found that highly volatile stocks were more sensitive to Brexit.

Eichengreen et al. (Eichengreen, 2019) present a study investigating the foreign exchange rate and the FDI flows and stocks (Bas Straathof, 2008), through a horizontal regression of the portfolios in terms of cross-border transactions and positions of debt and equity instruments, within a framework of a gravity model (Faeth, 2009). Belke and Ptok (Belke & Ptok, 2018) carried out a study on the impact that the economic and financial uncertainty associated with Brexit has brought on exports. The study relies on the hypothesis that exports show a hysteretic behavior by reacting in spurts when foreign exchange rates overpass a band of inaction also called “play area”, the authors then establish a non-linear model relating the exports to the real exchange rate, the excess of the exchange rate with respect to the boundaries of the play area and the industrial production (as a proxy of GDP). The play area is considered under two scenarios, a first one in which it is assumed to be constant and a second one in which it is variable and depends on the economic and financial uncertainty. An ordinary least squares (OLS) methodology is employed to identify the hysteretic path-dependencies in the exports between the EU and UK in both directions. To model the uncertainty the authors (Belke & Ptok, 2018) considered the EURO STOXX50, the treasury bill euro-dollar difference (TED-spread), that is the difference in rates for the 3 months LIBOR (USD denominated) and 3 months US government bonds. Authors suggest the suitability of this indicator, particularly for the banking sector. The European exports exhibited significant hysteretic behavior particularly for exchange rate and equity market volatilities, while British exports showed little evidence of hysteretic behavior. **Annexes 1** and **2** in the annex section summarize some of the most significant studies carried out for the effect of Brexit on different financial aspects and instruments at the European level.

1.9 Hypothesis and research questions for the thesis

Based on the previous literature review the following considerations have been made:

1. Banks' business model is highly leveraged and depends on many aspects of current and non-current debt, thus the CDS spreads show an impact on the perceived riskiness (Schiereck et al., 2016) of the financial markets and these financial institutions. Prior research on CDS spreads includes (Ansgar Belke, 2016; Finnerty, Miller, & Chen, 2013; Kiesel, Kolaric, & Schiereck, 2016) who have used 5 year senior CDS mid spread in $USD. The interest rate difference between the long and the short term from the interest rate term structure is also a proxy of the quality for financial intermediation activities.

2. Daot et al. (Dao et al., 2019) propose that besides the Brexit referendum results announcement, other relevant dates in the Brexit period could be the date of completion of the Brexit transition period, that is the formal day on which UK left the EU. Dao also points out that the announcement that a referendum would take place was a weak event. For us, the exit day should be at best a weak event since actors should already be prepared and actions have been already taken (S. R. Baker et al., 2016; Caporale et al., 2018), as shown by Breinlich et al. (Breinlich et al., 2018) who found a negative effect on stocks and GBP once expectations regarding the UK-EU trading agreement were updated**.** Dao also

observed the trading activity for currencies in terms of number (of transactions) and volume, and points at the fact that Evans and Lyons (Evans & Lyons, 2002) found a positive relationship between the currency returns and the signed volume of trade. Possible relevant dates include June 2018 Treasury drops mutual recognition (Theresa May made a statement referring to it in a public speech in 2017 (James et al., 2021)) and government white paper did use ambiguous language too (HM, 2018).

3. Economic uncertainty has been represented through various measurements such as: the EPU by (S. R. Baker et al., 2016) and the EPUI (Belke & Kronen, 2015), the volatility of real exchange rate (Belke, Göcke, & Werner, 2015), volatility of the stock market and the TED-spread (Belke & Ptok, 2018). It is argued that series correlation as well as volatility transmission provides information about investors' behavior and perception (Dao et al., 2019; Ederington, 1993; Tanner, 1997).

4. Brexit has impacted and changed the financial markets, which can be seen in the number of transactions, the volume of the transactions, and idiosyncratic characteristics**.** The instruments for which impact due to Brexit has been observed include CDS (Credit Default Swaps), Stocks, Bonds, and Currencies. In this regard, it is considered that the Sovereign Bond Yields, as well as the CDS spreads, are good indicators of the market expectations over a country's future economic health. These indicators are referred to in this work as ***financial variables***.

5. The factors that define a financial center can be classified into four groups:
    a. Human Capital
    b. Business & Regulatory environment
    c. Financial Sector Development
    d. Tax regime

6. The main financial hubs in Europe according to the Global Financial Centers Index (Michael Mainelli, 2021) are London, Frankfurt, and Zurich, the cities of Paris and Milan are also top financial hubs in Europe and play a major role in the financial industry in Europe. These financial hubs will be referred to as the group of financial hubs under analysis in this study.

We propose the following hypothesis for the present work:

"*Brexit impacted financial markets; its effect was reflected on several financial variables like instruments prices and indexes. Furthermore, after the Brexit announcement, the trade volumes in the financial markets at the main European financial hubs have changed in terms of magnitude and composition. Such changes could be modeled through an economic geography approach that considers the four categories of factors related defining the strength of financial hubs (Human Capital; Business & Regulatory Environment; Financial Sector Development; Tax Regime).*"

The hypothesis should be verifiable by answering the following three research questions that we have framed in order to guide us during the present work:

A. Did the referendum announcement, the referendum results announcement, the government announcements (by Theresa May and by the Treasury), the formal exit day of the UK, and the end of the transition period Brexit-associated event dates have a significant impact on the financial variables?

B. Were there changes in the time series behavior of hub-factors, market volumes, and financial variables after Brexit?

C. Can the hub-factors explain the changes in the behavior of the financial market volumes following Brexit, so that the restructuring process of the financial hubs explains the observed changes in the financial markets?

2. DATA: SOURCES & DATA PREPARATION

The time series for the financial variables, namely the yields for the 10 years and 3 months maturity Sovereign Bonds, the 10 yeas - 3Months yield spread, and the CDS-spread for the 10 Years maturity Sovereign Bonds for the United Kingdom (UK), Germany (DE), Switzerland (CH), France (FR) and Italy (IT) were retrieved from the database Refinitiv EIKON by Thomson Reuters (Reuters, 2021). The Yields time series were retrieved in a weekly frequency for the period between 27th of May 2011 and the 4th of July 2021, and always referring to the national currency Sovereign Bond. No pre-processing was needed for this data. The event dates are highlighted in yellow and correspond to the week in which the event date took place.

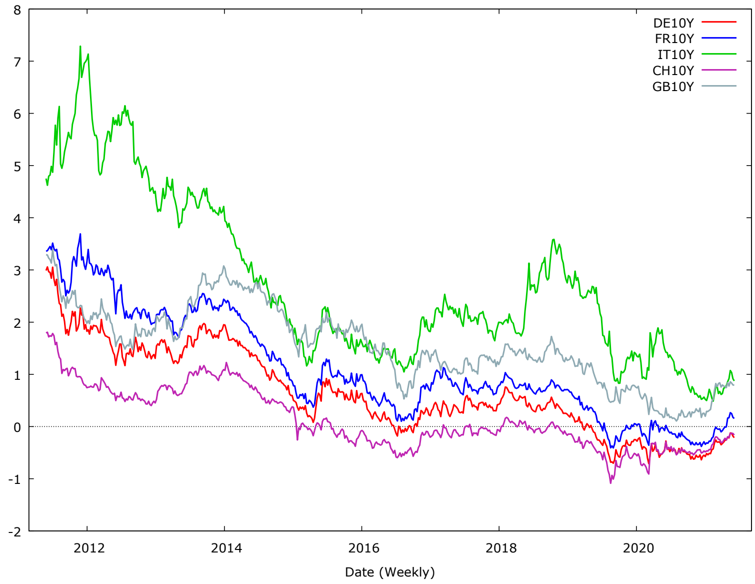


Figure 1 Yields of the 10-year Sovereign Bonds (Reuters, 2021)

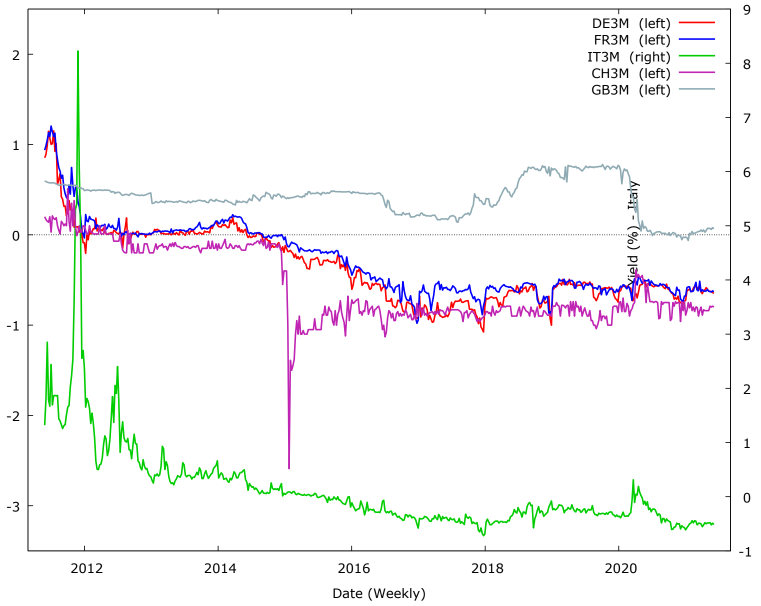


Figure 2 Yields of the 3-months Sovereign Bonds (Reuters, 2021)

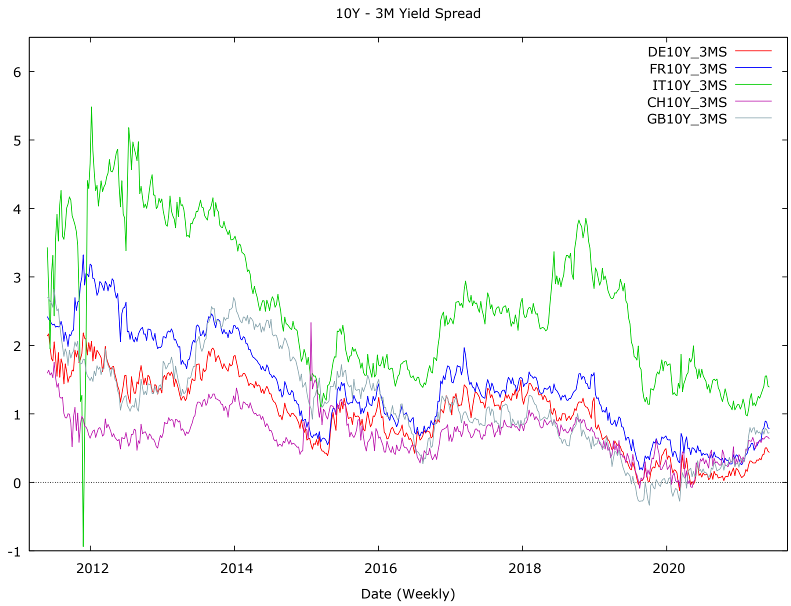


Figure 3 Spread of yields for the 10-year to 3-months Sovereign Bonds (Reuters, 2021).

Table 3 Summarizing statistics for the time series of Sovereign Bonds (Reuters, 2021)

Variable	Mean	Median	S.D.	Min	Max
DE10Y	0.645	0.454	0.843	-0.713	3.06
DE3M	-0.359	-0.538	0.399	-1.08	1.15
DE10Y_3MS	1.00	1.07	0.548	-0.123	2.18
FR10Y	1.11	0.808	1.03	-0.410	3.69
FR3M	-0.282	-0.485	0.396	-0.980	1.20
FR10Y_3MS	1.39	1.33	0.717	0.180	3.32

IT10Y	2.72	2.18	1.60	0.486	7.29
IT3M	0.139	-0.150	0.882	-0.720	8.23
IT10Y_3MS	2.58	2.48	1.06	-0.939	5.48
CH10Y	0.127	-0.0535	0.581	-1.09	1.81
CH3M	-0.577	-0.790	0.409	-2.59	0.510
CH10Y_3MS	0.704	0.709	0.324	-0.0870	2.33
GB10Y	1.54	1.48	0.753	0.106	3.40
GB3M	0.408	0.428	0.203	-0.0630	0.778
GB10Y_3MS	1.13	1.10	0.725	-0.334	2.82

Summary Statistics, using the observations 2011-05-27 - 2021-06-04.

The time series for the CDS spreads was also retrieved from the database Refinitiv EIKON (Reuters, 2021). The spreads were retrieved in a daily frequency for the period between the 21st of December 2007 and the 4th of June 2021. The data for the CDS spread of the UK 10 Year Bonds presented some incomplete data due to the differences in holidays of the exchanges where the transactions were held. In order to make the information coherent, the frequency of observations of the other European CDS spreads was taken as the default, and the missing data was adjusted by switching the position of the datapoint. For example, if the incoherence appeared due to data on a Friday for the EU CDSs while it appeared on a Monday for the UK CDSs, the data point of the Monday was assumed to correspond to that of the Friday, and the Monday was forcefully turned into a “non-traded” day; alternatively, the average of the observed values was assigned for when the gap was of two or three days. This softening of the time series for the UK CDS spreads was made to allow for the ESM analysis and while it did not occur near the event dates considered, it happened for the estimation/calibration period of the first event date, which will be described in detail in the following section.

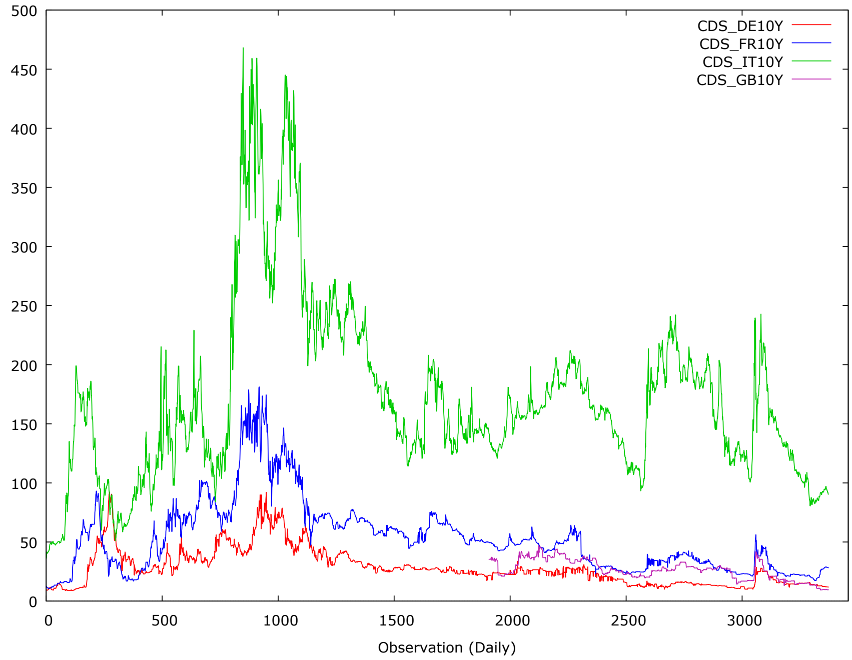


Figure 4 Credit Default Swap spread in basis points for the 10-year Sovereign Bonds (Reuters, 2021)

Table 4 Summarizing statistics for the CDS spreads time series (Reuters, 2021)

Variable	Mean	Median	S.D.	Min	Max
CDS_DE10Y	28.2	25.4	15.5	8.75	92.0
CDS_FR10Y	53.0	48.8	30.7	10.5	181.
CDS_IT10Y	171.	158.	74.4	36.0	468.
CDS_GB10Y	26.5	26.3	8.32	9.44	47.0

Summary Statistics, using the observations 1 - 3373

Finally, the time series for the market volumes of all the contract types which include equity, debt, and some standardized derivatives negotiated at the exchanges located at the financial hubs of London (UK), Frankfurt (DE), Zurich (CH), Paris (FR) and Milan (IT), were collected from the market share reporter (MSR) app within the Refinitiv EIKON database. These time series were collected with a monthly frequency for the period between January 2011 and June 2021. The data did not require any pre-treatment. The data collected corresponds to the market volumes of *i)* all instruments from all locations *ii)* all the instruments from the UK *iii)* all the instruments from the EU *iv)* all the instruments from the "*Rest of the world"* (RoW), that is that are not from the UK nor from the EU. Additionally, the time series for the number of trades in the London markets and for the aggregated markets of the EU were collected (ANNEX 3, ANNEX 4, ANNEX 5, ANNEX 6, ANNEX 7, ANNEX 8, ANNEX 9).

Table 5 Summarizing statistics for the market trade volumes (contracts/month) in the main financial hubs by instrument origin (Reuters, 2021)

Variable	**Mean** (contracts/month)	**Median**	**S.D.**	**Min**	**Max**
UK_All	$1.15 * 10^{11}$	$9.25 * 10^{10}$	6.96 * 10010	$3.55 * 10^{10}$	$4.88 * 10^{11}$
UK_EU	$1.07 * 10^{10}$	$9.08 * 10^{9}$	$6.35 * 10^{9}$	$1.85 * 10^{9}$	$3.93 * 10^{10}$
UK_UK	$7.55 * 10^{10}$	$6.63 * 10^{10}$	$3.69 * 10^{10}$	$1.76 * 10^{10}$	$2.77 * 10^{11}$
UK_World	$2.83 * 10^{10}$	$1.80 * 10^{10}$	$3.69 * 10^{10}$	$6.88 * 10^{9}$	$2.96 * 10^{11}$
EU_All	$8.21 * 10^{10}$	$7.87 * 10^{10}$	$2.03 * 10^{10}$	$1.69 * 10^{10}$	$1.47 * 10^{11}$
EU_EU	$7.74 * 10^{10}$	$7.51 * 10^{10}$	$1.88 * 10^{10}$	$1.56 * 10^{10}$0	$1.39 * 10^{11}$
EU_UK	$1.52 * 10^{9}$	$1.40 * 10^{9}$	$8.53 * 10^{8}$	$4.69 * 10^{8}$	$4.86 * 10^{9}$
EU_World	$3.25 * 10^{9}$	$2.90 * 10^{9}$	$1.67 * 10^{9}$	$8.32 * 10^{8}$	$1.06 * 10^{10}$
DE_All	$8.07 * 10^{9}$	$7.05 * 10^{9}$	$3.40 * 10^{9}$	$1.99 * 10^{9}$	$2.47 * 10^{10}$
DE_EU	$6.06 * 10^{9}$	$5.51 * 10^{9}$	$1.91 * 10^{9}$	$1.12 * 10^{9}$	$1.46 * 10^{10}$
DE_UK	$3.42 * 10^{8}$	$2.01 * 10^{8}$	$3.45 * 10^{8}$	$6.93 * 10^{7}$	$1.83 * 10^{9}$
DE_World	$1.67 * 10^{9}$	$1.10 * 10^{9}$	$1.55 * 10^{9}$	$5.64 * 10^{8}$	$9.55 * 10^{9}$
FR_All	$9.14 * 10^{9}$	$7.40 * 10^{9}$	$6.50 * 10^{9}$	$3.58 * 10^{9}$	$4.41 * 10^{10}$
FR_EU	$8.59 * 10^{9}$	$6.33 * 10^{9}$	$6.55 * 10^{9}$	$3.52 * 10^{9}$	$4.39 * 10^{10}$
FR_UK	$4.75 * 10^{8}$	$2.54 * 10^{8}$	$4.63 * 10^{8}$	$2.46 * 10^{7}$	$1.97 * 10^{9}$
FR_World	$7.54 * 10^{7}$	$6.67 * 10^{7}$	$6.99 * 10^{7}$	$5.86 * 10^{5}$	$3.23 * 10^{8}$
IT_All	$2.70 * 10^{10}$	$2.61 * 10^{10}$	$1.04 * 10^{10}$	$2.83 * 10^{9}$	$7.88 * 10^{10}$
IT_EU	$2.55 * 10^{10}$	$2.45 * 10^{10}$	$9.95 * 10^{9}$	$2.58 * 10^{9}$	$7.67 * 10^{10}$
IT_UK	$3.53 * 10^{8}$	$2.18 * 10^{8}$	$3.98 * 10^{8}$	$6.02 * 10^{7}$	$2.73 * 10^{9}$
IT_World	$1.11 * 10^{9}$	$4.76 * 10^{8}$	$1.28 * 10^{9}$	$2.41 * 10^{7}$	$4.58 * 10^{9}$
CH_All	$2.12 * 10^{9}$	$1.81 * 10^{9}$	$9.60 * 10^{8}$	$4.34 * 10^{8}$	$8.19 * 10^{9}$
CH_EU	$2.55 * 10^{8}$	$2.22 * 10^{8}$	$1.52 * 10^{8}$	$5.09 * 10^{7}$	$9.92 * 10^{8}$
CH_UK	$3.51 * 10^{7}$	$5.09 * 10^{6}$	$7.06 * 10^{7}$	$4.41 * 10^{5}$	$4.22 * 10^{8}$
CH_World	$1.83 * 10^{9}$	$1.58 * 10^{9}$	$8.27 * 10^{8}$	$3.74 * 10^{8}$	$6.99 * 10^{9}$

Summary Statistics, using the observations 2011:01 - 2021:06

The data regarding the number of Monetary Financial Institutions (MFI), or institutions with intermediation activity, registered in each country except Switzerland (UK, DE, FR, and IT) were collected from the ECB statistics web database ((ECB), 2021). This data has a monthly frequency and includes the data in the period from January 2011 until June 2021. Similarly, the time series for the number of investment funds (InvFunds) were retrieved from the ECB statistics, however, no data for the UK was found neither in the ECB registers nor in the Bank of England or FCA databases.

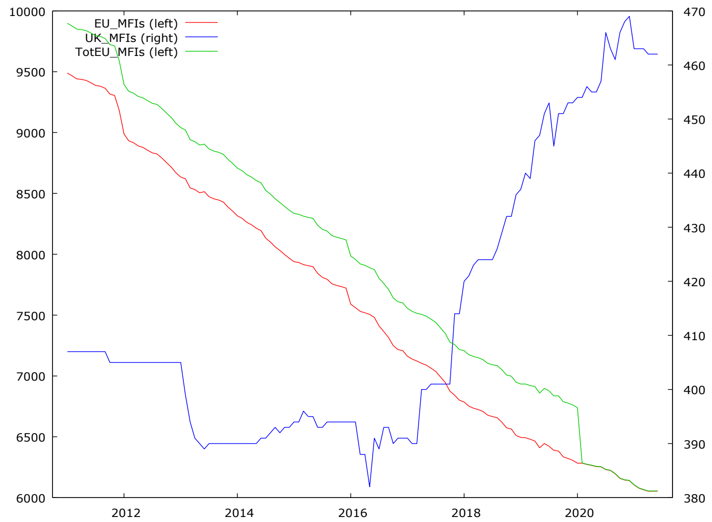


Figure 5 Number of Monetary Financial Institutions (MFI) in the EU excluding UK (EU_MFIs), EU including the UK up to departure (TotEU_MFIs) and UK (UK_MFIs) ((ECB), 2021)

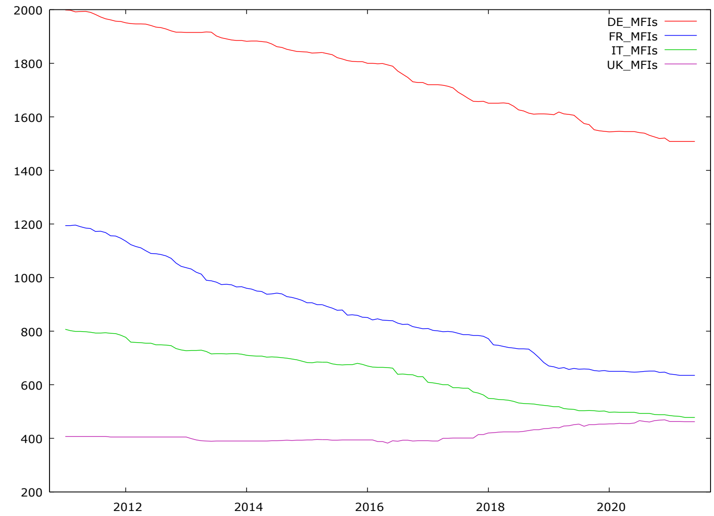


Figure 6 Number of MFIs in Germany (DE), France (FR), Italy (IT), United Kingdom (UK) ((ECB), 2021).

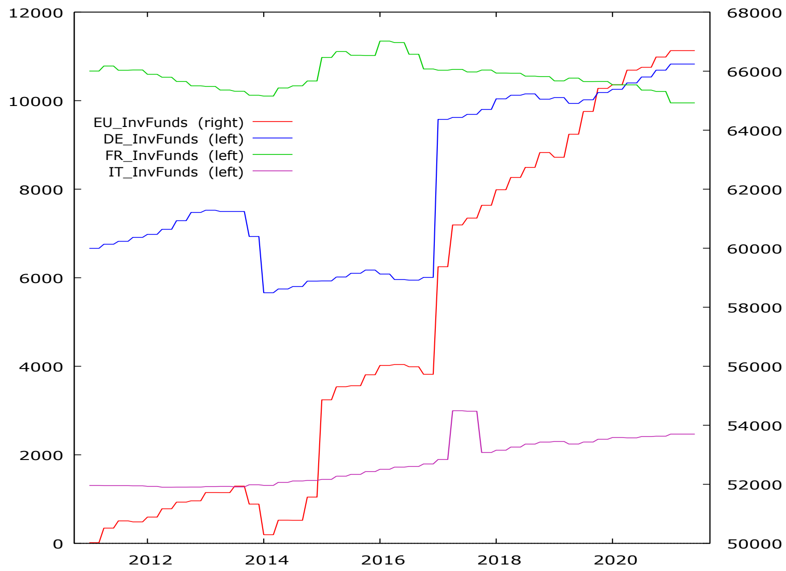


Figure 7 Number of Investment Funds in European Union (EU), Germany (DE), France (FR), and Italy (IT) ((ECB), 2021)

Based on the research previously developed in chapter 1.3, the financial hub factors used in the economic geography approach are Human Capital, Business & Regulatory Environment, Financial Sector Development, and Tax Regime. Each financial hub factor category can be further described by a set of sub-factors or representative variables as in Table 2, for which a quantitative and reliable measurement can be readily found.

The data relative to the financial hub factors was collected for the period between 2011 and 2021, with a yearly frequency or higher when available. The GFCI score is a representative measure balancing the overall score for the financial hubs in all the factors categories, thus constitutes an aggregated measurement. The Business and Regulatory Environment score are the average score for the Control of Corruption, Rule of Law, Regulatory Quality, Government Effectiveness and Political Stability and Absence of Violence collected from The Worldwide Governance Indicators (World-Bank, 2020). To have a score for the Sector Development category the score for the Ease of Doing Business was used, these values were retrieved from the World Bank rankings (World-Bank, 2020). For Human Capital, the percentage of the labor force with advanced education was used to provide a quantitative measurement, the values were retrieved from the World Bank Data Catalog ((ECB), 2021). Finally, to describe the Tax Regime the Corporative Tax Rate was employed as a representative variable and the values were collected from (KPMG, 2021). These values can be observed in **Annexes 10** and **11** at the annexes.

Due to the data being clustered for some of the previous categories at a national level, the reference to financial hubs is sometimes associated in this work with the national identity. No ambiguities arise since only one hub per country is considered in the present study, also due to notation convenience, the acronyms for each country are used instead of the hub's name. Some tables are labeled interchangeably with the acronym for the countries or with the financial hub name. It must be noticed that the present work refers to the financial hub factors associated with each financial hub, regardless of the factor being homogeneous in all the respective countries. The following table presents the notation that is interchangeably used in the present study to denote the main European financial hubs.

Table 6 Labels for the Financial Hubs and their hosting countries (Determined by Authors)

Financial Hub	Country	Acronym
London	United Kingdom	UK
Frankfurt	Germany	DE
Zurich	Switzerland	CH
Paris	France	FR
Milan	Italy	IT
	European Union	EU

3. METHODOLOGY

All the statistical analyses in the present work were carried out using the open-source statistical analysis software Gretl (Baiocchi G., 2003). The present work is divided into two major parts, conceptually. The first part is an event study, employing the event study methodology reported in the literature (Brooks). This first part analyzes the time series of the long- and short-term Sovereign Bonds Yields, the long- to short-term yield spread, and the CDS-spread for the long-term Sovereign Bonds, to determine if around the proposed six dates related to the Brexit process an abnormal change in these financial variables was observed so that these dates can be regarded as event dates.

Initially, a set of six event dates are proposed to be assessed as possible relevant dates with a significant impact on the markets during the Brexit process. First, the Brexit referendum announcement materialized the risk associated with such referendum. Second, the Brexit referendum results announcement, that turned out to be a surprise for many stakeholders. Third, the public speech by Theresa May announcing that the government would not seek at all cost to maintain access to the single market of the EU. Fourth, the Treasury announcement that nor access to the single market nor keeping the passporting equivalence for financial firms would be sought and the white paper presented to the UK parliament that used quite an ambiguous language to establish what the future of the negotiations would be. Fifth, the day of the formal departure of the UK from the EU. Sixth, the end of the transition period. These last two dates are considered due to how the negotiations evolved, for which the agreements were not approved until few hours before a hard Brexit or no-deal Brexit.

Therefore, the initial step was to assess which were the most important dates in the Brexit process to establish them as possible points of inflection for the behavior of market volumes time series. Initially, the Event Study Methodology was applied to assess the impact that the proposed six-event dates had had on different financial instruments and spreads that reflect the market perception, particularly in terms of the ***financial variables*** of the countries where the financial hubs considered in this study are located, namely: United Kingdom (UK), Germany (DE), Switzerland (CH), France (FR) and Italy (IT). The financial instruments used for this initial assessment correspond to the 10 years and 3 Months of sovereign bonds in the national currency and the CDS spread for the 10 Year Sovereign Bonds. The yields for the bonds, the CDS spreads and the 10 Year to 3 Month yield spreads were used to analyze the impact of the events on the markets. The sovereign bonds yields and the CDS-spreads were employed for this study since they are related to the perception of credit default risk that the countries may face, in other words, reflect the expectation about the future performance and health of the national economy while the spread of the long term and short-term rates is a proxy for the quality of the intermediation activity that mostly drives the banking sector, which is a keystone for the stability of the financial industry and almost any other economic sector.

3.1 Event Study Methodology (ESM) – Establishing Relevant Dates

The methodology for the ESM analysis in this work follows the guidelines reported in the literature (Brooks). The time series are analyzed in a time frame called observation window, which is divided into two sets, an estimation or calibration window, immediately followed by the event window. The estimation window initiates and ends before the event date, this segment of the data set is used to calibrate or estimate the parameters for a time series model that depending on the model used shall proxy the behavior of the variable of interest. Since the ESM has been typically used to analyze the returns of various financial instruments, the models whose parameters are calibrated with the data from the estimation period are of the form of the CAPM model or analogous, where to the market return a risk premium is added or discounted to adjust for the relative risk of the analyzed instrument. However, the methodology does not require a priori its usage for analyzing returns, and a model that can track a given time series could be used to conduct an event study over a variable different compared to returns. The returns are typically uncorrelated time series whose variance is instead correlated and not constant, therefore can in many cases be described through a (G)ARCH model. Nonetheless, there may exist some disadvantages or limitations to the interpretation of the results of an event study for variables different from returns.

The duration range for the estimation and event windows per each time series are reported in the following table (Table 7). The notation for marking the relative position of a particular observation concerning the event date defines as $t=0$ the event date, therefore the following dates have values of $t > 0$ and the previous observations are denoted with values of $t < 0$. When denoting an observation, this work refers to $t=N$, in which N is a natural number used under this notation.

Table 7 Description of Observation, Estimation, and Event Windows for the financial variables time series

	Observation Window			Estimation Window			Event Window		
Time Series	Beginning	End	***Observations***	Beginnig	End	***Observations***	Beginning	End	***Observations***
Bonds (Yields)	-113	-4	109	-3	4	8	-113	4	117
Bonds (Yields Spreads)	-113	-4	109	-3	4	8	-113	4	117
CDS-Spread	-720	-11	709	-10	14	25	-720	14	734
Market Volume	-60	-5	55	-4	6	11	-60	6	66

For the present work, during the event study, the calibration of the parameters for an ARMA model of unspecified order is carried out. The orders (p, q) of the ARMA model are determined iteratively for each time series for each estimation window of the six dates analyzed. The presence of deterministic elements in the model for describing the time series is proxied by looking at the stationarity test result using an Augmented Dickey-Fuller (ADF) test for three scenarios: *i)* No constant term and no trend *ii)* the only constant term is included *iii)* Constant term and a trend are considered, while the condition of stationarity is not required to perform an event study nor to calibrate a model this is used as a guide for an initial guess of whether to include any of these deterministic elements. The stationarity of a time series refers to the "conservation" of the properties or behavior of the overall time series in terms of the dependence with its own past (lags), when a constant or a trend term are considered, the stationarity implies that the effect of these two parameters on the behavior of the time series is always the same. Stationary time series have a bounded behavior, however, there is no certainty about their value in the future as no predictable patterns are identifiable, therefore when the test considers a constant (intercept correction) or a trend (time dependence) these behaviors are "discounted" in terms of predicting what the future value could possibly be for the variable of the time series.

The orders (p, q) are proxied by looking at the correlogram of the time series data points that fall within the estimation window. The order "p" for the moving average (MA) part should be that of the last lag order for which the auto-correlation function (ACF) is statistically significant or statistically different to zero, similarly, the order of the autoregressive (AR) part should be the last lag order for which the partial autocorrelation function (PACF) is statistically different to zero (Brooks). After an initial guess for the model has been made, two criteria are sought in order to regard the model as satisfactory for representing the time series, first that all the parameters are statistically significant and secondly that the residuals are uncorrelated among themselves or in other words that behave like white noise. For the first requirement that all the considered parameters and deterministic terms should be statistically different from zero, their p-value for the null hypothesis of being zero is observed, the value is computed by the program and shown in the results, and it is required to be lower than or equal to 0.05; when more than one parameter is statistically insignificant, they are retired from the model one by one starting from the one with the highest p-value and every time verifying the p-value of the remaining parameters. For the second requirement, the residuals correlogram is analyzed to verify that there is no correlation among the residuals, which implies a good fit of the model in describing the data of the time series without missing any major parameter. If any of the previous criteria are not met, then the order of the AR or MA part would be changed until meeting both of them, basically by following a user-guided iterative process.

Then the model is used to describe the expected value of the time series variable in the event window, by employing the observations up to t-1, that is static forecasting in which the "new" observations are included in the model to forecast the next value. The difference of the actual observed value and expected value for a given date is computed and labeled as abnormal residual (AR*) so that the classical notation of the ESM remains unchanged to what is typically known as "*abnormal return*". The AR* are computed for all data points in the observation window and their variance is computed. Then the cumulative abnormal residual (CAR) for the date j is calculated as the sum of AR* starting on the first event window's date (*-j'*) up to date *j*, the CARs are computed for the whole event window. The variance of the CAR for the date j corresponds to the product of the variance of the AR* time series and the difference "*j-(-j')+1"*, Then the CAR values are contrasted against the statistical irrelevance zone, which is in turn defined as the z-score of the normal distribution for a given probability (confidence interval) times the standard deviation for the CAR of that date.

$$AR_i^* = Observed\,Value_i - Expected\,Value_i = X_i - E(X)_i \qquad \text{Eq. 1}$$

$$CAR_j = \sum_{-j'}^{j} AR*_i \qquad \text{Eq. 2}$$

$$VAR_{CAR_i} = [j - (-j') + 1]\ VAR_{AR^*} \qquad \text{Eq. 3}$$

$$Irrelevance\,Zone_i = \pm z - score_{(Prob)} * \sqrt{VAR_{CAR_i}} \qquad \text{Eq. 4}$$

During this work, events for which CAR were larger than the irrelevance zone with a confidence interval of 90% or higher were referred to as strong-effect events and referenced on the tables under the symbol (“YES”), events for which the CAR was statistically significant with a confidence interval lower than 90% and higher than 80% were referred to as weak-effect events and referenced on the tables under the symbol (“NO*”), the events for which CAR was always statistically insignificant are no-effect events and the symbol assigned to them on the tables is (“NO”), finally a category of always significant CAR was identified under the symbol (“YES***”) on the tables and are equally considered to be strong-effect events.

In order to group the results and process them to provide a judgment over the relevance of the event and its date, a scoring table was proposed and used to assign a score to the event study result of each of the six dates for each of the twenty (20) time series. The scores are assigned based on the strength of the effect that the event had and in coherence with the symbol nomenclature described previously. The scores were summed for each studied date and later classified into one of five categories.

Table 8 Respective Score for the Observed type of CAR

Symbol	points given
YES	*100*
YES* **	*70*
NO*	*50*
NO* **	*25*
NO	*0*

Table 9 Type of Event Classification according to Average Score for the Date

CATEGORY	Score Range
STRONG	*76-100*
MILD	*46-75*
WEAK	*26-45*
VERY WEAK	*15-25*
NO	*0-15*

The previous grouping had as objective to facilitate the classification of each event date when considering the effect shown by the different time series in that date. In the end the studied dates were sorted in one of the previously mentioned categories based on the overall average score for that date across all the time series.

The second part corresponds to the analysis of the changes in the market volumes and number of trades before and after Brexit, and the assessment of whether these changes can be explained by the changes in the financial hub factors previously proposed.

3.2 Changes: Before and After Brexit

In order to evaluate and assess the presence of changes in the market volumes time series after Brexit, a series of analyses on statistical properties describing the time series was performed. Initially, the impact of the most relevant dates based on the event study carried out for the *financial variables*, over the market volumes was verified by implementing an ESM on the time series of the market volumes, the procedure implemented was the same as the one described in section 3.1. After having identified through the ESM the most relevant date for the behavior of the time-series, the following properties of the time series were analyzed before and after such date:

i) *Mean*
ii) *Standard Deviation*
iii) *Coefficient of variation*
iv) *Maximum value*
v) *Minimum value*
vi) *Auto-correlation Function (ACF)*
vii) *Partial Auto-correlation Function (PACF)*

Then an AR (1) model was adjusted to describe the time series before and after Brexit's most relevant date, with the interval for the coefficients of the model in two scenarios: *a)* Including a constant and a trend term *b)* Only a constant term. The scenarios were used to identify whether the intervals for the value for the coefficients and constants were overlapping, at a 95% confidence interval. In case the intervals did not overlap the coefficients were said to be fully different and most certainly a change in the behavior of the time series could be inferred.

The following step in the identification of changes before and after Brexit, consisted in the analysis of the correlation matrix for the time series grouped in two categories *i)* by the origin of instruments *ii)* by financial-hub market. The changes in the correlation coefficients of the time series were used to analyze possible changes in the behaviors before and after Brexit.

3.3 Regression of financial hub factors

In order to verify the impact of Brexit on the previously selected factors, hence the impact on the main European financial hubs, two analyses were performed. First, the time series for the number of investment funds in the country was regressed against the financial-hub factors. Three variations of the model were tested for the time series of the market volumes, all types of contracts from all origins altogether, which consisted in *i)*ARX(1,0) model including all the financial-hub factors *ii)* ARX(1,0) model with only the financial-hub factors whose coefficient was statistically significant *iii)* A horizontal regression including all the financial-hub factors and a constant term. For the previous models, the fitting quality was analyzed through the graphs showing the expected value of the data as described for the model and the actual value observed for the time-series, and the overall errors table which includes the mean error, the mean absolute error, the root mean squared error and the Theil's U value.

As the last step, the hypothesis that the financial hub factors could explain the changes in the behavior of the time series of the market volumes was verified. In order to carry out the verification, the time series of the market volumes between 2011 and 2021 were regressed in an exogeneous model that included the representative variables for the financial hub factors, namely Human Capital, Business & Regulatory Environment, Financial Sector Development, and Tax Regime, as presented at the end of section 2, as well as the GFCI score for each financial hub. For this analysis two models were analyzed, an exogeneous regression without lags with a constant term and all the financial-hub factors, and the second being an ARX (1) model with all the financial-hub factors and without a constant term. The fitting quality was evaluated through the same parameters as in the case of the investment funds, by looking at the graphs showing the expected value of the data as described for the model and the actual value observed for the time-series, and the overall errors table including the mean error, the mean absolute error, the root mean squared error and the Theil's U value.

As main guidelines for assessing the quality of the fitting of a model to the data, the following heuristics from the literature (Brooks) were employed:

1. A mean error far from 0 suggests the presence of a systematical error, i.e., the model tends to systematically over-or under-estimate the value for the variable.
2. The root mean squared error should be about the same order of magnitude or higher than the mean absolute error.
3. A Theil's U value lower than 1 indicates the model is fairly good and better than a naïve guessing in predicting the value of the variable.

4. RESULTS AND ANALYSIS

In order to have a rough idea of the behavior of the time series of the *financial variables* and to consider deterministic components in the ARMA models for conducting the event study methodology, the stationarity of the time series was assessed through the Augmented Dickey-Fuller test (ADF). It was found that some time series were non-stationary even when a constant and a trend term were considered, therefore the first-order difference was also tested for stationarity in hopes to determine whether the time series were of order I (0) or I (1).

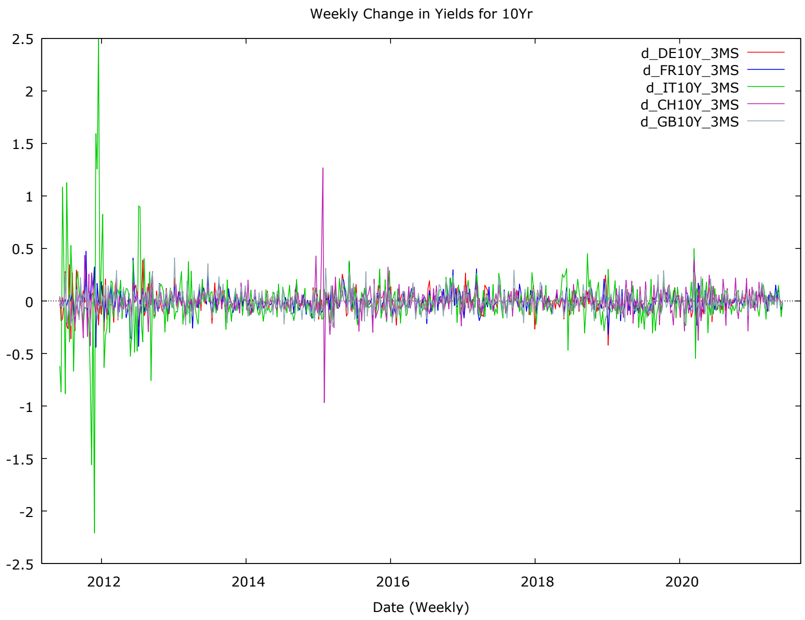


Figure 8 Weekly Change of the Yield for 10-Year Sovereign Bond (Reuters, 2021)

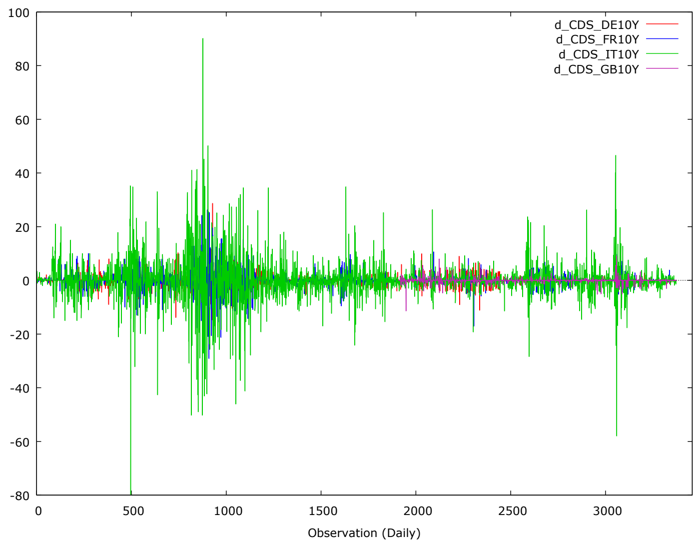


Figure 9 Weekly Change of the CDS spread for the 10-Year Sovereign Bonds (Reuters, 2021)

The results show that for the 10-year sovereign bonds yields all the time series are of order I(0) or stationary under at least one of the three evaluated model types. The 3 months yields time series of the UK and Switzerland are of order I(1), there is a unitary root that can be factored out when analyzing the first-order difference time series, as for the other yields time series their behavior is that of I(0). Finally, the long and short-term yield spreads for France and Italy appear to behave as non-stationary, and both are of order I(1), for the other countries their respective yield spreads time series are stationary

I(0). The statistic value (analogous to the p-value) for the ADF test applied to the time series of the yields and the yield spreads, as well as to their first-order difference are shown in ANNEX 12, ANNEX 13, ANNEX 14, and ANNEX 15. The null hypothesis was rejected for values equal to or lower than 0.05.

After having analyzed the stationarity of the time series the ESM was carried out for the proposed six dates related to the Brexit process, the methodology presented in section 3.1 was followed for this purpose. The step-by-step implementation of the methodology for one yields time series (Yield of the German government bond with 10 years maturity, also referred to as "*DE_10Y*") and for one CDS spread time series (CDS spread for the German government bond with a 10 years maturity, referred to as "*CDS_DE10Y*"), around one event date (Brexit referendum results announcement, also referred to as "2nd (second) proposed date) are shown in the following section before presenting the results of the event-study on all-time series and all dates.

4.1 Event Study for Yields Time Series - Detailed step-by-step DE_10Y

In order to evaluate the six proposed dates of events, an estimation window comprehending 109 observations prior to the date t=-3, was used to estimate the ARMA model parameters. The event window was defined between t=-3 and t=+4 observations (weeks), where t=0 corresponds to the week of the event, and in which the cumulative abnormal residuals (CAR) were observed to identify any impact possibly associated with the event on the time series. Initially, the stationarity was checked and used to find clues on whether deterministic elements should be included in the ARMA model.

Gretl Results 1 Stationarity Test (Baiocchi G., 2003) using an ADF test based on BIC information criteria for DE10Y Time Series in the Estimation Window for the second proposed event date

Augmented Dickey-Fuller Test for **Testing down from (lags)** **Unit-root null hypothesis: a=1**	**DE10Y** **50**
	p-value
Test without constant	*0,02224*
Test with constant	*0,3086*
Test with constant and trend	*0,4554*

The previous results suggested that an initial guess could omit the presence of deterministic elements for modeling this time series in the estimation window. Then a naïve estimation of the model order (p, q) was made based on the correlogram of the time series, that is the ACF and PACF of time series.

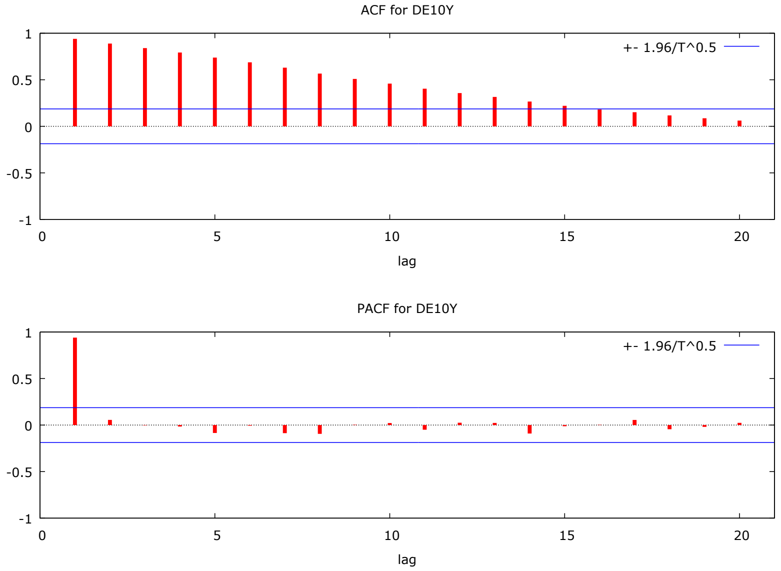


Figure 105 Auto-correlogram of the DE10Y Time Series around the second proposed date

It can be observed that for DE_10Y a model AR (1) could be potentially used to describe the time series, based on the behavior of the PACF, or a MA (16) based on the behavior of the ACF. In this case, initially, an ARMA (1,1) model without any deterministic components was estimated, for which all its coefficients are statistically significant, as it can be seen from the p-value for the null hypothesis in Table 10. Then the ARIMA model is estimated, based on the conditional maximum likelihood.

Table 10 ARMA (1,1) Model and properties (Baiocchi G., 2003) for the DE10Y Time Series using data from the Estimation Window

	Coefficient	Std. Error	z	p-value	
phi_1	0.977508	0.0108774	89.87	<0.0001	***
theta_1	−0.181716	0.0753262	−2.412	0.0158	**
Mean dependent var	0.646673	*S.D. dependent var*		0.368471	
Mean of innovations	0.002921	*S.D. of innovations*		0.084353	
R-squared	0.947374	*Adjusted R-squared*		0.946886	
Log-likelihood	115.9186	*Akaike criterion*		−225.8372	
Schwarz criterion	−217.7357	*Hannan-Quinn*		−222.5512	
	Real				
AR					
Root 1	1.0230				
MA					
Root 1	5.5031				

Model 44: ARMA, using observations 2014-04-25:2016-05-27 (T = 110)

Dependent variable: DE10Y

After having set a model up, for which its parameters are statistically significant, the appropriateness of the model was verified by checking the correlogram of the residuals for the selected model, the residuals should behave as a white noise for the model to be considered good enough in describing the time series.

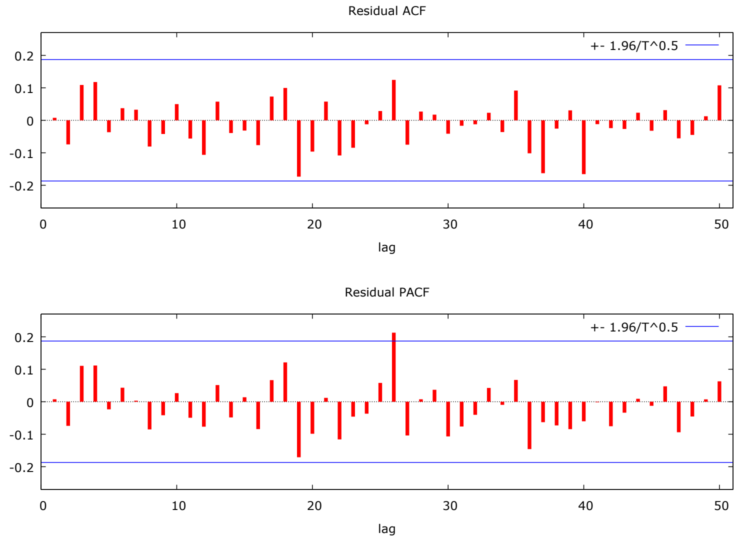


Figure 11 Auto-correlogram for the residuals of the fitted data using an ARMA(1,1) model for DE10Y in the Estimation Window

From the residuals correlogram, it can be observed that the ARMA (1,1) is a model able to describe the behavior of the time series. The dynamic forecast (Figure 12) of the model for the event window is presented, however, this does not constitute the event study methodology and is shown just for matters of illustrating the adequacy of the model in forecasting the time series behavior based on the observations up to the end of the estimation window.

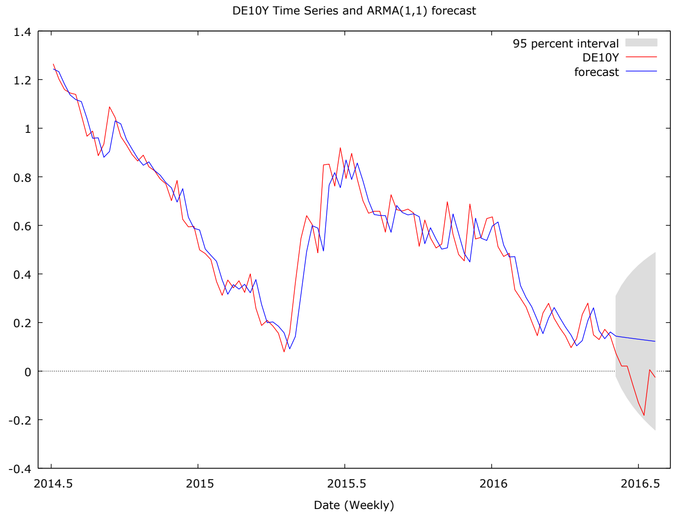


Figure 12 Actual and Fitted Data for DE10Y with a Dynamic Forecast for the Event Window (Gray area is the 90% Confidence Interval)

The static forecast (Figure 13) is also presented, in fact, the spread between the curves of the actual values and the values estimated by the models are the abnormal residuals (AR*) that will be analyzed during the ESM.

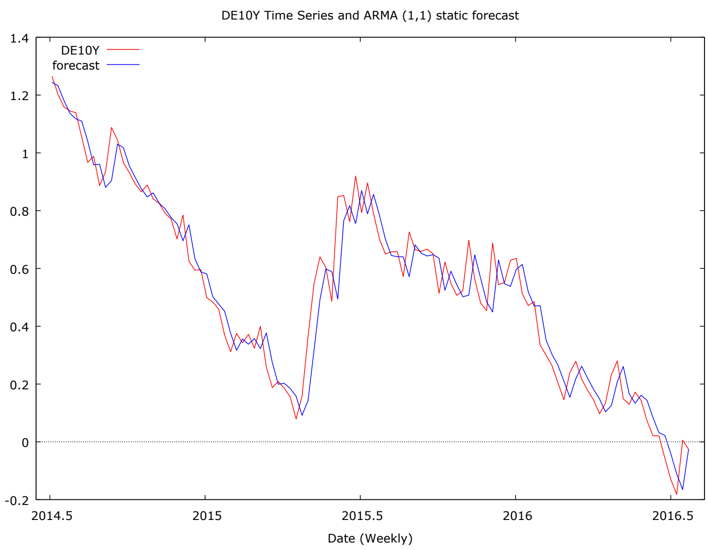


Figure 13 Actual and Fitted Data for DE10Y with a Static Forecast for the Event Window

The model is used to forecast the expected yield, the abnormal residual (as the difference between the actual yield and the expected yield), and the cumulative abnormal residual. Then the significance of the CAR is given by the statistic considering CAR/S.D.(CAR), which according to literature shall have a unitary normal distribution with mean equal to 0; the indifference zone is built by defining the confidence interval and calculating the z-score associated with it, then multiplying it times S.D. for the CAR up to the time of the corresponding data-point, following the equations 1 to 4 from section 3.1.

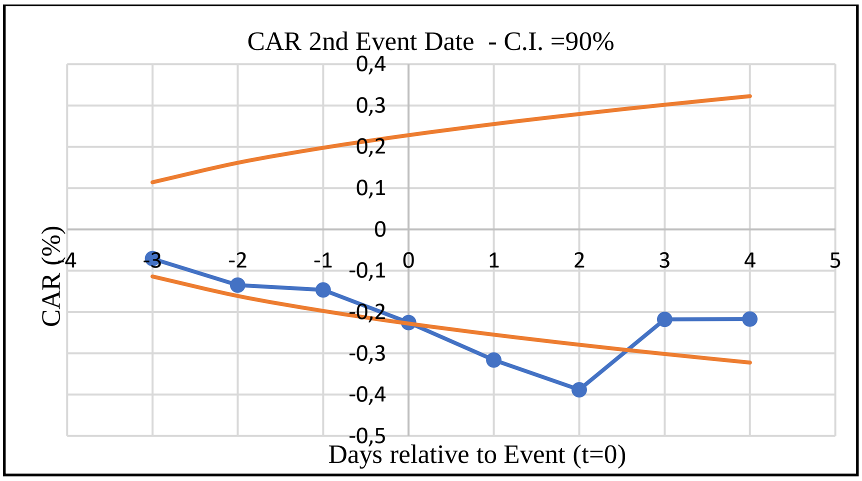


Figure 14 CAR for DE10Y in the Event Window around the second proposed date

In this case, it is observed that starting from the event date and up to the following two weeks there were significant cumulative abnormal returns, hence it is likely that the event of the reference day had caused an impact on the market as proposed. The CAR graph for the 1st (first) event date is shown beneath for comparison purposes.

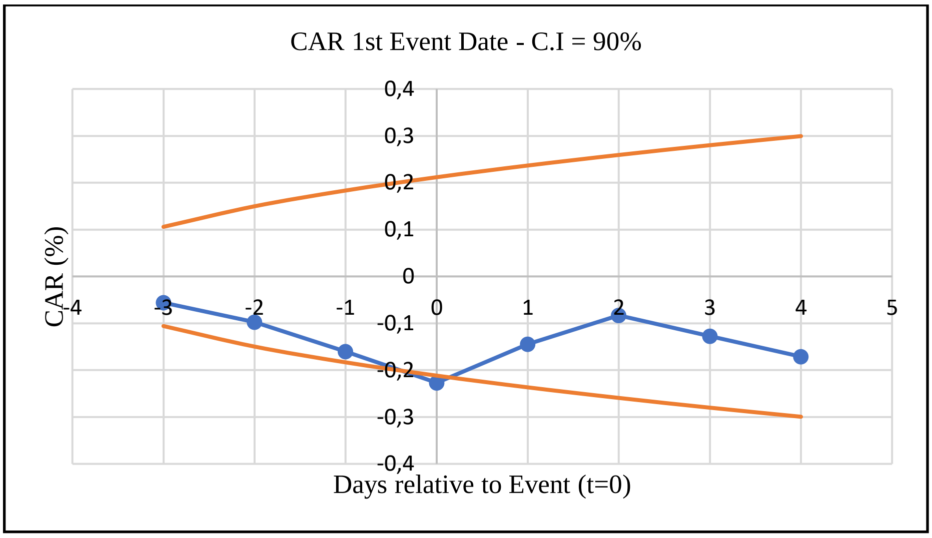


Figure 15 CAR for DE10Y in the Event Window around the first proposed date

An alternative could be to use a model based on a market reference like the US bond yields for the equivalent maturity. Here we present the forecast by two models considering the Yield of the 10-year government bond for the USA, without and with lag (1). However, arguably, it is not a conceptually good model as the reference currencies are different, yet on the other hand, the ARIMA models are intended to describe a process under a black box model rather than mechanistically suggesting causality.

4.2 Event Study for CDS spreads - Detailed step-by-step CDS_DE10Y

A similar process was followed for the CDS data, in which an estimation of the ARMA model parameters is done based on the correlogram (ACF and PACF) for the time series in the estimation windows before the event window. The estimation window comprehends the observations from t=-720 until t=-11 for a total of 709 observations. The event window comprehends from observation for t=-10 until t=14, for a total of 24 observations. The stationarity of the time series was also assessed following an ADF test and using it again as a naïve proxy on whether deterministic components could have been required. Once an ARIMA model is defined its appropriateness for representing the data is verified through the analysis of the residuals correlograms which should indicate a white noise behavior, that is no statistically significant values for the ACF or PACF. In case the assessed model was not good to describe the data, another ARIMA model is estimated considering the ACF and PACF of the time series and the residuals of the previous model in order to verify if a higher AR/MA order was needed. Finally, the appropriateness is once again verified through the correlogram of the residual. If the results were satisfactory such model was used for the ESM, otherwise, the process is repeated until convergence.

For the event study the estimated value for the CDS spread is computed using the selected model, previously described, and relying on the previous observations up to the last day of the estimation window. The AR*s were computed, and the CARs are computed for the event window. The irrelevance zone is computed based on the variance for the AR* in the estimation window as described in section 3.1. The procedure for data of CDS spreads analysis is described step-by-step for the CDS spread of the 10-year German Government Bond, around the second proposed event date (Brexit referendum results announcement).

Initially, the stationarity was checked and used to find clues on whether deterministic elements should be included in the ARMA model.

Gretl Results 2 Stationarity Test using an ADF test (Baiocchi G., 2003) based on BIC information criteria for CDS_DE10Y Time Series in the Estimation Window for the second proposed event date

Augmented Dickey-Fuller Test for Testing down from (lags) Unit-root null hypothesis: a=1	**CDS_DE10Y 180**
	p-value
Test without constant	*0,4676*
Test with constant	*0,0006908*
Test with constant and trend	*0,0007807*

The previous results suggested that an initial guess could omit the presence of deterministic elements for modeling this time series in the estimation window. Then a naïve estimation of the model order (p, q) was made based on the correlogram of the time series, that is the ACF and PACF of time series.

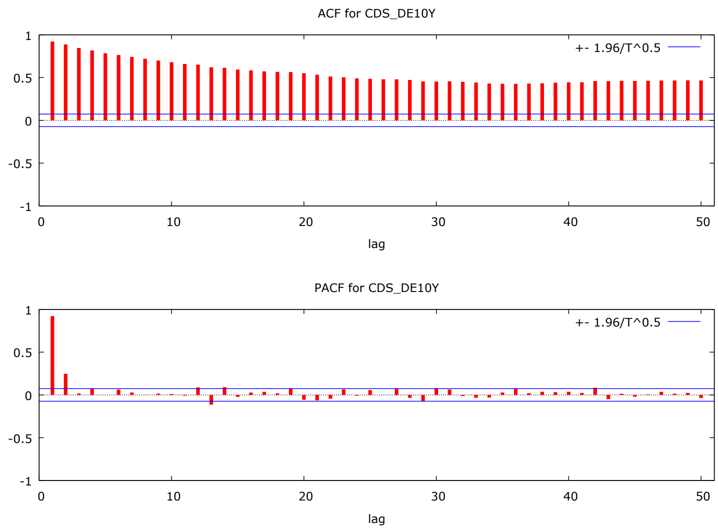


Figure 16 Auto-correlogram of the CDS_DE10Y Time Series around the second proposed date

It can be observed that for CDS_DE10Y a model AR (2) could be potentially used to describe the time series, based on the behavior of the PACF, or a MA (+50) based on the behavior of the ACF. In this case, initially, an ARMA ([1,2,6],0) model without any deterministic components was estimated, for which all its coefficients are statistically significant, as it can be seen from the p-value for the null hypothesis in ANNEX 16**.** Then the ARIMA model is estimated, based on the conditional maximum likelihood.

After having set a model up, for which its parameters are statistically significant, the appropriateness of the model was verified by checking the correlogram of the residuals for the selected model, the residuals should behave as a white noise for the model to be considered good enough in describing the time series (ANNEX 17)

From the residuals correlogram, it can be observed that the ARMA ([1;2;6],0) is a model able to describe the behavior of the time series. The dynamic forecast (ANNEX19) of the model for the event window is presented. However, this does not constitute the event study methodology and is shown just for matters of illustrating the adequacy of the model in forecasting the time series behavior based on the observations up to the end of the estimation window. The static forecast is also presented (ANNEX 18), in fact, the spread between the curves of the actual values and the values estimated by the models are the abnormal residuals (AR*) that will be analyzed during the ESM.

The model is used to forecast the expected CDS spread, the abnormal residual (as the difference between the actual yield and the expected yield), and the cumulative abnormal return. Then the significance of the CAR is given by the statistic considering CAR/S.D.(CAR), which according to literature shall have a unitary normal distribution with mean equal to 0; the indifference zone is built by defining the confidence interval and calculating the z-score associated with it, then multiplying it times the S.D. for the CAR up to the time of the corresponding data-point, following the equations 1 to 4 from section 3.1.

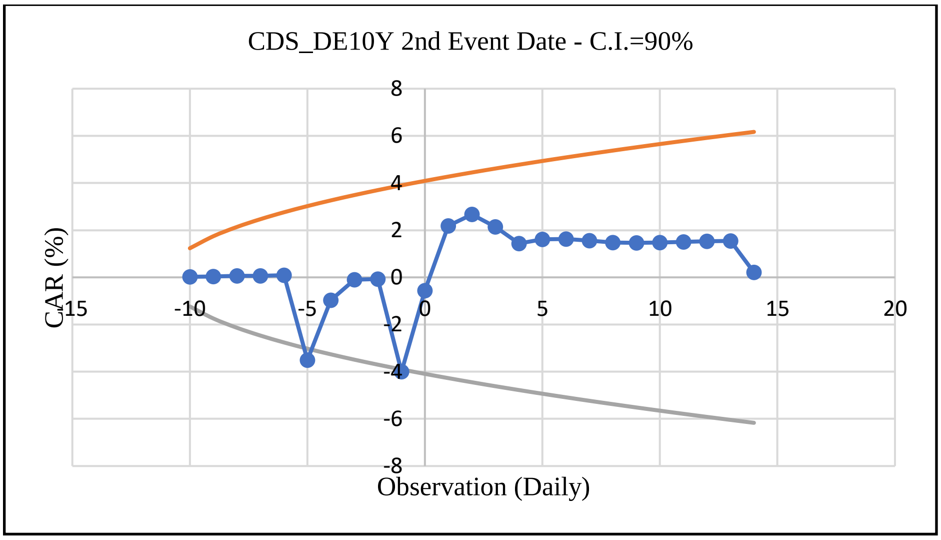


Figure 17 CAR for CDS_DE10Y in the Event Window around the second proposed date

In this case, it is observed that prior to the event date just on two occasions at t=-5 and t=-1 there were significant cumulative abnormal returns, hence it is likely that the event of the reference day had not caused a significant impact on the CDS spread for this instrument around this proposed date. In the following section, the results of the event study for the *financial variables* are presented and discussed.

4.3 Results of Event Study for Financial Variables

Table 11 Summarizing Results for the ESM to the 10-Year Sovereign Bonds Time Series

*	**Weakly**							
***	**Strange Data Behavior**							
Event Study (10Y-Yields)								
			1st	**2nd**	**3rd**	**4th**	**5th**	**6th**
DE	***Mean***	0,645	YES***	YES	YES	NO	NO*	NO
	SD	0,843						
FR	***Mean***	1,107	NO	YES	YES	NO*	YES	NO
	SD	1,027						
IT	***Mean***	2,722	NO*	NO***	YES	YES***	YES	NO
	SD	1,600						
CH	***Mean***	0,126	NO*	YES	NO	NO*	YES	NO
	SD	0,5811						
UK	***Mean***	1,537	NO	YES	NO	NO	NO*	NO
	SD	0,7533						
		Avg Score	34	85	60	34	80	0
		1ST	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**

It was observed that for the 10 Years maturity yields of the sovereign bonds, the two dates with major noticeable impacts were the second and fifth dates, corresponding to the referendum results announcement and the treasury announcement together with the white paper submission to the British parliament, which revealed the intentions of not maintaining access to the single market. The second date had noticeable effects for the yields of all the main economies associated with a main European financial hub. Italy was affected less severely, and it may be due to the lower rating for the Italian sovereign bonds compared to the other centers in Europe, which may make this instrument subject to higher volatilities and behave less like the lower risk bonds. The first, third, and fourth dates exhibit a mild impact with few time series having significant cumulative abnormal residuals, overall, the impact seems ambiguous and likely correspond to weak events for these instruments in these dates. The third date, corresponding to the speech by Theresa May seems to have had an impact on the EU instruments specifically. The sixth date corresponds to the end of the transition period after the UK formally left the EU, around this date no significant impact was evidenced supporting the idea that after several months of the Brexit process all the future possible scenarios were already internalized by the market by the time Brexit actually translated into real barriers.

Table 12 Summarizing Results for the ESM to the 3-Months Sovereign Bonds Time Series

* ***		Weakly Strange Data Behavior						
Event Study (3M-Yields)								
			1st	2nd	3rd	4th	5th	6th
DE	*Mean* *SD*	-0,359 0,399	YES	NO*	NO*	NO*	NO	NO*
FR	*Mean* *SD*	-0,281 0,396	NO*	YES	YES***	NO	NO	NO
IT	*Mean* *SD*	0,139 0,882	NO	YES	NO	NO	NO	NO
CH	*Mean* *SD*	-0,577 0,409	NO	NO*	NO	NO*	NO*	NO
UK	*Mean* *SD*	0,408 0,203	NO	YES	NO*	YES***	NO*	NO
		Avg Score	30	80	34	34	20	10
		1ST	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**

The 3 months maturity sovereign bonds yields appear to be significantly impacted the most by the referendum results announcement. However, the impact was apparently stronger for the UK, France, and Italy, while Germany and Switzerland seem to have suffered a more moderated impact, yet the yields of the sovereign bonds for all considered countries seem to have been affected in some way. The other dates showing weak or mixed impacts are the first, third and fourth, which correspond to news releases. Particularly, Italian and Swiss bonds seem to exhibit no significant abnormal behavior around these weak events, while German, French, and British short-term bonds had mixed results. For this type of short-maturity instrument, the formal leave of the UK and the end of the transition period did not appear to have had any impact.

Table 13 Summarizing Results for the ESM to the long to short term Yields Spread Time Series

*	Weakly								
***	Strange Data Behavior								
Event Study (10Y-3M Spreads)									
			1st	**2nd**	**3rd**	**4th**	**5th**	**6th**
DE	*Mean*	1,004	NO	YES	NO*	YES*	NO*	NO
	SD	0,548						
FR	*Mean*	1,389	NO	NO*	NO*	NO*	YES	NO
	SD	0,717						
IT	*Mean*	2,583	NO	NO	YES***	YES***	YES	NO
	SD	1,061						
CH	*Mean*	0,704	NO	NO	NO	YES	NO*	NO
	SD	0,324						
GB	*Mean*	1,129	NO	YES	NO	YES	NO*	NO
	SD	0,725						
		Score	0	50	34	78	70	0
		1ST	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**

The time series of the long-term and short-term maturities yield spread, which is an indicator of the quality of the credit or intermediation activity, suggests that the date with the highest impact was the fourth date. This observation is in coherence with the passporting rights and access to the single market as one of the main topics of concern for the financial industry and the financial lobby in continental Europe and in the UK. The fact that the British government had announced to drop any intention to push for this objective during the Brexit negotiations implied an increased risk for the financial institutions serving clients on both markets and particularly for the banking sector as the increase in risk would have direct implications in terms of capital requirements and reduced returns. The second and the fifth date seem to have had mixed impacts on the spread. The second date appears to have impacted more strongly the reference bonds for the currency par involved, that is German and British ones. The fifth date had a stronger impact on French and Italian yield spreads and weaker effects on the other yield spread. Once again, the sixth date shows no signs of any unusual behavior for the time series around the date of the event.

Table 14 Summarizing Results for the ESM to the CDS Spread of the 10-Year Sovereign Bonds Time Series

* ***	Weakly Strange Data Behavior							
Event Study (10Y-CDS Spread)								
			1st	**2nd**	**3rd**	**4th**	**5th**	**6th**
DE	*Mean*	28,21	YES***	YES*	NO*	NO	NO	NO
	SD	15,537						
FR	*Mean*	52,961	NO	NO*	YES	NO*	NO	NO
	SD	30,658						
IT	*Mean*	170,77	NO*	NO	NO	YES***	NO*	NO
	SD	74,362						
CH	*Mean*	NA	NA	NA	NA	NA	NA	NA
	SD	NA						
UK	*Mean*	26,396	YES***	YES	NO*	YES***	NO	NO
	SD	8,4571						
		Avg Score	47,5	55	50	47,5	12,5	0
		1ST	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**

The credit default swap spread suggests the second event date as the one with the strongest impact for the time series, around that date a statistically significant impact was observed for the CDS spread of the 10-year sovereign bonds from Germany and the UK, and a weak impact on the French homolog. The third, the first, and the fourth dates followed respectively in the magnitude of the impact over the financial variables. Finally, the fifth and noticeably the sixth dates suggested no abnormal behavior of any of the spreads.

Table 15 Summary of the ESM classification for each date per time series, average score, and event date classification

ESM – Summarizing Table and Score						
	1st	***2nd***	***3rd***	***4th***	***5th***	***6th***
10Y	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
3M	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
10Y-3M Spread	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
CDS (10Y) Spread	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
	V. WEAK	***STRONG***	***WEAK***	***WEAK***	***WEAK***	***NO***
Average Score	**18,75**	**80**	**42,5**	**43,75**	**40**	**0**

After considering the various behaviors of the time series for the financial variables around the six proposed dates, and the amount of time series that showed unusual behaviors around the proposed dates, the previous results were summarized in Table 22**.** It is noticeable that the second event date was the one registering consistently for all the financial variables a strong to medium impact around it, followed by the third and fourth dates and in a less measure the fifth. The average score obtained by the date following the score table described in section 3.1, leads to a classification of “strong event date” for the second date, a result in line with previous studies about the Brexit referendum results announcement impact on different instruments. The third, fourth and fifth event dates appear as weak events, suggesting that some information was internalized by the markets as these events occurred yet did not affect all the financial variables under consideration to a big enough extent to be globally influential. This classification is coherent with the view of the Brexit negotiation as a path full of uncertainty, in which this major news served for different stakeholders to correct their expectations on what a possible outcome could be. While the formal exit of the UK from the EU, that is the fifth date, may not have been a complete surprise as it was only surrounded by uncertainty regarding whether there would be a hard Brexit or not. In fact, the transition agreement was ratified just days before the deadline for the UK departure. The sixth event date suggests that after the tortuous path that lasted several years, most of the hedging was already in place and the associated risk was already priced-in for which little to no impact was observed around this date. This result offers some clarity to suggestions previously made by some researchers on what other possible dates could be considered event dates in the Brexit process. The announcement of a referendum had been regarded as a weak event date, after the analysis here conducted the conclusion is that for the selected financial variables it appears as a very weak event date.

4.4 Market Volumes Analysis

The time series corresponding to the market volumes were initially described and analyzed, in order to better understand their behavior. The stationarity of the time series was analyzed through the ADF test, and under the same three types of models as for the *financial variables* (no constant, constant, constant and trend, in ANNEX 20).

From this stationarity analysis, a diverse behavior per-financial hub and per origin of contracts can be observed. In the case of the London (UK) market volumes, the disaggregated data appear to be stationary when a constant term and a trend are considered, yet the time series for the aggregated data for all instruments regardless of their origin (UK_All) does not seem to be stationary even under this consideration. The European Union aggregated market volumes (EU_) have a stationary behavior under some of the considered scenarios. For the Frankfurt related (DE_) time series the stationarity is seen for the aggregated instruments (DE_All) and the European instruments (DE_EU), while for the others, it is not found based on the ADF test. Similarly, the Paris-related time series (FR_) the British (FR_UK), and the rest of the world time series (FR_RoW) are stationary under at least one of the scenarios considered. The other two time series are not. For Milan, the time series referred to Milanese market volumes all of them are stationary under some of the considerations, and for the Zurich-based data it is also the case, except for the British instruments in the Swiss market (CH_UK) which does not appear to be stationary. The lack of stationarity may be due to the presence of seasonality for the before mentioned time series, as the presence of a trend is addressed in one of the three model types under analysis.

The analysis of the market volumes time series is composed of three stages. In the first one, the market volumes time series are analyzed under an ESM to verify if, around the most relevant event dates (the second and fourth proposed dates), identified during the event study for the *financial variables*, the market volumes also experienced an impact possibly associated to the event; derived from this event study the most impactful date was used as a milestone to determine the pre-Brexit and the post-Brexit segments in the time series. The methodology followed is the same as the one described in section 3.1 and implemented for the *financial variables*, the main difference is the change in the data frequency, which is on a monthly basis, yet it is coherent as market volumes reflect major changes in the activities and structure of market participants that occur in larger time scales compared to the *financial variable*. Secondly, the changes in the properties and behavior of the market volumes time series before and after Brexit (referred to as before and after the most impactful date identified in the first stage) were analyzed following the methodology and statistical properties described in section 3.2. Thirdly and finally, the time series of the number of investment funds and of the market volumes for all instruments from all origins at each of the financial hub's markets were regressed against the financial-hub factors from the theoretical model. The appropriateness of these factors for describing both time series was verified as described in section 3.3 and used to evaluate the appropriateness and correctness of the model.

4.4.1 Market Volumes Event Study Results

The market volumes time series were analyzed following the ESM procedure described in section 3.1, in order to analyze the two proposed dates with the highest relevance based on the assigned score from section 4.3 and. The two most relevant dates were the second and the fourth, which correspond to the referendum results announcement and the government announcements and legislative white paper. Since the frequency for the market volumes data is monthly when referring to the event date the referral month is the month in which the event occurred. The results for the different time series were grouped according to the main financial hub of referral (London, Frankfurt, and Zurich) and at an aggregated EU level (EU), a score was assigned using the same scheme as the one presented in section 3.1 and implemented in section 4.3.

The implementation step-by-step of the ESM to the market volumes time series is presented before showing the results derived from its implementation to all-time series around the two most relevant proposed dates. The implementation shown below corresponds to the market volumes in London for all the instruments regardless of their origin (UK_All) around the second proposed date (Brexit referendum results announcement).

Initially, the stationarity was checked and used to find clues on whether deterministic elements should be included in the ARMA model.

Gretl Results 3 Stationarity Test using an ADF (Baiocchi G., 2003) test based on BIC information criteria for UK_All Time Series in the Estimation Window for the second proposed event date

Augmented Dickey-Fuller Test for Testing down from (lags) Unit-root null hypothesis: a=1	**UK_All 28**
	p-value
Test without constant	*0,5629*
Test with constant	*0,00667*
Test with constant and trend	*0,4803*

The previous results suggested that an initial guess could omit the presence of deterministic elements for modeling this time series in the estimation window. Then a naïve estimation of the model order (p, q) was made based on the correlogram of the time series, that is the ACF and PACF of time series.

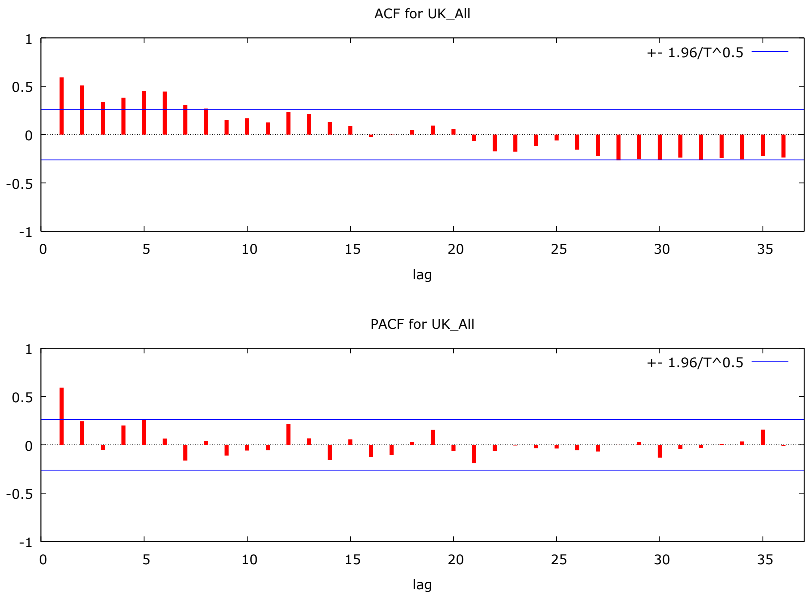


Figure 18 Auto-correlogram of the UK_All Time Series around the second proposed date

It can be observed that for UK_All a model AR (2) could be potentially used to describe the time series, based on the behavior of the PACF, or a MA (8) based on the behavior of the ACF. In this case, initially, an ARMA ([1;2;5],0) model without any deterministic components was estimated, for which all its coefficients are statistically significant, as it can be seen from the p-value for the null hypothesis in **ANNEX 21**. Then the ARIMA model is estimated, based on the conditional maximum likelihood.

After setting up a model with statistically significant parameters, the appropriateness of the model was verified by checking the correlogram of the residuals for the selected model, the residuals should behave as a white noise for the model to be considered good enough in describing the time series (ANNEX 22).

From the residuals correlogram, it can be observed that the ARMA ([1;2;5],0) is a model able to describe the behavior of the time series. The dynamic forecast (ANNEX 24) of the model for the event window is presented, however, this does not constitute the event study methodology and is shown just for matters of illustrating the adequacy of the model in forecasting the time series behavior based on the observations up to the end of the estimation window. The static forecast is also presented (Figure 19), in fact, the spread between the curves of the actual values and the values estimated by the models are the abnormal residuals (AR*) that will be analyzed during the ESM.

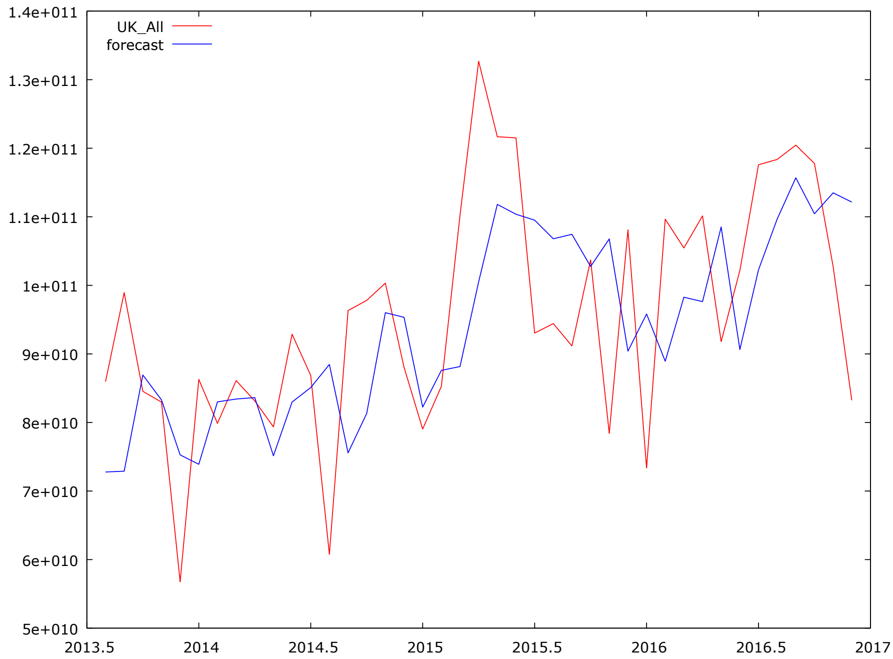


Figure 19 Actual and Fitted Data for UK_All with a Static Forecast for the Event Window

The model is used to forecast the expected yield, the abnormal residual (as the difference between the actual yield and the expected yield), and the cumulative abnormal residual. Then the significance of the CAR is given by the statistic considering CAR/S.D.(CAR), which according to literature shall have a unitary normal distribution with mean equal to 0; the indifference zone is built by defining the confidence interval and calculating the z-score associated with it, then multiplying it times the S.D. for the CAR up to the time of the corresponding data-point, following the equations 1 to 4 from section 3.1.

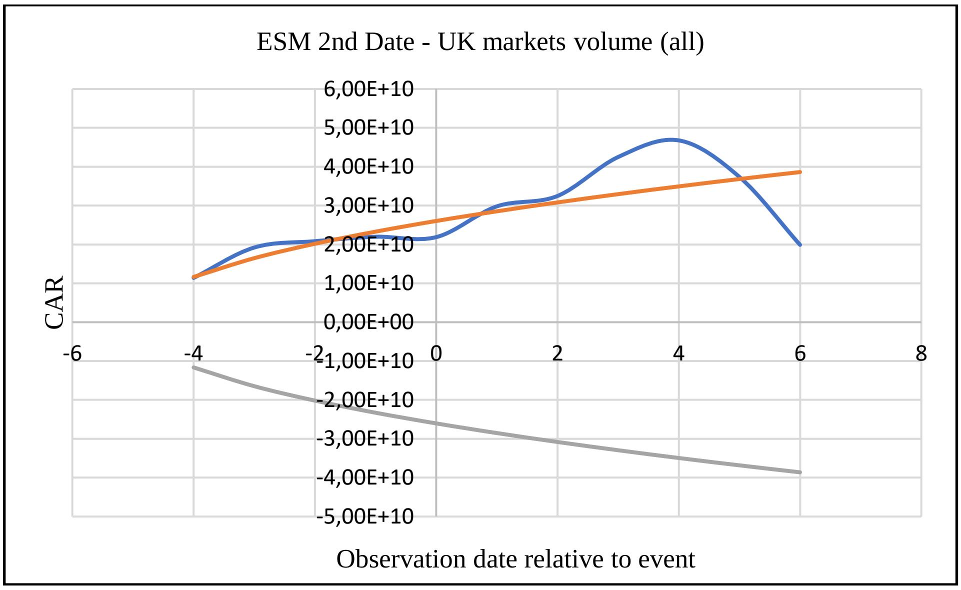


Figure 20 CAR for UK_All in the Event Window around the second proposed date

In this case, it is observed that starting from the observation following the event date and up to the fifth observation post-event, there were significant cumulative abnormal returns, hence it is likely that the event of the reference day had caused an impact on the market volumes in London as proposed. The aggregated results are shown in Table 16 and the disaggregated results are shown in Table 17 and Table 18.

Table 16 Summary of Aggregated Results of ESM of Time Series for each Financial Hub

SUMMARY FOR EVENT DATES BY MARKET (AGGREGATED)			
	2nd		**4th**
UK	YES		NO
EU	YES		YES*
DE	YES*		YES*
CH	YES*		YES*

The previous table summarizes based on the average score for the four-time series of each financial hub market, whether the date is an event date (YES), or if it appears to have been an event date for at least two of the time series (YES*) or for none of the time series (NO). Based on this analysis the strongest event date is the second proposed date or the referendum results announcement, while the fourth date seems to have been meaningful for the continental European markets, a result in coherence with the observations from the event study of the financial variables (sections 4.1 to 4.3). The following tables Table 26 and Table 27, show the disaggregated results of the ESM for each time series and some notes on when and how the significant CAR was observed, additionally the mean and standard deviation for the whole time series, for the observation window of the second date and for the observation window of the fourth date.

The notes in the following table describe how the observation of the significant CAR appeared for that time series in the event window. The appearance of significant CAR for t<0 is described as "*in advance*", while for t>0 it is described as "*delayed*". The prolongation of significant CAR for more than three months is described as "*long*" and when the duration was less than two months it was described as "*short(ly)*".

Table 17 Summary of Results of ESM of Time Series by Origin of Contracts for each Financial Hub -ESM around second proposed Date (Reuters, 2021)

Summary ESM (DIS-AGGREGATED)							
		Overall		**2^{nd} Event Date**			
		Oveall Statistics		**ESM Result & Notes**		**Pre-2nd Event Statistics**	
UK	*All*	*Mean*	1,15 * 10^{11}			*Mean*	8,05 * 10^{10}
		S.D	*6,95 * 10^{10}*	YES	IN ADVANCE & DELAYED	*S.D*	*1,81 * 10^{10}*
	EU	*Mean*	1,07 * 10^{10}			*Mean*	7,90 * 10^{9}
		S.D	*6,32 * 10^{9}*	YES	IN ADVANCE - SHORT	*S.D*	*2,72 * 10^{9}*
	UK	*Mean*	7,60 * 10^{10}			*Mean*	5,96 * 10^{10}
		S.D	*3,67 * 10^{10}*	YES	IN ADVANCE - LONG	*S.D*	*1,30 * 10^{10}*
	RoW	*Mean*	2,84 * 10^{10}			*Mean*	1,31 * 10^{10}
		S.D	*3,70 * 10^{10}*	YES	SHORTLY	*S.D*	*7,42 * 10^{9}*
EU	*All*	*Mean*	8,26 * 10^{10}			*Mean*	8,52 * 10^{10}
		S.D	*1,95 * 10^{10}*	YES	DELAYED	*S.D*	*1,65 * 10^{10}*
	EU	*Mean*	7,78 * 10^{10}			*Mean*	8,07 * 10^{10}
		S.D	*1,80 * 10^{10}*	YES	DELAYED	*S.D*	*1,58 * 10^{10}*
	UK	*Mean*	1,53 * 10^{9}			*Mean*	1,10 * 10^{9}
		S.D	*8,51 * 10^{8}*	YES	IN ADVANCE	*S.D*	*5,03 * 10^{8}*
	RoW	*Mean*	3,27 * 10^{9}			*Mean*	3,44 * 10^{9}
		S.D	*1,66 * 10^{9}*	YES	IN ADVANCE & DELAYED	*S.D*	*1,05 * 10^{9}*
DE	*All*	*Mean*	8,11 * 10^{9}			*Mean*	6,94 * 10^{9}
		S.D	*3,37 * 10^{9}*	NO		*S.D*	*1,87 * 10^{9}*
	EU	*Mean*	6,10 * 10^{9}			*Mean*	5,85 * 10^{9}
		S.D	*1,87 * 10^{9}*	NO		*S.D*	*1,53 * 10^{9}*
	UK	*Mean*	3,44 * 10^{8}			*Mean*	1,65 * 10^{8}
		S.D	*3,46 * 10^{8}*	YES	IN ADVANCE - LONG	*S.D*	*1,26 * 10^{8}*
	RoW	*Mean*	1,67 * 10^{9}			*Mean*	9,24 * 10^{8}
		S.D	*1,55 * 10^{9}*	YES	IN ADVANCE - LONG	*S.D*	*3,42 * 10^{8}*
CH	*All*	*Mean*	2,13 * 10^{9}			*Mean*	1,62 * 10^{9}
		S.D	*9,52 * 10^{8}*	YES	SHORTLY	*S.D*	*3,78 * 10^{8}*
	EU	*Mean*	2,57 * 10^{8}			*Mean*	1,54 * 10^{8}
		S.D	*1,51 * 10^{8}*	YES	IN ADVANCE - SHORT	*S.D*	*5,23 * 10^{7}*
	UK	*Mean*	3,53 * 10^{7}			*Mean*	3,86 * 10^{6}
		S.D	*7,09 * 10^{7}*	YES	IN ADVANCE - LONG	*S.D*	*3,64 * 10^{6}*
	RoW	*Mean*	1,84 * 10^{9}			*Mean*	1,46 * 10^{9}
		S.D	*8,20 * 10^{8}*	NO		*S.D*	*3,50 * 10^{8}*

It can be observed how around the second event there was a significant effect for all the instruments volumes at the British markets and at an EU level. For the markets in Frankfurt, the grouped effect over all the instruments of all origins was not evident as well as for the EU securities. No observable effect for the instruments of the "rest of the world" in the Swiss markets at Zurich was detected. However, for all the time series, there was a significant effect for the British contracts and instruments.

Table 18 Summary of Results of ESM of Time Series by Origin of Contracts for each Financial Hub -ESM around fourth proposed Date (Reuters, 2021)

Summary ESM (DIS-AGGREGATED) 4th Event Date				Pre-4th Event Statistics	
		ESM Result & Notes			
UK	*All*	NO		*Mean*	$9,99 * 10^{10}$
				S.D	$2,17 * 10^{10}$
	EU	NO*	(80%) IN ADVANCE - ALTERNATED	*Mean*	$9,28 * 10^{9}$
				S.D	$2,57 * 10^{9}$
	UK	NO*	(80%) IN ADVANCE	*Mean*	$7,01 * 10^{10}$
				S.D	$1,40 * 10^{10}$
	RoW	NO*	(85%) IN ADVANCE	*Mean*	$2,06 * 10^{10}$
				S.D	$1,01 * 10^{10}$
EU	*All*	YES	SHORTLY	*Mean*	$8,21 * 10^{10}$
				S.D	$1,59 * 10^{10}$
	EU	YES	SHORTLY	*Mean*	$7,74 * 10^{10}$
				S.D	$1,51 * 10^{10}$
	UK	NO*	IN ADVANCE - SHORT	*Mean*	$1,55 * 10^{9}$
				S.D	$6,60 * 10^{8}$
	RoW	NO		*Mean*	$3,21 * 10^{9}$
				S.D	$1,43 * 10^{9}$
DE	*All*	YES	IN ADVANCE - SHORT	*Mean*	$6,03 * 10^{9}$
				S.D	$9,38 * 10^{8}$
	EU	YES	SHORTLY	*Mean*	$4,88 * 10^{9}$
				S.D	$6,33 * 10^{8}$
	UK	YES	IN ADVANCE - SHORT & DELAYED SHORT	*Mean*	$1,46 * 10^{8}$
				S.D	$6,30 * 10^{7}$
	RoW	NO*	IN ADVANCE - SHORT	*Mean*	$1,00 * 10^{9}$
				S.D	$4,88 * 10^{8}$
CH	*All*	NO		*Mean*	$1,80 * 10^{9}$
				S.D	$4,03 * 10^{8}$
	EU	YES	IN ADVANCE	*Mean*	$2,25 * 10^{8}$
				S.D	$1,23 * 10^{8}$
	UK	YES	LONG	*Mean*	$3,92 * 10^{6}$
				S.D	$6,60 * 10^{6}$
	RoW	NO		*Mean*	$1,58 * 10^{9}$
				S.D	$3,40 * 10^{8}$

It can be noticed how around the fourth date no effect was seen for any instrument regardless of their origin in the London market. At an EU level, the impact was observable for the aggregated data and for the EU instruments. In Frankfurt, however, the aggregated, the British and the EU instruments registered a significant impact. Finally, in Zurich, only the EU and the British instruments reviled a significant effect. As a result, the fourth date appears to be a weak event date with mostly effects across the different financial hub centers on the EU instruments. Moreover, the previous results match with the event studies previously reported in the literature, in which the Brexit announcement (referendum results announcement) has been regarded as a strong event, while the announcement of a referendum was a very weak event.

4.4.2 Changes Pre- and Post-Brexit Announcements in Market Volumes

After having identified the second proposed date as the main event date for the market volumes time series, it was used as a breaking point marking the "Brexit event". The time series were analyzed as described in section 3.2 to observe changes in the properties and behavior before and after the Brexit announcement, the data corresponds, as described in section 2 to the monthly observations for the market volumes from January 2011 until June 2021. The time series, disaggregated by the origin of instruments for each financial-hub market are presented in the following graphs and briefly analyzed, followed by the statistical analysis of the time-series properties.

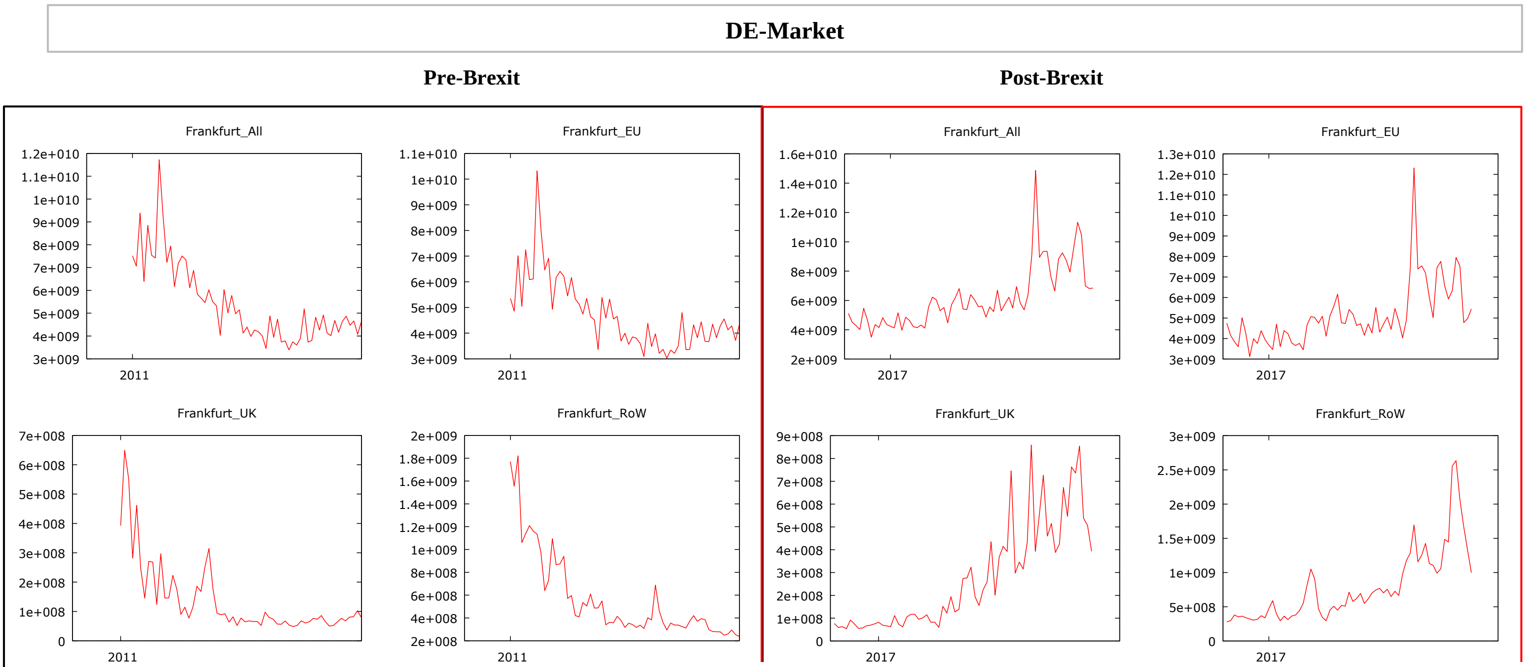


Figure 21 Market Volumes (Reuters, 2021) in Frankfurt by Origin of Contracts

The time series for the Frankfurt-based markets volumes show a general decrease in the period preceding the Brexit announcement followed by a subtle increase and a more pronounced increase in volatility which can be identified by the short peaks that last for a very short time.

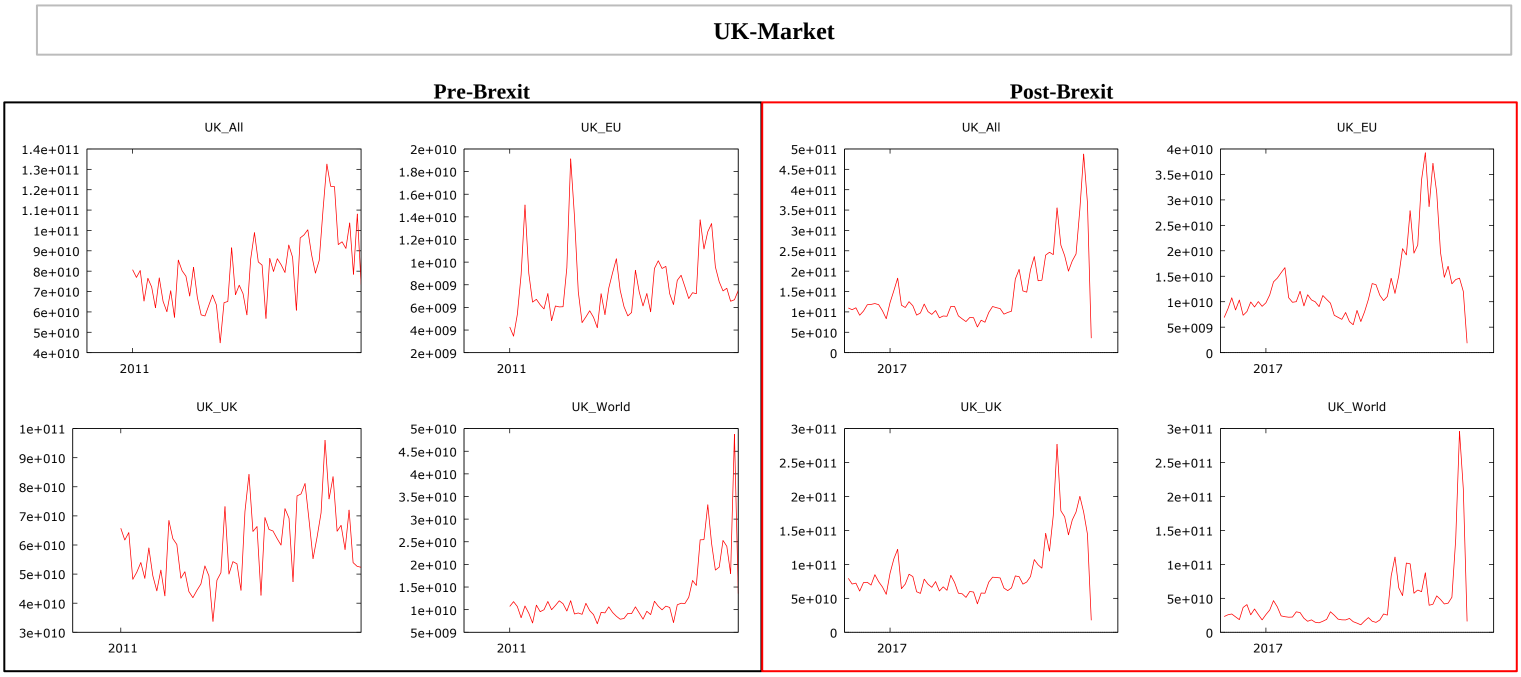


Figure 22 Market Volumes in London by Origin of Contracts

The time series for the London-based market volumes show a constant to increasing partner before the Brexit announcement, the general level of the time series keep their behavior after the Brexit announcement with a stronger increase towards the end of the analyzed period and higher fluctuations around that period as well.

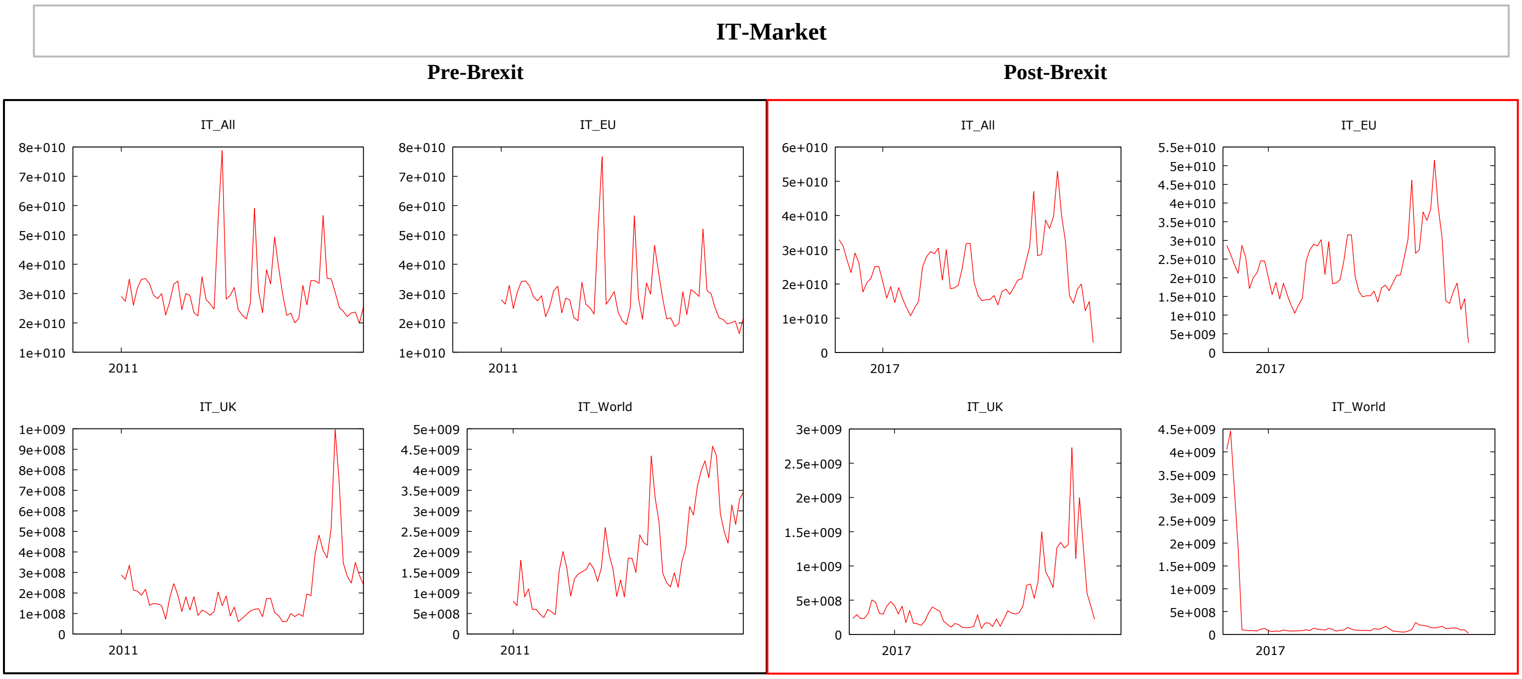


Figure 23 Market Volumes in Milan by Origin of Contracts

The market volumes for the markets in Milan show constant or slightly decreasing behaviors before the Brexit announcement for the instruments from different geographies, after the Brexit announcement most time series seem to have reverted to an increasing behavior within 1 and 2 years after the referendum results announcement. There was a strong reduction in the trade volumes of instruments belonging to the "*rest of the world"* (IT_RoW) category, that is contracts and instruments from countries other than the UK or the group of the EU.

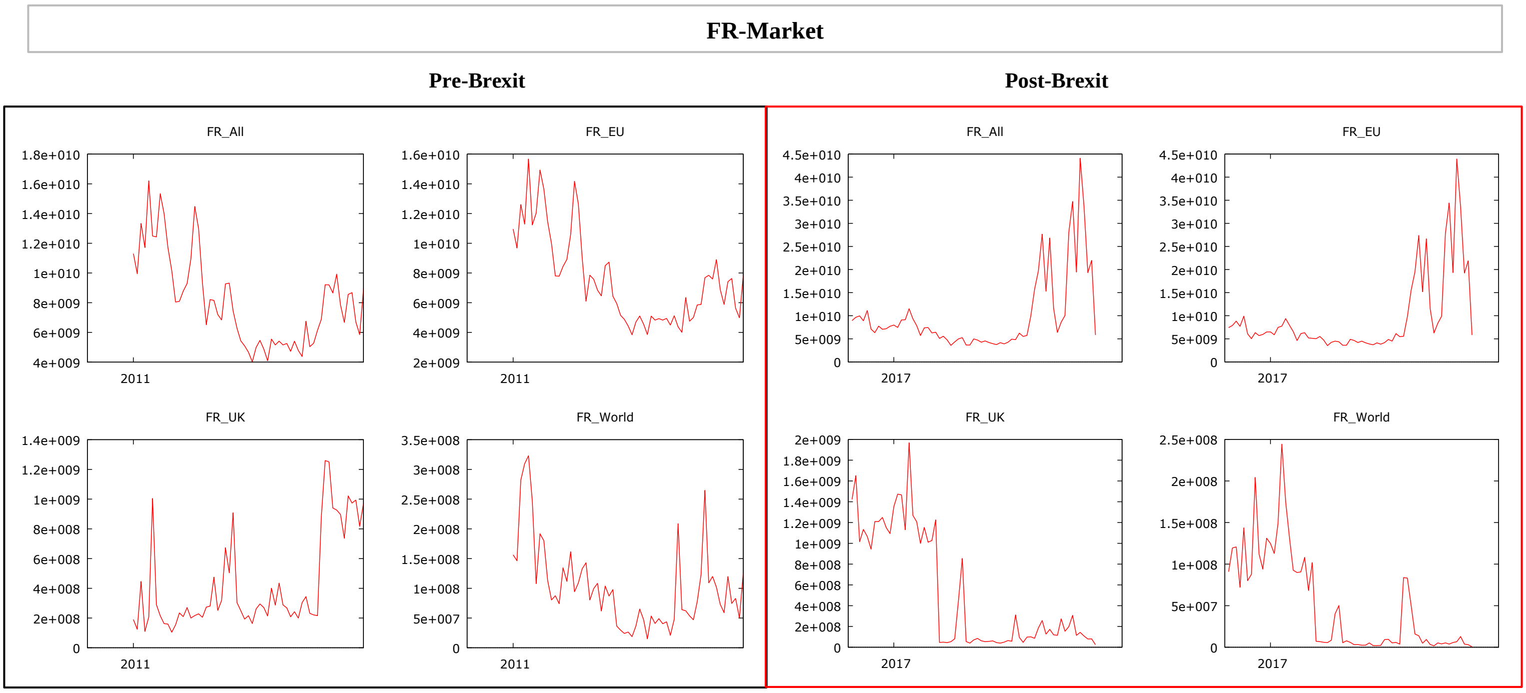


Figure 24 Market Volumes in Paris by Origin of Contracts

The market volumes in the Paris market show an overall reduction before the Brexit announcement, followed by a stabilization period that carried on after the Brexit announcement up until before the increase towards the end of the observation period in the case of the aggregated (FR_All) and the EU time series. In the case of the RoW instruments, the initial reduction is also present, followed by a small increase post-Brexit announcement and a strong reduction between 2018 and 2019. However, the time series for the UK instruments in Paris shows an initial increase before the Brexit announcement that carried on shortly after the Brexit announcement before having a strong fall again between 2018 and 2019.

CH-Market

Pre-Brexit | **Post-Brexit**

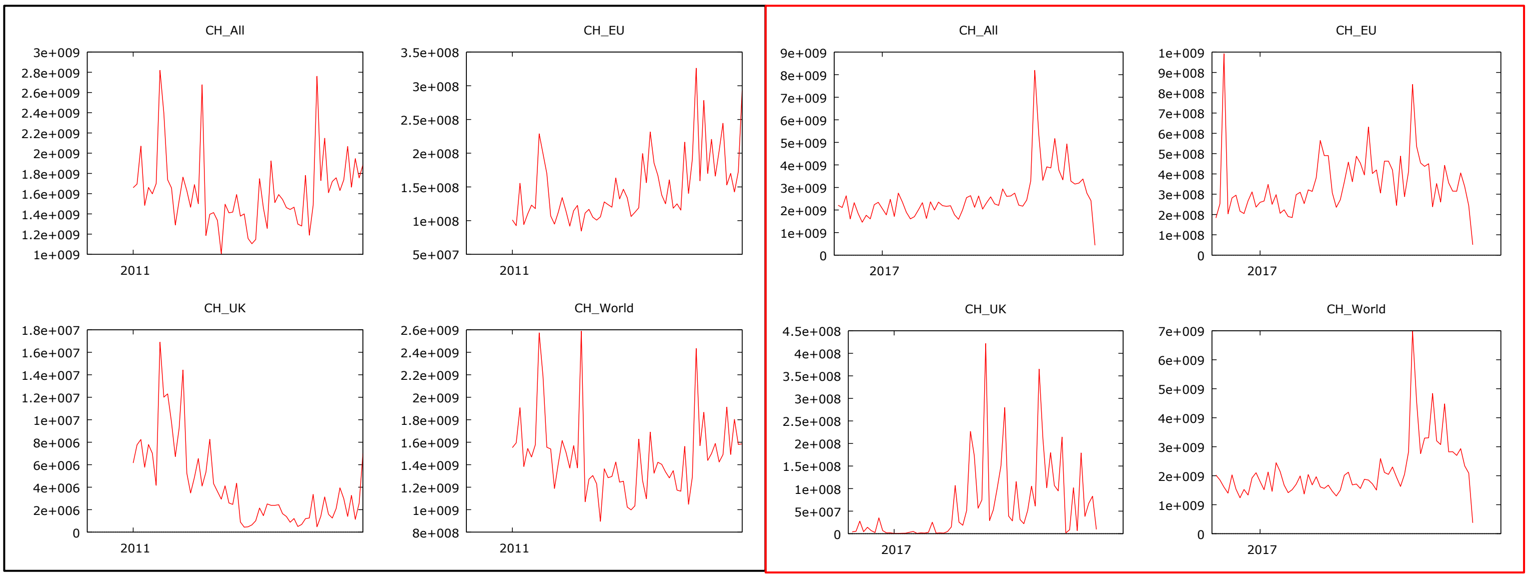


Figure 25 Market Volumes in Zurich by Origin of Contracts

The market volume data for the time series of the instruments in Zurich do not appear to have an overall clear behavior. In the case of the aggregated (CH_All) and the "*rest of the world*" (CH_RoW) time series, it seems to have a constant behavior before and after the Brexit announcement until few observations before the end of the observation window when a slight increase can be observed. The time series for the EU instruments (CH_EU) shows an increasing behavior before and after the Brexit announcement. It is particularly noticeable how shortly after the Brexit announcement there was a significant increase for this time series that, however, did not continue for long. The UK instruments appear to have had a decreasing behavior before the Brexit announcement which remained constant for some time after the Brexit announcement and then proceeded to boost to about ten times higher with a lot of variation in the short period.

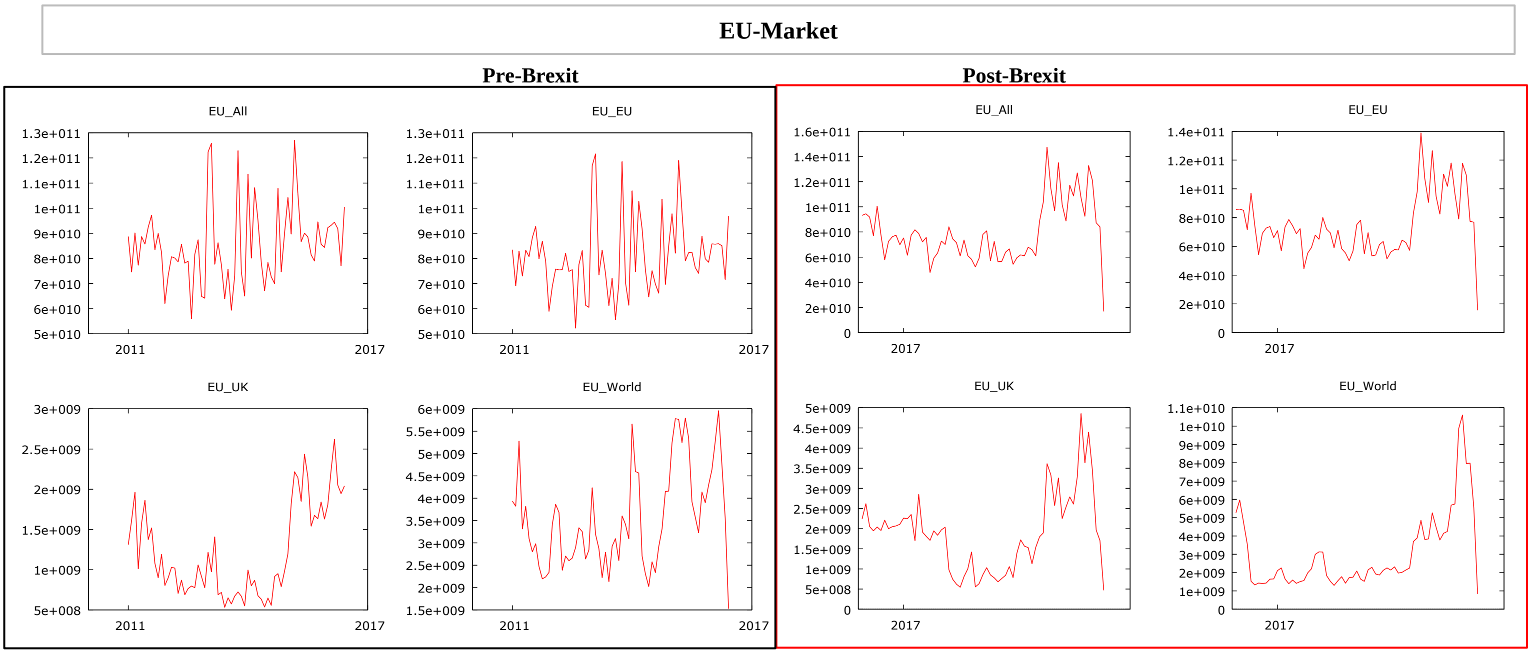


Figure 26 Market Volumes in all the EU by Origin of Contracts

At an EU level, the behavior of time series for aggregated instruments (EU_All) and for EU instruments (EU_EU) appears to be constant or slightly increasing before Brexit. After Brexit, there is a small reduction until 2019, after which a strong increase of almost 50% is observable. It is noticeable that the EU instruments are the major component of the volume trade of all instruments at an EU level. The time series for British instruments show an increasing behavior before the Brexit announcement, the increase sustains for some time after the Brexit announcement and between 2018 and 2019 it returns to previous levels. Finally, there is a huge increase between 2020 and 2021. In conclusion, the instruments not belonging to the UK or the EU, oscillated around a stable level before the Brexit announcement, after which they strongly fell until 2020 when a noticeable increase was observed.

Based on the observations we can make based on the previous figures, it appears that after the Brexit announcement some time series experienced strong changes, in particular for the volumes of the "*rest of the world*" in Paris and Milan, as well as the volumes of the UK instruments in Zurich. Others seem to keep the behavior presented before the Brexit announcement. For almost all the time series previously presented, there seems to be a significant increase in volume by the end of the observation window, however, it is worth considering that this behavior may be associated with the SARS-COV19 pandemic and the subsequent impact on the global economies and all the financial markets. In fact, for 2020, there was an unusual level of transactions, therefore inflating the figures of market volumes and many securities suffered high price variations through the whole year, with some un-usual returns.

In ANNEX 25 and ANNEX 26 the time series are shown before and after the Brexit announcement while grouped according to the region of origin of the instruments rather than the financial-hub market. The time series of all instruments, regardless of their location of origin (All), in Milan, Zurich, Paris, and on EU level tended to remain around the same value without any major trend except for the mentioned increase at the end of the observation window which is common across all the time series. London maintained an increasing volume behavior which was accelerated by the end of the observation window. For Frankfurt, the time series was decreasing before the Brexit announcement and started increasing shortly after before another accelerated increase by the end of the observation period.

There seems to have been a slight increase in the EU securities volume in Zurich and Frankfurt after the Brexit announcement. For the time series of the volumes in London, there seems to have been no change before the 2020 spike, the same can be noticed for the volumes in Paris. However, at an EU level, there seems to have been a small increase that could remain after the volatile 2020, yet it is just a claim made based on the observation of the lowest points, for the period between 2020 and 2021, being higher than the previous peaks.

The UK instruments volume in London had an increasing behavior before Brexit that vanished after Brexit, before peaking by 2020 and 2021. On the EU level, there was a sharp increase shortly before the Brexit announcement that lasted few months after the announcement before returning to previous levels to later increase sharply by the end of the observation window. The volumes in Milan tended to remain at the same level except for the already mentioned increase by 2020. In Zurich, the trend before the Brexit announcement seemed to be a decreasing one until two years before the announcement when it stabilized and remained at that level for some time after, however, there was a significant set of increases observable as thin pikes for the coming period even before the 2020 general increase. The volumes in France exhibited an increase shortly before the Brexit announcement and sustained at that level for some time after to later fall beneath original levels. In Frankfurt, there was a decreasing behavior before Brexit until sometime between 2014 and 2016 when the time series stabilized, after the Brexit announcement it remained around that level until 2018 to later start increasing and peaking during 2020.

As for the "*rest of the world*" instruments, in London, the volumes increased before the Brexit announcement to later remain constant until 2019 and then having two major increases in 2020 and 2021. In Paris, there was a decreasing behavior before the announcement to later increase post-announcement until 2018 when it sharply dropped beneath any previous levels. In Milan, the pre-Brexit trend was increasing, and then shortly after the announcement dropped to levels not seen before within the observation window. In Zurich, there was a subtle increasing trend that was accentuated in 2020 and 2021. In Frankfurt, the reversal from a decreasing to an increasing trend is also seen for these instruments. On an EU level there was no noticeable tendency before the announcement, then shortly after the levels decreased until late 2019 when they recovered and later boosted during 2020 and 2021.

In order to have a more quantitative analysis of the changes before and after the Brexit announcement, some properties of the time series were observed**.** ANNEX 27 contains the mean, standard deviation, coefficient of variation, maximum and minimum values for the time series, as well as the last significant lag for the auto-correlation (ACF) and partial autocorrelation function (PACF), which serve as indicators of the behavior of the time series in terms of its dependency on the past and how long in the past that dependency extends.

The changes in mean, coefficient of variation, and last significant lags for the ACF and PACF are shown in the following table, along with a qualitative classification of whether there seems to be a difference in the time series properties before and after the Brexit announcement.

Table 19 Change of Descriptive Statistics for Market Volumes Time Series Before and After Brexit Announcement

		Changes in Statistics				
		Δ Mean	**Δ CV**	**Δ ACF**	**Δ PACF**	**Δ (Overall)**
London	**All**	6,8E+10	3,4E-01	2	-1	Yes (+)
	EU	5,6E+09	1,8E-01	6	-1	YES(+)
	UK	3,2E+10	2,7E-01	6	0	YES(+)
	RoW	3,0E+10	5,2E-01	-6	1	YES(+)
Frankfurt	**All**	7,4E+08	2,4E-02	0	-1	YES(+)
	EU	3,8E+08	5,1E-03	-4	-1	YES(+)
	UK	1,3E+08	-5,0E-02	6	1	YES (+)
	RoW	2,2E+08	1,2E-02	2	0	YES(+)
Zurich	**All**	9,9E+08	1,9E-01	8	1	YES(+)
	EU	2,1E+08	5,9E-02	-3	-2	YES(+)
	UK	6,1E+07	5,0E-01	-6	-2	YES(+)
	RoW	7,2E+08	2,2E-01	8	1	YES(+)
Paris	**All**	2,1E+09	4,6E-01	-1	0	YES(+)
	EU	2,0E+09	5,0E-01	-1	0	YES(+)
	UK	1,1E+08	3,1E-01	8	0	YES(+)
	RoW	-5,1E+07	4,8E-01	7	0	YES(-)
Milan	**All**	-7,6E+09	4,0E-02	2	0	YES(-)
	EU	-6,2E+09	2,3E-02	2	0	YES(-)
	UK	2,9E+08	2,1E-01	5	1	YES(+)
	RoW	-1,7E+09	2,1E+00	-5	1	YES(-)
EU	**All**	-4,8E+09	9,0E-02	8	1	YES(-)
	EU	-5,2E+09	7,8E-02	8	1	YES(-)
	UK	7,7E+08	5,5E-02	4	-1	YES(+)
	RoW	-4,3E+08	3,8E-01	7	1	YES(-)

The time series for the volumes in London, Frankfurt, and Zurich had a general increase as can be seen from the previous table, however, this is likely due to higher values at the end of the analyzed period as the coefficient of variation also increased considerably for most of them. Except for the time series DE_EU and DE_UK, whose variation of the coefficient of variation is too small and negative respectively, the overall increase could be more significant and correspond to an actual sustained change in the behavior of the volumes. The time series for Paris, except FR_RoW, behave similarly to the previous group, while the latter (and similar to most of the volumes in Milan and EU) suggest a decrease in the time series. However, the change of coefficient of variation is also significant for this group in which outliers may be present. The series for British instruments in Milan (IT_UK) and European ones as well (EU_UK), contrarily to the rest of the group, had an increase in the mean but once again the coefficient of variation is significantly high.

To better understand the change in behavior of the time series before and after the Brexit announcement an AR(1) model was estimated for the time series. The mean value of each parameter as well as the range for a 95% confidence interval in which each parameter can be found. The characterization of the residuals correlogram is presented in the following table. The observation on the residuals is used as an indicator of how well the AR(1) model represents the data, as a good fitting model should lead to residuals behaving as white noise, denoted as "YES", shall that not be the case the accompanying note is "NO". When a residual in particular was statistically significant at a given lag, it was written in parenthesis to provide the reader with potentially useful information for spotting any missing consideration in performing this analysis.

In ANNEX 28 the above-mentioned parameters information for an AR(1) model including a constant and a trend are shown for all the time series before and after the Brexit announcement.

Then an analysis was carried out on whether an overlap for the ranges at 95% confidence existed for each of the parameters of the model in order to spot potentially statistically significant variations in the constant term or the dependence between the time and the immediately preceding observation. This analysis of the ranges rather than of the mean values is preferred, as different values for the time series may be due to subtle changes in a limited sample size which would lead to different mean values, while the ranges could still be significantly overlapping. The results for the analysis are expressed in terms of a Boolean value, for which 1 indicates there is no overlap, and the parameters are likely different and 0 otherwise. Thus, a value of 1 indicates that it is probable that the behavior has changed.

Table 20 Boolean Table for overlap of coefficients range for Pre-Brexit announcement and Post-Brexit announcement AR (1) models with constant (m0) and trend (m1) – Phi1 is the coefficient for first-order lag.

		(Boolean) Overlapping		
		Δ m0	**Δ m1**	**Δ Phi1**
		1: No-Overlap 0: Overlapped ranges		
London	All	**1**	0	**1**
	EU	0	0	0
	UK	0	0	0
	RoW	0	0	**1**
Frankfurt	All	**1**	**1**	0
	EU	**1**	**1**	0
	UK	**1**	**1**	0
	RoW	**1**	**1**	0
Zurich	All	**1**	0	0
	EU	0	0	0
	UK	**1**	**1**	0
	RoW	**1**	0	0
Paris	All	0	0	0
	EU	0	**1**	0
	UK	**1**	**1**	**0**
	RoW	0	0	**0**
Milan	All	0	0	**1**
	EU	0	0	0
	UK	0	0	0
	RoW	0	0	0
EU	All	**1**	0	**1**
	EU	**1**	0	**1**
	UK	0	0	0
	RoW	0	0	0

The results suggest there were changes after the Brexit announcement for some time series from London, mainly the aggregated instruments (All) and the "*rest of the world"* (RoW), for which in both cases the dependency with the past presents changes. Such changes probably indicate higher volatility, and a change for the constant term for the aggregated (All) series, suggesting a change in the base level. All the time series from Frankfurt are likely to have had changes in terms of the baseline and the relation with time. For the volumes in Paris mainly the FR_EU and FR_UK time series are likely to have had a change in the behavior as well. For volumes in Milan, these results suggest very much the behavior remained the same except for IT_All for which a change in terms of volatility was significant. On the EU level, a likely change in the time series for all instruments and for EU instruments is observed.

Although the previous analysis concerning changes of the time series is coherent with the analysis from the time-series graphs, the analysis is made based on a model that imposes a time dependency for the volume variable, which may be redundant or inaccurate especially for time series with changes in the trend. In fact, the values seen for the time series associated with the Frankfurt markets tend to remain around the same value as some time series for markets from Milan. Therefore, the same analysis was repeated for an AR(1) model only including a constant term. The following two tables show the parameters' mean values and the ranges for a 95% confidence, as well as the lags for which the residuals ACF are statistically significant (ANNEX 29, ANNEX 30). The analysis for the overlap of the parameters' ranges was performed again, following the same Boolean notation as described before. Additionally, the change of the parameters' mean value is also presented in the following table.

Table 21 Boolean Table for overlap of coefficients range for Pre-Brexit announcement and Post-Brexit announcement AR (1) models with constant (m0) – Phi1 is the coefficient for first-order lag.

		Boolean Overlapping			
		Difference		**Overlapping**	
		Δ m0	Δ phi1	m0	phi1
		1: No-Overlap **0**: Overlapped ranges			
London	All	-1,7E+10	0,332	0	0
	EU	-1,7E+09	0,319	0	0
	UK	-1,5E+10	0,358	0	0
	RoW	2,3E+09	0,316	0	0
Frankfurt	All	2,5E+08	-0,001	0	0
	EU	3,4E+08	-0,040	0	0
	UK	2,9E+07	0,052	0	0
	RoW	2,0E+07	0,073	0	0
Zurich	All	-2,4E+08	0,381	0	0
	EU	2,0E+08	-0,221	**1**	0
	UK	4,5E+07	-0,403	**1**	0
	RoW	-3,3E+08	0,411	0	0
Paris	All	1,3E+09	-0,076	0	0
	EU	1,2E+09	-0,067	0	0
	UK	-6,4E+07	0,127	0	0
	RoW	-2,5E+07	0,147	0	0
Milan	All	-1,6E+10	0,434	**1**	**1**
	EU	-1,4E+10	0,417	**1**	0
	UK	9,1E+07	-0,050	0	0
	RoW	-3,5E+08	0,007	0	0
EU	All	-5,0E+10	0,568	**1**	**1**
	EU	-4,7E+10	0,564	**1**	**1**
	UK	1,3E+08	0,000	0	0
	RoW	-6,8E+08	0,185	0	0

Based on the ranges overlap analysis for an AR (1) model with constant, none of the time series for the London, Paris, and Frankfurt-based volumes seems likely to have suffered any change in the process of the time series. For the Zurich-based volumes of the UK and EU instruments, there seems to have been a change in the constant term, an increase of the base level based on the difference of the mean value of the parameters. Milan-based market volumes seem to have decreased their base levels for all the instruments (IT_All) and for the EU instruments (IT_EU), while the former time series is likely to have increased its dependence on the past behavior. On an EU level, it seems likely that a reduction on the base level given by the constant term has happened while the dependence on the past would have increased for EU_All and EU_EU after Brexit, in a very similar way as the Milan time series for EU and aggregated (All) instruments.

Finally, in an attempt to better understand changes in the relation between markets after the Brexit announcement, the correlation matrices for the time series were analyzed. The analysis was carried out for time series of the same financial hub or market, and for time series of instruments with the same origin.

ANNEX 31 presents the correlation matrices for the time series before and after the Brexit announcement by financial hub.

The difference of the correlation coefficients was calculated to understand the changes in the relationships among the different time series and the volumes of the different types of instruments within the markets of each financial hub. These matrices of differences are presented below, followed by the colored graphs of the correlation matrices before and after the Brexit announcement under both grouping strategies.

Table 22 Change in correlation coefficients for Market Volumes - Post-Brexit Announcement minus Pre-Brexit Announcement Correlation of Time Series of each Financial Hub (Baiocchi G., 2003)

Correlation Matrix / By Financial Hub (Difference)

	UK_All	UK_EU	UK_UK	UK_RoW
UK_All	0	0,2003	-0,0234	0,1543
UK_EU		0	0,474	0,0364
UK_UK			0	0,1503
UK_RoW				0

	CH_All	CH_EU	CH_UK	CH_RoW
CH_All	0	-0,0399	0,1478	-0,0058
CH_EU		0	0,4645	-0,0634
CH_UK			0	0,0244
CH_RoW				0

	FR_All	FR_EU	FR_UK	FR_RoW
FR_All	0	0,0036	-0,165	-0,8742
FR_EU		0	-0,1256	-0,9094
FR_UK			0	0,7351
FR_RoW				0

	DE_All	DE_EU	DE_UK	DE_RoW
DE_All	0	-0,0061	0,157	0,0426
DE_EU		0	0,1848	0,0371
DE_UK			0	0,0116
DE_RoW				0

	IT_All	IT_EU	IT_UK	IT_RoW
IT_All	0	0,0014	0,2275	-0,0404
IT_EU		0	0,2678	-0,0135
IT_UK			0	-0,6974
IT_RoW				0

The correlation matrices by financial hubs show that for most financial hubs, the volumes of the different instruments were positively correlated, yet the correlation seems high just for some particular cases. Among the most significant positive correlations are the series UK_UK and UK_All; CH_RoW and CH_All; FR_EU and FR_All; DE_EU and DE_All; IT_EU and IT_All. The previous evidence confirms the major components in terms of what type of instruments from what region are the most traded at the markets of each financial hub. This is more easily perceived on the **ANNEX 32 and ANNEX 33** showing the correlation matrix on a colored scale.

Before the Brexit announcement, the total volumes for the markets in Milan were strongly correlated with the volumes for EU instruments in the same market, while the correlation among the volume of other instruments was very subtle and close to zero, however, the correlation of UK instruments volumes with RoW instruments volumes was slightly significant. For the volumes in Paris, the total volume was strongly correlated with that of the EU instruments and with the RoW instruments, while the EU instruments volumes were also strongly correlated with the RoW volumes. In Zurich, the correlation of total volumes was the strongest with RoW instruments followed by EU and UK respectively, yet among them, the correlation was almost zero. In Frankfurt, the strongest correlation of the total volumes was with EU instruments, followed by RoW and UK instruments respectively; EU and UK instruments volumes were slightly correlated in this market while a strong correlation of UK and RoW instruments volumes was found for this hub. Finally, in London the correlation was strongest for the total of volumes with the volumes for UK instruments, followed by a much weaker correlation with RoW and EU instruments Remarkably, for most of the markets the correlation in the volumes of UK and EU instruments was almost zero, except for Frankfurt where it was just weak.

After the Brexit announcement the correlation of the total volumes in London with the other regio-specific volumes increased in general, noticeably the correlation of EU instruments volumes with UK instruments volumes increased considerably, another increase was seen by UK instrument volumes with RoW volumes. The increase in the correlation coefficients also happened for the volumes in Frankfurt, among almost all volumes time series and particularly between the UK and EU instruments. In Zurich, there was a smaller increase in the correlation coefficients among the volumes time series, also between the UK and EU instruments. However, in Paris there was a decrease in the correlation of some volumes time series, in particular between the total volumes and the volumes for RoW instruments, also a small decrease was seen between UK and EU instruments volumes correlation. In Milan, there was a very small increase in the correlation between some volumes time series, and between EU and UK instruments the increase was very subtle. Therefore, after the Brexit announcement for the major financial hub markets the correlation of the volumes for EU and UK instruments increased significantly.

ANNEX 34 presents the correlation matrices for the time series grouped by origin of the instruments in the periods before and after the Brexit.

The difference of the correlation coefficients was calculated to understand the changes in the relationships among the different time series and the volumes at each market for the different origins of the instruments.

Table 23 Change in correlation coefficients for Market Volumes - Post-Brexit Announcement minus Pre-Brexit Announcement Correlation of Time Series by Origin of the contracts (Baiocchi G., 2003)

Correlation Matrix / By Origin of Contracts (Difference)					
	UK_All	**FR_All**	**IT_All**	**CH_All**	**DE_All**
UK_All	0	0,7582	0,1659	0,3575	0,8939
FR_All		0	-0,036	0,0644	-0,1636
IT_All			0	0,4279	0,3859
CH_All				0	0,3517
DE_All					0
	UK_EU	**FR_EU**	**IT_EU**	**CH_EU**	**DE_EU**
UK_EU	0	0,1136	0,4794	0,0141	0,5826
FR_EU		0	-0,091	0,2542	-0,2521
IT_EU			0	0,1389	0,4189
CH_EU				0	0,4544
DE_EU					0
	UK_UK	**FR_UK**	**IT_UK**	**CH_UK**	**DE_UK**
UK_UK	0	-0,5822	0,3544	0,4814	0,826
FR_UK		0	-0,8336	-0,2455	-0,3402
IT_UK			0	0,2598	0,6376
CH_UK				0	-0,1822
DE_UK					0
	UK_RoW	**FR_RoW**	**IT_RoW**	**CH_World**	**DE_RoW**
UK_World	0	-0,2075	-0,6942	0,0647	0,7765
FR_World		0	0,3757	-0,6992	-1,0692
IT_World			0	-0,1582	0,308
CH_World				0	0,3253
DE_RoW					0

When analyzed by origin of the contracts, the total volumes for most financial hubs markets appeared to have had little correlation among themselves before the Brexit announcement, except for those in Frankfurt and Paris, noticeably Frankfurt and London had a slightly negative correlation. The UK contracts were positively correlated for London with Paris and Milan, yet a negative correlation existed for UK contracts volumes between London and Zurich as well as between Paris and Frankfurt. The EU instruments volumes were mostly uncorrelated for most financial hubs markets, except between Paris and Frankfurt. Finally, the volumes for instruments from RoW, the time series for London and Milan have slightly positively correlated as well as the series for Paris and Frankfurt, yet the series for Milan and Frankfurt were negatively correlated.

After the Brexit announcement, the total volumes were positively correlated for most markets, particularly for London with Frankfurt and Paris, Paris with Frankfurt, and Milan with Zurich. For the UK instruments the relationships changed for some couples of time series, in particular, there was a negative correlation for the time series for the UK instruments volumes in Paris with those in Zurich, and in Frankfurt, London had a positive correlation with Milan for this type of instruments. The EU instruments implied positive or no correlation post Brexit announcement, which meant a general increase in the correlation among time series, Frankfurt was mildly positively correlated with all the other financial hubs, yet the value of the correlation with Paris decreased, London however also had a mild positive correlation with Italy. Finally, for the RoW instruments volumes, the time series for Paris was negatively correlated with that from Frankfurt, similarly to Zurich with Paris and Milan with Frankfurt; a mild positive correlation was observed for the volumes in Frankfurt with the volumes in London, which is a considerable change in the degree of correlation which used to be negative before the Brexit announcement. It can be confirmed through these observations that Frankfurt displaced Paris and Milan in the EU as the main market for UK securities and RoW instruments.

4.4.3 Regression of financial hub factors

The number of monetary financial institutions (MFIs) and investment firms (InvFunds) in some of the countries hosting the financial hubs in consideration in this analysis are shown below. The data shown corresponds to Germany, France, Italy, and the EU on an aggregated level, the data for the MFIs in the UK is also presented.

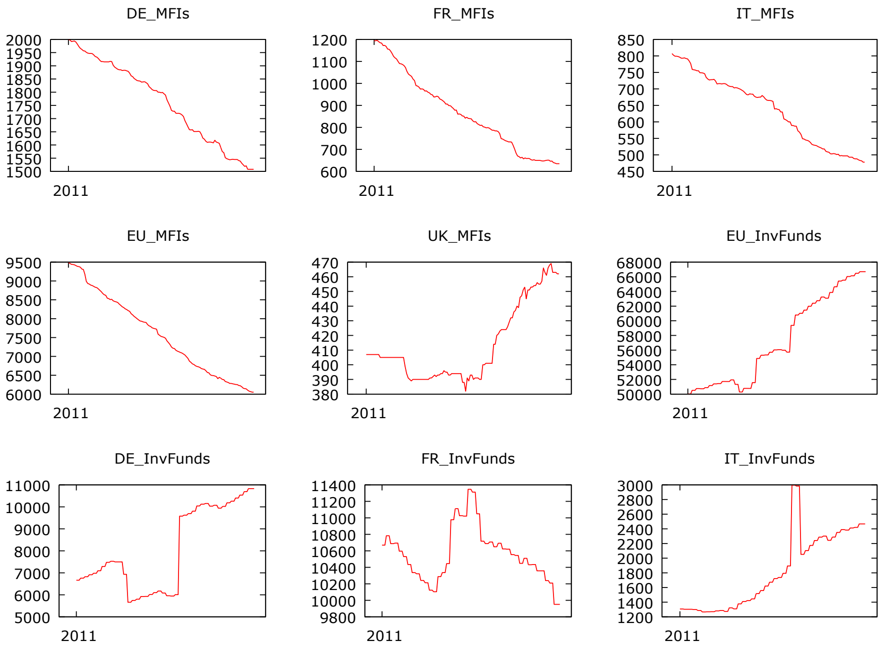


Figure 27 Time Series for the number of MFIs and Investment Funds (InvFunds) in various Financial Hubs ((ECB), 2021)

For all the locations except for the UK, the number of MFIs, that is institutions performing intermediation activities in the market, has reduced in the last years, a trend of consolidation well known in the banking sector. The number of InvFunds however exhibits different behaviors depending on the location analyzed.

Literature recognizes a set of factors impacting the attractiveness a financial center has. In this work, the GFCI score has been considered which is an overall score aggregating the four types of factors, namely: Human Capital; Business and Regulatory Environment; Financial Sector Development; Tax Regime.

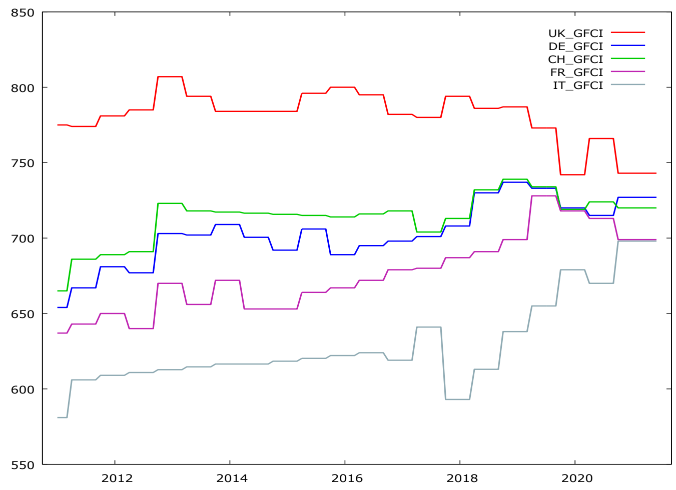


Figure 28 GFCI Score for the five analyzed Financial Hubs: London (UK), Frankfurt (DE), Zurich (CH), Paris (FR), and Milan (IT) (Michael Mainelli, 2021)

It has also been considered a measure for each of the previous categories. For the Business Regulatory Environment, the average score, on a scale of 0 to 2, of the scores for the control of corruption, rule of law, regulatory quality, government effectiveness, and political stability, and absence of violence, is considered as a variable representing the performance of each hub.

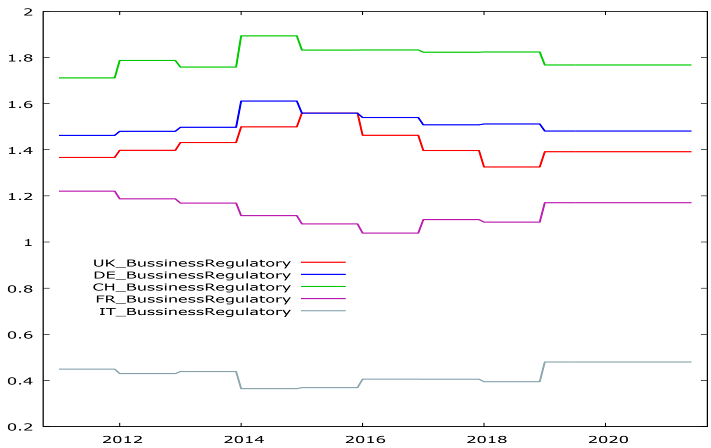


Figure 29 Score for the Business and Regulatory Environment for the five analyzed Financial Hubs: London (UK), Frankfurt (DE), Zurich (CH), Paris (FR), and Milan (IT) (World-Bank, 2020)

For the Financial Sector Development factor, the score for the ease of doing business was considered as a representative variable.

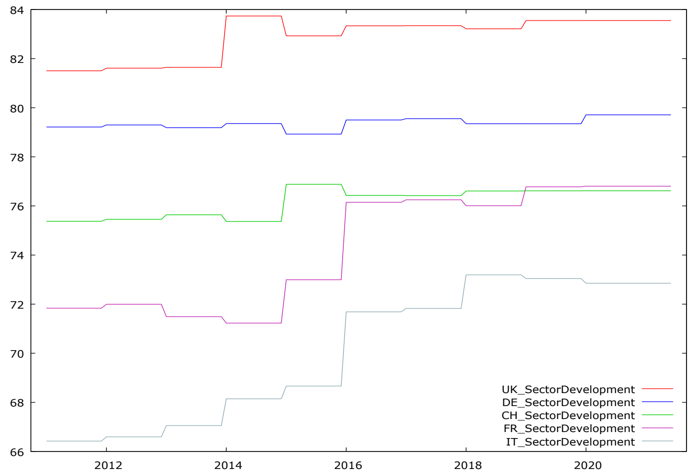


Figure 30 Score for the Financial Sector Development for the five analyzed Financial Hubs: London (UK), Frankfurt (DE), Zurich (CH), Paris (FR), and Milan (IT) (World-Bank, 2020)

As for Human Capital, the percentage of the total labor force with advanced education is considered as a representative variable in this category.

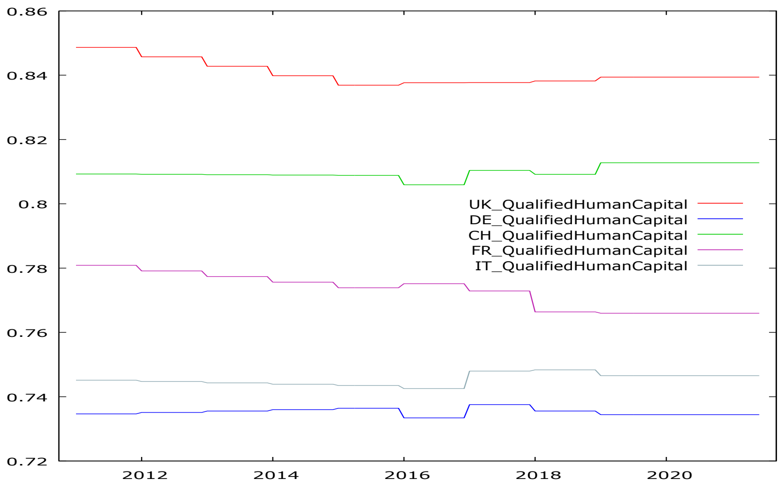


Figure 31 Score for the Human Capital for the five analyzed Financial Hubs: London (UK), Frankfurt (DE), Zurich (CH), Paris (FR), and Milan (IT) (World-Bank, 2020)

Finally, for the Tax Regime, the average corporate tax per country is used as a representative variable in this category.

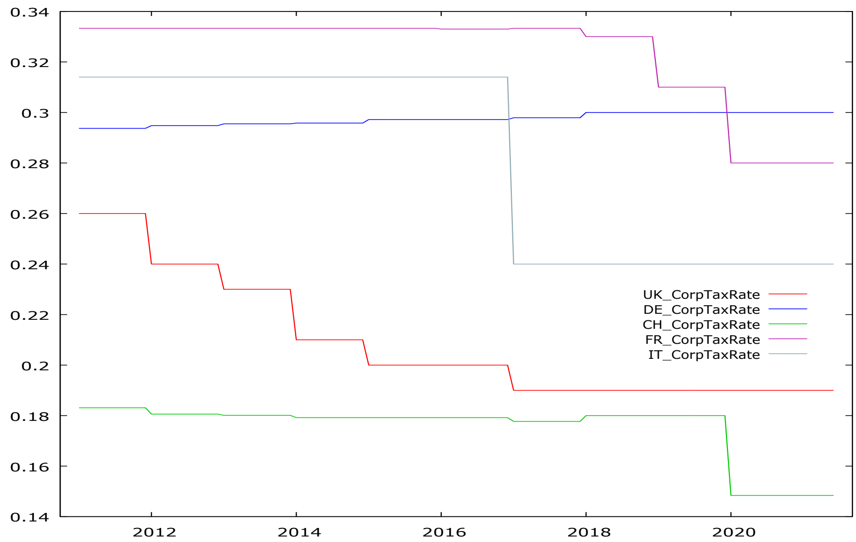


Figure 32 Tax Regime as Corporate Tax Rate for the five analyzed Financial Hubs: London (UK), Frankfurt (DE), Zurich (CH), Paris (FR), and Milan (IT) (World-Bank, 2020)

The following graph shows the number of investment funds (InvFunds) and the GFCI score in each of the EU's main financial hubs. For all the hubs it can be seen there has been an improvement in the score while only Frankfurt and Milan have seen it translated in a sustained increase in the number of funds. Whether the financial hub factors can explain the presence of funds in the financial hubs is explored in the following section.

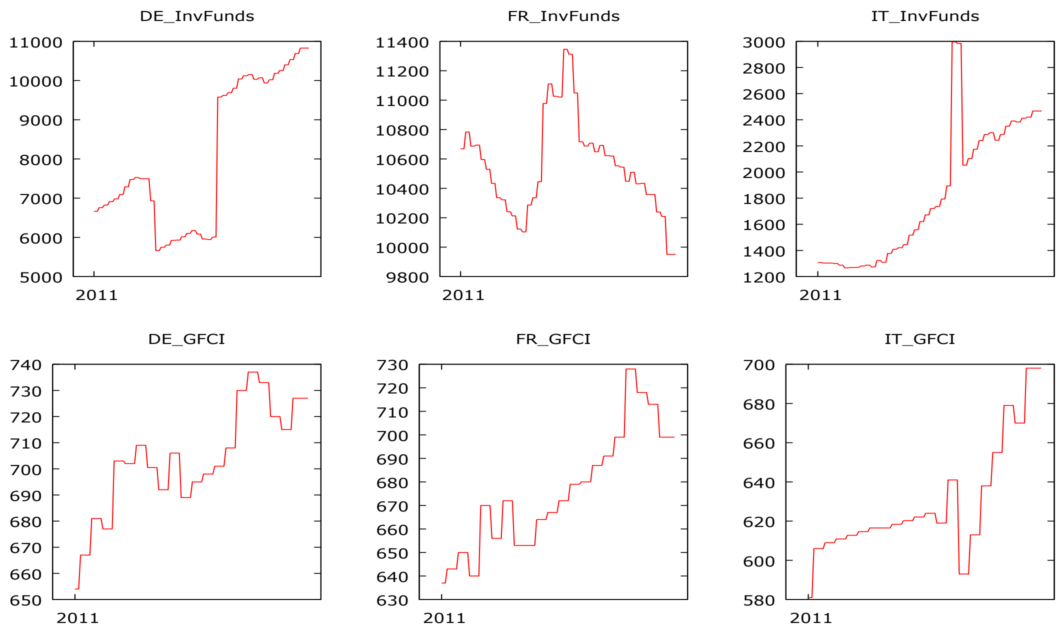


Figure 33 Number of Investment Funds ((ECB), 2021) and the GFCI (World-Bank, 2020) score for the three EU financial hubs considered in the study

4.4.3.a Number of Investment Funds and Financial Hub Factors

In order to assess the impact that the financial hub factors have on the number of investment funds, a regression analysis was carried out. This section analyses the estimated models, considering the financial hub factors as explanatory variables in an AR model, and their capacity to describe the data corresponding to the number of funds in the main financial hubs in the EU, namely Frankfurt, Paris, and Milan.

For each hub a figure for the considered time series is presented, followed by three models: *i)* The first considers an ARX(1,0) model for which the parameters values and significance of the associated p-value are shown *ii)* The second corresponds to a model with a constant term and only exogenous variables as explanatory variables, the model is accompanied by the graphs of the fitted model against the observed data and the statistics for the quality of fitting as described in section 3.3 *iii)* The third model is an ARX(1,0) model for which all the considered variables have a statistically significant parameter, this model is accompanied by the same table of fitting statistics. In order to find the third model, the non-significant variables from the first model were eliminated one by one starting from the one with the highest p-value and actualizing the model estimated parameters value and associated p-values each time.

The plots for the data corresponding to Frankfurt are presented first. It is noticeable that at the beginning there was a reduction in the number of funds, yet shortly after the Brexit announcement the number of funds increased considerably and has kept on increasing ever since. As for the GFCI score, Frankfurt has been improving constantly since 2011. Sector Development is the factor that has improved the most since 2011, while the Tax Regime is the one that has worsened the most. The Business Regulatory Environment and the Human Capital had small variations yet for the former the improvement is subtle and for the latter remains almost unchanged.

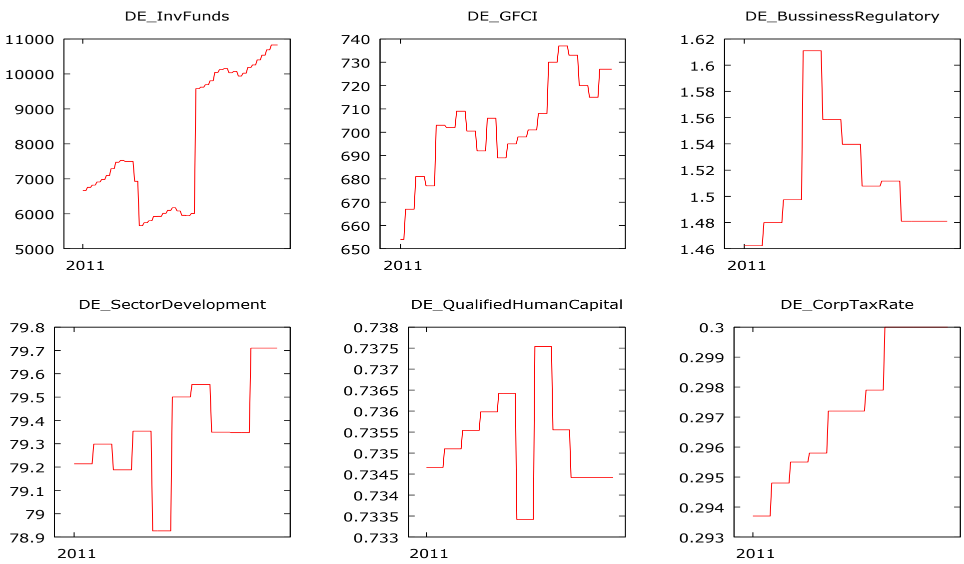


Figure 34 Number of Investment funds ((ECB), 2021) and Financial Hub Factors in Germany (DE) (World-Bank, 2020)

The regression considering one lag and all the financial factors and the GFCI score indicates that not all are statistically significant for describing the data. The regression considering the significant explanatory variables uses the Tax Regime, Regulatory Environment, and Sector Development as main explanatory variables. A good fit is achieved, with a small mean error that is less than 0.2%, indicating the model is not biased. The Theil's U value indicates the model is good for predicting one period ahead of the data.

```
Model 1: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: DE_InvFunds

                  coefficient   std. error      z      p-value
  ------------------------------------------------------------------
  phi_1              0.904156    0.0386027  23.42    2.55e-121 ***
  DE_GFCI           −1.16696     3.37492    −0.3458  0.7295
  DE_BussinessRegu~ −2862.82     1143.11    −2.504   0.0123    **
  DE_SectorDevelop~ −104.830     144.296    −0.7265  0.4675
  DE_QualifiedHuma~ −8964.80     14293.8    −0.6272  0.5305
  DE_CorpTaxRate     70173.2     32049.6     2.190   0.0286    **
```

Figure 35 AR (1) model for Number of Investment Funds in Germany with all Financial Hub Factors as explanatory variables.

Model 3: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: DE_InvFunds

	coefficient	std. error	z	p-value	
phi_1	0.906236	0.0329287	27.52	9.80e-167	***
DE_BussinessRegu~	−3014.00	1066.24	−2.827	0.0047	***
DE_SectorDevelop~	−159.380	83.5841	−1.907	0.0565	*
DE_CorpTaxRate	60514.0	25612.5	2.363	0.0181	**

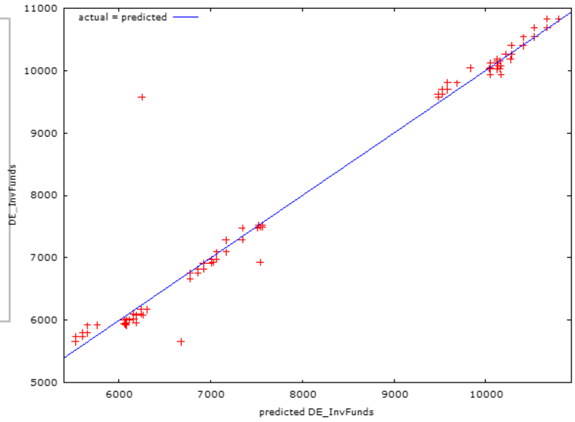
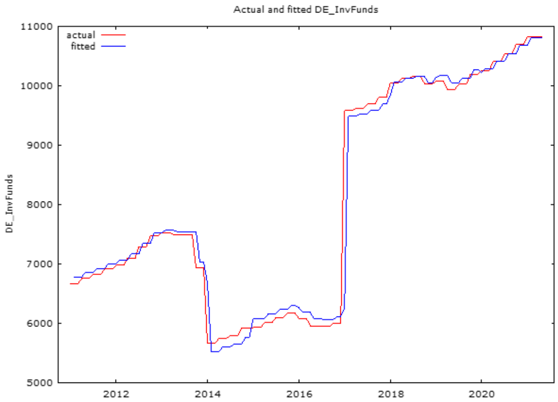


Figure 36 AR (1) model for Number of Investment Funds in Germany with only Financial Hub Factors with significant coefficients as explanatory variables [Left]. Fitted value (Blue line) and Actual value (Red crosses) of Number of Investment Funds [Right]



Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 340.253

Forecast evaluation statistics using 124 observations

Mean Error	-0.19616
Root Mean Squared Error	334.72
Mean Absolute Error	128.09
Mean Percentage Error	-0.18497
Mean Absolute Percentage Error	1.7182
Theil's U	0.95593

Figure 37 Actual and Fitted values for the Number of Investment Funds in Germany (Time Series) [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

A model considering a constant and all the financial hub factors plus the GFCI score indicates that all the exogenous variables are statistically significant. It can be seen from the figure that a good level fit is achieved with the model, this is confirmed by the Theil's U value lower than one. The small mean error, corresponding to less than 0.2% confirms that the model is not biased.

```
Model 5: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: DE_InvFunds

                    coefficient   std. error     z       p-value
  ---------------------------------------------------------------
  const               −642136      28896.3     −22.22   2.10e-109 ***
  DE_GFCI               20.1301     3.19898     6.293   3.12e-010 ***
  DE_BussinessRegu~  −24509.9      807.401    −30.36   2.06e-202 ***
  DE_SectorDevelop~    2234.33     182.784     12.22   2.32e-034 ***
  DE_QualifiedHuma~  517512       31417.3      16.47   5.82e-061 ***
  DE_CorpTaxRate     387671       31022.4      12.50   7.80e-036 ***
```

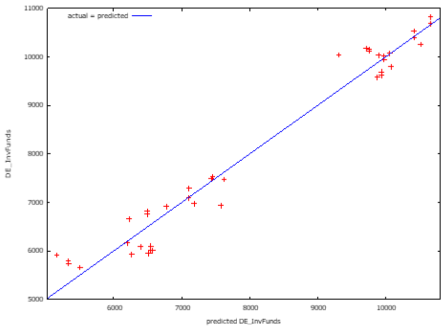


Figure 38 Horizontal Regression model for Number of Investment Funds in Germany with all Financial Hub Factors as explanatory variables [Left]. Fitted value (Blue line) and Actual value (Red crosses) of Number of Investment Funds [Right].


```
Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 357.205

  Forecast evaluation statistics using 125 observations
  Mean Error                      -6.3113e-010
  Root Mean Squared Error          348.53
  Mean Absolute Error              281.11
  Mean Percentage Error           -0.18673
  Mean Absolute Percentage Error   3.9196
  Theil's U                        0.9015
```

Figure 39 Actual and Fitted values for the Number of Investment Funds in Germany (Time Series) [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The number of funds in Paris has slightly decreased since 2011, despite having increased before the Brexit announcement, the gain was reversed in the subsequent years. The decrease of funds occurred despite an increase in the GFCI score and particularly an improvement of the Sector Development and Tax Regime. Nevertheless, the Regulatory Environment and particularly the Human Capital indicators decreased.

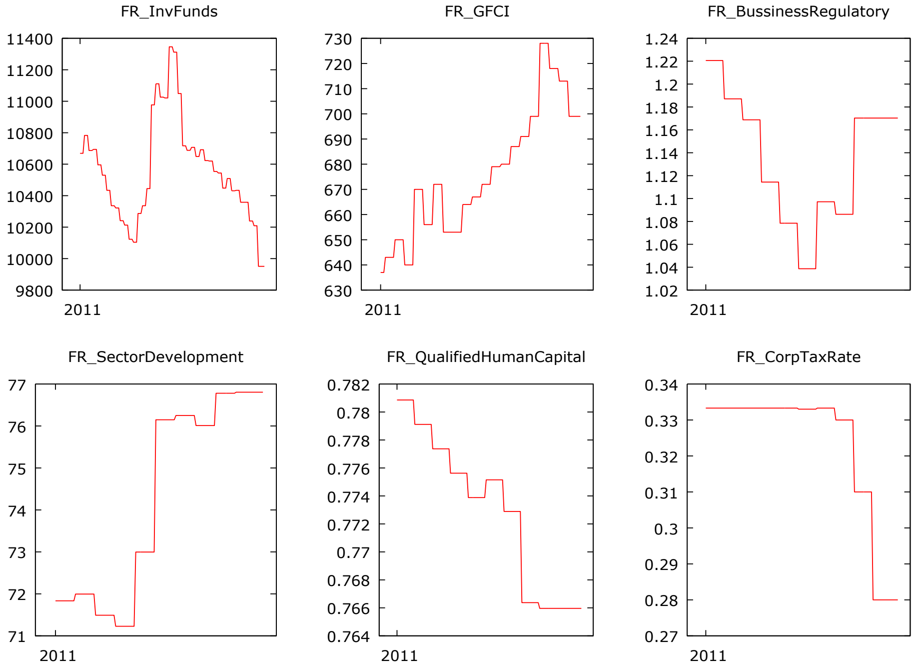


Figure 40 Number of Investment funds ((ECB), 2021) and Financial Hub Factors in France (FR) (World-Bank, 2020)

The first ARX(1,0) model with all the exogenous variables does not suggest a statistically significant exogenous variable, after the discard process, only the Regulatory Environment and the Human Capital variables appear to be statistically significant for describing the number of funds in the hub. The fit of the model is satisfactory, with a mean error close to zero which is less than 0.1%, and very low RMSE and MAE. The Theil's U value confirms the high adequacy of the model.

```
Model 11: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: FR_InvFunds

                  coefficient  std. error     z     p-value
  -----------------------------------------------------------------
  phi_1              0.928126   0.0354287  26.20   2.88e-151 ***
  FR_GFCI           −0.458309   0.644004   −0.7117  0.4767
  FR_BussinessRegu~ −320.453    205.965    −1.556   0.1197
  FR_SectorDevelop~    3.24762    7.64262   0.4249  0.6709
  FR_QualifiedHuma~  1403.92    912.233     1.539   0.1238
  FR_CorpTaxRate      310.906   749.307     0.4149  0.6782
```

Figure 41 AR (1) model for Number of Investment Funds in France with all Financial Hub Factors as explanatory variables

```
Model 15: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: FR_InvFunds

                  coefficient  std. error    z      p-value
  ---------------------------------------------------------------
  phi_1            0.936235   0.0300260  31.18   1.94e-213 ***
  FR_BussinessRegu~  −381.096   175.722    −2.169  0.0301    **
  FR_QualifiedHuma~  1423.21    607.097     2.344  0.0191    **
```

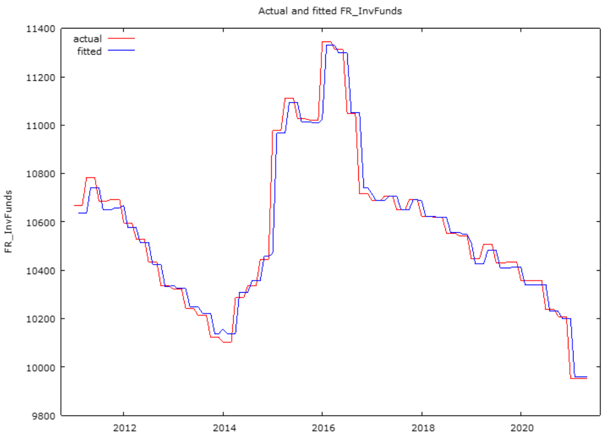
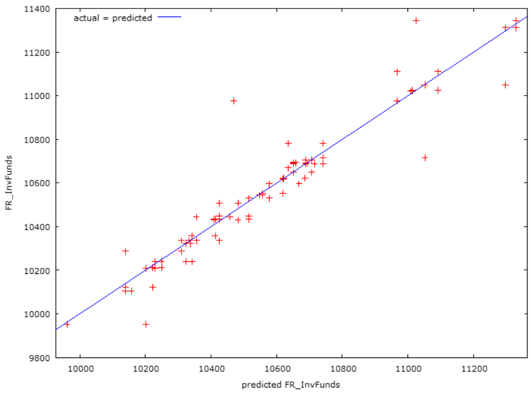


Figure 42 AR (1) model for Number of Investment Funds in France with only Financial Hub Factors with significant coefficients as explanatory variables [Left]. Actual and Fitted values for the Number of Investment Funds in France (Time Series) [Right]




```
Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 81.011

 Forecast evaluation statistics using 124 observations
  Mean Error                      -0.034374
  Root Mean Squared Error          80.025
  Mean Absolute Error              39.482
  Mean Percentage Error           -0.0063239
  Mean Absolute Percentage Error   0.37143
  Theil's U                        0.97349
```

Figure 43 Fitted value (Blue line) and Actual value (Red crosses) of Number of Investment Funds in France [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

The model considering only the financial hub factors as explanatory variables and a constant term has as statistically significant variables to all the financial hub factors. The model has co-movements following the observed variable values, yet the fit is a little off, the previous is confirmed by Theil's U value. However, in terms of fitting the data, the model is unbiased as the mean error suggests and the RMSE, as well as the MAE, are not particularly different from the values for the models fitted to the InvFunds in the other locations.

Model 12: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: FR_InvFunds

	coefficient	std. error	z	p-value	
const	−13682.7	8285.05	−1.651	0.0986	*
FR_GFCI	−5.05022	2.04143	−2.474	0.0134	**
FR_BussinessRegu~	−1998.15	513.553	−3.891	9.99e-05	***
FR_SectorDevelop~	113.808	17.0411	6.678	2.42e-011	***
FR_QualifiedHuma~	25783.1	9758.76	2.642	0.0082	***
FR_CorpTaxRate	4768.14	1906.64	2.501	0.0124	**

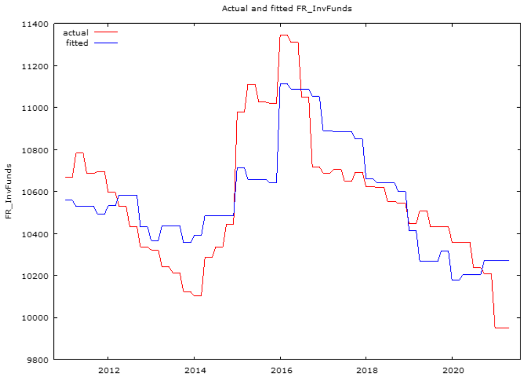
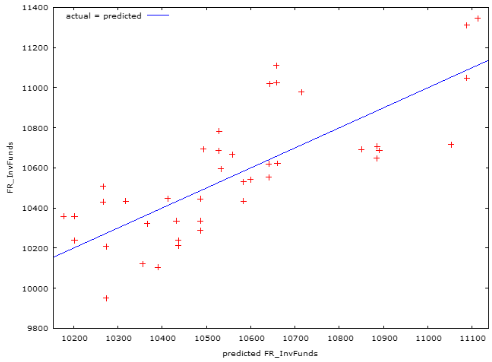


Figure 44 Horizontal Regression model for Number of Investment Funds in France with all Financial Hub Factors as explanatory variables [Left]. Actual and Fitted values for the Number of Investment Funds in France (Time Series) [Right].



Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 209.619

Forecast evaluation statistics using 125 observations

Mean Error	3.6962e-012
Root Mean Squared Error	204.53
Mean Absolute Error	174.22
Mean Percentage Error	-0.037138
Mean Absolute Percentage Error	1.6446
Theil's U	2.5019

Figure 45 Fitted value (Blue line) and Actual value (Red crosses) of Number of Investment Funds in France [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The number of funds in Milan has increased since 2011, it had a steep peak for a short time by the end of 2017, yet the increasing trend sustained after it. This financial hub has seen an improvement in all the related factors since 2011, despite a short-lived decrease around 2016 and 2017.

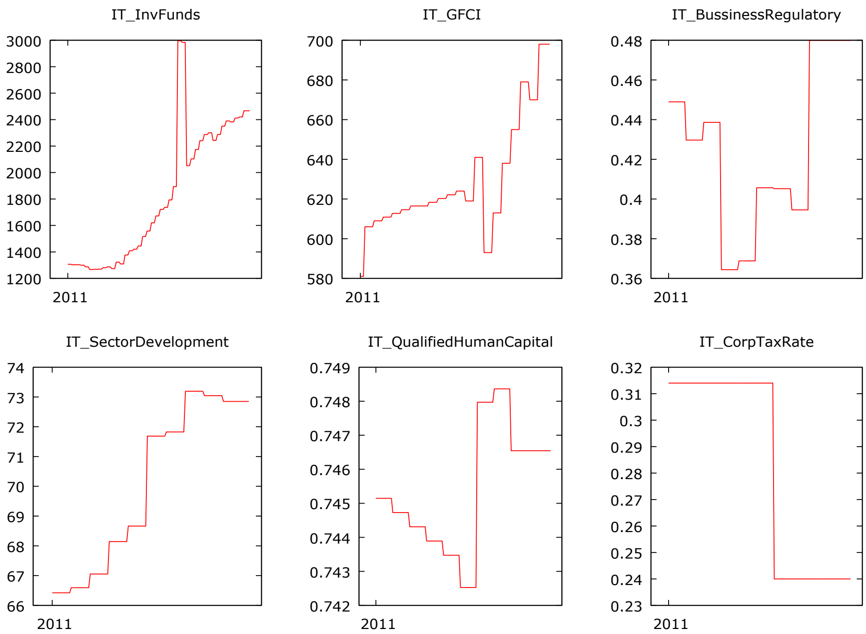


Figure 46 Number of Investment funds ((ECB), 2021) and Financial Hub Factors in Italy (IT) (World-Bank, 2020).

The ARX (1,0) model with all the factors as explanatory variables shows all but two factors as statistically significant factors. The reduced ARX (1,0) has only three statistically relevant exogenous variables which are the GFCI score, the Regulatory Environment, and the Tax Regime. The fit of the model is satisfactory, a fact anticipated in the graph of the fitted and the observed values and confirmed by Theil's U value. The errors are in line with those of other models, no bias is detected from the mean error, while the RMSE and MAE are in line with those of other models.

```
Model 16: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: IT_InvFunds

                    coefficient   std. error     z      p-value
  ----------------------------------------------------------------
  phi_1               0.687017    0.0570303  12.05    2.02e-033 ***
  IT_GFCI             2.16912     0.614252    3.531   0.0004    ***
  IT_BussinessRegu~  −900.548    370.589     −2.430   0.0151    **
  IT_SectorDevelop~    11.2648     8.74645    1.288   0.1978
  IT_QualifiedHuma~  −556.604    937.044     −0.5940  0.5525
  IT_CorpTaxRate    −2768.43     727.194     −3.807   0.0001    ***
```

Figure 47 AR (1) model for Number of Investment Funds in Italy with all Financial Hub Factors as explanatory variables

Model 18: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: IT_InvFunds

	coefficient	std. error	z	p-value	
phi_1	0.730352	0.0495675	14.73	3.87e-049	***
IT_GFCI	2.67487	0.495330	5.400	6.66e-08	***
IT_BussinessRegu~	−1017.31	350.057	−2.906	0.0037	***
IT_CorpTaxRate	−2672.04	515.420	−5.184	2.17e-07	***

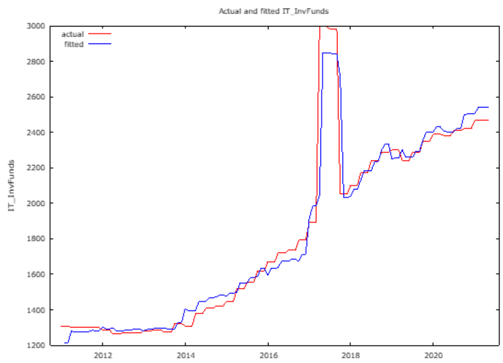
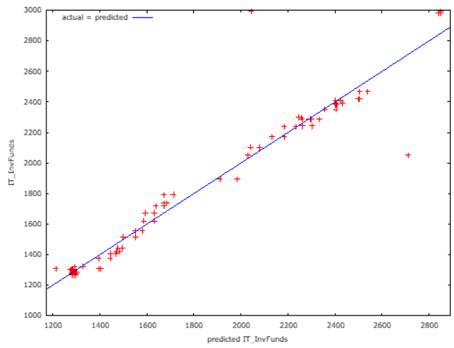


Figure 48 AR (1) model for Number of Investment Funds in Italy with only Financial Hub Factors with significant coefficients as explanatory variables [Left]. Actual and Fitted values for the Number of Investment Funds in Italy (Time Series) [Right]



Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 118.714

Forecast evaluation statistics using 124 observations

Mean Error	0.24835
Root Mean Squared Error	116.78
Mean Absolute Error	53.821
Mean Percentage Error	-0.2598
Mean Absolute Percentage Error	2.7698
Theil's U	0.93023

Figure 49 Fitted value (Blue line) and Actual value (Red crosses) of Number of Investment Funds in Italy [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

The model considering only a constant term and all the financial hub factors show only the GFCI score, Regulatory Environment, and Sector Development as significant explanatory variables. The model does not seem to incur systemic errors in modeling the data based on the mean error, yet the mean error is higher than for any other model. Theil’s U value also suggests a not-so-good prediction of the one-step-ahead values, however, the figure of the fitted and actual value indicates the model is still useful for providing a rough estimation of the number of funds in Milan.

```
Model 19: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: IT_InvFunds

              coefficient  std. error    z    p-value
  -------------------------------------------------------------
  const          −43068.0     39140.4    −1.100  0.2712
  IT_GFCI            5.17494    1.19716   4.323  1.54e-05 ***
  IT_BussinessRegu~  −1425.01     549.837  −2.592  0.0096  ***
  IT_SectorDevelop~     70.0869    23.6043   2.969  0.0030  ***
  IT_QualifiedHuma~  51683.9    48391.4     1.068  0.2855
  IT_CorpTaxRate     −4250.35    3937.83   −1.079  0.2804
```

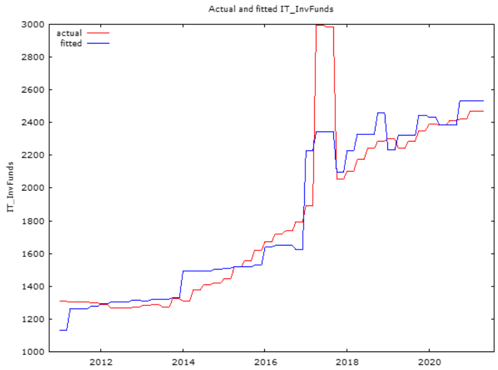
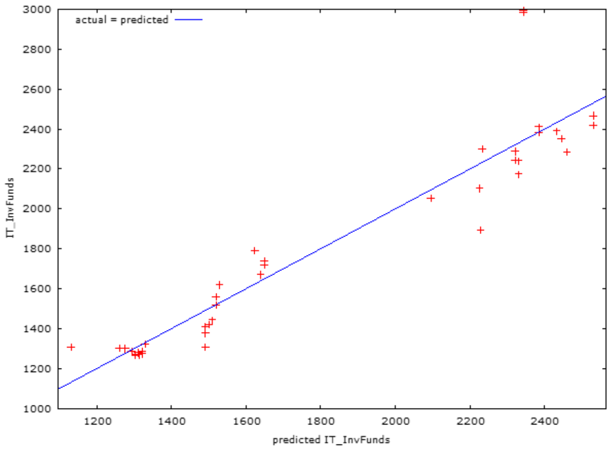


Figure 50 Horizontal Regression model for Number of Investment Funds in Italy with all Financial Hub Factors as explanatory variables [Left]. Actual and Fitted values for the Number of Investment Funds in Italy (Time Series) [Right].




```
Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 176.077

 Forecast evaluation statistics using 125 observations
 Mean Error                      3.2232e-011
 Root Mean Squared Error         171.8
 Mean Absolute Error             103.65
 Mean Percentage Error           -0.57967
 Mean Absolute Percentage Error  5.2631
 Theil's U                       1.2704
```

Figure 51 Fitted value (Blue line) and Actual value (Red crosses) of Number of Investment Funds in France [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The models in general prove that the financial hub factors can explain the number of investment funds present in the financial hubs. There is a better performance of the model when a first-order lag for the dependent time series variable is considered, suggesting the existence of a certain degree of inertia in the dependent variable. Such inertia makes sense as the relocation of a fund is at best a mid-term commitment.

4.4.3. b Market Volumes, Financial Hub Factors, and Number of Financial Institutions

A similar analysis as the one from section 4.4.3. a was performed in order to assess the hypothesis of this work, whether the financial hub factors can be used to explain the changes in the volumes time series in the main financial hubs markets in Europe. In order to carry out the regression analysis the different financial hub factors, as well as the number of MFIs and InvFunds when available are considered as exogenous explanatory variables. For this analysis two AR models were estimated *i)* The first considers a constant and all the exogenous variables *ii)* The second considers an ARX(1,0) model with all the exogenous variables and no constant. The two types of models considered are accompanied by a graph of the actual data and the fitted model, and a summary of the fitting statistics proposed in section 3.3.

The volume of trades in London has been increasing since 2011, similarly to the number of MFIs. The financial hub factors had however different behaviors, the Sector Development and the Tax Regime improved since 2011. Nevertheless, the overall GFCI score, the Regulatory Environment and Human Capital decreased or remained stagnant since 2011.

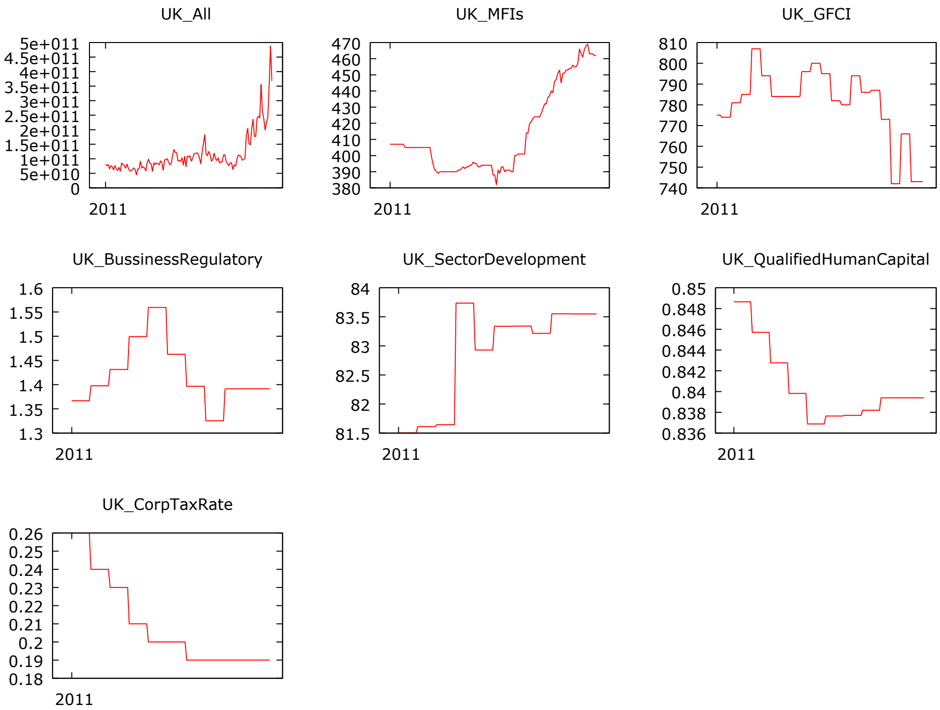


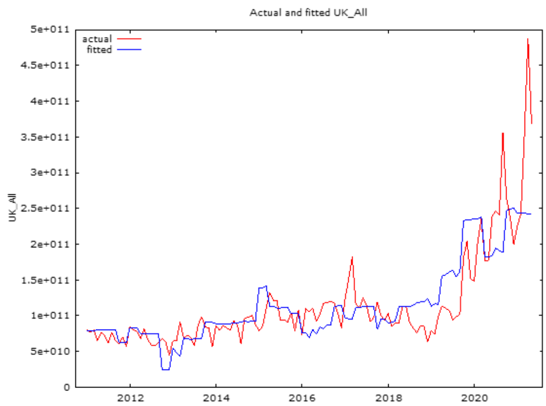
Figure 52 Market Volumes (Reuters, 2021) in London, Financial Hub factors (World-Bank, 2020) and Number of Financial Institutions (MFIs) ((ECB), 2021).

The model considering only the constant and the exogenous variables have only the GFCI score and number of MFIs as statistically significant variables. The mean error is slightly negative, and the mean percentage error is around 5%; the mean error is close enough to zero to suggest the absence of systemic error. Although, Theil's U is larger than one it can be seen from the figures that the model provides a good indication of the level of trade volumes.

```
Model 24: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: UK_All

                  coefficient   std. error     z     p-value
  ---------------------------------------------------------------
  const            1.24992e+013  8.33036e+012   1.500   0.1335
  UK_MFIs          1.13536e+09   4.48261e+08    2.533   0.0113   **
  UK_GFCI         −2.28672e+09   4.04384e+08   −5.655   1.56e-08 ***
  UK_BussinessRegu~  1.18960e+011 1.27341e+011  0.9342  0.3502
  UK_SectorDevelop~ −1.37343e+010 1.25205e+010 −1.097   0.2727
  UK_QualifiedHuma~ −1.22252e+013 1.06415e+013 −1.149   0.2506
  UK_CorpTaxRate     8.50431e+011 1.86442e+012  0.4561  0.6483
```

Figure 53 Horizontal Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in London.




```
Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 4.33628e+010

 Forecast evaluation statistics using 125 observations
 Mean Error                       -0.0073452
 Root Mean Squared Error          4.2131e+010
 Mean Absolute Error              2.6094e+010
 Mean Percentage Error            -5.6179
 Mean Absolute Percentage Error   22.249
 Theil's U                        1.3821
```

Figure 54 Actual (red) and fitted (blue) value of Time Series for Market Volumes in London [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The model considering the first-order lag has a better performance than the model only with constant and exogenous variables, both in terms of mean error and Theil's U value. In fact, Theil's U value is lower than one, therefore has a higher prediction capacity.

Model 30: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: UK_All

	coefficient	std. error	z	p-value	
phi_1	0.753440	0.0652836	11.54	8.19e-031	***
UK_MFIs	2.34095e+08	2.35521e+08	0.9939	0.3202	
UK_GFCI	−6.10884e+08	3.02807e+08	−2.017	0.0437	**
UK_BussinessRegu~	8.71667e+010	5.87286e+010	1.484	0.1377	
UK_SectorDevelop~	−5.23125e+09	8.53817e+09	−0.6127	0.5401	
UK_QualifiedHuma~	9.81606e+011	1.12739e+012	0.8707	0.3839	
UK_CorpTaxRate	−5.01826e+011	4.82328e+011	−1.040	0.2981	

Figure 55 AR (1) Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in London.

Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 3.00586e+010

Forecast evaluation statistics using 124 observations

Mean Error	-3.169e+005
Root Mean Squared Error	2.9198e+010
Mean Absolute Error	1.8783e+010
Mean Percentage Error	-3.0627
Mean Absolute Percentage Error	15.742
Theil's U	0.91736

Figure 56 Actual (red) and fitted (blue) value of Time Series for Market Volumes in London [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

The number of MFIs in Frankfurt has been decreasing since 2011, while the volume of trades faced an initial decrease to later recover after 2016.

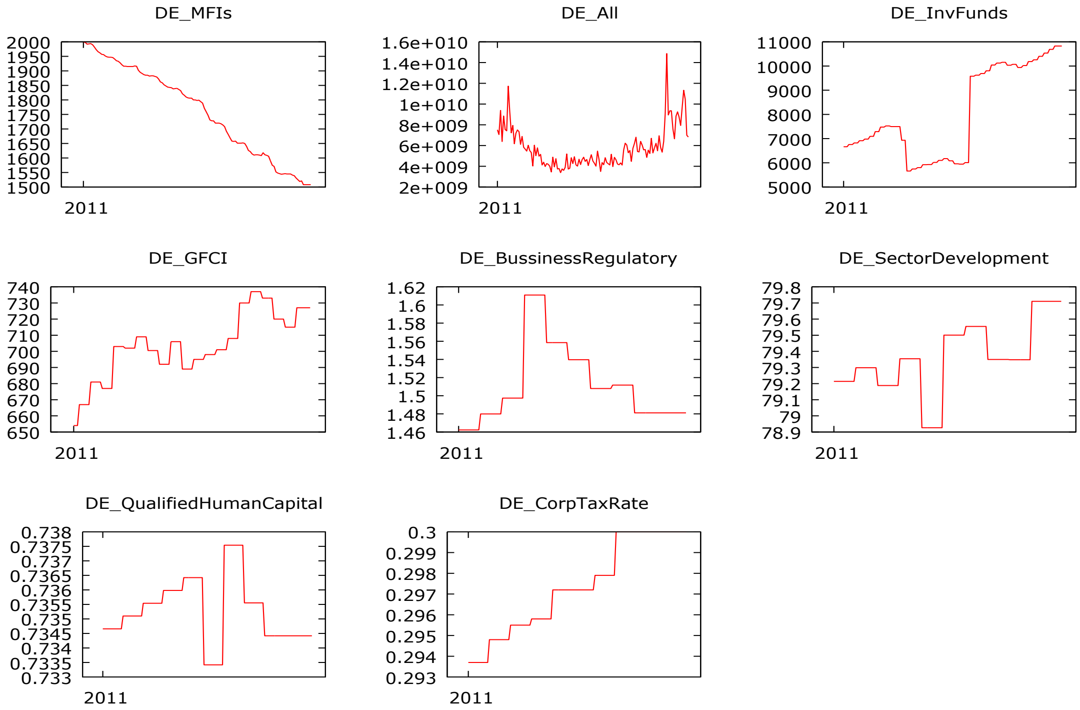


Figure 57 Market Volumes in Frankfurt (Reuters, 2021), Financial Hub factors (World-Bank, 2020) and Number of Financial Institutions (MFIs & InvFunds)

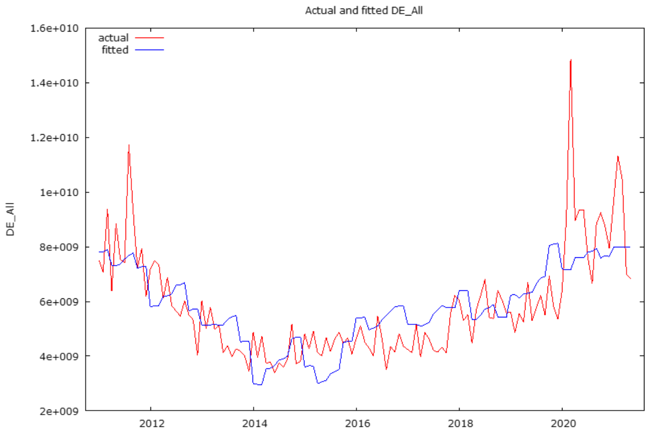
((ECB), 2021).

The model with a constant and exogeneous variable has almost all coefficients but the Regulatory Environment's one is statistically significant. The model has a small mean error, and a mean percentage error of about 3%, a Theil's U value larger than one yet once again providing a descent estimation for the variable level.

Model 35: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: DE_All

	coefficient	std. error	z	p-value	
const	1.25945e+012	3.01448e+011	4.178	2.94e-05	***
DE_MFIs	−1.37783e+07	5.07295e+06	−2.716	0.0066	***
DE_InvFunds	1.17215e+06	358250	3.272	0.0011	***
DE_GFCI	−5.17869e+07	1.44474e+07	−3.585	0.0003	***
DE_BussinessRegu~	9.52982e+09	9.35783e+09	1.018	0.3085	
DE_SectorDevelop~	−2.91667e+09	1.29960e+09	−2.244	0.0248	**
DE_QualifiedHuma~	−9.14064e+011	2.22368e+011	−4.111	3.95e-05	***
DE_CorpTaxRate	−1.05351e+012	3.48621e+011	−3.022	0.0025	***

Figure 58 Horizontal Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Frankfurt



Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 1.3955e+009

Forecast evaluation statistics using 125 observations

Mean Error	0.00081982
Root Mean Squared Error	1.3501e+009
Mean Absolute Error	1.0087e+009
Mean Percentage Error	-3.7051
Mean Absolute Percentage Error	17.512
Theil's U	1.1675

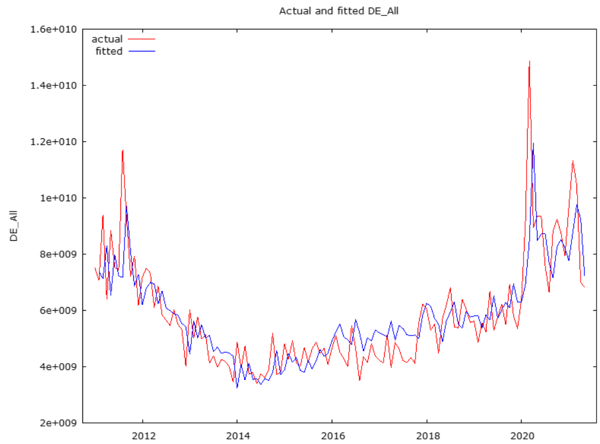
Figure 59 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Frankfurt [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The model considering the first-order lag does not consider statistically significant any of the other exogenous variables coefficients. The performance, however, is better and the Theil's U value is lower than one, both can be appreciated from the graph for the fitted and actual data.

Model 37: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: DE_All

	coefficient	std. error	z	p-value	
phi_1	0.586155	0.0746923	7.848	4.24e-015	***
DE_MFIs	−1.42947e+06	3.76238e+06	−0.3799	0.7040	
DE_InvFunds	21898.2	206969	0.1058	0.9157	
DE_GFCI	−1.52373e+07	1.20774e+07	−1.262	0.2071	
DE_BussinessRegu~	−7.88074e+09	5.42927e+09	−1.452	0.1466	
DE_SectorDevelop~	7.61539e+08	5.47195e+08	1.392	0.1640	
DE_QualifiedHuma~	−5.84562e+010	1.07501e+011	−0.5438	0.5866	
DE_CorpTaxRate	3.33815e+010	1.98480e+011	0.1682	0.8664	

Figure 60 AR (1) Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Frankfurt.



Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 1.2141e+009

Forecast evaluation statistics using 124 observations

Mean Error	65567
Root Mean Squared Error	1.1743e+009
Mean Absolute Error	8.2211e+008
Mean Percentage Error	-2.8109
Mean Absolute Percentage Error	13.755
Theil's U	0.95594

Figure 61 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Frankfurt [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

The volume of trades in Paris faced a decreasing trend until 2019, after which had a strong increase just like most of the volumes time series for the other hubs. The number of MFIs follows a decreasing trend, probably due to the consolidation trend seen in the banking sector.

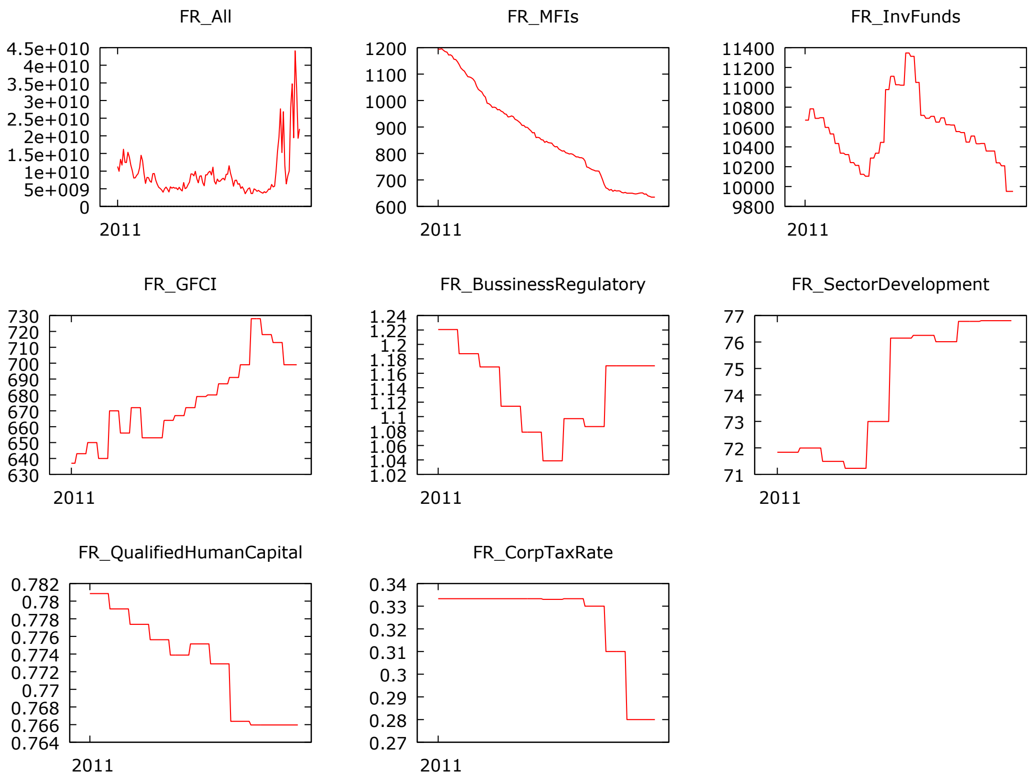


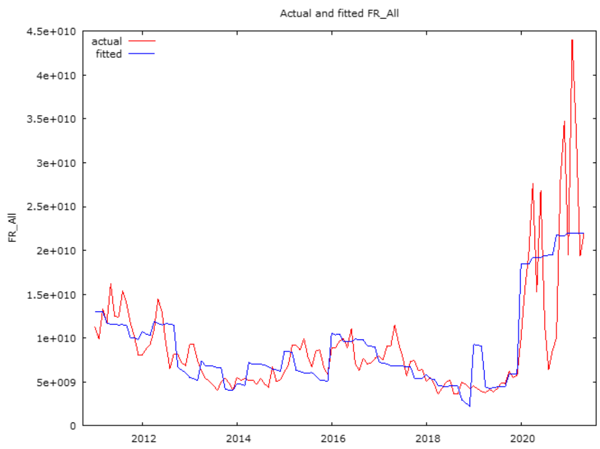
Figure 62 Market Volumes in Paris (Reuters, 2021), Financial Hub factors (World-Bank, 2020) and Number of Financial Institutions (MFIs & InvFunds) ((ECB), 2021).

The first model considering the constant term and the exogeneous variables has a mean percentage error corresponding to almost -8%, suggesting that the model cannot fully describe the data and tends to underestimate it. The Theil's U value is larger than one, however, just like with other models it is observable that the model serves as a rough estimator.

Model 38: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: FR_All

	coefficient	std. error	z	p-value	
const	7.81765e+010	2.16117e+011	0.3617	0.7176	
FR_MFIs	2.11512e+07	1.47172e+07	1.437	0.1507	
FR_InvFunds	−1.93007e+06	1.98847e+06	−0.9706	0.3317	
FR_GFCI	−1.59167e+08	4.84172e+07	−3.287	0.0010	***
FR_BussinessRegu~	−2.66289e+010	1.88641e+010	−1.412	0.1581	
FR_SectorDevelop~	1.53945e+09	4.27621e+08	3.600	0.0003	***
FR_QualifiedHuma~	1.16635e+011	2.74152e+011	0.4254	0.6705	
FR_CorpTaxRate	−4.12964e+011	4.59219e+010	−8.993	2.41e-019	***

Figure 63 Horizontal Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Paris.



Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 4.15847e+009

Forecast evaluation statistics using 125 observations

Mean Error	-2.8564e-005
Root Mean Squared Error	4.0232e+009
Mean Absolute Error	2.5102e+009
Mean Percentage Error	-8.5284
Mean Absolute Percentage Error	28.305
Theil's U	1.378

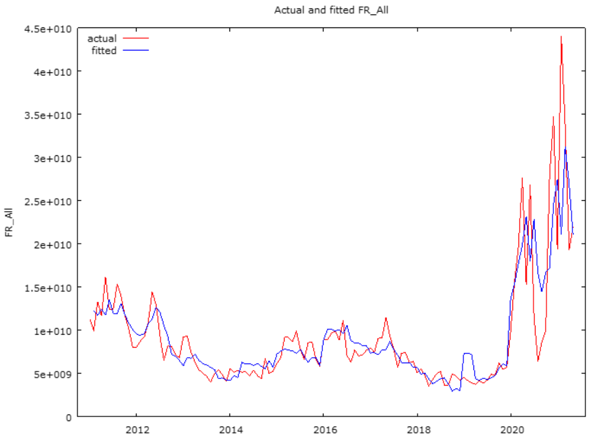
Figure 64 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Paris [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The model considering the first-order lag has statistically significant coefficients for four exogenous variables and outperforms the model with only constant and exogenous variables. The mean percentage error is smaller and close to -6% and the Theil's U value is lower than one.

Model 39: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: FR_All

	coefficient	std. error	z	p-value	
phi_1	0.411413	0.0794618	5.177	2.25e-07	***
FR_MFIs	1.03080e+07	1.03690e+07	0.9941	0.3202	
FR_InvFunds	−483277	1.79705e+06	−0.2689	0.7880	
FR_GFCI	−9.27410e+07	4.55284e+07	−2.037	0.0417	**
FR_BussinessRegu~	−1.37703e+010	1.56737e+010	−0.8786	0.3796	
FR_SectorDevelop~	8.52381e+08	4.10498e+08	2.076	0.0379	**
FR_QualifiedHuma~	1.28608e+011	4.94816e+010	2.599	0.0093	***
FR_CorpTaxRate	−2.55866e+011	5.01806e+010	−5.099	3.42e-07	***

Figure 65 AR (1) Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Paris.



Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 3.76369e+009

Forecast evaluation statistics using 124 observations

Mean Error	2.2455e+005
Root Mean Squared Error	3.6403e+009
Mean Absolute Error	2.0167e+009
Mean Percentage Error	-6.0586
Mean Absolute Percentage Error	20.765
Theil's U	0.99614

Figure 66 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Paris [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

The trade volumes in Zurich have been increasing since 2011, similarly, the financial hub factors have also improved.

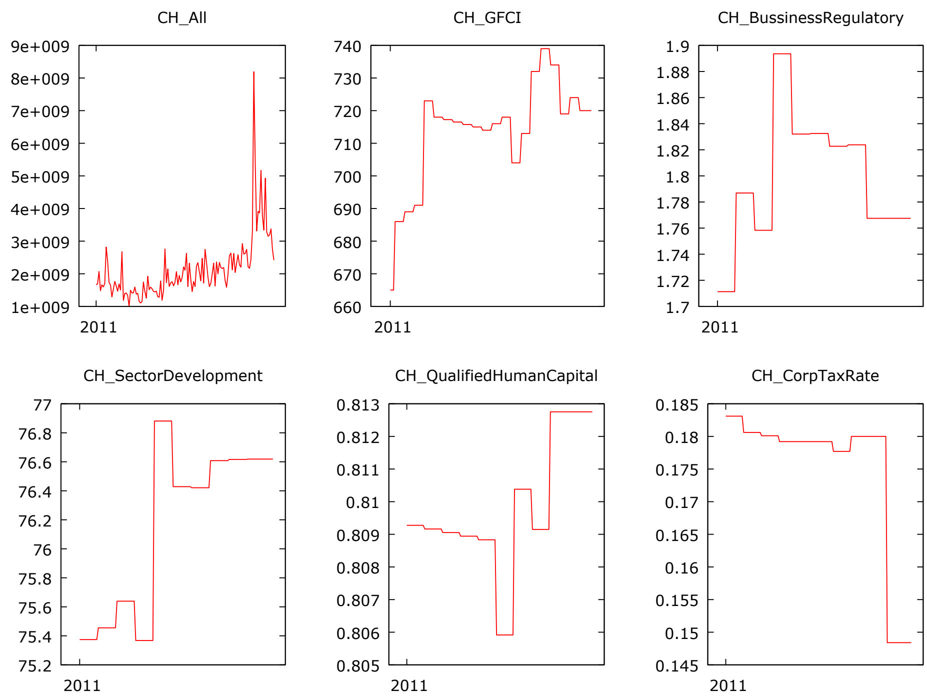


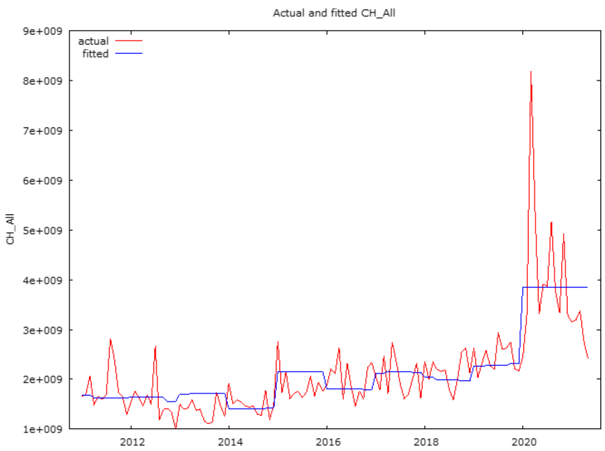
Figure 67 Market Volumes in Zurich (Reuters, 2021), Financial Hub factors (World-Bank, 2020) and Number of Financial Institutions (MFIs) ((ECB), 2021).

The model considering a constant and exogeneous variable has the Sector Development and the Tax Regime as the only financial hub factors with statistically significant coefficients. The model performance is satisfactory, with a close to zero mean error and a mean percentage error of only -4.1%. The Theil's U value is considerably lower than one, with respect to the other models for the time series in other financial hubs. This model shows that a good description can be made based only on the financial hub factors for the trade volumes in Zurich.

```
Model 40: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: CH_All

                  coefficient   std. error     z     p-value
  -----------------------------------------------------------------
  const            −6.06213e+010 3.49725e+010 −1.733  0.0830   *
  CH_GFCI            −2.60073e+06  4.89701e+06  −0.5311 0.5954
  CH_BussinessRegu~  −1.67889e+09  1.44540e+09  −1.162  0.2454
  CH_SectorDevelop~   4.23217e+08  1.24030e+08   3.412  0.0006   ***
  CH_QualifiedHuma~   5.42750e+010 4.10132e+010  1.323  0.1857
  CH_CorpTaxRate     −4.86836e+010 6.66829e+09  −7.301  2.86e-013 ***
```

Figure 68 Horizontal Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Zurich.



Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 6.22712e+008

Forecast evaluation statistics using 125 observations

Mean Error	-5.2208e-005
Root Mean Squared Error	6.0758e+008
Mean Absolute Error	3.8096e+008
Mean Percentage Error	-4.5165
Mean Absolute Percentage Error	17.084
Theil's U	0.89415

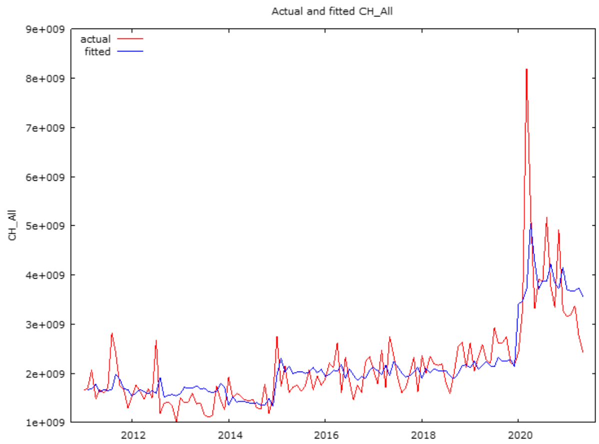
Figure 69 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Zurich [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The model considering the first-order lag shows an even better performance in describing the data in terms of Theil's U value and the mean percentage error. It can be seen from the corresponding graph how the model can describe to a good extent the actual data.

Model 41: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: CH_All

	coefficient	std. error	z	p-value	
phi_1	0.273423	0.0876933	3.118	0.0018	***
CH_GFCI	−173528	4.62626e+06	−0.03751	0.9701	
CH_BussinessRegu~	−2.01084e+09	1.27414e+09	−1.578	0.1145	
CH_SectorDevelop~	2.82909e+08	1.22086e+08	2.317	0.0205	**
CH_QualifiedHuma~	−1.13049e+010	1.00054e+010	−1.130	0.2585	
CH_CorpTaxRate	−4.04283e+010	7.15576e+09	−5.650	1.61e-08	***

Figure 70 AR (1) Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Zurich.



Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 6.08616e+008

Forecast evaluation statistics using 124 observations

Mean Error	-1.1059e+005
Root Mean Squared Error	5.9371e+008
Mean Absolute Error	3.6772e+008
Mean Percentage Error	-4.4113
Mean Absolute Percentage Error	16.654
Theil's U	0.86964

Figure 71 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Zurich [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

The trade volumes in Milan have slightly decreased since 2011, there was a short-lived dip by the end of 2017 from which the market recovered. The time series is characterized for high a higher variance than for other time series. The number of MFIs has had a decreasing trend just like in the other European financial hubs.

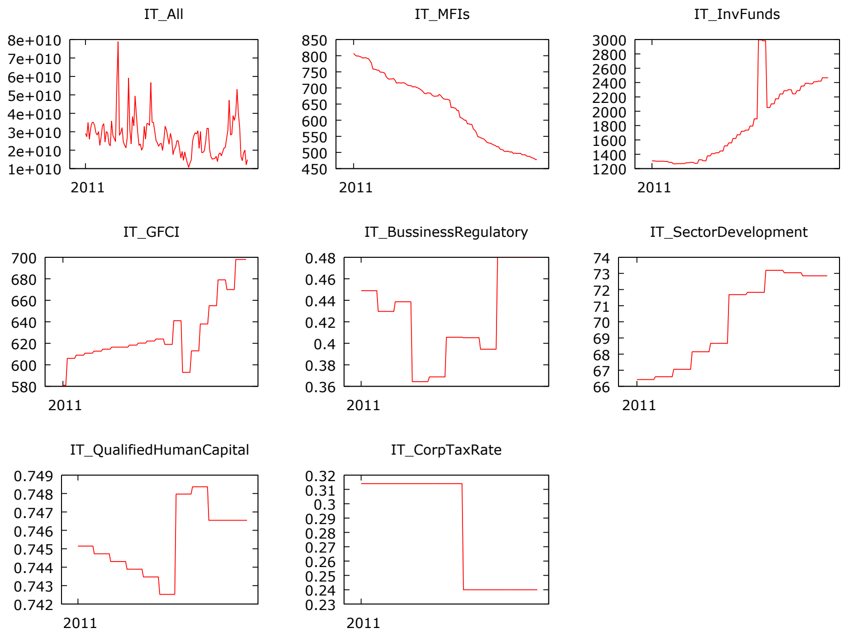


Figure 72 Market Volumes in Milan (Reuters, 2021), Financial Hub factors (World-Bank, 2020) and Number of Financial Institutions (MFIs & InvFundsd) ((ECB), 2021).

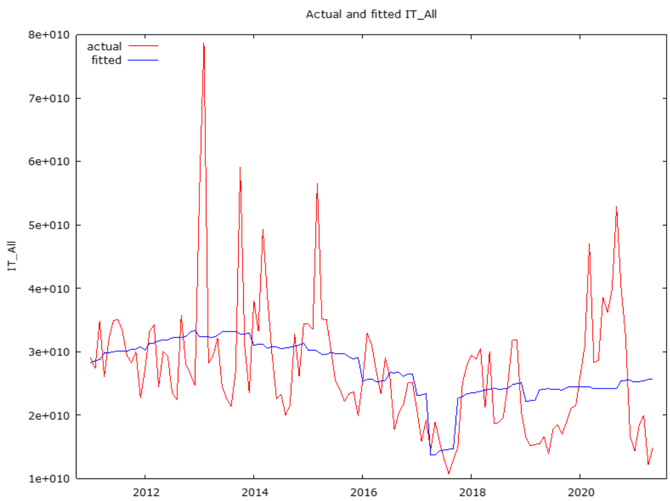
The model with constant term and exogenous variables only has a statistically significant coefficient for the number of investment funds. The model has a small mean error, suggesting a low bias, yet the mean percentage error is about 25%, one of the highest.

The Theil's U value is larger than one, yet the model can capture the macro-movements seen in the observed data.

Model 42: ARMAX, using observations 2011:01-2021:05 (T = 125)
Estimated using least squares (conditional ML)
Dependent variable: IT_All

	coefficient	std. error	z	p-value	
const	−1.54664e+012	2.25831e+012	−0.6849	0.4934	
IT_MFIs	−6.10025e+07	5.25922e+07	−1.160	0.2461	
IT_InvFunds	−9.81665e+06	5.55700e+06	−1.767	0.0773	*
IT_GFCI	3.99745e+07	8.10188e+07	0.4934	0.6217	
IT_BussinessRegu~	9.42124e+09	3.34263e+010	0.2819	0.7781	
IT_SectorDevelop~	−6.27286e+08	1.50703e+09	−0.4162	0.6772	
IT_QualifiedHuma~	2.12920e+012	2.85109e+012	0.7468	0.4552	
IT_CorpTaxRate	2.05752e+011	2.65007e+011	0.7764	0.4375	

Figure 73 Horizontal Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Milan.



Model estimation range: 2011:01 - 2021:05
Standard error of the regression = 9.46387e+009

Forecast evaluation statistics using 125 observations

Mean Error	0.0011575
Root Mean Squared Error	9.156e+009
Mean Absolute Error	6.6184e+009
Mean Percentage Error	-9.022
Mean Absolute Percentage Error	25.19
Theil's U	1.1507

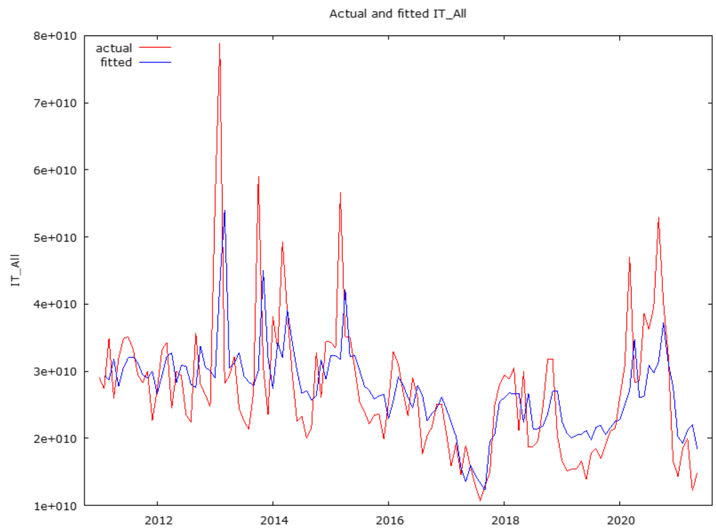
Figure 74 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Milan [Left]. Measurements for the quality of the fit for the Horizontal Regression model [Right].

The model considering the first-order lag only has a statistically significant coefficient for the first lag. This model presents a relatively high error, whose value suggests the model tends to underestimate the actual data. However, the mean percentage error is much lower and close to 6%. The Theil's U is also better than the value for the first model, with a value lower than one.

```
Model 43: ARMAX, using observations 2011:02-2021:05 (T = 124)
Estimated using least squares (conditional ML)
Dependent variable: IT_All

                 coefficient   std. error     z    p-value
  ---------------------------------------------------------------
  phi_1              0.463096     0.0828166     5.592  2.25e-08 ***
  IT_MFIs           −3.44631e+07  4.41071e+07  −0.7814 0.4346
  IT_InvFunds       −5.38181e+06  5.02826e+06  −1.070  0.2845
  IT_GFCI           −1.47523e+07  6.80006e+07  −0.2169 0.8283
  IT_BussinessRegu~  8.44244e+09  2.87132e+010  0.2940 0.7687
  IT_SectorDevelop~ −6.61175e+08  1.15232e+09  −0.5738 0.5661
  IT_QualifiedHuma~  1.19099e+011 1.49663e+011  0.7958 0.4262
  IT_CorpTaxRate     3.35181e+010 8.70579e+010  0.3850 0.7002
```

Figure 75 AR (1) Model with all Financial Hub Factors and Number of Financial Institutions as explanatory variables for Market Volumes in Milan.




```
Model estimation range: 2011:02 - 2021:05
Standard error of the regression = 8.4522e+009

  Forecast evaluation statistics using 124 observations

  Mean Error                      -171.81
  Root Mean Squared Error          8.175e+009
  Mean Absolute Error             5.5897e+009
  Mean Percentage Error            -6.7138
  Mean Absolute Percentage Error   20.334
  Theil's U                       0.94041
```

Figure 76 Actual (red) and fitted (blue) value of Time Series for Market Volumes in Milan [Left]. Measurements for the quality of the fit for the AR (1) model [Right].

In general, the models with only a constant term and exogenous variables are able to provide a good rough estimate of the level for the trades volume and are useful in recapitulating the macro-trends of these time series. For all the models of this type and for all the time series, the mean error is relatively low suggesting the absence of bias, yet Theil’s U value is larger than one, except for the Zurich time series. The models considering the first-order present a smaller mean percentage error and a Theil’s U value lower than one, yet their mean error is larger in modulus than that of the first type of models (with the constant term), these mean errors are lower than zero suggesting that all of them systematically sub-estimate the data. The higher systemic misestimation is likely due to the presence of series of narrow and short-lived spikes in the volumes time series.

4.4.4 Contracts per Trade Time Series

The average number of contracts per trade was estimated for the EU at an aggregated level and for the UK, by diving the values of the trade volumes time series values by the number of trades time series values. The figures show the behavior of the calculated time series in both geographies for the total of instruments and disaggregated by region of origin of the contracts.

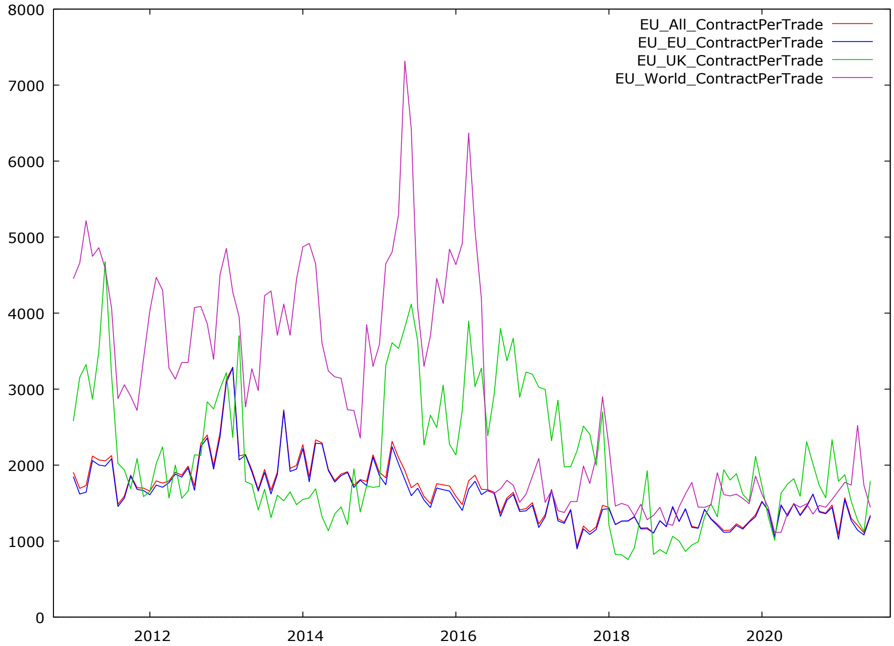


Figure 77 Average Number of Contracts per Trade in EU by Origin of Contracts

On EU level, since 2008 there has been a convergence to smaller trades. Until mid-2016 the largest trades were related to RoW instruments, to later converge at levels of the EU instruments.

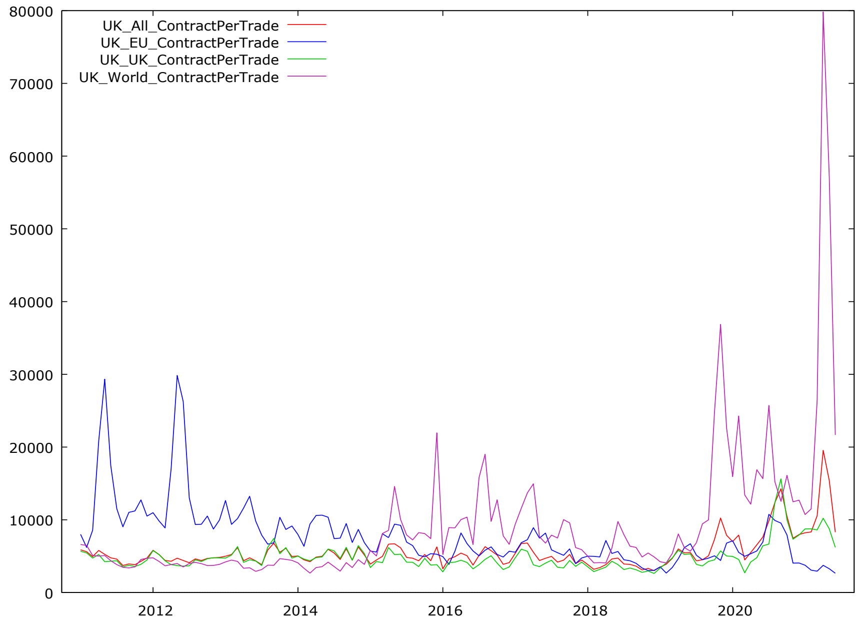


Figure 78 Average Number of Contracts per Trade in the UK (London) by Origin of Contracts

Conversely, for London, the size of the trades has increased mainly for RoW and UK instruments. The EU instruments' trade sizes have decreased since 2011.

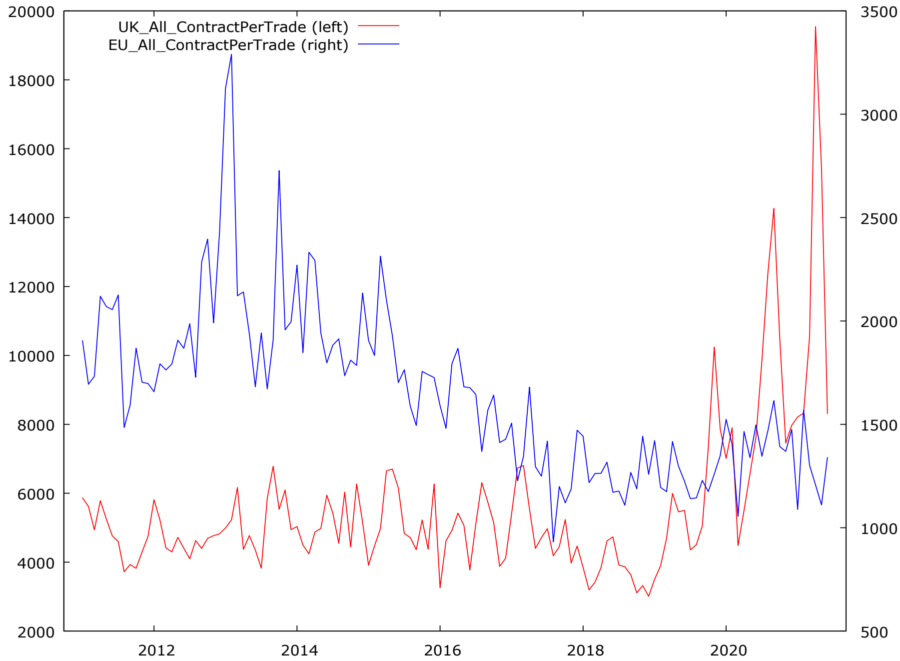


Figure 79 Average Number of Contracts per Trade for contracts from all origins in EU and UK (London).

For the aggregated of all instruments, in EU the trade sizes have decreased while in London has increased.

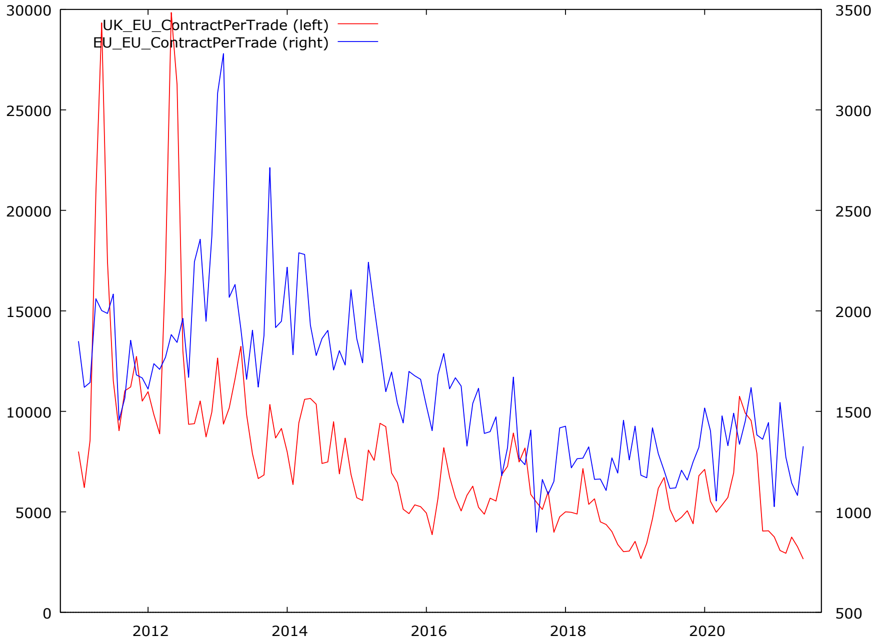


Figure 80 Average Number of Contracts per Trade for contracts from EU in EU and UK (London).

For EU instruments the size of the trades has decreased in both markets.

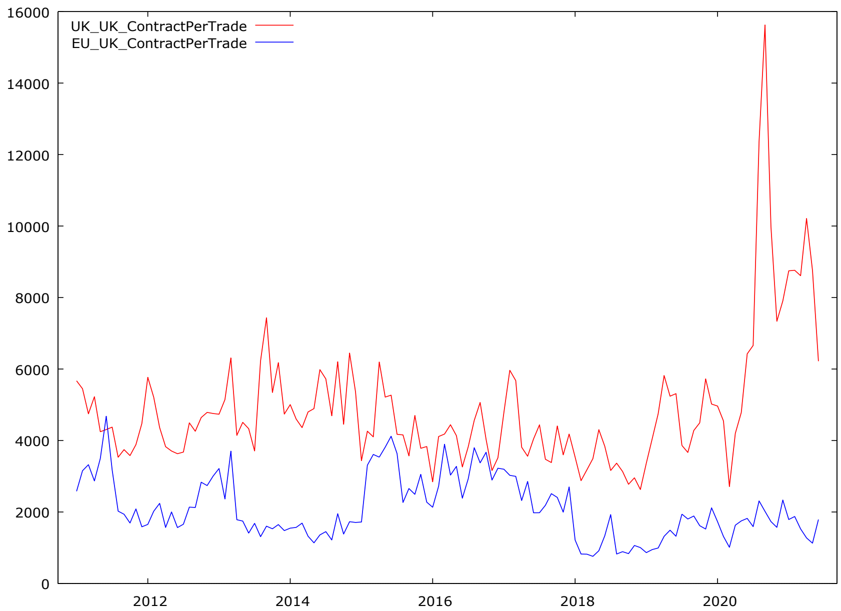


Figure 81 Average Number of Contracts per Trade for contracts from UK in EU and UK (London).

For UK instruments, the trade size has slightly been reduced in the EU, while in London it has increased.

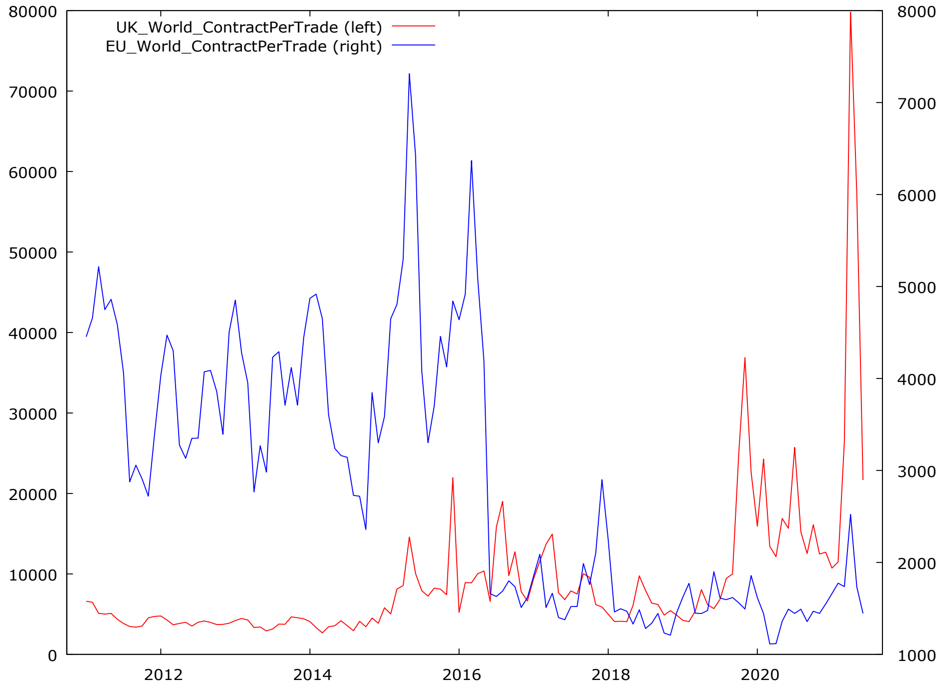


Figure 82 Average Number of Contracts per Trade for contracts from RoW (Rest of the World) in EU and UK (London).

The trades size for RoW instruments in the EU sharply decreased after 2016 to less than half of the previous value. In London, the size of the trades increased first in 2015 and later in 2019.

The trade size may be related to the presence of financial firms and their composition, however, given the lack of more detailed information regarding the composition and type of funds present in each geography no further analysis can be made on the causality for the contrasting trends in each geography. A possible explanation could be due to the new presence of financial firms in the main EU financial hubs, that act as subsidiaries of the larger global firm and thus manage a smaller capital at the EU markets, oriented mainly towards EU instruments, thus the trades of securities from other locations occupy smaller portions in the portfolios and thus are smaller trades. At the same time, in London, the trend towards becoming a global financial hub makes it convenient for various firms to allocate a larger portion of their portfolios here thus increasing the trades size, except for

EU instruments that would be more efficiently traded in Europe due to the easiness to find counterparties and avoid risks of further changes in the regulatory environment. Although the previously composed hypothesis may explain the figures previously presented, a rigorous study on this matter would be required to confirm whether that is what has happened that had led the trades size to re-structure in different directions at both ends of the English Channel/La Manche.

5. CONCLUSIONS AND LIMITATIONS

The impact of Brexit on the financial markets of the main financial hubs in Europe was analyzed in this work. Initially, an event study, following the event study methodology (ESM) was carried out to assess the relevance of six major events during the Brexit process over a set of *financial variables* and assess whether on these dates an “event” was considered to have occurred. The yields for sovereign bonds with maturities of 10 years and 3 months, the spread between these yields, and the credit default swap (CDS) spreads were selected as *financial variables* to observe in the event study. The Brexit announcement (referendum results announcement) was the event date for which the largest impact over the *financial variables* analyzed was observed. The *financial variables* are related to the countries’ stability and performance outlook, both of which are factors considered by financial firms in deciding their strategies. The widespread cumulative abnormal residuals (CARs) observed around the Brexit announcement make it a strong event. Other dates considered range between weak, very weak, and no-events. In particular, the referendum announcement in February of 2016 was observed to be a very weak event, while the British government announcements giving up the seek to maintain access to the single market were weak event dates. The formal exit of the UK from the EU in 2020 was likely a weak event, however, the market anticipation of the SARS-COVID19 pandemic may have been included within the event window, leading to the abnormal behavior seen for the *financial variables* seen around this date. Around the end of the transition period, no abnormal behavior of the analyzed variables was observed, therefore it was considered as a no-event date. The low to inexistent impact on the *financial variables* around the UK formal exit and the end of the transition period suggests that the market had already prepared for the scenario change, particularly after a long period of negotiations and high uncertainty, which made the market braced for the worst scenario. The findings of the event study are in coherence with previous studies and confirm the hypothesis that by the time of Brexit completion the market would already have priced-in and re-structured for the changes. This work also provides insights into how the release of new information regarding the progress of the negotiations had a certain impact on the market, yet it was less severe than the initial announcement of Brexit since this new information corrected the expectations.

In general, there was a migration in terms of total trade volumes from Paris and Milan to Germany, this is not inversely related to London volumes which kept on increasing, especially for UK and RoW instruments. For EU instruments Paris and Milan do not seem to be on an increasing trend while Frankfurt is in an increasing trend, London seems to have a small decrease while Zurich appears to have a slight increase. In general, Germany seems to be the winner in this rearrangement in terms of volumes as it has recovered from a shrinking trend pre-Brexit and has managed to surpass France. This observation is backed by the evolution of the various financial-hub factors, and particularly for the GFCI score which has considerably improved for Frankfurt with respect to Paris in the last years, thus positioning Frankfurt as the most attractive financial hub in the EU. Zurich seems to have been the hedge option to accommodate what cannot or would not be a great fit in London or the EU. There has been an overall increase in the market volumes at this location. However, information on the number of investment funds and financial institutions could not be analyzed for Switzerland in this work due to lack of availability.

Frankfurt and London seem to be consolidated as main financial hubs where a large volume of contracts and instruments are traded. Despite the consolidation of Frankfurt as the main financial hub where the largest volume of transactions take place and where more funds are located than in any other of the main financial hubs of EU, the volume of contracts trades hosted at the German city is not as high as the volume in London, which was by 2020 about twenty times larger. Frankfurt concentrates mainly on EU and RoW instruments transactions, being the largest share of EU instruments. London balances almost at the same ratio UK securities and RoW securities volumes, consolidating its plan of being a global financial hub. Zurich is a global financial hub where most of the trades correspond to RoW instruments transactions and a very small extent host some trades of UK and EU instruments. Paris and Milan host mainly EU instruments trades, as UK instruments trade decayed between 2016 and 2018. It was observed how after the Brexit announcement the composition in the volume of trades at the EU financial hubs and London changed as well as the correlation among them. The most subtle change in composition and correlation was for the total volume of trades in Zurich. Thus, London seems to have realized its plan of re-orienting towards a global financial hub while Frankfurt seems to have taken the place of the main financial hub in the EU hosting most of the trade volumes for EU instruments.

It is very likely, based on the evidence here presented, that the Brexit process and in particular, after the Brexit announcement the financial hubs re-structured. The firms seem to have moved and duplicated their presence to maintain strategic access to the main financial hubs. London, contrary to the rest of Europe, showed an increase in MFIs, suggesting it attracts more firms thanks to its privileged position as a global financial hub, in that way the city of London seems to be counteracting the macro trend of consolidation and reduction in the total number of MFIs seen in Europe.

Based on the analysis for the number of funds and market volumes based on the financial hub factors variables, it seems likely that economic geography provides a good framework to understand the impact of Brexit on the financial hubs of Europe. The financial hub factors could describe on their own the presence of funds in the corresponding geography. Similarly, they can be used on a statistical model to provide a good level of reference for the market volumes at the main financial hubs' markets. When an autoregressive model of one lag was considered, the performance for all the models improved considerably, indicating the existence of certain inertia or past dependence for the number of funds and the market volumes. Such inertia in the number of funds is likely due to the fact that locating at a certain hub is a medium to long-term commitment. In the case of the market volumes, the inertia is likely due to the variance dependence to past behavior and the relation of returns to the signed volume of trades, both of which have been well documented in the literature. The previous two hypotheses combined imply that for periods of high volatility, i.e., large changes in the returns, there are absolute high volumes of trades for the instruments and since the volatility is strongly related to previous volatilities, the absolute trade volumes do also exhibit a past dependence. it takes relatively long periods to dissipate and so would do the market volumes. Therefore, the financial hub factors can be used to explain the changes in the market volumes seen at the main financial hub markets.

There could be an explanation for the change in the trade sizes, leading to larger trades in London while smaller trades are occurring in the EU, and such explanation could be rooted in the re-location of the financial firms that have been explored in this work. However, further studies are required to confirm the hypothesis.

Finally, we would like to specify that the findings of this thesis are limited to the effect the Brexit event has had on the European financial centers, hence not providing an analysis of the changes in the status of London (or the other European financial hubs) as a global financial center. Brexit has also had an impact on the equilibrium on a global scale, modifying the trade volumes in other cities such as New York and Hong Kong, but these effects have not been studied in this work.

In addition, we would like to specify that this thesis does not provide a predictive model for the future of the European leading financial center but is instead limited to an analysis of the measurable impact Brexit has had up to the end of the analyzed time series. The general feeling is that Brexit has certainly disrupted the equilibrium, forcing a re-arrangement of European financial activity, but as of today, London seems to have maintained its dominant position in Europe. This may change in the future as Brexit will probably have lasting effects in the years to come. Further studies are required to analyze such issues.

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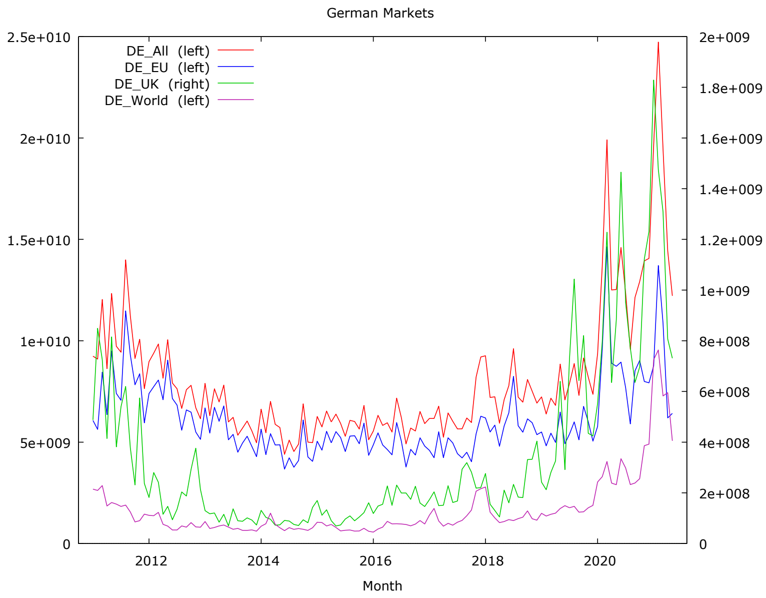
ANNEX

ANNEX 1 Summary of previous studies about the Brexit impact on financial markets and financial variables [Part 1].

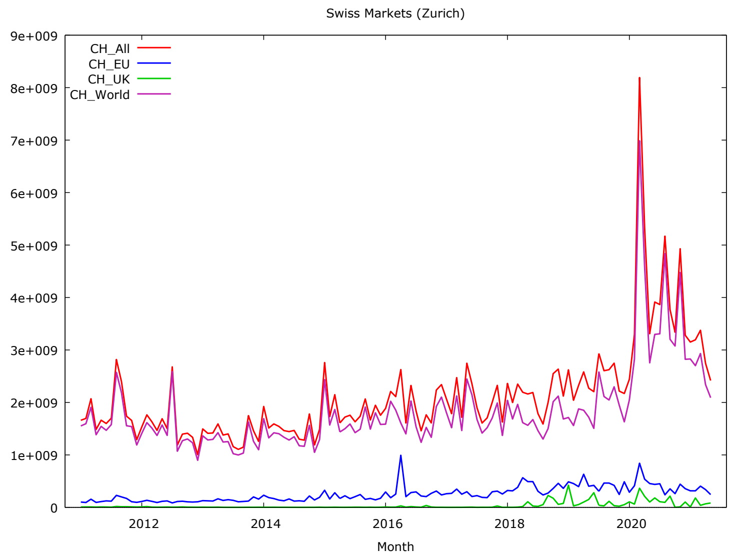
First Author	Year	Title	Ref	Topic	Results
Andreas Oehler	2016	Brexit: Short-term Stock Price Effects and the Impact of Firm-level Internationalization	[98]	Event study analysisto determine short term abnormal returns (AR) after Brexit referendum and whether firm-specific level of internationalization (in terms of % of sales) explains those AR.	It indeed helps to explain the differences in negative abnormal returns and the behavior observed, reflecting a high market efficiency.
Usman Bashir	2019	Differential market reactions to pre and post Brexit referendum	[95]	Dynamic linkages between stock price and exchange rate for the UK and four other EU countries, considering the periods before and after the Brexit referendum	UK markets changed post referendum, while for EU it is not seen immeadetly. An anti-persistent shift was observed for the stocks market while the currency market exhibited an shift to persistency after Brexit. In pre-Brexit it was found a weak negative dependence between stock and currency markets overall, regardless of the time scale. As for the relations post Brexit are mostly significantly negative and therefore matching the flow model for foreign exchange rate [9], by which investors would invest in the stock market in presence of a devaluated currency. For the UK , the correlation depended on the time-scale exhibiting weak negative or even sligthly positive correlations pre-Brexit and a significant negative correlation post-brexit.
Dirk Schiereck	2016	Brexit: (Not) another Lehman moment for banks?	[4]	Analyzed behavior of stocks and CDS spreads for Brexit in contrast to Lehman Brothers.	Drop in prices of stocks mainly for EU and UK banks (in contras to 2007 Lehman), an increase of CDS spreads mostly for EU and UK banks, the changes were similar and affected both sides in the same way; however, changes for non-european banks with presence in UK impact was lesser. While there was a recovery some days after for stocks, Brexit's was much slower and not a full recovery.
Tihana Skrinjaric	2019	Stock Market Reactions to Brexit: Case of Selected CEE and SEE Stock Markets	[90]	Effect of Brexit referendum on CEE (Central & Eastern European) and SEE (South & Eastern European) martkets by using ESM (Event Study Methodology)	Effects on CEE were small, negative CAR yet non-signficant, for this market excess volatility was found to be short termed. As for SEE, AR were positiove and particularly significant after +3 day, yet it seems unrelated with Brexit vote itself, while when window is shortened the AR are negative; excess volatility is confirmend around the Brexit announcement. Results were mixed, however it is observed a volatility increase, indicating a spillover fue to Brexit.
E.F. Guedes	2019	An econophysics approach to study the effect of BREXIT referendum on European Union stock markets	[97]	Analyzed the auto-correlation of several EU markets' indices and the cross-correlation between UK stock market with other EU markets.	The auto-correlation exponent did not change before and after, stayed around 0.5 for most markets thus showing efficient markets. As for the cross-correlation, it decreased after Brexit for UK with other EU markets, indicating an increased segmentation or a lower integration.
Thong M. Dao	2019	The Brexit vote and currency markets	[96]	Studied the impact of Brexit referendum on high frequency correlation and volatility spillover in the foreign exchange market	Increased correlation amongst safe haven currencies, indicating a flight to quality, a decreased correlation of them with respect to the involved currencies in the event. A decrease of volatility transmission between GBP and EUR, reflecting a lower level of market integration, despite a general increase of volatility transmission for all currencies. Referendum announcement of voting was a weak event, the most relevant was the voting results announcement while completion date of transition phase might be a future event (points out Jan 31st of 2020)
Juan Antonio Galán-Gutiérrez	2021	Cointegration between the structure of copper futures prices and Brexit	[52]	Study about the cointegration between the structure of copper futures and the BUKHI50P a stock index measuring the impact of Brexit on UK companies, in a context of market shortage.	Evolution of companies with large exposure to Brexit impact is cointegrated with the variation in the structure of copper futures. Brexit related events that imply a wweakening of UK's economy have a detrimental effect on the structure of copper futures, a reduction of futures prices with respecto to spot prices leading to a narrower contango or even to a backwardation.
Ansgar Belke	2018	British-European Trade Relations and Brexit: An Empirical Analysis of the Impact of Economic and Financial Uncertainty on Exports	[165]	Non-linear model to study how uncertainity in fin. Markets and UK-EU trade relations affect export companies; since exports react in spurts when exchange rate overpass a threshold (Exports as function of some parameter/variables related to market uncertainity and macroEconomic indicators for the country).	The selected variables showed adequateness for modelling uncertainity: the RER volatility, the stock change Stoxx50 index, EPUI. However TED spread exhibited mixed results. Exchange rate volatility, stock indices and combined play areas with multiple uncertainity variables produced most clearly interpretable results. It is suggested the usage of a TED spread equivalent within the EUR-denominated area.
Guglielmo Maria Caporale	2018	Brexit and Uncertainty in Financial Markets	[119]	Study effect of Brexit on the degree of persistence of FTSE100 Implied volatility index (IVI) and GBP implied volatility (IV) vis-à-vis main currencies traded in Foregin Exchange market.	Increased degree of persistence for all pairs of currencies except for GBP-YEN implied volatility which decreased post-Brexit. For FTSE100 IVI it increased before announcement but has been decreasing ever since, consistent with the interpretation that global british firms are better potitioned to manage the risk, while market participants appear to keep hedging the risk of currency exchange fluctutations.

ANNEX 2 Summary of previous studies about the Brexit impact on financial markets and financial variables [Part 2].

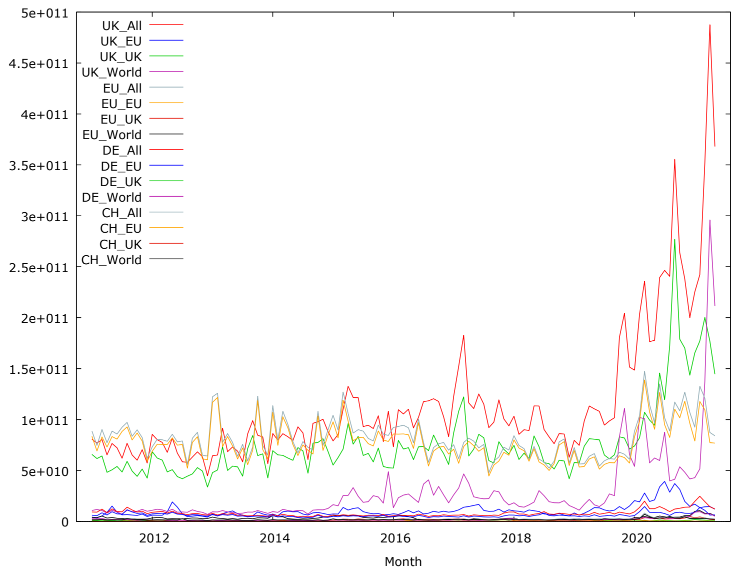
First Author	Year	Title	Ref	Method	Data source	NOTE
Andreas Oehler	2016	Brexit: Short-term Stock Price Effects and the Impact of Firm-level Internationalization	[98]	Standard event study methdology (ESM) based on abnormal returns (AR) and cummulative abnormal returns (CAR)	Thomas Reuters EIKON (% of domestic sales) & Thomas Reuters Data-Stream	
Usman Bashir	2019	Differential market reactions to pre and post Brexit referendum	[95]	Detrended Fluctuation Analysis (DFA), Detrended cross-correlation coefficient analysis (DCCA), Granger causality test [led to ambigous results]. Methodology proposed by [19,20]	Wind Financial Database	Points that other studies using OLS, VAR, co-integrated models, impulse-response model, generalized methods of movements , ARCH and Dynamic conditional correlation analysis have led to ambigous results
Dirk Schiereck	2016	Brexit: (Not) another Lehman moment for banks?	[4]	System regression SUR (Seemingly unrelated regression framework), rather than ESM. Employs a model in which individual returns depend on market returns (Stocks) or are mean-reversin (CDS), to compute the CARs and significance of them	Tomson Reuters (EOD)	
Tihana Skrinjaric	2019	Stock Market Reactions to Brexit: Case of Selected CEE and SEE Stock Markets	[90]	ESM, based on calculating AR and CAR employing an asset pricing model to estimate the expected return (avg of pre-event return). Employed three parametric test to asses whether the event had a significant effect over the outcome, one of them being the Wilcoxon test. As for volatility, ESM literature applied to study it is not extensive, here they use a GARCH (1,1) model to estimate its value and determine and implementing a cross-sectional test for abnormal volatility. Methodology by Doidge 2015 and Schäfer 2016 and using SUR framework by Zellner 1962	Thomson Reuters	
E.F. Guedes	2019	An econophysics approach to study the effect of BREXIT referendum on European Union stock markets	[97]	Implements the DFA and DCCA analyses, and the change in the cross-correlation function from the DCCA.	Datastream	
Thong M. Dao	2019	The Brexit vote and currency markets	[96]	Used an AR(p) model for currency returns, while for the variances a GARCH (1,1) process is implemented. Employs the DCC model of Engle 2002 which measures correlation over time using covariance of standardized residuals from the AR-GARCH process. Fitted parameter following Akaike information criterion. For volatility transmission, employed a VAR framework, to enhance variance decomposition and following Deibold 2012 analyses the variance decomposition to estiamte the spillover indeces. Points to ESM as an alternative approach for an individual instrument study rather than a relationship of several series oriented approach, yet less reliable for long horizons.	Thomson Reuters Tick History	Very detailed methodology, clear and easy to understand …
Juan Antonio Galán-Gutiérrez	2021	Cointegration between the structure of copper futures prices and Brexit	[52]	Used the Granger causality theory to analyse the relationship between the non-stationary series, to chechk for non-stationarity employed different test as KPSS, Leybourne, McCabe, Dickey-Fuller, Phillips-Perron, DF-GLS and ADF. For non-stationary series, used the Box-cox transformation instead of iterative approach, resulting serie tested with ADF for stationarity. Causality based cointegration test is then applied (Engle & Granger 1987) and consequently a VAR can be calculated and the basis for the trace test and lambda-max in search for a cointegration relationship. Fitting parameters were found by OLS.	LME (Cu contracts' prices) CBOE's index	
Ansgar Belke	2018	British-European Trade Relations and Brexit: An Empirical Analysis of the Impact of Economic and Financial Uncertainty on Exports	[165]	Usage of OLS to determine the hysteretic path dependencies in exports as a model of transversal correlation with explanatory variables: Real exchange rate, uncertainity variables for the play area, industrial production (as proxy of GDP). For the variable play area it is also linealy regressed as a function of multiple uncertainity variables and a deterministic component (constant).	Eurostat	
Guglielmo Maria Caporale	2018	Brexit and Uncertainty in Financial Markets	[119]	Fractional integration method for analysing non-stationary series, specially aiming to investigate transitory effects post-shock. An ARFIMA (p,d,q) model is used. Followed non-parametric method proposed by Bloomfield 1973 and Gil-Alana 2004 and an alternative semi-parametric method by Robinson 1995, without assumptions about the behaviour of the error term.	Thomson Reuters Data Stream	



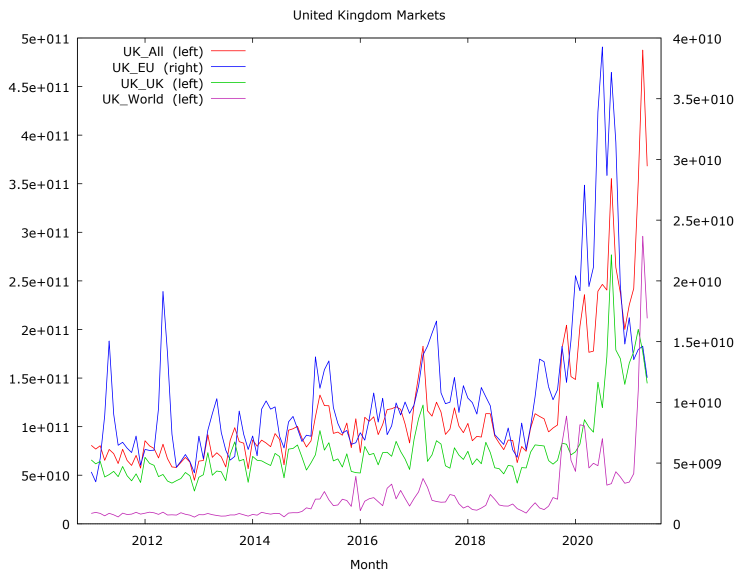
ANNEX 3 Market trade volumes by instrument origin in Frankfurt (Reuters, 2021)



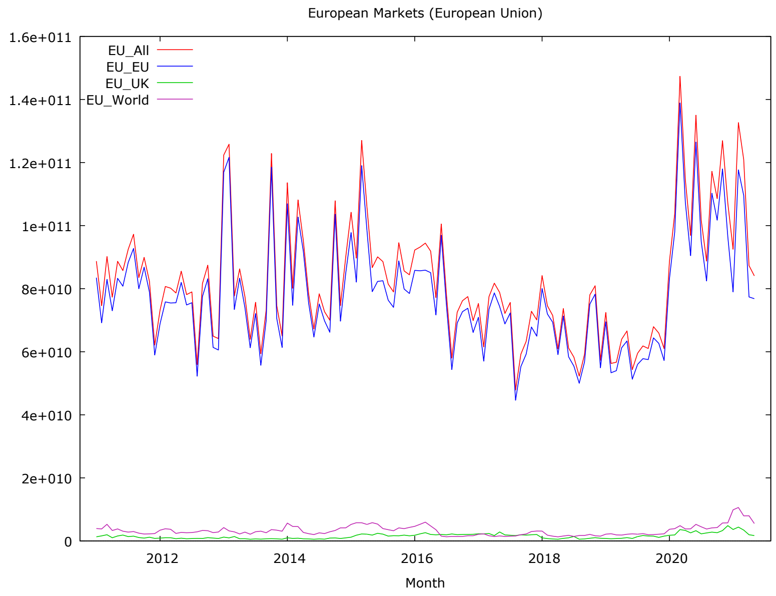
ANNEX 4 Market trade volumes by instrument origin in Zurich (Reuters, 2021)



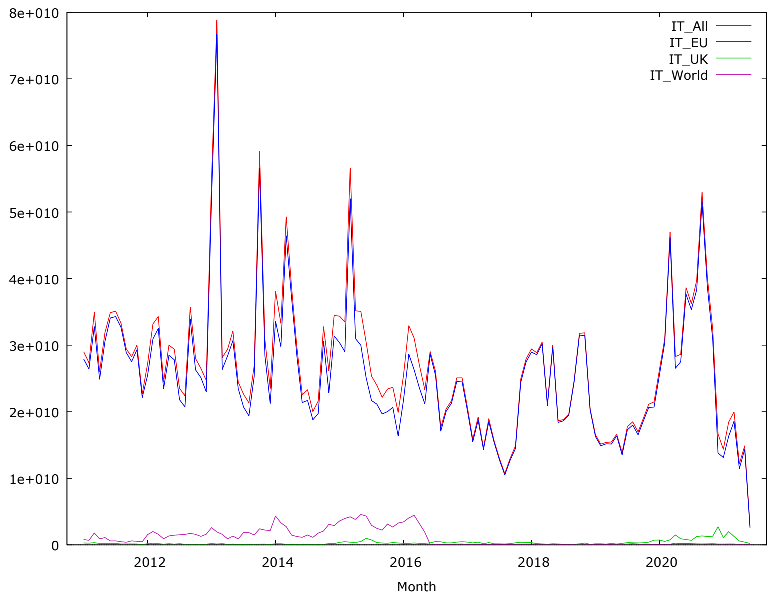
ANNEX 5 Market trade volumes by instrument origin (EU, Germany, UK, and Switzerland) (Reuters, 2021)



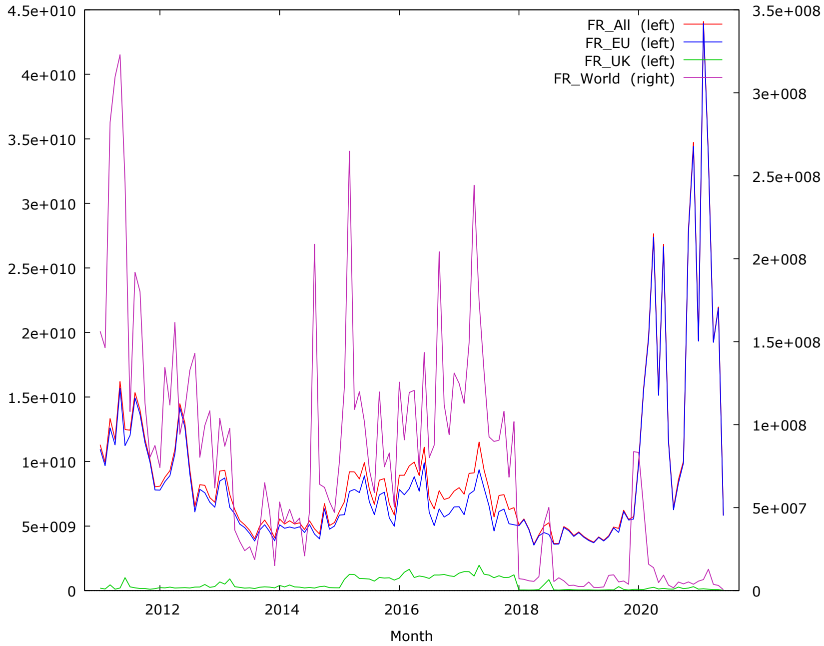
ANNEX 6 Market trade volumes by instrument origin in London (Reuters, 2021)



ANNEX 7 Market trade volumes by instrument origin in the European Union (EU) (Reuters, 2021)



ANNEX 8 Market trade volumes by instrument origin in Milan (Reuters, 2021)



ANNEX 9 Market trade volumes by instrument origin in Paris (Reuters, 2021)

ANNEX 10 Financial Hub Factors Scores (World-Bank, 2020) - Part 1

	GFCI Score					***Business & Regulatory Environment***					***Ease of Doing Business (Sector Development)***				
	UK	**DE**	**CH**	**FR**	**IT**	**UK**	**DE**	**CH**	**FR**	**IT**	**UK**	**DE**	**CH**	**FR**	**IT**
2011	775,0	654,0	665,0	637,0	581,0	1,37	1,46	1,71	1,22	0,45	81,50	79,21	75,37	71,83	66,42
2012	781,0	681,0	689,0	650,0	609,0	1,40	1,48	1,79	1,19	0,43	81,61	79,30	75,46	71,99	66,59
2013	807,0	703,0	723,0	670,0	612,8	1,43	1,50	1,76	1,17	0,44	81,64	79,19	75,64	71,49	67,05
2014	784,0	709,0	717,3	672,0	616,5	1,50	1,61	1,89	1,11	0,36	83,74	79,35	75,37	71,23	68,14
2015	784,0	692,0	715,8	653,0	618,4	1,56	1,56	1,83	1,08	0,37	82,93	78,93	76,88	73,00	68,66
2016	800,0	689,0	714,0	667,0	622,1	1,46	1,54	1,83	1,04	0,41	83,34	79,50	76,43	76,15	71,69
2017	782,0	698,0	718,0	679,0	619,0	1,40	1,51	1,82	1,10	0,41	83,34	79,55	76,42	76,25	71,83
2018	794,0	708,0	713,0	687,0	593,0	1,33	1,51	1,82	1,09	0,39	83,22	79,35	76,61	76,01	73,19
2019	787,0	737,0	739,0	699,0	638,0	1,39	1,48	1,77	1,17	0,48	83,55	79,35	76,62	76,78	73,04
2020	742,0	720,0	719,0	718,0	679,0	1,39	1,48	1,77	1,17	0,48	83,55	79,71	76,62	76,80	72,85
2021	743,0	727,0	720,0	699,0	698,0	1,39	1,48	1,77	1,17	0,48	83,55	79,71	76,62	76,80	72,85

ANNEX 11 Financial Hub Factors Scores (World-Bank, 2020) - Part 2

	Human Capital - Labor force w/ advanced education (% of total L. force)					***Tax Regime - Corporative Tax Rate (%)***				
	UK	***DE***	***CH***	***FR***	***IT***	***UK***	***DE***	***CH***	***FR***	***IT***
2011	0,85	0,73	0,81	0,78	0,75	26,0%	29,4%	18,3%	33,3%	31,4%
2012	0,85	0,74	0,81	0,78	0,74	24,0%	29,5%	18,1%	33,3%	31,4%
2013	0,84	0,74	0,81	0,78	0,74	23,0%	29,6%	18,0%	33,3%	31,4%
2014	0,84	0,74	0,81	0,78	0,74	21,0%	29,6%	17,9%	33,3%	31,4%
2015	0,84	0,74	0,81	0,77	0,74	20,0%	29,7%	17,9%	33,3%	31,4%
2016	0,84	0,73	0,81	0,78	0,74	20,0%	29,7%	17,9%	33,3%	31,4%
2017	0,84	0,74	0,81	0,77	0,75	19,0%	29,8%	17,8%	33,3%	24,0%
2018	0,84	0,74	0,81	0,77	0,75	19,0%	30,0%	18,0%	33,0%	24,0%
2019	0,84	0,73	0,81	0,77	0,75	19,0%	30,0%	18,0%	31,0%	24,0%
2020	0,84	0,73	0,81	0,77	0,75	19,0%	30,0%	14,8%	28,0%	24,0%
2021	0,84	0,73	0,81	0,77	0,75	19,0%	30,0%	14,8%	28,0%	24,0%

ANNEX 12 ADF Test (Baiocchi G., 2003) for Stationarity of the 10-Year Bonds Time Series

Yields 10Y	Unit Root test - Dickey-Fuller		
		WHOLE	
	No constant	**Constant**	**Constant and Trend**
DE	0,002383	0,09158	0,03053
DE(I=1)	$2,11*10^{-39}$	$6,80*10^{-36}$	$1,22*10^{-52}$
FR	0,008049	0,2044	0,29
FR(I=1)	$5,01*10^{-40}$	$2,34*10^{-37}$	$7,59*10^{-52}$
IT	0,001292	0,0314	0,1708
IT(I=1)	$1,57*10^{-39}$	$2,28*10^{-37}$	$4,93*10^{-48}$
CH	0,002236	0,05223	0,1742
CH(I=1)	$4,46*10^{-40}$	$9,05*10^{-38}$	$3,27*10^{-51}$
UK	0,04567	0,1868	0,1307
UK(I=1)	$2,58*10^{-39}$	$8,01*10^{-36}$	$1,22*10^{-52}$

ANNEX 13 ADF Test (Baiocchi G., 2003) for Stationarity of the 3-Months Bonds Time Series

Yields 3M	Unit Root test - Dickey-Fuller		
		WHOLE	
	No constant	**Constant**	**Constant and Trend**
DE	0,1638	0,02712	0,07835
DE(I=1)	$4,66*10^{-36}$	$7,61*10^{-31}$	$1,29*10^{-51}$
FR	0,09571	0,03799	0,02926
FR(I=1)	$3,05*10^{-37}$	$1,29*10^{-42}$	$6,06*10^{-58}$
IT	$7,93*10^{-5}$	0,001762	$3,06*10^{-5}$
IT(I=1)	$6,94*10^{-27}$	$2,98*10^{-28}$	$5,06*10^{-32}$
CH	0,306	0,1185	0,0911
CH(I=1)	$1,61*10^{-41}$	$4,08*10^{-50}$	$7,20*10^{-79}$
UK	0,183	0,7503	0,924
UK(I=1)	$2,61*10^{-35}$	$6,43*10^{-30}$	$2,72*10^{-51}$

ANNEX 14 ADF Test (Baiocchi G., 2003) for Stationarity of the long to short term Yields Spread Time Series

Yield Spreads		Unit Root test - Dickey-Fuller **WHOLE**	
10Y-3M Spread	**No constant**	**Constant**	**Constant and Trend**
DE	0,09819	0,4011	0,01446
DE(I=1)	$4{,}79*10^{-35}$	$3{,}37*10^{-39}$	$2{,}83*10^{-50}$
FR	0,137	0,3879	0,2066
FR(I=1)	$6{,}17*10^{-39}$	$3{,}24*10^{-35}$	$1{,}07*10^{-52}$
IT	0,2324	0,355	0,23
IT(I=1)	$5{,}70*10^{-28}$	$1{,}20*10^{-29}$	$4{,}40*10^{-34}$
CH	0,0497	0,004722	0,008986
CH(I=1)	$2{,}90*10^{-41}$	$1{,}99*10^{-49}$	$3{,}50*10^{-76}$
UK	0,04423	0,2024	0,1981
UK(I=1)	$7{,}83*10^{-39}$	$4{,}99*10^{-35}$	$1{,}06*10^{-52}$

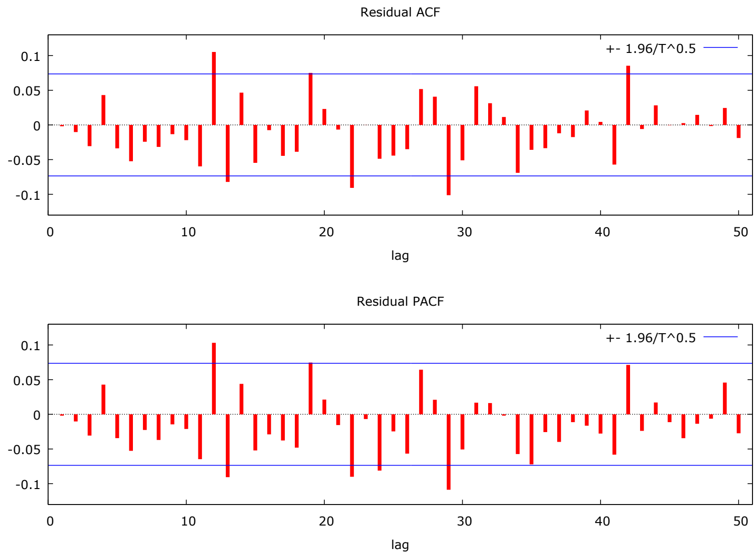
ANNEX 15 ADF Test (Baiocchi G., 2003) for Stationarity of the CDS Spread Time Series

CDS Spread 10Y			
		WHOLE	
	No constant	**Constant**	**Constant and Trend**
DE	0,183	0,06749	0,01892
DE(I=1)	$1{,}00*10^{-4}$	$1{,}00*10^{-4}$	$1{,}55*10^{-133}$
FR	0,2211	0,1056	0,08826
FR(I=1)	$1{,}30*10^{-13}$	$2{,}08*10^{-26}$	$1{,}07*10^{-137}$
IT	0,235	0,0252	$8{,}77*10^{-2}$
IT(I=1)	$4{,}58*10^{-19}$	7,17E-33	$1{,}23*10^{-134}$
GB	0,200	0,4019	0,173
GB(I=1)	$1{,}53*10^{-15}$	$5{,}16*10^{-19}$	$1{,}45*10^{-86}$

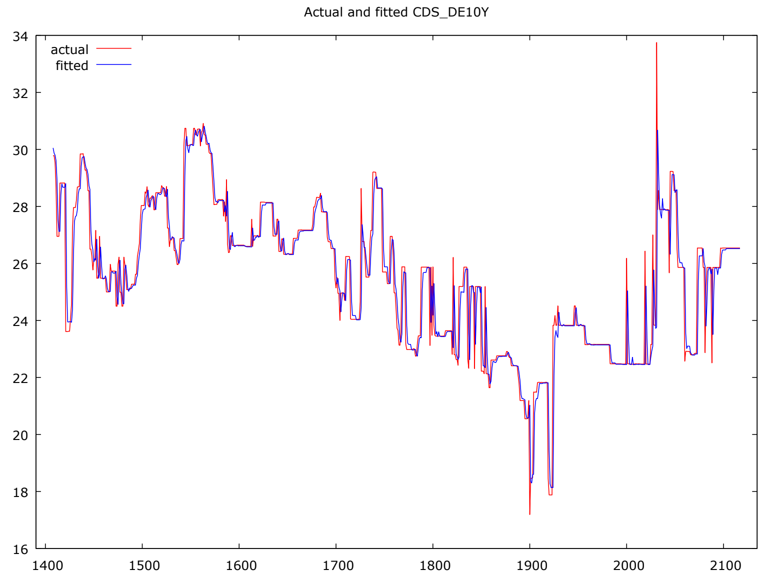
ANNEX 16 ARMA ([1;2;6],0) Model and properties (Baiocchi G., 2003) for the CDS_DE10Y Time Series using data from the Estimation Window

	Coefficient	***Std. Error***	***z***	***p-value***	
phi_1	0.696363	0.0364871	19.09	<0.0001	***
phi_2	0.234393	0.0397963	5.890	<0.0001	***
phi_6	0.0684800	0.0240311	2.850	0.0044	***
Mean dependent var	25.50274	S.D. dependent var	2.519323		
Mean of innovations	0.011610	S.D. of innovations	0.938273		
Uncentered R-squared	0.863991	Centered R-squared	0.861687		
Log-likelihood	−960.7059	Akaike criterion	1927.412		
Schwarz criterion	1941.108	Hannan-Quinn	1932.702		
	Real				
AR					
Root 1	1.0005				
Root 2	-1.6744				
Root 3	1.1554				
Root 4	1.1554				
Root 5	-0.8185				
Root 6	-0.8185				

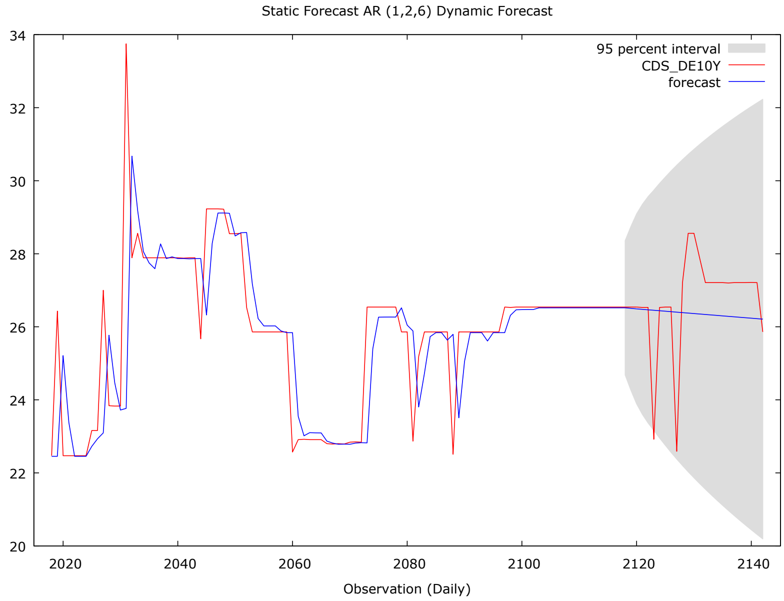
Model 20: ARMA, using observations 1408-2117 (T = 710)
Dependent variable: CDS_DE10Y



ANNEX 17 Auto-correlogram for the residuals of the fitted data using an ARMA ([1;2;6],0]) model for CDS_DE10Y in the Estimation Window



ANNEX 18 Actual and Fitted Data for CDS_DE10Y with a Static Forecast for the Event Window



ANNEX 19 Actual and Fitted Data for CDS_DE10Y with a Dynamic Forecast for the Event Window (Gray area is the 90% Confidence Interval)

ANNEX 20 ADF Test (Baiocchi G., 2003) for Stationarity of the Market Volumes (of trade) Time Series

	No Constant	Constant	Constant and Trend
UK_All	0,992	0,9978	0,1374
UK_EU	0,1056	0,02882	0,06847
UK_UK	0,09417	0,008909	0,007111
UK_World	0,919	0,9737	0,0119
EU_All	0,2434	$1,94*10^{-6}$	$2,18*10^{-5}$
EU_EU	0,239	$3,43*10^{-7}$	$3,97*10^{-6}$
EU_UK	0,104	0,03203	0,06991
EU_World	0,07149	0,007069	0,03863
DE_All	0,1145	0,01277	0,04497
DE_EU	0,1112	0,0001	0,001099
DE_UK	0,7308	0,8238	0,7897
DE_World	0,949	0,9925	0,9966
FR_All	0,8441	0,9437	0,9970
FR_EU	0,877	0,9707	0,9993
FR_UK	0,02895	0,02732	0,1003
FR_World	0,02207	0,02747	0,000306
IT_All	0,04313	$5,03*10^{-6}$	$5,79*10^{-6}$
IT_EU	0,03566	$1,63*10^{-6}$	$2,46*10^{-6}$
IT_UK	0,06652	0,1124	0,1326
IT_World	0,0873	0,2631	0,2475
CH_All	0,234	0,0001702	$1,55*10^{-5}$
CH_EU	0,2298	0,005436	$3,91*10^{-10}$
CH_UK	0,6272	0,6677	1,00
CH_World	0,4389	$6,21*10^{-5}$	$1,81*10^{-5}$

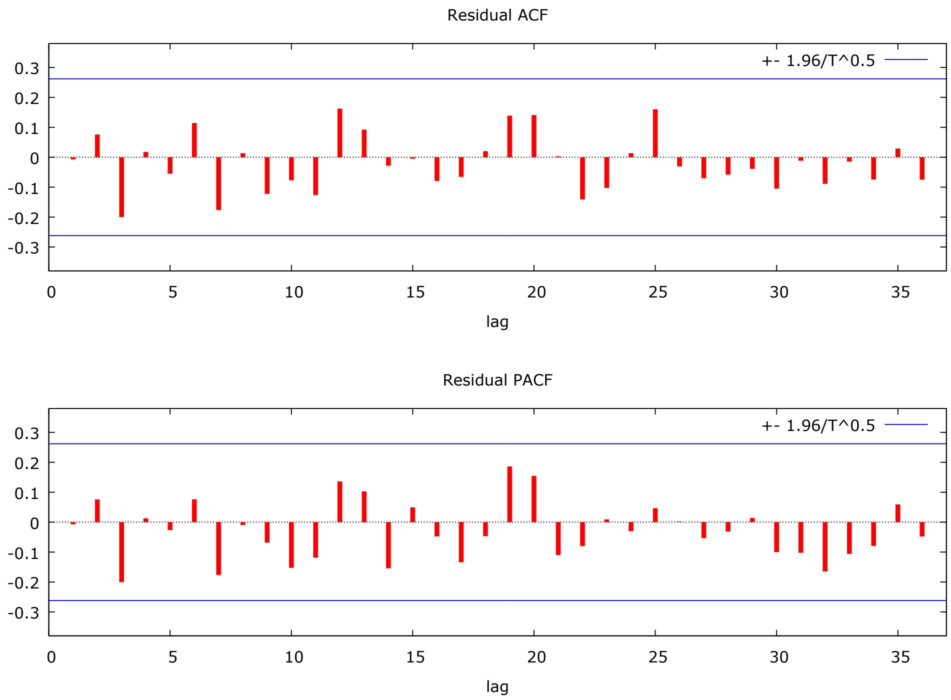
ANNEX 21 ARMA ([1;2;5],0) model and properties (Baiocchi G., 2003) for the UK_All Time Series using data from the Estimation Window

	Coefficient	*Std. Error*	*z*	*p-value*	
phi_1	0.393912	0.131695	2.991	0.0028	***
phi_2	0.266619	0.128581	2.074	0.0381	**
phi_5	0.342436	0.105115	3.258	0.0011	***

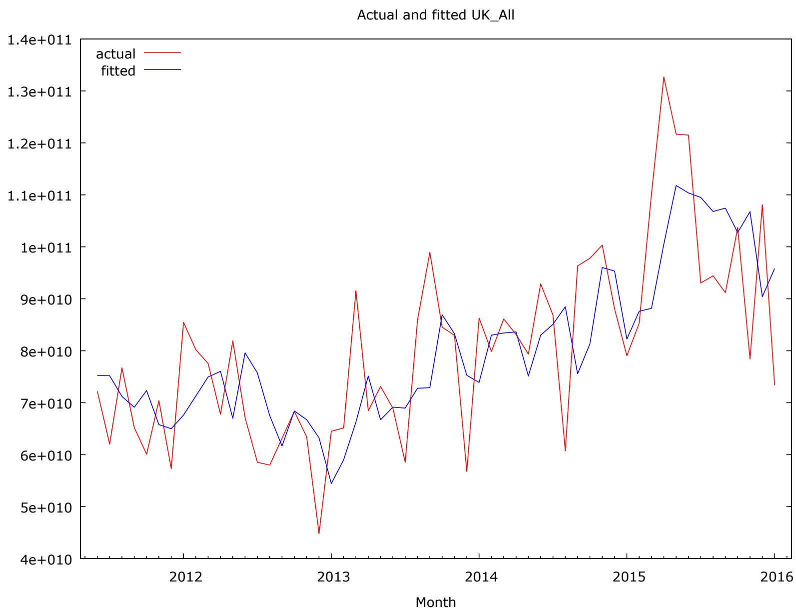
Mean dependent var	8.05 * 10 10	S.D. dependent var	1.81 * 10 10
Mean of innovations	3.85 * 10 08	S.D. of innovations	1.38 * 10 10
Uncentered R-squared	0.451725	Centered R-squared	0.436540
Log-likelihood	−1385.479	Akaike criterion	2776.958
Schwarz criterion	2783.034	Hannan-Quinn	2779.314

	Real	*Imaginary*	*Modulus*	*Frequency*
AR				
Root 1	0.9989	0.0000	0.9989	0.0000
Root 2	-1.0670	-0.7423	1.2998	-0.4033
Root 3	-1.0670	0.7423	1.2998	0.4033
Root 4	0.5675	-1.1868	1.3155	-0.1790
Root 5	0.5675	1.1868	1.3155	0.1790

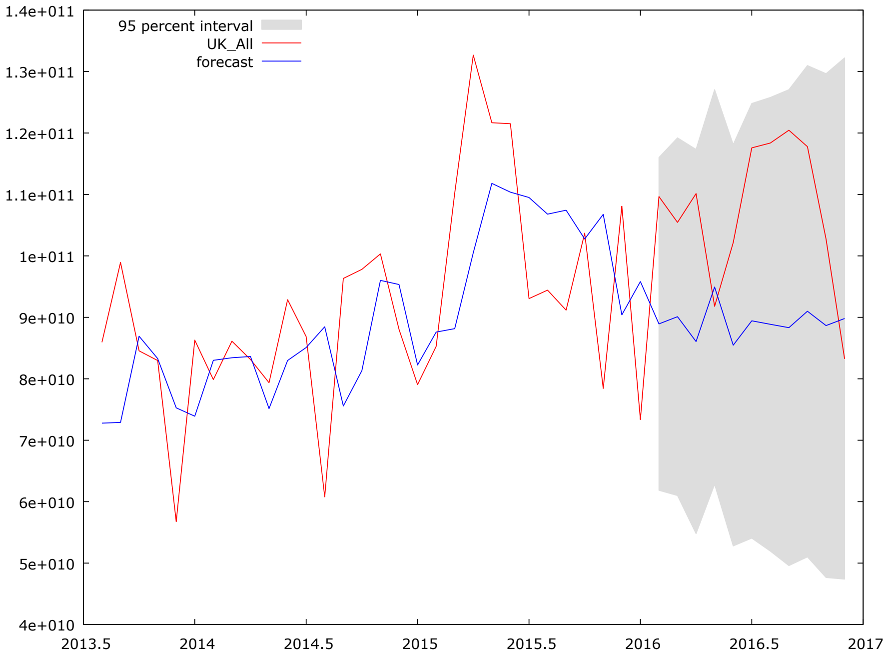
Model 154: ARMA, using observations 2011:06-2016:01 (T = 56)
Dependent variable: UK_All



ANNEX 22 Auto-correlogram for the residuals of the fitted data using an ARMA ([1;2;5],0) model for UK_All in the Estimation Window



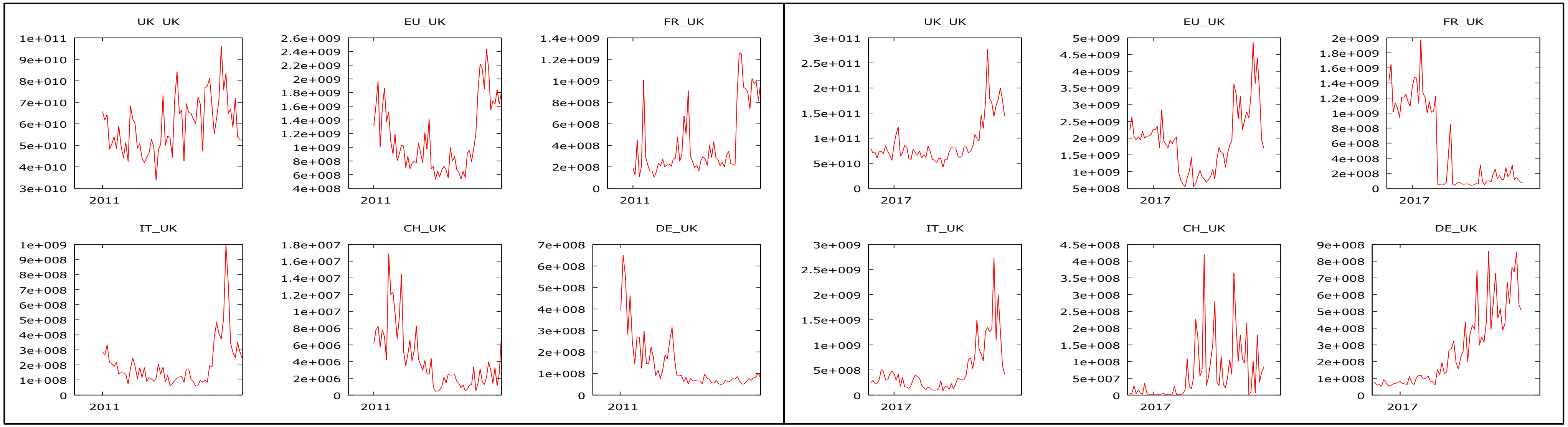
ANNEX 23 Actual and Fitted Data for UK_All during Estimation Window



ANNEX 24 Actual and Fitted Data for UK_All with a Dynamic Forecast for the Event Window

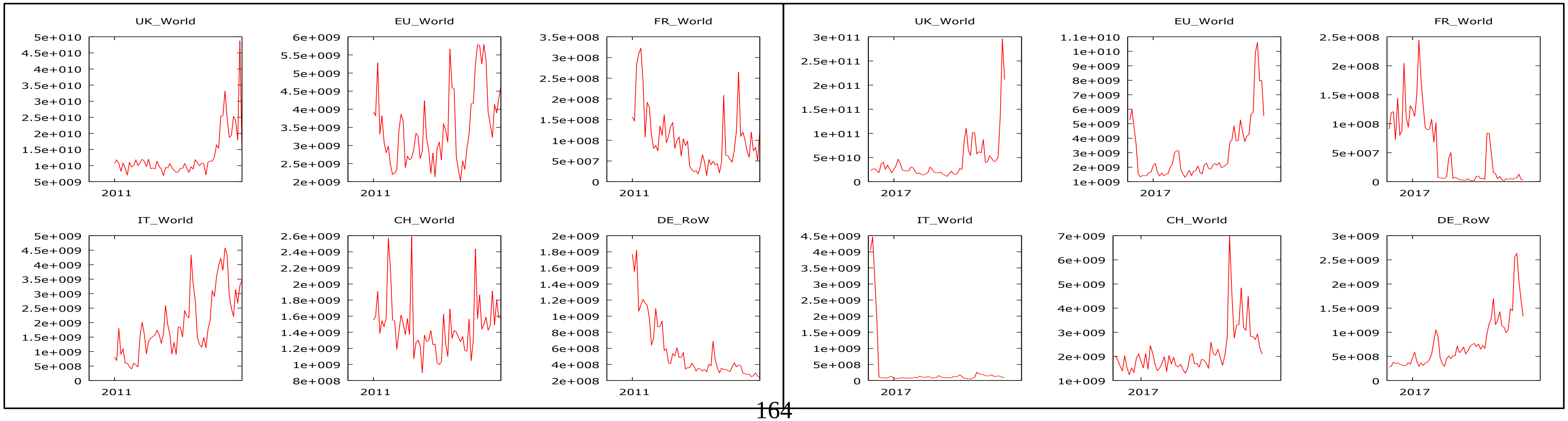
UK

Pre-Brexit **Post-Brexit**

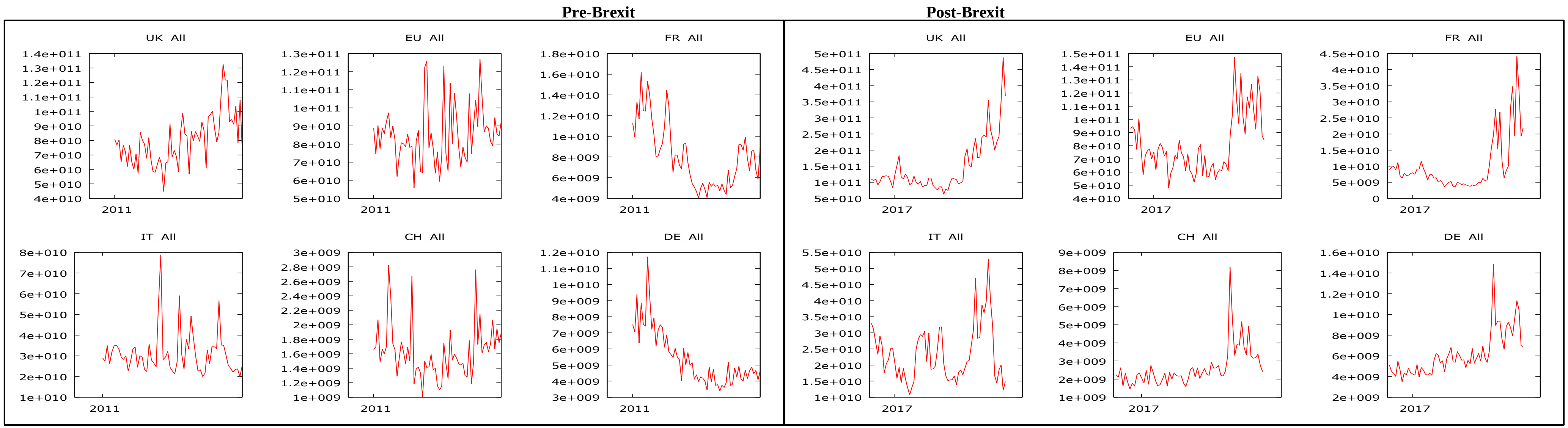


RoW

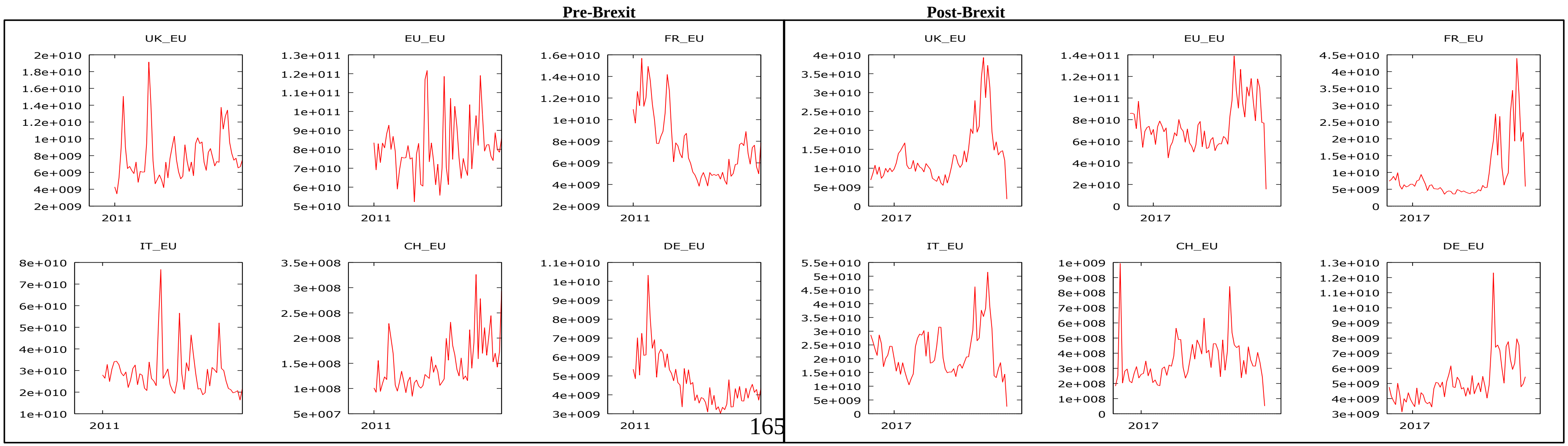
Pre-Brexit **Post-Brexit**



All



EU



ANNEX 26 Market Volumes for UK Contracts and for RoW Contracts

ANNEX 27 Market Volumes Time Series (Reuters, 2021) Descriptive Statistical Properties Before and After Brexit Announcement

		Pre-Brexit							Post-Brexit						
		Mean	**SD**	**CV**	**Max**	**Min**	**ACF**	**PACF**	**Mean**	**SD**	**CV**	**Max**	**Min**	**ACF**	**PACF**
London	**All**	8,0E+10	1,7E+10	0,22	1,3E+11	4,5E+10	8	2	1,5E+11	8,3E+10	0,56	4,9E+11	6,3E+10	10	1
	EU	7,9E+09	2,9E+09	0,37	1,9E+10	3,5E+09	1	2	1,3E+10	7,4E+09	0,55	3,9E+10	5,5E+09	7	1
	UK	5,9E+10	1,3E+10	0,21	9,6E+10	3,4E+10	2	1	9,2E+10	4,5E+10	0,49	2,8E+11	4,2E+10	8	1
	RoW	1,3E+10	7,1E+09	0,56	4,9E+10	6,9E+09	8	2	4,3E+10	4,7E+10	1,08	3,0E+11	1,1E+10	2	3
Frankfurt	**All**	5,4E+09	1,7E+09	0,32	1,2E+10	3,4E+09	12	2	6,2E+09	2,1E+09	0,34	1,5E+10	3,5E+09	12	1
	EU	4,7E+09	1,4E+09	0,29	1,0E+10	3,0E+09	12	2	5,1E+09	1,5E+09	0,30	1,2E+10	3,1E+09	8	1
	UK	1,4E+08	1,2E+08	0,90	6,5E+08	4,8E+07	9	1	2,7E+08	2,3E+08	0,85	8,6E+08	5,4E+07	15	2
	RoW	5,7E+08	3,8E+08	0,66	1,8E+09	2,4E+08	11	1	7,8E+08	5,3E+08	0,67	2,6E+09	2,8E+08	13	1
Zurich	**All**	1,6E+09	3,7E+08	0,23	2,8E+09	1,0E+09			2,6E+09	1,1E+09	0,41	8,2E+09	1,5E+09	8	1
	EU	1,5E+08	5,2E+07	0,35	3,3E+08	8,5E+07	3	2	3,6E+08	1,5E+08	0,40	9,9E+08	1,8E+08		
	UK	4,1E+06	3,6E+06	0,87	1,7E+07	4,4E+05	11	3	6,5E+07	9,0E+07	1,38	4,2E+08	6,7E+05	5	1
	RoW	1,5E+09	3,4E+08	0,23	2,6E+09	9,0E+08			2,2E+09	9,8E+08	0,45	7,0E+09	1,2E+09	8	1
Paris	**All**	8,1E+09	3,1E+09	0,38	1,6E+10	4,0E+09	12	1	1,0E+10	8,5E+09	0,84	4,4E+10	3,6E+09	11	1
	EU	7,6E+09	3,0E+09	0,40	1,6E+10	3,8E+09	12	1	9,6E+09	8,6E+09	0,90	4,4E+10	3,5E+09	11	1
	UK	4,2E+08	3,2E+08	0,76	1,3E+09	1,0E+08	7	1	5,3E+08	5,6E+08	1,06	2,0E+09	4,0E+07	15	1
	RoW	1,0E+08	7,1E+07	0,69	3,2E+08	1,5E+07	4	1	5,1E+07	6,0E+07	1,17	2,4E+08	1,7E+06	11	1
Milan	**All**	3,1E+10	1,0E+10	0,33	7,9E+10	2,0E+10	1	1	2,3E+10	8,7E+09	0,37	5,3E+10	1,1E+10	3	1
	EU	2,9E+10	1,0E+10	0,35	7,7E+10	1,6E+10	1	1	2,3E+10	8,4E+09	0,37	5,1E+10	1,1E+10	3	1
	UK	2,1E+08	1,6E+08	0,79	9,9E+08	6,0E+07	5	1	5,0E+08	5,0E+08	1,00	2,7E+09	8,7E+07	10	2
	RoW	2,0E+09	1,1E+09	0,56	4,6E+09	4,0E+08	7	1	3,2E+08	8,4E+08	2,66	4,5E+09	5,0E+07	2	2
EU	**All**	8,5E+10	1,6E+10	0,19	1,3E+11	5,6E+10	0		8,0E+10	2,2E+10	0,28	1,5E+11	4,8E+10	8	1
	EU	8,0E+10	1,5E+10	0,19	1,2E+11	5,2E+10	0	0	7,5E+10	2,0E+10	0,27	1,4E+11	4,5E+10	8	1
	UK	1,1E+09	5,0E+08	0,44	2,4E+09	5,3E+08	6	2	1,9E+09	9,5E+08	0,50	4,9E+09	5,5E+08	10	1
	RoW	3,5E+09	1,0E+09	0,30	5,8E+09	2,0E+09	3	1	3,1E+09	2,1E+09	0,68	1,1E+10	1,3E+09	10	2

ANNEX 28 Pre-Brexit Announcement AR (1) model with constant (m0) and trend (m1) for Market Volumes Time Series- Mean and 95% confidence range for model coefficients (Baiocchi G., 2003)

		Pre-Brexit									**White Noise Residual**
		m0			**m1(Trend)**			**phi1**			
		Value	***95% C.I - Range***		***Value***	***95% C.I - Range***		***Value***	***95% C.I - Range***		
London	All	4,0E+10	*2,4E+10*	*5,7E+10*	4,0E+08	*1,5E+08*	*6,5E+08*	3,4E-01	*9,5E-02*	*5,9E-01*	YES
	EU	3,5E+09	*1,5E+09*	*5,4E+09*	9,4E+06	*-2,7E+07*	*4,6E+07*	5,3E-01	*3,1E-01*	*7,5E-01*	YES (*12)
	UK	3,3E+10	*1,9E+10*	*4,6E+10*	2,3E+08	*5,5E+07*	*4,1E+08*	3,2E-01	*7,9E-02*	*5,7E-01*	YES
	RoW	3,6E+09	*3,8E+08*	*6,8E+09*	1,6E+08	*5,8E+07*	*2,6E+08*	3,3E-01	*8,7E-02*	*5,8E-01*	YES
Frankfurt	All	4,3E+09	*2,4E+09*	*6,3E+09*	-4,1E+07	*-6,5E+07*	*-1,8E+07*	4,4E-01	*2,0E-01*	*6,7E-01*	YES (*6)
	EU	3,8E+09	*2,2E+09*	*5,4E+09*	-3,2E+00	*-5,1E+07*	*-1,3E+07*	4,1E-01	*1,7E-01*	*6,5E-01*	YES
	UK	1,1E+08	*3,4E+07*	*1,8E+08*	-1,7E+06	*-3,2E+06*	*-2,4E+05*	5,9E-01	*3,8E-01*	*8,0E-01*	NO(*3;6)
	RoW	2,7E+08	*8,0E+07*	*4,6E+08*	-3,8E+06	*-7,1E+06*	*-3,9E+05*	6,9E-01	*5,4E-01*	*8,5E-01*	YES
Zurich	All	1,6E+09	*1,4E+09*	*1,9E+09*	2,4E+05	*-6,2E+06*	*6,7E+11*	2,3E-01	*-1,3E-02*	*4,7E-01*	YES
	EU	1,0E+08	*7,4E+07*	*1,3E+08*	1,6E+06	*8,9E+05*	*2,4E+06*	1,8E-01	*-7,2E-02*	*4,4E-01*	YES
	UK	4,2E+06	*1,7E+06*	*6,6E+06*	-6,5E+04	*-1,2E+05*	*-1,5E+04*	4,9E-01	*2,4E-01*	*7,3E-01*	YES
	RoW	1,2E+09	*7,7E+08*	*1,6E+09*	-9,3E+05	*-5,9E+06*	*4,1E+06*	2,1E-01	*-4,5E-02*	*4,6E-01*	YES
Paris	All	2,4E+09	*1,7E+08*	*4,5E+09*	-1,8E+07	*-4,8E+07*	*1,3E+07*	7,7E-01	*6,0E-01*	*9,5E-01*	YES
	EU	2,6E+09	*4,2E+08*	*4,9E+09*	-2,4E+07	*-5,5E+07*	*7,9E+06*	7,4E-01	*5,6E-01*	*9,3E-01*	YES
	UK	3,3E+07	*-8,0E+07*	*1,5E+08*	4,5E+06	*7,3E+05*	*8,2E+06*	6,1E-01	*4,1E-01*	*8,2E-01*	YES
	RoW	6,0E+07	*1,6E+07*	*1,0E+08*	-6,2E+05	*-1,5E+06*	*2,4E+05*	6,0E-01	*3,9E-01*	*8,1E-01*	YES
Milan	All	2,3E+10	*1,3E+10*	*3,2E+10*	-3,1E+07	*-1,8E+08*	*1,2E+08*	3,0E-01	*5,6E-02*	*5,5E-01*	YES
	EU	2,3E+10	*1,3E+10*	*3,2E+10*	-6,8E+07	*-2,1E+08*	*7,7E+07*	2,9E-01	*3,8E-02*	*5,4E-01*	YES
	UK	1,8E+07	*-3,8E+07*	*7,4E+07*	1,1E+06	*-5,1E+05*	*2,7E+06*	7,4E-01	*5,7E-01*	*9,1E-01*	YES
	RoW	2,0E+08	*-1,2E+08*	*5,2E+08*	1,8E+07	*5,3E+06*	*3,1E+07*	6,3E-01	*4,3E-01*	*8,3E-01*	YES (*9)
EU	All	7,0E+10	*4,8E+10*	*9,3E+10*	1,6E+08	*-7,8E+07*	*3,9E+08*	1,2E-01	*-1,4E-01*	*3,7E-01*	NO (*10;12)
	EU	7,0E+10	*4,8E+10*	*9,1E+10*	1,3E+08	*-9,5E+07*	*3,6E+08*	8,4E-02	*-1,7E-01*	*3,4E-01*	NO(*4;10;12)
	UK	1,5E+08	*-6,5E+07*	*3,6E+08*	2,7E+06	*-1,8E+06*	*7,2E+06*	8,0E-01	*6,4E-01*	*9,6E-01*	YES
	RoW	8,8E+08	*2,3E+08*	*1,5E+09*	1,1E+07	*-8,2E+05*	*2,2E+07*	6,5E-01	*4,6E-01*	*8,5E-01*	NO(*9;12)

		Post-Brexit									**White Noise Residuals**
		m0			**m1(Trend)**			**Phi1**			
		Value	***95% C.I - Range***		***Value***	***95% C.I - Range***		***Value***	***95% C.I - Range***		
London	All	-3,8E+10	*-9,2E+10*	*1,5E+10*	7,6E+08	*6,6E+07*	*1,5E+09*	0,805	*0,641*	*0,969*	YES(*7)
	EU	-4,9E+08	*-5,4E+09*	*4,5E+09*	3,3E+07	*-2,8E+07*	*9,5E+07*	0,810	*0,656*	*0,964*	YES(*3)
	UK	-1,21E+10	*-4,4E+10*	*2,0E+10*	4,0E+08	*-5,2E+06*	*8,0E+08*	0,737	*0,567*	*0,906*	YES
	RoW	-3,0E+10	*-6,9E+10*	*7,8E+09*	4,5E+08	*1,7E+07*	*8,9E+08*	0,777	*0,583*	*0,972*	YES
Frankfurt	All	-9,0E+08	*-2,6E+09*	*7,6E+08*	4,6E+07	*2,0E+07*	*7,2E+07*	0,451	*0,224*	*0,678*	YES(*13)
	EU	2,4E+08	*-1,1E+09*	*1,6E+09*	2,9E+07	*1,0E+07*	*4,8E+07*	0,420	*0,188*	*0,652*	YES(*13)
	UK	-5,5E+08	*-7,7E+08*	*-3,2E+08*	8,0E+06	*5,0E+06*	*1,1E+07*	0,252	*0,011*	*0,493*	NO(*5;8;10;13)
	RoW	-3,5E+08	*-7,2E+08*	*8,2E+06*	6,2E+06	*1,3E+06*	*1,1E+07*	0,729	*0,557*	*0,900*	YES(*4)
Zurich	All	-2,3E+08	*-1,3E+09*	*8,1E+08*	1,9E+07	*5,1E+06*	*3,2E+07*	0,424	*0,193*	*0,656*	YES(*13)
	EU	1,5E+08	*-3,1E+07*	*3,3E+08*	1,7E+06	*-3,0E+05*	*3,6E+06*	0,145	*-0,106*	*0,397*	YES
	UK	-1,2E+08	*-2,3E+08*	*-1,3E+07*	1,9E+06	*7,0E+05*	*3,1E+06*	0,118	*-0,132*	*0,368*	YES(*7)
	RoW	-2,5E+08	*-1,2E+09*	*7,0E+08*	1,5E+07	*3,5E+06*	*2,7E+07*	0,455	*0,228*	*0,682*	NO(*5;8;13)
Paris	All	-4,7E+09	*-1,2E+10*	*2,6E+09*	8,8E+07	*4,3E+06*	*1,7E+08*	0,665	*0,479*	*0,852*	NO(*3;8;16)
	EU	-5,9E+09	*-1,3E+10*	*1,5E+09*	1,0E+08	*1,4E+07*	*1,9E+08*	0,652	*0,463*	*0,841*	NO(*3;8)
	UK	8,8E+08	*2,7E+08*	*1,5E+09*	-7,6E+06	*-1,3E+07*	*-2,1E+06*	0,680	*0,496*	*0,864*	YES(*14)

	RoW	9,8E+07	*3,0E+07*	*1,7E+08*	-8,6E+05	*-1,5E+06*	*-2,2E+05*	0,622	*0,424*	*0,819*	YES
Milan	All	5,0E+09	*-3,1E+09*	*1,3E+10*	1,1E+07	*-7,0E+07*	*9,2E+07*	0,735	*0,561*	*0,909*	YES
	EU	5,4E+09	*-2,7E+09*	*1,3E+10*	1,1E+07	*-7,0E+07*	*9,2E+07*	0,715	*0,534*	*0,895*	YES
	UK	-3,7E+08	*-8,4E+08*	*1,0E+08*	6,1E+06	*6,0E+05*	*1,2E+07*	0,593	*0,387*	*0,800*	YES
	RoW	-1,1E+08	*-5,4E+08*	*3,3E+08*	1,1E+06	*-3,3E+06*	*5,6E+06*	0,857	*0,767*	*0,947*	NO(*1;2;3;4;6)
EU	All	1,0E+10	*-1,0E+10*	*3,1E+10*	1,9E+08	*-3,3E+07*	*4,1E+08*	0,649	*0,462*	*0,836*	YES(*8)
	EU	1,3E+10	*-7,4E+09*	*3,3E+10*	1,8E+08	*-3,5E+07*	*3,9E+08*	0,609	*0,413*	*0,805*	YES(*3)
	UK	1,5E+08	*-5,5E+08*	*8,5E+08*	2,3E+06	*-5,3E+06*	*9,9E+06*	0,807	*0,658*	*0,956*	YES
	RoW	-8,8E+08	*-2,0E+09*	*2,6E+08*	1,5E+07	*1,2E+06*	*2,8E+07*	0,842	*0,721*	*0,963*	YES(*4)

ANNEX 29 Pre-Brexit Announcement AR (1) model with constant (m0) for Market Volumes Time Series - Mean and 95% confidence range for model coefficients (Baiocchi G., 2003)

		Pre-Brexit						**Lag of Significant Residuals**
		m0 (cte)			**phi1**			
		Value	**95% C.I. Range**		**Value**	**95% C.I. Range**		
London	All	3,28E+10	1,57E+10	4,99E+10	0,59	0,38	0,80	0
	EU	3,68E+09	1,90E+09	5,46E+09	0,54	0,33	0,75	12
	UK	3,08E+10	1,70E+10	4,45E+10	0,48	0,25	0,71	5
	RoW	5,69E+09	2,56E+09	8,82E+09	0,56	0,35	0,77	0
Frankfurt	All	1,27E+09	3,34E+08	2,20E+09	0,76	0,60	0,92	1
	EU	1,44E+09	5,27E+08	2,35E+09	0,69	0,51	0,88	1;3
	UK	2,90E+07	-7,22E+04	5,80E+07	0,76	0,60	0,91	1;2;3;6;9
	RoW	7,12E+07	3,81E+06	1,38E+08	0,83	0,73	0,93	1
Zurich	All	1,25E+09	8,31E+08	1,67E+09	0,23	-0,02	0,48	0
	EU	8,77E+07	4,88E+07	1,27E+08	0,43	0,18	0,68	2;5;7;12
	UK	1,22E+06	2,22E+05	2,22E+06	0,70	0,52	0,89	0
	RoW	1,16E+09	7,79E+08	1,54E+09	0,21	-0,04	0,46	0
Paris	All	1,29E+09	1,01E+08	2,47E+09	0,84	0,70	0,97	0
	EU	1,19E+09	7,80E+07	2,29E+09	0,84	0,70	0,97	0
	UK	1,16E+08	2,35E+07	2,08E+08	0,75	0,57	0,93	0
	RoW	3,31E+07	9,59E+06	5,66E+07	0,67	0,48	0,86	0
Milan	All	2,16E+10	1,35E+10	2,96E+10	0,31	0,06	0,55	0
	EU	2,01E+10	1,26E+10	2,77E+10	0,30	0,06	0,55	0
	UK	4,39E+07	2,05E+06	8,57E+07	0,78	0,62	0,94	0
	RoW	3,54E+08	3,69E+07	6,71E+08	0,84	0,70	0,98	12
EU	All	7,28E+10	5,07E+10	9,48E+10	0,14	-0,11	0,40	12
	EU	7,19E+10	5,09E+10	9,29E+10	0,11	-0,15	0,36	12
	UK	2,10E+08	2,17E+07	3,99E+08	0,82	0,67	0,97	12
	RoW	9,73E+08	3,18E+08	1,63E+09	0,72	0,54	0,90	12

ANNEX 30 Post-Brexit Announcement AR (1) model with constant (m0) for Market Volumes Time Series - Mean and 95% confidence range for model coefficients (Baiocchi G., 2003)

		Post-Brexit						Lag Significant Residuals
		m0 (cte)			phi1			
		Value	95% C.I. Range		Value	95% C.I. Range		
London	All	1,58E+10	-5,06E+09	3,67E+10	0,9222	0,794756	1,04956	7
	EU	1,98E+09	5,40E+07	3,90E+09	0,8578	0,732244	0,983428	3
	UK	1,61E+10	2,20E+09	3,00E+10	0,8376	0,699087	0,976076	0
	RoW	8,04E+09	-1,98E+09	1,81E+10	0,877	0,703479	1,05058	0
Frankfurt	All	1,52E+09	4,74E+08	2,56E+09	0,7579	0,596807	0,919071	0
	EU	1,78E+09	7,84E+08	2,78E+09	0,6524	0,464434	0,840381	0
	UK	5,80E+07	5,92E+06	1,10E+08	0,8074	0,659351	0,955496	1;4;5;6;10
	RoW	9,07E+07	-8,43E+06	1,90E+08	0,9038	0,796862	1,01068	4
Zurich	All	1,01E+09	4,62E+08	1,56E+09	0,6145	0,419179	0,80984	5;8
	EU	2,84E+08	1,90E+08	3,79E+08	0,2071	-0,0373224	0,451443	0
	UK	4,58E+07	1,99E+07	7,18E+07	0,3007	0,0641098	0,53738	3
	RoW	8,30E+08	3,67E+08	1,29E+09	0,6236	0,429897	0,817227	5;8
Paris	All	2,60E+09	4,20E+08	4,78E+09	0,7596	0,591799	0,927456	3;8
	EU	2,38E+09	2,97E+08	4,46E+09	0,7696	0,604245	0,934885	3;8
	UK	5,19E+07	-4,09E+07	1,45E+08	0,879	0,760075	0,997919	7
	RoW	7,79E+06	-3,41E+06	1,90E+07	0,8165	0,675667	0,957238	0
Milan	All	5,99E+09	1,71E+09	1,03E+10	0,7392	0,568779	0,909607	0
	EU	6,27E+09	2,02E+09	1,05E+10	0,7192	0,543555	0,894925	0
	UK	1,35E+08	1,68E+07	2,52E+08	0,7322	0,56327	0,90103	1;2
	RoW	3,84E+06	-7,57E+07	8,34E+07	0,847	0,766705	0,927355	1;3;4
EU	All	2,29E+10	8,45E+09	3,74E+10	0,7132	0,539405	0,886926	3;8
	EU	2,47E+10	1,04E+10	3,91E+10	0,6706	0,486668	0,854568	3;8
	UK	3,41E+08	3,87E+07	6,44E+08	0,8197	0,677065	0,962423	0
	RoW	2,94E+08	-1,03E+08	6,90E+08	0,9082	0,800069	1,01633	0

ANNEX 31 Correlation Matrices for Market Volumes Before and After Brexit Announcement - Correlation of Time Series of each Financial Hub (Baiocchi G., 2003)

Correlation Matrix / By Financial Hub (Pre-Brexit)

	UK_All	UK_EU	UK_UK	UK_RoW
UK_All	1	0,4186	0,8935	0,6952
UK_EU		1	0,2031	0,2594
UK_UK			1	0,3352
UK_RoW				1

	CH_All	CH_EU	CH_UK	CH_RoW
CH_All	1	0,5326	0,3682	0,992
CH_EU		1	-0,0425	0,4217
CH_UK			1	0,3924
CH_RoW				1

	FR_All	FR_EU	FR_UK	FR_RoW
FR_All	1	0,9939	0,0389	0,7287
FR_EU		1	-0,0704	0,702
FR_UK			1	0,1335
FR_RoW				1

	DE_All	DE_EU	DE_UK	DE_RoW
DE_All	1	0,9764	0,7078	0,7929
DE_EU		1	0,566	0,6459
DE_UK			1	0,8518
DE_RoW				1

	IT_All	IT_EU	IT_UK	IT_RoW
IT_All	1	0,9931	0,0537	0,2377
IT_EU		1	-0,027	0,1232
IT_UK			1	0,5988
IT_RoW				1

Correlation Matrix / By Financial Hub (Post-Brexit)

	UK_All	UK_EU	UK_UK	UK_RoW
UK_All	1	0,6189	0,8701	0,8495
UK_EU		1	0,6771	0,2958
UK_UK			1	0,4855
UK_RoW				1

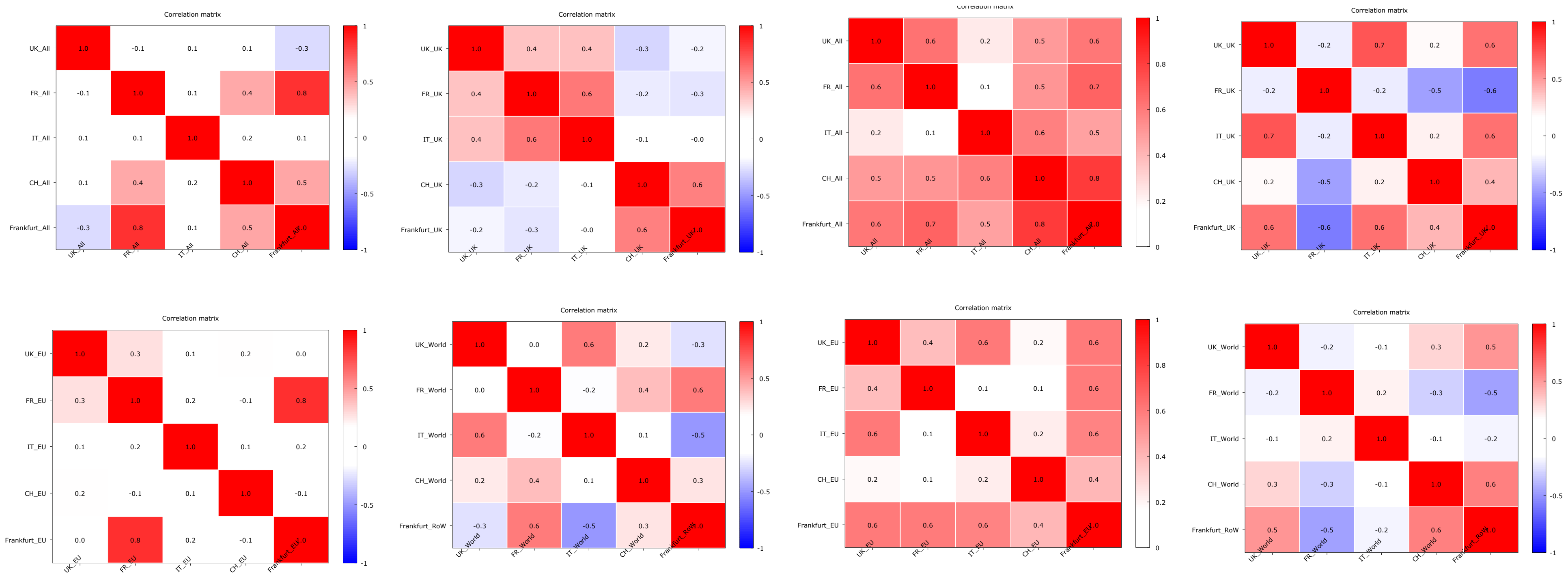
	CH_All	CH_EU	CH_UK	CH_RoW
CH_All	1	0,4927	0,516	0,9862
CH_EU		1	0,422	0,3583
CH_UK			1	0,4168
CH_RoW				1

	FR_All	FR_EU	FR_UK	FR_RoW
FR_All	1	0,9975	-0,1261	-0,1455
FR_EU		1	-0,196	-0,2074
FR_UK			1	0,8686
FR_RoW				1

	DE_All	DE_EU	DE_UK	DE_RoW
DE_All	1	0,9703	0,8648	0,8355
DE_EU		1	0,7508	0,683
DE_UK			1	0,8634
DE_RoW				1

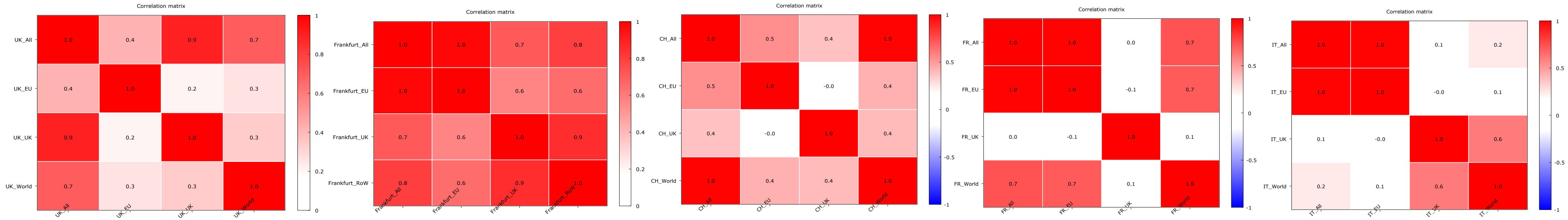
	IT_All	IT_EU	IT_UK	IT_RoW
IT_All	1	0,9945	0,2812	0,1973
IT_EU		1	0,2408	0,1097
IT_UK			1	-0,0986
IT_RoW				1

Pre-Brexit **Post-Brexit**

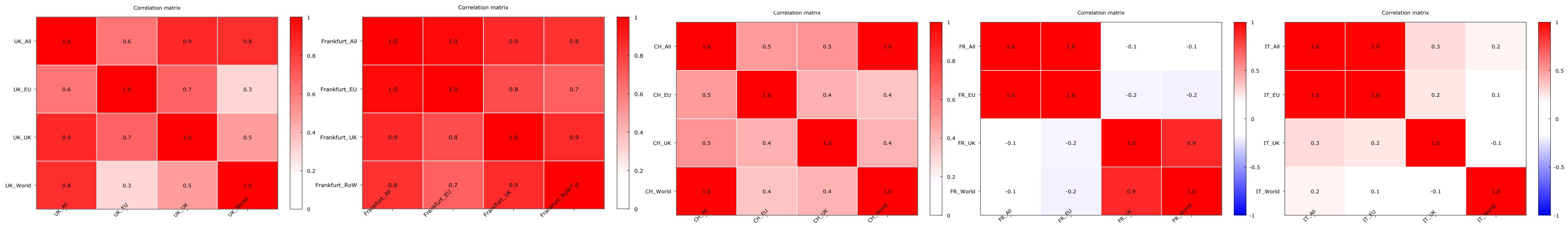


ANNEX 32 Correlation Matrices for Market Volumes Before and After Brexit Announcement - Correlation of Time Series by Origin of contracts

Pre-Brexit



Post-Brexit



ANNEX 33 Correlation Matrices for Market Volumes Before and After Brexit Announcement - Correlation of Time Series of each Financial Hub

ANNEX 34 Correlation Matrices for Market Volumes Before and After Brexit Announcement - Correlation of Time Series by Origin of contracts (Baiocchi G., 2003)

Correlation Matrix / By Origin of Contracts (Pre-Brexit)					
	UK_All	FR_All	IT_All	CH_All	DE_All
UK_All	1	-0,132	0,065	0,1354	-0,2855
FR_All		1	0,1322	0,4465	0,8399
IT_All			1	0,1505	0,084
CH_All				1	0,4566
DE_All					1
	UK_EU	FR_EU	IT_EU	CH_EU	DE_EU
UK_EU	1	0,2667	0,1241	0,1695	0,0151
FR_EU		1	0,1564	-0,1244	0,8476
IT_EU			1	0,0809	0,1506
CH_EU				1	-0,056
DE_EU					1
	UK_UK	FR_UK	IT_UK	CH_UK	DE_UK
UK_UK	1	0,3625	0,3676	-0,3011	-0,1998
FR_UK		1	0,6082	-0,2302	-0,2512
IT_UK			1	-0,0506	-0,0084
CH_UK				1	0,5828
DE_UK					1
	UK_RoW	FR_RoW	IT_World	CH_World	DE_RoW
UK_World	1	0,0036	0,5979	0,2365	-0,2658
FR_World		1	-0,1722	0,3816	0,5993
IT_World			1	0,0805	-0,5073
CH_World				1	0,2538
DE_RoW					1

Correlation Matrix / By Origin of Contracts (Post-Brexit)					
	UK_All	FR_All	IT_All	CH_All	DE_All
UK_All	1	0,6262	0,2309	0,4929	0,6084
FR_All		1	0,0962	0,5109	0,6763
IT_All			1	0,5784	0,4699
CH_All				1	0,8083
DE_All					1
	UK_EU	FR_EU	IT_EU	CH_EU	DE_EU
UK_EU	1	0,3803	0,6035	0,1836	0,5977
FR_EU		1	0,0654	0,1298	0,5955
IT_EU			1	0,2198	0,5695
CH_EU				1	0,3984
DE_EU					1
	UK_UK	FR_UK	IT_UK	CH_UK	DE_UK
UK_UK	1	-0,2197	0,722	0,1803	0,6262

FR_UK		1	-0,2254	-0,4757	-0,5914
IT_UK			1	0,2092	0,6292
CH_UK				1	0,4006
DE_UK					1
	UK_RoW	**FR_RoW**	**IT_RoW**	**CH_RoW**	**DE_RoW**
UK_World	1	-0,2039	-0,0963	0,3012	0,5107
FR_World		1	0,2035	-0,3176	-0,4699
IT_World			1	-0,0777	-0,1993
CH_World				1	0,5791
DE_RoW					1