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Ansgar Belke

Irina Dubova

Thomas Osowski

Policy Uncertainty and International Financial Markets: The Case of Brexit

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Vogelpothsweg 87, 44227 Dortmund, Germany

Universität Duisburg-Essen, Department of Economics
Universitätsstr. 12, 45117 Essen, Germany

RWI Leibniz-Institut für Wirtschaftsforschung
Hohenzollernstr. 1-3, 45128 Essen, Germany

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Ansgar Belke, Irina Dubova, and Thomas Osowski[1]

Policy Uncertainty and International Financial Markets: The Case of Brexit

Abstract

This study assesses the impact of the uncertainty caused by Brexit, on both the UK and international financial markets, for the first and second statistical moments (i.e. on changes and the standard deviations of the respective variables.) As financial markets are by nature highly interlinked, one might expect that the uncertainty engendered by Brexit also has an impact on financial markets in several other countries. By analysing the impact of Brexit on financial markets, we might also gain some insights into market expectations about the magnitude of the economic impact beyond the UK and which other country might be most affected. For this purpose, we first use both the Diebold and Yilmaz (2012) and the Hafner and Herwartz (2008) method to estimate the time-varying interactions between UK policy uncertainty, which to a large extent is attributed to uncertainty about Brexit, and UK financial market volatilities (second statistical moment) and try to identify the direction of causality among them. Second, we use two other measures of the perceived probability of Brexit before the referendum, namely daily data released by Betfair and results of polls published by Bloomberg. Based on these datasets, and using both panel and single-country SUR (seemingly unrelated regressions) estimation methods, we analyse the Brexit effect on levels of stock returns, sovereign credit default swaps (CDS), 10-year interest rates in 19 predominantly European countries, and those of the British pound and the euro (first statistical moment). We show that Brexit-induced policy uncertainty will continue to cause instability in key financial markets and has the potential to damage the real economy in both the UK and other European countries, even in the medium run. The main losers outside the UK are the 'GIIPS' economies: Greece, Ireland, Italy, Portugal and Spain.

JEL Classification: C58, D81, E44, F36, G15

Keywords: Brexit; causality tests; financial instability; Pound sterling; uncertainty; spillovers

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1 Ansgar Belke, UDE, Centre for European Policy Studies (CEPS), Brussels, and Institute for the Study of Labor (IZA), Bonn; Irina Dubova, RGS Econ and UDE; Thomas Osowski, UDE. – All correspondence to: Thomas Osowski, University of Duisburg-Essen, Universitätsstraße 12, 45117 Essen, Germany, e-mail: thomas.osowski@uni-due.de

Introduction

The majority of the British citizens has decided that the UK will leave the European Union (EU) in the near future. Although the result was very close, the supporters of the leave campaign led by Boris Johnson and Nigel Farage have succeeded. However, it could be seen as a political disaster for the EU as the first country ever is going to actually leave. Several institutions, academics, and politicians have warned of negative economic effects for the UK and the European countries alike, arguing that Britain leaving the EU would generate a "lose-lose" situation.[2]

As Brexit can surely be regarded as the most significant political issue in the first half of 2016, poll updates, as well as the actual result on 24th of June, greatly affected international financial markets (European Commission, 2016). As financial markets are highly linked in general and several countries apart from the UK might be negatively affected, one may feel legitimized to expect that Brexit does not only have an impact on financial markets in Britain. By analyzing the impact of Brexit on financial markets, we might also get some insights about market's expectations about the magnitude of the economic impact beyond the UK and which country beyond the UK may be mostly affected.

In our view, the topic is too complex to just check for trade and financial linkages in order to determine the most affected countries partly because the institutional framework of the EU and the Euro area has generated additional dependencies between countries. According to the dividend discount model (Gordon and Shapiro, 1956), *expectations about future effects* on the real economy generated by Brexit will immediately affect stock returns and several other financial market variables. Therefore, we give a short overview of the possible effects of enduring Brexit uncertainty on the UK's and other countries' real economy, particularly the remaining EU countries. Of course, an increase in policy uncertainty itself can be expected to affect financial markets as well. Among others, these kinds of uncertainty typically lead to option value effects, i.e. a "wait-and-see attitude" with investment-type decisions.

We also have to address the discussion in the literature of whether and why volatility means uncertainty. In the empirical part of this paper, we use actual asset price changes instead of only unanticipated ones, but at the monthly horizon, the anticipated change is usually close to zero. Hence actual and unanticipated changes should give the same results and we feel legitimized

[2] For a survey of the related arguments see, for instance, London School of Economics (2016). Fears of Brexit do not come by chance but have been indicated by systematic differences in monetary policies on both sides of the channel. See D'Addona and Musumeci (2011).

to strictly follow, for instance, Belke and Gros (2002) and use also historical volatilities (i.e. the standard deviation) or GARCH estimates as measures of uncertainty.

So our interest is in the direction of spillovers among policy uncertainty and financial market volatilities in the UK itself. Our second research question is whether we can expect contagion from the UK to other countries not only through the political and institutional channel, for instance, other EU member countries also asking "Why can't we also be exceptions?" For this purpose, we also empirically check for spillovers of Brexit uncertainty to a variety of asset classes on international financial markets (Begg, 2016).

The remainder of this paper is organized as follows. The next section provides a brief overview of the possible effects of enduring Brexit uncertainty on the UK and other countries' real economy. In Section 3, we investigate the effect of Brexit on UK financial market volatilities. Our main focus is on the Diebold and Yilmaz (2009) and the Hafner and Herwartz (2004, 2008) method to estimate spillovers of policy uncertainty on financial volatility (second statistical moment). What is more, we try to identify the direction of causality among them. In section 4, we empirically assess the impact of Brexit on international financial markets and a variety of asset categories (first statistical moment), employing both panel as well as single-country SUR estimation methods. Section 5 finally concludes.

1. Potential effects of enduring Brexit uncertainty on the UK's and other countries' real economy

Leaving the EU can be expected to have large implications for the British economy through the following channels: trade in goods and services, investment, immigration, productivity and fiscal costs.[3] As Brexit is a political novelty, it is very difficult to estimate the effect of each channel as well as the overall impact on the British economy. Uncertainty around the effects is further increased by the fact that the British government and the EU will have to completely reevaluate the political and economic relationship. Furthermore, the British government will have to make significant political decisions e.g. regarding prudential and regulatory laws.

As a starting point of our empirical study, it is important to note that, except for a weaker pound and lower UK interest rates, the referendum has not caused much of an enduring impact (Gros, 2016). Financial markets tumbled for a couple of weeks after the referendum, but have recovered since then. Consumer spending remains rather stable. Even more surprisingly, investment

[3] In the following, we do not discuss the various arguments surrounding immigration and fiscal costs. For a broad survey on the potential economic impacts of Brexit see IMF (2016).

has remained relatively constant, in spite of significant uncertainty about Britain's future trade relations with the EU. So, have the costs of Brexit been overblown? One may argue that "(t)he United Kingdom's vote to 'Brexit' the EU is of course to become the year's biggest non-event" (Gros, 2016). But how to explain the current lack of impact? It may just be because Brexit has not yet happened (Begg, 2016). Hence, a big economic impact of Brexit can still not be excluded for the future. Furthermore, CEIC Data for July 2016 already indicates that business and consumer confidence has declined by about 4% and 12% respectively.

Regarding the trade channel, the most important aspect is the fact that the UK will most probably *lose its access to the European Single Market*. The EU is the most important trading partner of the UK. Nearly half of UK exports in goods and services are delivered into the EU (approx. 13% of UK GDP in 2014). Apart from an absence of tariffs, the single market guarantees the principle of mutual recognition and the so-called "single passport" - a system which allows services operators legally established in one member state to provide their services in the other member states without further authorization requirements (EC, 2016). Therefore, non-European firms can set up headquarters in the UK in order to access the single market and offer their services in the entire EU. The financial sector is a key component of the UK economy with London being one of the largest financial centers in the world.[4] Financial services generate about 8 percent of national income (EU average: nearly 5%), trade in financial services alone is about 3% of the nominal GDP in 2014 (EU average: nearly 1%). and 40% of total financial service exports are exported to the EU. The financial center of London would lose significantly in terms of attractiveness as it could no longer generate access to the European Single Market.[5]

The effects will crucially depend on the results of the negotiations between the UK and EU about the future economic (and political) relationship. If the UK keeps its access to the single market, the effects via trade might be small.[6] However, in the worst scenario, the trade relationship default to the WTO framework, if no alternative agreement is reached (Blockmans and Emerson, 2016). In that event, it appears to be highly probable that trading linkages between the UK and the EU will be weakened or even disrupted, generating decreases in UK incomes

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[4] UK is the world leader in fixed-income and derivatives transactions and far ahead of EU peers in private equity, hedge funds, and cross-border bank lending (Bank of England, 2015). The UK's insurance industry is the largest in Europe and the third largest in the world.

[5] Several asset managing companies (e.g. M&G, Columbia Threadneedle) and several banks have expressed intentions to move staff out of the UK capital and/or set up fund ranges in neighboring EU countries in fear of being locked out of European fundraising (FT, 2016). However, this "escape" from the UK is not limited to the financial sector, because Vodafone has already announced that it might move its headquarter if the UK leaves the single market (WSJ, 2016).

[6] An alternative might be the Norwegian model (EEA) or Swiss model.

from export.[7] Effects are not only limited to trade relationships with the EU. Firstly, the UK will not be part of future FTAs which are currently negotiated between the EU and countries like Brazil, China, and the USA. Secondly, UK will no longer be subject to FTAs which have been successfully negotiated by the EU and thereby experience further limitation in trading possibilities.[8] It remains questionable whether the UK might be able to offset the decrease in trade with the EU and corresponding national income by focusing its trade ambitions on other (faster-growing) markets. While it might be possible for the UK to negotiate new FTA, it will probably take longer than Britain's withdrawal from the EU under Article 50 generating a potential disruption of trade as trade relationships with those countries will default to WTO rules. Furthermore, it appears questionable whether the UK can simply substitute European markets by other exports markets especially in the short- to mid-term.

The UK has been subject to large FDI especially from EU countries – almost half of total FDI. It appears reasonable to assume that the amount of FDI coming from the EU will be adversely affected as a strong link between EU membership and inward FDI has been documented by several studies (Fournier et al. 2015, Bruno et al. 2015, Dhingra et al. 2016b). Furthermore, FDI from outside the EU might decrease as well, as the UK can no longer provide a gateway to the single market. According to the Office for National Statistics (ONS), the average flow of inward FDI has been about 5 percent of GDP between 1999 and 2015. The UK as a financial center is dependent on inward FDI and financial flows in general. If the London loses its status as a global financial center, FDI will decrease and so probably will consumption and investment.

Critics of the EU argue that many regulations imposed by EU institution are generating costs, inflexible and are limiting business opportunities for companies. OpenEurope (2015) argue that benefits from deregulation might compensate trade losses. However, the space for further deregulation appears to be limited in the UK. According to OECD, the UK ranks at a level with the USA with regard to product market liberalization. Labor market flexibility is relatively high - especially compared with European countries like France and Germany. Therefore, it appears questionable whether this limited potential of deregulation will boost productivity enough to offset trade losses that further deregulation is political enforceable and desirable. LSE (2013) concludes that the UK is already deregulated and a more skilled workforce and a better infrastructure are more potent sources of further productivity enhancements.

[7] This view is backed by empirical results underscoring that the reduction in trade barriers due to EU membership has increased UK incomes (Crafts (2016), Campos et al. (2014)).
[8] For an overview, see Van der Loo and Blockmans (2016).

Figure 2.1 represents a survey of studies which attempt to quantify the long- and short-term effects for 2018 in the case of Brexit. According to the IMF (2016) under their adverse scenario, UK might experience a strong drop in GDP in 2017 causing a severe recession. While some studies even indicate positive (long-term) effects (Minford, 2016, OpenEurope, 2015, Mansfield, 2014), the majority of studies indicates large negative short- and long-term effects which are likely to be considerable. Differences in the results of studies presented in Figure 2.1 can be mainly traced back to differences in the assumptions of the underlying economic model, different emphasis on specific channels and different projections about the future economic relationship between the EU und the UK. Studies which find negative effects put more emphasis on negative trade and investment effects.

The few studies describing positive net results focus on gains from deregulation and enhanced productivity. The short-term effects (for 2018) of Brexit are uniformly negative, but also vary in magnitude. These studies underline the possibility of a severe recession or at least decrease in growth. Apart from academic arguments, the monetary and fiscal policies seem to support this view. In July, the decision of Bank of England to decrease its bank rate to 0.25% has been justified the adverse effects of Brexit on the economy. On the fiscal policy side, UK's finance minister Hammond has made several statements about the possibility of a more aggressive fiscal approach in order to cope with the short- to mid-term effects of Brexit.[9]

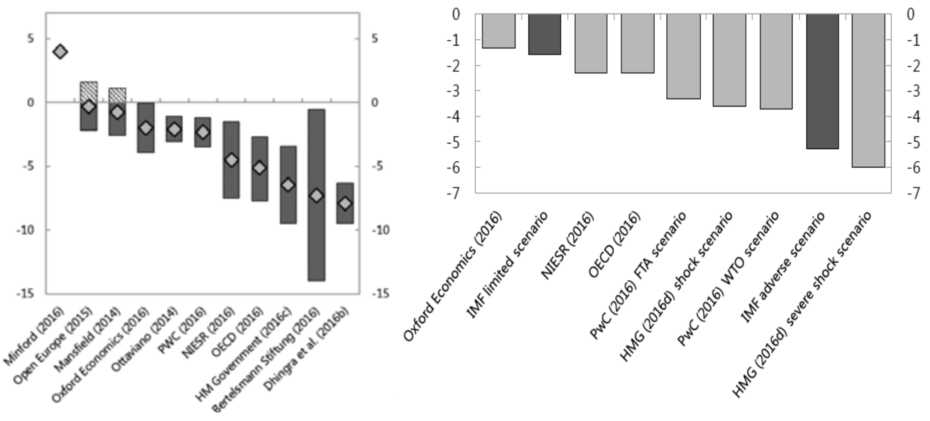
Considering short-run effects, the Brexit decision resulted in immediate financial turmoil after the vote - stock markets have slid in response to the Brexit vote in an orderly decline and the British pound suffered big losses. Since the exit of a large, established member of the EU has never been tested, it could take at least two years for the UK to formally leave the 28-nation bloc, and it is unclear how much the country's relationship with the EU will change. This means that markets are likely to remain volatile at least until it becomes clear what a Brexit scenario means for the UK and the rest of the EU.[10]

[9] See http://uk.reuters.com/article/uk-britain-eu-economy-hammond-idUKKCN1020O7.

[10] One vision in this respect is the so-called Continental Partnership Proposal delivered by Bruegel (2016) including much free trade and less free movement of labour between the EU and Great Britain. The idea is that free trade substitutes labour mobility.

Figure 2.1 - *Economic effects of Brexit on the UK GDP*

a) Long-term effects b) Short-term effects



Source: IMF (2016)
Note: Deviation from baseline (=UK remains in the EU)

It has already been shown in the literature that during crises and particular political events financial market volatility generally increases sharply and spills over across markets. Thus, Brexit uncertainty and the consequent decision to leave the EU might not only directly influence stock and exchange markets, but might also be a trigger for increased spillovers across them. Financial instabilities, such as an increase in FX volatilities, pose further potential adverse effects for the economy, implying that firms will postpone new investments and hiring decisions into the future benefiting from the so-called “option value of waiting” (Belke and Gros, 2002). Given the important nexus between financial volatility and output, investment and consumption described above, we will estimate the Brexit uncertainty effects on the UK financial markets’ volatilities in section 3.

The potential effects of Brexit are of course not limited to the UK. Obviously, there is a large potential of spillover especially for the other EU countries via trade and financial linkages. However, once again the impact is highly uncertain and will depend on the future political and economic relationship between the UK and the EU. According to a vast majority of papers, other countries are likely to lose economically. Based on trade linkages (exports to the UK in % of own GDP), Ireland (11.2%), the Netherlands (6.7%) and Belgium (7.5%) are primarily exposed. Regarding banking linkages, the Irish, Dutch, Swedish and German banking sectors are highly connected with the British. Based on capital market linkages (FDI and portfolio investment), Ireland, the Netherlands, Luxembourg and France are mostly exposed.

IMF (2016) analyzes spillover effects to other (European) countries. Based on financial and trading linkages, Ireland (-0.6 to -2% of GDP), the Netherlands (-0.3% to -0.7% of GDP) and Belgium (-0.25 to -0.65% of GDP) are the most affected countries. The other countries are less affected. Output falls by 0.2 to 0.5 percent below baseline in the rest of the EU. The European Commission (2016) highlights that "the referendum has created an extraordinary uncertain situation". According to its forecasts, the result of the referendum is expected to put pressure on investment and consumption. Therefore, the EC has reduced its GDP growth forecasts for the Euro area by 0.1-0.2% for 2016 and 0.2-0.5 for 2017.

Apart from direct economic linkages, Brexit might also generate political and institutional uncertainty about the EU. While the EU will still have 27 members left, the UK will be the first country to actually leave the EU under Article 50 which is far from delivering a concrete divorce procedure (Lazowski, 2016). Furthermore, the UK is not the only country where anti-EU movements have gained support. Economic issues and especially the sovereign debt crisis have facilitated political campaigns especially in France, the Netherlands, and Italy to leave the EU. Also, we are not of the opinion that the existence of the EU is endangered by Brexit, the success of the Brexit movements might generate momentum for similar movements in other countries increasing the probability of more countries leaving the EU. This might damage the reputation of the EU as a sustainable and irrevocable institution decreasing its political power, influence, and ability to negotiate new supranational contracts like FTA.

Therefore, political uncertainty may spread across Europe especially affecting countries whose sovereign solvency is heavily linked with the existence of the EU and the Euro area – namely Spain, Portugal, Italy and Greece. Without the Euro area or sufficient contributors, the installed rescue mechanisms like the ESM would cease to exist or be perceived too small to act as a safeguard if member states are in financial difficulties. Furthermore, these countries are still struggling to reach a moderate level of growth and still have troubles in its banking sectors especially Italy. Therefore, existing trade and financial linkages might deliver an incomplete picture about the (relative) magnitude of country-specific spillover effects.[11] Since the Brexit

[11] Gros (2016), however, puts the assessment of the literature reviewed in section 2 into perspective and states: "(b)eyond a weaker pound and lower UK interest rates, the referendum has not had much of a lasting impact. Financial markets wobbled for a few weeks after the referendum, but have since recovered. Consumer spending remains unmoved". While it is true that consumer spending stayed rather unmoved, we mention in this section that business and consumer confidence went down. See also our remarks in Section 4.

referendum was held just in the recent past, the first assessments of the Brexit were dedicated to the financial markets' effects. Raddant (2016) analyzes financial data of the UK, Germany, France, Spain, and Italy. The author performs several standard estimation techniques comparing the behavior of European stock returns, stock market volatility, and exchange rates before and after the referendum. In contrast to our study, Raddant (2016) focuses more on the immediate impact after the referendum. His study shows that stock markets fell after Brexit (losses ranging between 10-15%) and had similar effects across Europe. In line with our argumentation above, the Italian stock market is mostly affected by Brexit (including the UK) despite being the least connected with the UK (in terms of trade and financial linkages). Regarding exchange rate developments, the British Pound immediately lost 10% vis-à-vis the USD (8% vis-à-vis the euro). Looking at the response of the sterling exchange to poll numbers accordingly find that investors appear to view Brexit as a negative event (Arnorsson and Zoega, 2016).

The second relevant study for our research is the short paper by Krause et al. (2016) argue that the referendum in the UK created a high degree of uncertainty about possible consequences and that this could also be seen in financial markets in the run-up to the referendum. According to their empirical investigation, poll results pointing toward Brexit resulted in short-term declines in returns of bank indices. According to the authors, this suggests that negative consequences of exiting the EU are expected not only for the UK but also for the EU. Their results point at a strong depreciation of the UK Sterling relative to the euro or the Swiss franc which might reflect the (expected) decline in the attractiveness of the UK as a financial center and reduced demand for the UK Sterling.

Their results cannot be compared in quantitative terms with ours due to differences in the variables measuring the Brexit probability. They employ a pure dummy variable using poll results from "whatukthinks.org" amounting to 0 if the probability falls below 50 percent and is equal to 1 if the probability is higher than 50 percent. In our view, this risks being a too crude measure which does not adequately measure the likelihood of Brexit and therefore its potential adverse effects. A general critique against measuring Brexit effects using poll results is presented by Gerlach (2016). He argues that poll data do not contribute much to the explanation of financial market developments. Therefore, we utilize more sophistic measures by using the probability of Brexit based on data from betting agencies.

The third, again less comprehensive, study comparable to ours is Gerlach and Di Giamberardino (2016). They come up with the results that the outcome of the UK's referendum on EU membership could have a significant effect on sterling. They estimate the potential size of this effect by looking at the relationship between daily changes in the sterling exchange rate and bookmakers' odds of Brexit. According to their estimations, movements of between 5% and 15% seem plausible. We use an almost identical approach, but do not restrict our estimations on the effects on exchange rates.

2. Brexit and its effect on UK financial market volatilities

3.1 Data

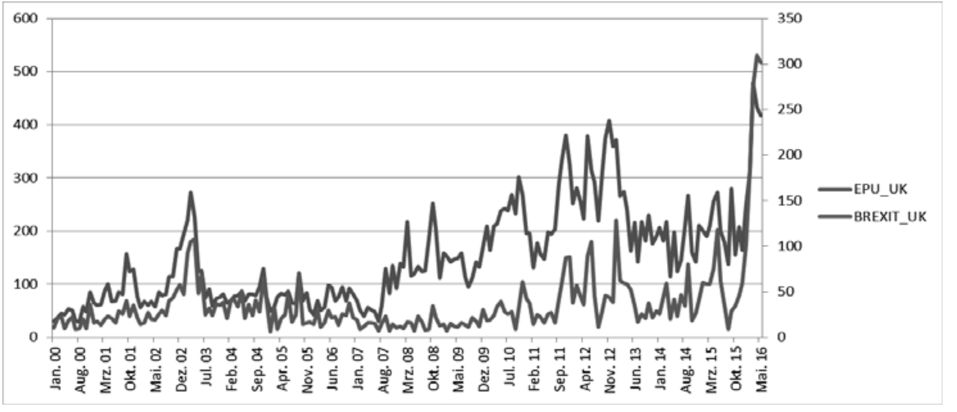
In this section, we estimate the magnitude and the sign of short-run Brexit effects which are related to an environment of increased policy uncertainty during the time preceding the referendum and directly after Brexit-vote on UK financial markets. Our focus here is on volatilities (second statistical moments) instead of changes of the levels (first statistical moment).

As a measure of uncertainty, we employ the Economic Policy Uncertainty index (EPU) developed by Scott R. Baker, Nicholas Bloom and Steven J. Davis[12] which draws upon newspapers and other written sources and is calculated as scaled counts of articles containing 'uncertain' or 'uncertainty', 'economic' or 'economy', and one or more policy-relevant terms ('tax', 'policy', 'regulation', 'spending', 'deficit', 'budget', or 'central bank'). Policy-driven uncertainty is shown to raise during political turmoil or elections, as well as during the implementation of major policies and programs and reflects the level of doubt and confusion in the private sector caused by government policies. Thus, according to its definition, using the EPU Index should be a good proxy for the estimations of Brexit uncertainty and Brexit-vote effects. The other index provided by the same source - the Brexit Uncertainty index – is calculated by multiplying the EPU index by the share of EPU articles that contain 'Brexit', 'EU' or 'European Union'. By nature, it is available only until May 2016.

Figure 3.1 shows that the EPU index in the United Kingdom in the near-referendum time is hovering at its highest point surpassing previous records during the Scottish referendum, the Eurozone crisis, the Gulf war and the global financial crisis of 2008. Further visual inspection of the EPU and Brexit uncertainty reveals a strong, although time-varying, correlation of both during the period before the referendum.

[12] See http://www.policyuncertainty.com/index.html.

Figure 3.1 *UK economic policy uncertainty and Brexit uncertainty*



In our empirical estimations, we will use EPU instead of Brexit uncertainty for two reasons. Firstly, Brexit uncertainty data is available only for the period preceding the referendum, while EPU data is highly correlated with the Brexit uncertainty during the time preceding the referendum and therefore also reflects the uncertainty triggered by the referendum. In this context, it is important to note that the current lack of impact can be explained just by the fact that Brexit has not yet happened (Begg, 2016).

Secondly, since financial markets are very flexible and are able to react to news immediately using daily EPU data could be beneficial in contrast to Brexit uncertainty which is only available at monthly frequencies.

Our model includes the following variables:

- Daily stock market volatility[13] calculated as the annualized daily percent standard deviation of daily high and low FTSE 250 prices:

$$FTSE250v_t = 100\sqrt{365 \times 0.361 \times \left[ln\left(FTSE250_t^{high}\right) - ln\left(FTSE250_t^{low}\right)\right]^2}$$

  We have decided to consider FTSE 250 prices instead of FTSE 100 since the first might be a better gauge of domestically-oriented share prices than the FTSE 100 which is dominated by multinationals of which some have little exposure to the UK economy (Sheffield, 2016).

- Daily United Kingdom pound sterling volatility calculated as the annualized daily percent standard deviation of intraday high and low exchange rate GBP/USD:

[13] For more details about the construction of daily volatilities please refer to Alizadeh et al. (2002).

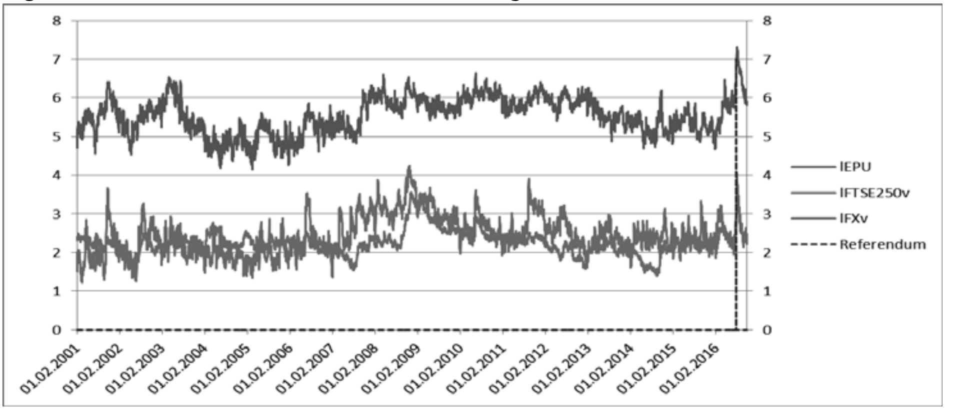
$$FXv_t = 100\sqrt{365 \times 0.361 \times \left[ln\left(FX_t^{high}\right) - ln\left(FX_t^{low}\right)\right]^2}$$

- Daily EPU index[14] constructed by Baker et al. (2015)

Additionally, in order to disentangle domestic policy uncertainty from global uncertainty, we have included the CBOE Volatility Index (VIX Index)[15] as an exogenous variable.

The sample contains 4105 observations, from 2001:01:01 to 2016:23:09, all variables are taken in logs and plotted in Figure 3.2 below.

Figure 3.2 *Financial volatilities and EPU index, logs*



In Figure 3.2, we observe that both stock prices and exchange rate went through a major period of volatility during the global financial crisis. Stock prices have also experienced an increased amount of volatility around August 2011, which could be explained by the effects of the euro crisis (Gros, 2011). Moreover, there is a considerable upward spike at the time of the referendum (23, June 2016 marked as a vertical line) for all variables under consideration as magnitudes reach levels comparable with previous maxima.

[14] In cases when the index was equal to 0, we have replaced it with the value from the previous day.

[15] Empirical realizations of the VIX index, intraday high and low values of FTSE250 and the GBP/USD exchange rate are obtained from the Datastream database.

3.2 Estimation approach

In order to estimate the effect of policy uncertainty on volatility in financial markets, we will use the empirical approach proposed by Diebold and Yilmaz (2009, 2012) based on VAR variance decompositions.[16]

Firstly, we estimate the VAR(p) model:

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t, \tag{1}$$

where $\varepsilon \in (0, \Sigma)$ is the i.i.d. errors vector.

The moving average representation, thus, could be written as

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}, \tag{2}$$

where $A_i = \sum_{k=1}^{p} \Phi_k A_{i-k}$, A_0 is the identity matrix $I_{N\times N}$ and $A_i = 0$ for $i < 0$.

Our further analysis relies on variance decompositions which allow assessing the fraction of the H-step-ahead error variance in forecasting x_i that is due to shocks to x_j. In order to deal with contemporaneous correlations of VAR shocks, we use the generalized VAR framework, which produces variance decompositions which are invariant to choice of ordering. The generalized approach allows correlated shocks taking into account the historically observed distribution of errors.

The H-step-ahead forecast error variance decomposition is calculated as

$$\theta_{ij}^{g}(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' A_h e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h e_i)}, \tag{3}$$

where Σ is the variance matrix for the errors ε, σ_{ii} is the standard deviation of the error term for the i-th equation of VAR and e_i is a vector which contains one as i-th element and zeros otherwise.

The *total volatility spillover index* is then constructed as:

[16] Alternatively, Hafner and Herwartz (2006b) proposed a concept of impulse response functions tracing the effects of independent shocks on volatility and then considered the effect of historical shocks, such as “Black Wednesday” and an announcement by the European Community finance ministers on August 2, 1993, on foreign exchange market. However, we believe that the identification of a “Brexit shock” is not trivial and should not be constrained only to the day of the announcement of the referendum results but should include the days preceding the referendum as well. Moreover, the applied approach in this paper allows us to take into account the time-varying volatility of multivariate financial time series.

$$S^g(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \widetilde{\theta_{ij}^{g}}(H)}{\sum_{i,j=1}^{N} \widetilde{\theta_{ij}^{g}}(H)} \times 100, \quad (4)$$

where $\widetilde{\theta_{ij}^{g}}(H)$ is normalized value for $\theta_{ij}^{g}(H)$, so that $\widetilde{\theta_{ij}^{g}}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}$. The total spillover index, thus, measures the contribution of spillovers of shocks across variables under consideration to the total forecast error variance.

In order to investigate the direction of spillovers across financial volatilities and policy uncertainty, i.e. the portion of total spillover index that comes from x_i to all other variables, *the directional spillover* is applied:

$$S_i^g(H) = \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \widetilde{\theta_{ji}^{g}}(H)}{\sum_{j=1}^{N} \widetilde{\theta_{ji}^{g}}(H)} \times 100 \quad (5)$$

The net spillover from variable *i* to all other variables *j* is obtained as the difference between gross shocks transmitted to and gross shocks received from all other markets:

$$S_i^g(H) = \left(\frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \widetilde{\theta_{ji}^{g}}(H)}{\sum_{j=1}^{N} \widetilde{\theta_{ji}^{g}}(H)} - \frac{\sum_{\substack{j=1 \\ j \neq i}}^{N} \widetilde{\theta_{ij}^{g}}(H)}{\sum_{j=1}^{N} \widetilde{\theta_{ij}^{g}}(H)} \right) \times 100 \quad (6)$$

The last spillover measure of interest is *the net pairwise spillover* index between variables x_i and x_j which is defined as the difference between gross shocks transmitted from x_i to x_j and gross shocks transmitted from x_j to x_i:

$$S_i^g(H) = \left(\frac{\widetilde{\theta_{ij}^{g}}(H)}{\sum_{k=1}^{N} \widetilde{\theta_{ik}^{g}}(H)} - \frac{\widetilde{\theta_{ji}^{g}}(H)}{\sum_{k=1}^{N} \widetilde{\theta_{jk}^{g}}(H)} \right) \times 100 \quad (7)$$

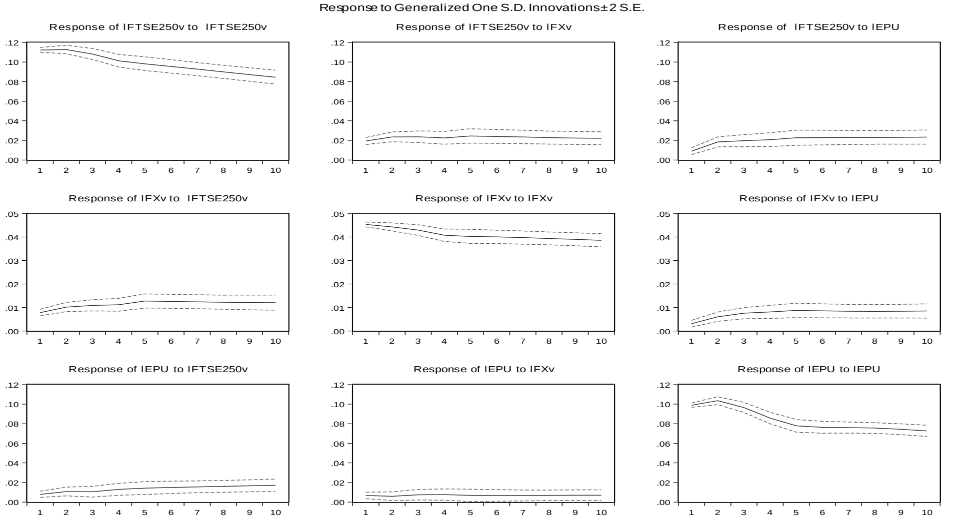
The chosen approach allows us to investigate the dynamics of spillovers in form of rolling regressions, and thus, the time variations of total, directional, net and net-pairwise spillovers in the periods before and after the Brexit referendum, which are of particular interest of this study.

The lag length of five was chosen according to the Akaike Information Criterion, the residuals are not serially correlated, according to the unit root test the model could be considered as dynamically stable[17].

[17] Our VAR model specification tests are presented in Table A1 in Appendix.

The generalized impulse responses are significant and display the expected signs.[18]

Figure 3.3 - *Generalized impulse responses functions, full-sample estimations*



According to the Granger causality test whose results are presented in Table 3.1a, policy uncertainty indeed Granger-causes stock and exchange rate volatilities. Apart from the standard Granger causality approach in the recent empirical literature, a number of new causality-in-variance tests have been developed, for instance, a Portmanteau test of Cheung and Ng (1996), a Lagrange Multiplier Test of Hafner and Herwartz (2006a) and a Wald test of Hafner and Herwartz (2008). Based on Monte Carlo investigations the latter two methodologies are shown to be preferable for applied work (Hafner and Herwartz 2006a, 2008). In this study, we perform a causality test based on Quasi Maximum-Likelihood methods proposed by Hafner and Herwartz (2008). The approach relies on multivariate GARCH estimations and consequent Wald testing of appropriate coefficients' set. Our test results (see Table 3.1b) indicate some evidence of bi-directional causality between the policy uncertainty and financial volatilities which means that not only policy uncertainty affects financial markets, but also exaggerated financial volatility adds to uncertainty about policy measures to support the economy and thereby mitigate downside risks.

[18] Different Cholesky orderings do not change the signs and the significance of the impulse responses. The results are available upon request.

Table 3.1 - *Causality tests*

a) *VAR Granger Causality/Block Exogeneity Wald Tests*

Dependent variable: lFTSE250v				Dependent variable: lFXv				Dependent variable: lEPU			
Excluded	*Chi-sq*	*df*	*Prob*	*Excluded*	*Chi-sq*	*df*	*Prob*	*Excluded*	*Chi-sq*	*df*	*Prob*
lFXv	8.04	5	0.15	lFTSE250v	19.43	5	0.00	lFTSE250v	16.57	5	0.01
lEPU	37.31	5	0.00	lEPU	22.66	5	0.00	lFXv	3.13	5	0.68
All	*47.91*	*10*	*0.00*	*All*	*48.33*	*10*	*0.00*	*All*	*20.28*	*10*	*0.03*

b) *Variance causality test based on Hafner and Herwartz (2008)*

MV-GARCH, BEKK - Estimation by BFGS
1) Test for causality of EPU to FTSE250, FX Chi-Squared(4)=46.35 or F(4,*)=11.59 with Significance Level 0.000
2) Test for causality of FTSE250, FX to EPU Chi-Squared(4)=86.39 or F(4,*)=21.60 with Significance Level 0.000

For the rolling estimations, we have set a rolling window of 500 working days and a forecast horizon of 10 working days[19].

3.3 Estimation results

We start with the analysis of our results in Table 3.2 which provides an input–output decomposition of the total spillover index based on full-sample estimations. According to the table, policy uncertainty shocks contributed 4.1% (3rd column, first row) and 3.2% (3rd column, second row) to the variance decompositions of stock market and exchange rate volatilities respectively, and itself was mostly affected by stock volatilities (2.63 %), whereas the FX market does not seem to significantly induce policy uncertainty, since its contribution to the forecast error variance is only 0.64%. The total spillover index for all variables is thus equal to 7.5 %. However, this value should be taken with caution, since the estimation was performed employing data for the full sample. Thus, the spillover index is only the average measure of spillovers in the period from January 2001 to September 2016. In order to assess the extent and nature of the *spillovers variation over time*, we continue with the rolling-estimations.

[19] As robustness check we performed estimations with different lag length, rolling windows and forecast horizons - the basic results remain, see Figure A1 in the Appendix.

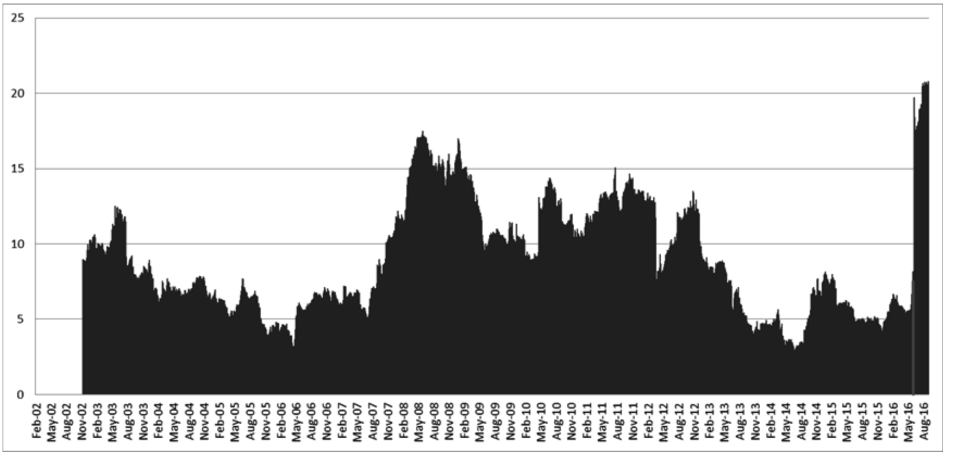
Table 3.2 - *Full-sample spillover table*

	lFTSE250v	lFXv	lEPU	From Others:
lFTSE250v	91.02	4.88	4.1	*9*
lFXv	7.03	89.77	3.2	*10.2*
lEPU	2.63	0.64	96.73	*3.3*
Contribution to others:	*9.7*	*5.5*	*7.3*	*22.5*
Contribution including own:	*100.7*	*95.3*	*104*	*7.50%*

Note: The *ij*-th element of the table represents the estimated contribution to the forecast error variance of x_i coming from innovations to x_j.

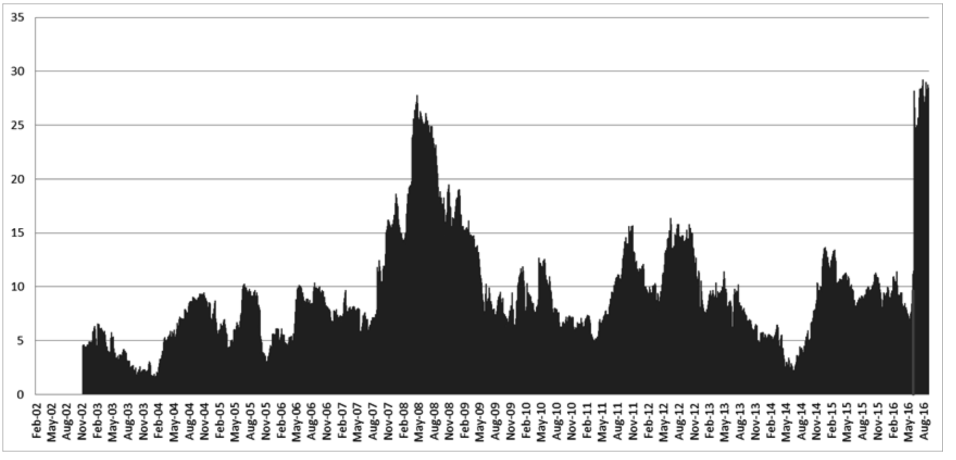
Our rolling estimations for total spillovers between stock volatility, FX volatility and policy uncertainty (see Figure 3.4) show an increase in spillovers during the period from the end of 2008 till the end of 2012 which could be attributed to the subprime-mortgage crisis, global financial crisis, and sovereign debt crisis. The consequent huge rise of the spillover index directly after Brexit-Referendum has exceeded all historical maxima.

Figure 3.4 - *Total Spillover Index*



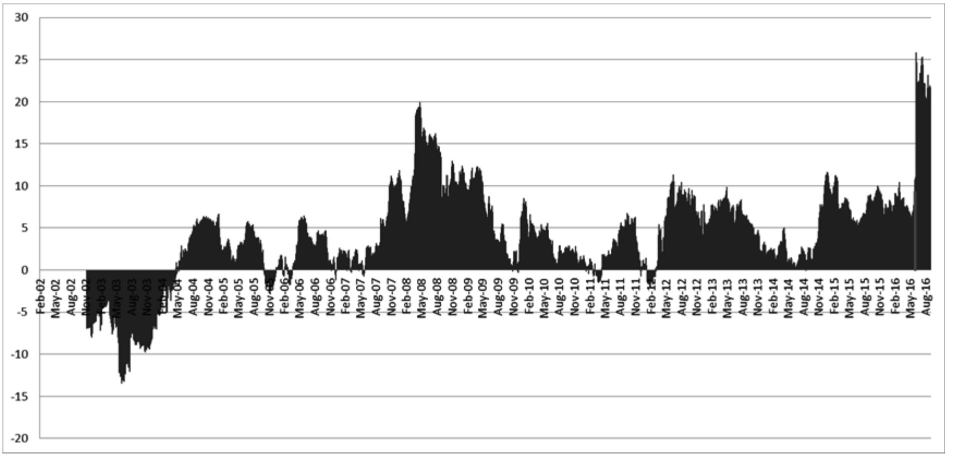
In Figure 3.5, we observe that the spike of total spillover index at the end of our sample is indeed due to increased spillovers *from policy uncertainty to financial market volatilities*.

Figure 3.5 - *Directional Spillovers from EPU to Financial Volatilities*



According to our results in Figure 3.6, starting in May 2004, the index of net spillovers from EPU to financial volatilities has a positive value apart from some minor exceptions. This means that since 2004 policy uncertainty has been a net shock contributor for financial market volatilities, or in other words, policy uncertainty shocks have influenced financial markets to a larger extent than it was affected by financial market volatility shocks itself. However, the value of the net spillover index changed dramatically after the Brexit-vote and increased from 9 % to 26 % and remains dominant until the end of our sample.

Figure 3.6 - *Net spillovers from EPU to Financial Volatilities*



Our final empirical exercise in this section is to look at the pairwise net spillovers (Figures 3.7 to 3.9) in order to reveal bilateral relationships between the variables under consideration. According to Figure 3.7, stock prices volatility was a net receiver of policy uncertainty shocks starting in February 2016 – the month, when the Brexit-referendum was announced.

Figure 3.8 provides the net spillovers between exchange rate volatility and EPU. Starting in May 2006, policy uncertainty shocks dominate in net terms apart from some exceptions. Similar to the net spillovers between stock volatility and EPU, the Brexit-referendum resulted in an increase in net spillovers between FX volatility and policy uncertainty.

From the net spillovers between stock and FX volatilities presented in Figure 3.9, we observe that the FX market was a net recipient of large levels of stock volatility shocks starting in 2007 till the end of 2013, and afterwards became a net transmitter to the stock market. The time right before and after the Brexit-vote does not exhibit any extraordinary patterns in the relationship between financial volatilities.

Figure 3.7 - *Net pairwise spillovers between Stock volatility and EPU*

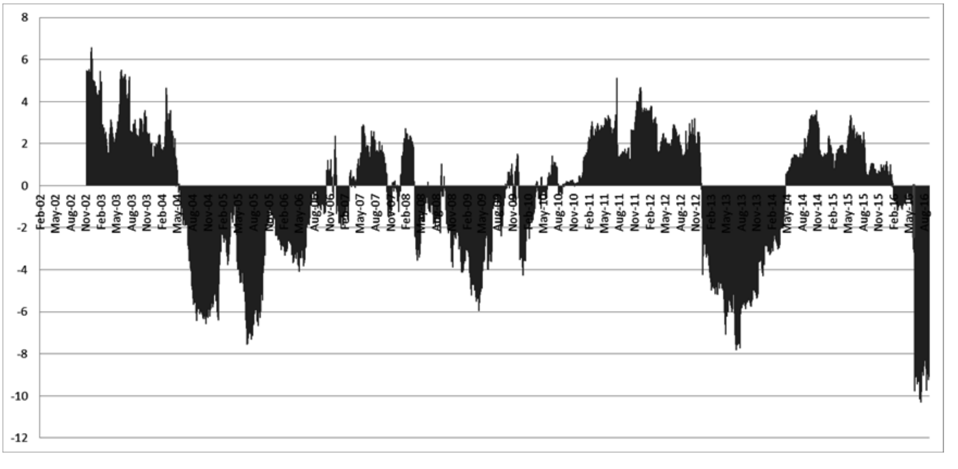


Figure 3.8 - *Net pairwise spillovers between FX volatility and EPU*

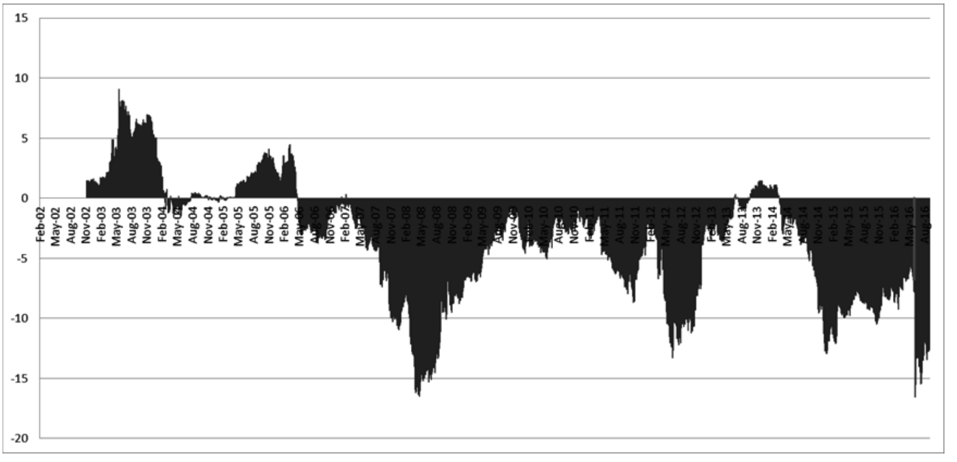
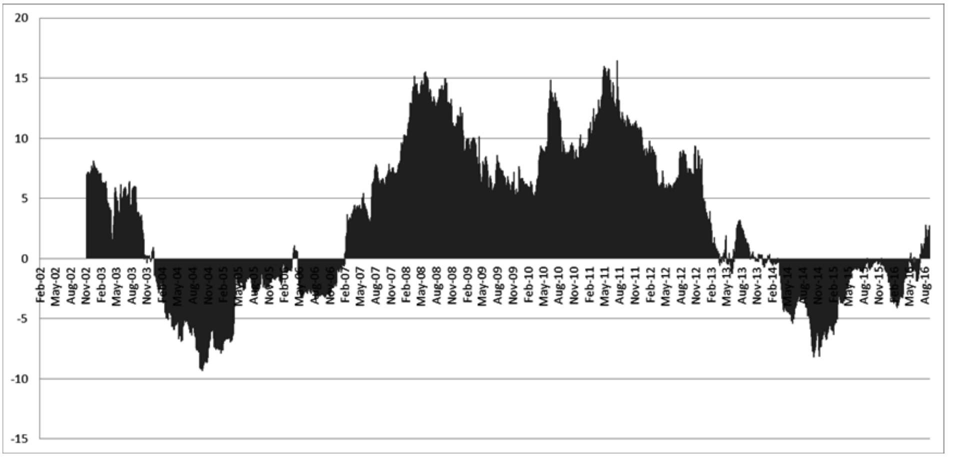


Figure 3.9 *Net pairwise spillovers between Stock volatility and FX volatility*



To conclude this section, our estimation results reveal the substantial role of policy uncertainty on financial market volatilities. Policy uncertainty after 23, June 2016 induced huge spillovers to financial markets which exceeded all previous historical maxima. Interestingly, policy uncertainty spillovers have remained strong since then and could be considered as empirical evidence that policy uncertainty concerning the development of the relationship between the United Kingdom and the EU causes turbulence to financial markets even 3 months after the referendum which can further weaken investment and hiring in the UK (and Europe). Overall, we can corroborate the view of IMF (2016) and others that Brexit uncertainty has caused instability in key financial markets. Our analysis, however, also provides evidence that the observed immediate effect has not disappeared and remains to be steadily high, and thus, might prevail also over the medium run.

4. Brexit and its effects on international financial markets

4.1 Data

In this section, we analyze the effect of Brexit on international financial markets. In this context, we estimate the impact of an increase in the likelihood that the citizens of the UK will vote in favor of Brexit on several financial variables. We use daily data between the 1st April and 23rd June 2016. Thereby, we examine the critical phase before the EU-Referendum took place. We include data from the following countries: Austria, Belgium, Canada, Denmark, Finland, France, Germany, Netherlands, Norway, Italy, Japan, Portugal, Spain, Sweden, Switzerland, United Kingdom and the United States.

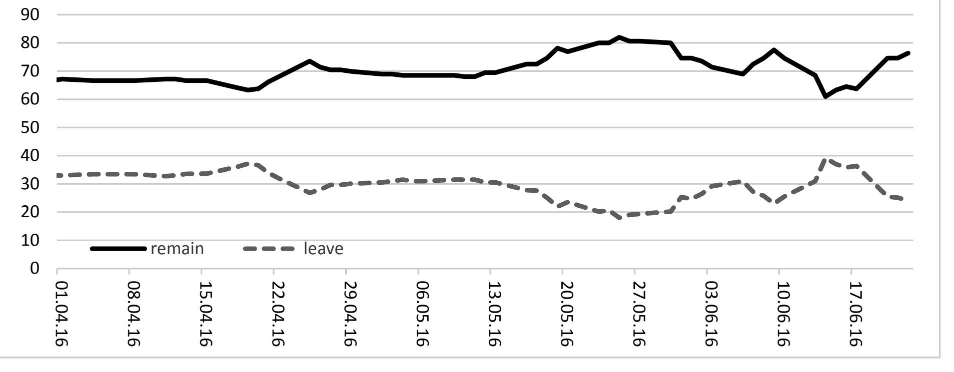
Table 4.1 – *National stock indices*

Country	**Stock index**	**Country**	**Stock index**
Austria	ATX	Ireland	ISEQ20
Belgium	Bel20	Italy	FTSE MIB
Canada	S&P/TSX Composite	Japan	Nikkei 225
Denmark	OMX Copenhagen 20	Portugal	PSI-20
Finland	OMX Helsinki 25	Spain	IBEX 35
France	CAC 40	Sweden	OMX Stockholm 30
Germany	DAX	Switzerland	SMI
Greece	ASE	United Kingdom	FTSE 100
Netherlands	AEX	United States	S&P 500
Norway	OBX		

Our measures of daily stock returns are based on closing prices of the most important stock indexes of the countries under observations which (see Table 4.1). Furthermore, we analyze the impact on 10-year government yields and sovereign CDS for 10-year bonds which measure sovereign credit risk. In order to examine the impact of an increase in the probability of Brexit on the external value of the British currency, we use the exchange rate of the British pound vis-à-vis the Canadian Dollar, Danish Krone, Euro, Japanese Yen, Norwegian Krone, Swedish Krona, Swiss Franc and the US-Dollar. When not stated otherwise, the data is obtained from Thomson Reuters Datastream.

The most crucial variables of this study are the variables which are supposed to track the probability of Brexit. Because the corresponding coefficients are most relevant for answering our research question, we use two different measures in order to check for robustness of our results. Firstly, we use probability data in percentage points (*Brexit_Prob*) based on decimal odds of the online betting exchange 'Betfair.' As probabilities vary intra-daily, we have to make a choice regarding the time of day. We use the 4pm (GMT) values. As financial markets are considered to be very fast in processing new information, we assume that new information arriving at 4pm (GMT) should be fully reflected in the daily closing prices.[20] Secondly, we attempt to measure the probability of Brexit by using survey (poll) data collected by Bloomberg (*Brexit_Poll*).[21] Our variables to track the probability of Brexit are presented in Figures 4.1 and 4.2.

Figure 4.1 – *Probability of Brexit (in percentage points)*



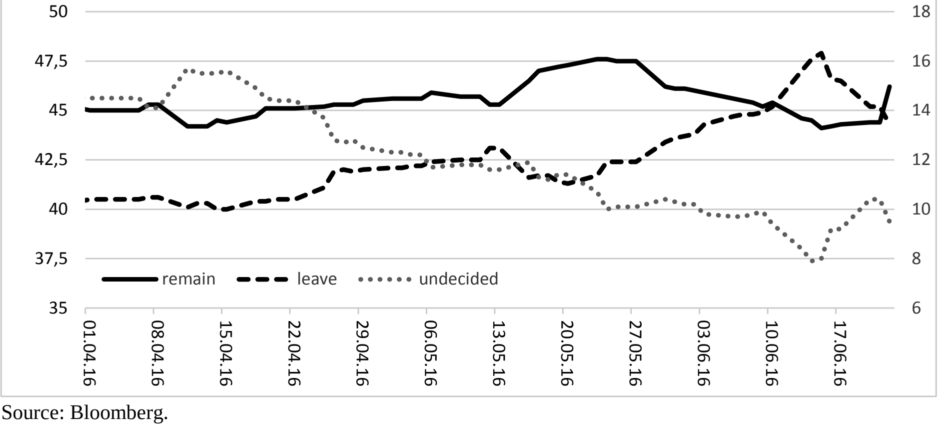
Source: Betfair.

Both figures show a similar evolution about the implied chance of Brexit. In both cases, we can observe a sideways movement till mid-May followed by a noticeable strengthening of the "remain" campaign. However, starting around the end of May, the "leave" campaign gains momentum till mid-June. Although the Brexit probability does not reach 50%, the "leave" campaign overtakes the "remain"-side in polls in mid-June. Close to the referendum, we see another strong increase for the "remain"-campaign in both variables.

[20] Additionally, we performed several estimations using 12pm (GMT) values and obtain nearly identical results.
[21] Further information can be found here: http://www.bloomberg.com/graphics/2016-brexit-watch/

Although we include both Brexit variables alternatively in our estimations, we focus our analysis mainly on *Brexit_Prob*. As shown by Gerlach (2016), the information content of polls and survey data for explaining developments of financial variables is generally low. We can confirm this argument because the explanatory power of *Brexit_Poll* is low in general as indicated by the R^2 in our estimations.

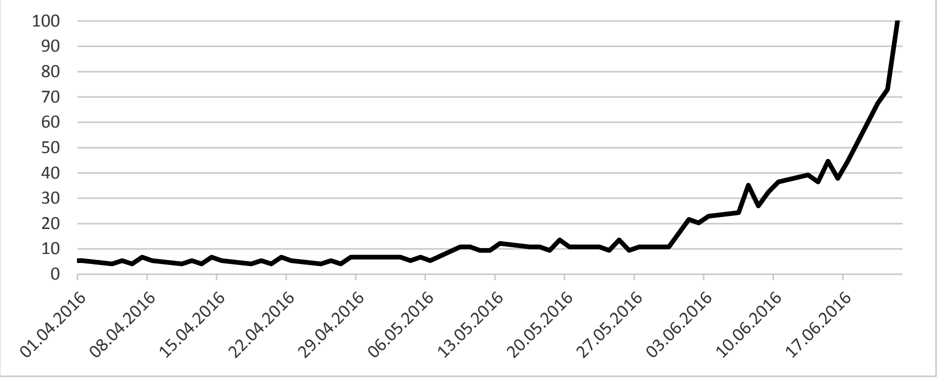
Figure 4.2 – *Summary of Brexit polls*



Source: Bloomberg.

While it can be assumed that changes in the probability of Brexit should have an impact on fast information processing markets, it is straightforward to assume that the timing also matters. An increase in the probability three months before the date of the referendum might have a smaller effect compared to a similar increase one day before the vote. Similarly, one may assume that during times of high public attention the effects on financial markets might be stronger. Both aspects are highly interconnected because public interest should be at its high point just before the vote takes place.

Figure 4.3 – *Public attention based on Google search requests*



Source: Google Trends.

In order to account for these aspects, we use Google Trends data to check for the public interest in Brexit based on google search requests.[22] The values displayed in Figure 4.3 presents a measure of "public attention" for Brexit in the entire United Kingdom and are ratios compared to the day with the highest attention within the time period under observation.

4.2 Estimation procedures

In order to analyze the impact of Brexit, we use standard econometric procedures. As the first step of our analysis, panel estimation is used to obtain first results. As common in the literature, our choice of the specific panel estimator depends on the results of the Hausman-test. In our study, the null hypothesis of the test is accepted for every specification. Therefore, we exclusively use the *random effects* estimator. Afterward, we perform SUR estimations in order to obtain country-specific results. The SUR approach consists of several regression equations which are linked by allowing for cross-equation correlations of the error terms. This appears to be an appropriate assumption because financial markets are highly connected. Although every country-specific equation can be consistently estimated by GLS, the use of SUR estimation increases the efficiency of the estimations. Additionally, in order to account for the timing of the change in Brexit probability, we estimate specifications in which the observations points are weighed based on Google Trends data.

[22] The values are based on the search topic: "United Kingdom European Union membership referendum, 2016" which combines several different research requests corresponding with the Brexit topic. The following additional options are used: Search Category: "News", Search: "News-Search".

Table 4.2 - *Overview of variables used in estimation*

Variable	Description	Variable	Description
$Brexit\_Prob_t$	The change in the Brexit probability in t	CDS_t^i	The percent change in the CDS in t of country i
$Brexit\_Poll_t$	The change in the support for the leave campaign in t	$Comm_t$	The percent change in commodity prices in t
$stock_t^i$	The percent change in stock prices in t in country i	ExR_t^i	The percent change in the British Pound against the national currency of country i in t
$IR10_t^i$	The change in the 10-year interest yield in t for country i	$diff\_IR10_t^i$	The change in the long-term interest rate differential ($IR10_t^i - IR10_t^{UK}$) in t.
$Future3x6_t^i$	The change in the 3-month future for the 3-month interest rate in t in country (currency area) i	$diff\_IR10_t^i$	The change in the 3-month future of the 3-month interest rate differential ($Future3x6_t^i - IFuture3x6_t^{UK}$) in t.

We include several control variables which are likely to affect financial variables. Firstly, we control for changing expectations about the monetary policy by including 3-month futures of the 3-month interest rate ($Futures3x6_t^i$). For similar reasons, we include the national long-term interest yield ($IR10_t^i$) as explanatory variable in several specifications. Secondly, we use the S&P commodity price index ($COMM_t$) which is supposed to be an indicator of changing expectation about the performance of the global economy. Table 4.2 presents an overview of our variables.

4.3 Estimation results

4.3.1 Impact on international stock returns

Our first objective is to analyze the effect of the Brexit probability on international stock markets. In our opinion, the effect on stock markets can be assumed to be universally negative. However, there might be differences regarding the magnitude based on the strength of trade and financial linkages between the UK and the economy under observation.

In accordance with the assumption that financial markets and especially stock markets are (information) efficient, we do not include lagged values of the Brexit variables. Because all new information are supposed to be included into prices on arrival, information which has already been available on previous days should have no effect on present-day stock market returns.[23]

[23] We performed several estimation with lags of the variables. In the vast majority of cases, the lagged variable turned out to be insignificant. The same argument also applies to the other estimations in this section.

The dividend discount model assumes that stock prices are not only influenced by the expected level of dividends (and therefore by expectation about the general economic development) but also by current and future (short-term) interest rates (see section 1). According to announcements made by the BoE and to a lesser extent the ECB, it could be expected that central banks would react in their attempt to counterbalance potential adverse effects.[24] Therefore, the effect of the Brexit likelihood on the stock markets might be underestimated if a variable measuring expectations about the future monetary policy is not included in the model.

Table 4.3 – *Effect of Brexit likelihood on stock markets* ($stock_t^i$) *; Panel estimation*

	Random Effects							
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
$Brexit\_Prob_t$	-0.1372 (0.000)	-0.1421 (0.000)	-0.1373 (0.000)	-0.1258 (0.000)				
$Brexit\_Poll_t$					-0.4243 (0.000)	-0.4385 (0.000)	-0.4163 (0.000)	-0.4052 (0.000)
$Future3x6_t^i$		-0.0207 (0.1284)				-0.0227 (0.2132)		
$IR10_t^i$			-0.0555 (0.000)				-0.5564 (0.000)	
$Comm_t$				0.2691 (0.000)				0.2780 (0.000)
Pseudo R^2	0.0791	0.0818	0.1348	0.1712	0.0209	0.0219	0.0788	0.1214
Hausman p-value		0.4123	0.9100			0.2876	0.8333	

Note: Constants are included. p-values are presented in brackets. The Newey-West estimator is used for the calculation of the covariance matrix. Individual and time effects are included.

Our estimation results are presented in Tables 4.3 and 4.4. The estimated coefficients of the Brexit variables presented in both tables measure the effects of a one percentage point increase in the Brexit probability ($Brexit\_Prob$) or Brexit polls ($Brexit\_Poll$) on stock prices, in percent. Our panel estimations reveal significant evidence that an increase in the Brexit likelihood (based on both variables) has a strong negative effect on stock prices. For $Brexit\_Prob$, we find a decrease in stock prices of around 0.13 percent. A one percentage point increase in $Brexit\_Poll$ leads to a decrease of around 0.42 percent. Both results appear to be robust to the inclusion of commodity prices as well as indicators of future monetary policy.

The SUR estimation results confirm the panel results but shed light on country differences. While the largest effects are found for UK stocks when measured in USD, effects on US and Canadian stock prices turn out to be weaker than the effects on the European economies. For both economies, the results become insignificant when we include additional control variables

[24] In August 2016, the BoE decreased the bank rate to 0.25% justifying their decision by potential effects of the Brexit vote on future inflation and growth.

such as $COMM_t$. Regarding differences between European countries, the effects are overall similar. Therefore, it appears somewhat difficult to trace back the results to the strength of trade, banking or capital market linkages. However, we observe a tendency that the effects for the GIIPS[25] states is stronger with the exception of Greece. Based on the amount of economic ties between the UK and Ireland, it does not come as a surprise that Irish stock prices are strongly affected due to economic ties. For Italy, Spain and Portugal the strong effect is surprising and cannot be solely explained by the strength of economic ties with the UK. When we weight the observation by Google Trends data, the effects are stronger and significant for all countries indicating that the timing does in fact matter.

[25] The GIIPS states comprise Greece, Ireland, Italy, Portugal and Spain.

Table 4.4 – *Effect of Brexit likelihood on stock markets $stock_t^i$; SUR Estimation*

	(1)	(2)[26]	(3)	(4)	(5)	(6)
Exo. Variables	$Brexit\_Prob_t$	$Brexit\_Prob_t$ $Future3x6_t^i$	$Brexit\_Prob_t$ $IR10_t^i$	$Brexit\_Prob_t$ $Comm_t$	$Brexit\_Prob_t$ (weighted estimation)	$Brexit\_Poll_t$
Austria	-0.1500 (0.004)	-0.1426 (0.012)	-0.1494 (0.005)	-0.1337 (0.001)	-0.2268 (0.000)	-0.5023 (0.062)
Belgiun	-0.1503 (0.003)	-0.1473 (0.005)	-0.1524 (0.001)	-0.1395 (0.001)	-0.2292 (0.000)	-0.3684 (0.209)
Canada	-0.0452 (0.067)	-0.0452 (0.066)	-0.0316 (0.205)	-0.0318 (0.053)	-0.0690 (0.000)	-0.2503 (0.003)
Denmark	-0.1709 (0.001)	-0.1492 (0.000)	-0.1627 (0.001)	-0.1624 (0.001)	-0.2269 (0.000)	-0.3508 (0.005)
Finland	-0.0968 (0.182)	-0.0943 (0.203)	-0.1025 (0.150)	-0.0797 (0.193)	-0.2245 (0.000)	-0.4785 (0.000)
France	-0.1818 (0.002)	-0.1771 (0.002)	-0.1823 (0.001)	-0.1689 (0.000)	-0.2750 (0.000)	-0.4979 (0.063)
Germany	-0.1586 (0.006)	-0.1543 (0.008)	-0.1559 (0.008)	-0.1449 (0.002)	-0.2545 (0.000)	-0.5272 (0.040)
Greece	-0.1223 (0.246)	-0.1249 (0.233)	-0.0219 (0.803)	-0.1122 (0.294)	-0.0897 (0.000)	-0.6213 (0.401)
Netherlands	-0.1692 (0.005)	-0.1640 (0.007)	-0.1734 (0.003)	-0.1548 (0.001)	-0.2626 (0.000)	-0.5415 (0.022)
Norway	-0.1225 (0.004)	-0.1220 (0.004)	-0.0938 (0.029)	-0.1053 (0.000)	-0.1935 (0.000)	-0.3352 (0.215)
Ireland	-0.1972 (0.002)	-0.2003 (0.002)	-0.1939 (0.001)	-0.1853 (0.001)	-0.3140 (0.000)	-0.6048 (0.015)
Italy	-0.2132 (0.005)	-0.2081 (0.004)	-0.1784 (0.006)	-0.1869 (0.003)	-0.2574 (0.000)	-0.3305 (0.338)
Japan	-0.1542 (0.002)	-0.1170 (0.025)	-0.1385 (0.012)	-0.1391 (0.002)	-0.1940 (0.000)	-0.5348 (0.243)
Portugal	-0.2003 (0.000)	-0.1999 (0.000)	-0.1768 (0.000)	-0.1852 (0.000)	-0.2823 (0.000)	-0.4811 (0.212)
Spain	-0.2076 (0.000)	-0.2125 (0.000)	-0.1921 (0.000)	-0.1881 (0.000)	-0.2871 (0.000)	-0.4336 (0.181)
Sweden	-0.1405 (0.013)	-0.1386 (0.013)	-0.1362 (0.017)	-0.1247 (0.007)	-0.2476 (0.000)	-0.5170 (0.008)
Switzerland	-0.1218 (0.013)	-0.1213 (0.0149)	-0.1180 (0.014)	-0.1112 (0.008)	-0.2026 (0.000)	-0.5954 (0.002)
UK	-0.1108 (0.074)	-0.1069 (0.063)	-0.1034 (0.092)	-0.0970 (0.068)	-0.2101 (0.000)	-0.4852 (0.007)
UK (in USD)	-0.2336 (0.008)	-0.2163 (0.006)	-0.2163 (0.009)	-0.2116 (0.004)	-0.3872 (0.000)	-0.6823 (0.009)
US	-0.0469 (0.048)	-0.0332 (0.215)	-0.0130 (0.548)	-0.0411 (0.046)	-0.0514 (0.000)	-0.1849 (0.151)
Average R^2	0.1121	0.1514	0.1412	0.2014	0.4152	0.0231

Notes: The reported values represent the estimated coefficient of the Brexit variable. The Newey-West estimator is used for the calculation of the covariance matrix.

[26] We gain very similar results for 6x9 und 9x12 Futures.

4.3.2 Impact on long-term interest rates and sovereign credit risk

The impact on long-term interest rate and sovereign credit risk can be expected to show a larger degree of heterogeneity across countries. In this regard, some countries might benefit from increased uncertainty, because their bonds are considered to be a safe haven in times of market turmoil.

We believe that those countries rated AAA are most likely to benefit from decreased bond yields. Table 4.5 presents the panel results for the 10-year interest yield. Because we assume different effects, we divide the sample into two groups: While the first group contains countries which are considered to be nearly “risk-free” indicated by a rating of AAA, the second group contains countries which have a credit rating of below AA.[27]

Table 4.5 – *Effects on long-term interest rates* $(IR10_t^i)$*; panel estimations*

	Random Effects							
	AAA				<AA (GIIPS)			
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
$Brexit\_Prob_t$	-0.3283 (0.000)	-0.2750 (0.000)	-0.3023 (0.000)		0.7246 (0.000)	0.7177 (0.000)	0.6991 (0.000)	
$Brexit\_Poll_t$				-0.5710 (0.000)				1.6459 (0.000)
$Future3x6_t^i$		0.4420 (0.000)				0.2412 (0.7315)		
$Comm_t$			0.3784 (0.000)				-0.5829 (0.0670)	
Pseudo R^2	0.0521	0.2022	0.0761	0.0098	0.0356	0.0360	0.0425	0.0051
Hausman p-value		0.3190					0.2151	

Note: Constants are included. P-values are presented in brackets. The Newey-West estimator is used for the calculation of the covariance matrix. Individual and time effects are included.

We find that a one percentage point increase in Brexit probability leads to a decrease of about 0.3 basis points in AAA bonds, but increases interest rates of riskier countries by about 0.7 basis points. Again, our results are not driven by other developments as indicated by the results of regressions which include additional variables. Apart from the effects of Brexit probability, we obtain the surprising results, that an increase in expected future interest rates increases AAA long-term yields, but has no significant effect on yields of riskier country

[27] Ratings are taken from Fitch Ratings. The AAA group contains: Canada, Denmark, Germany, Netherlands, Norway, Sweden, Switzerland and the USA. The second group contains only the so-called GIIPS states.

Table 4.6 – *Effects on sovereign credit risk perception* (CDS_t^i)*; panel estimations*

	AAA				<AA (GIIPS)			
	(i)	(ii)	(iii)	(iv)	(vi)	(vii)	(viii)	(ix)
$Brexit\_Prob_t$	0.0064 (0.3847)	0.0068 (0.373)	0.0051 (0.454)		0.0923 (0.011)	0.1029 (0.002)	0.0847 (0.019)	
$Brexit\_Poll_t$				0.2127 (0.003)				0.6682 (0.015)
$Future3x6_t^i$		-0.0271 (0.278)				0.3706 (0.001)		
$Comm_t$			-0.0361 (0.064)				-0.1808 (0.001)	
Pseudo R^2	0.0191	0.0156	0.0171	0.0223	0.0117	0.0318	0.0251	0.0165
Hausman p-value		0.3521				0.9012		

Note: Constants are included. P-values are presented in brackets. The Newey-West estimator is used for calculation of the covariance matrix. Individual and time effects are included.

Table 4.6 presents the panel estimation results for CDS. Overall, our results confirm differences between the two groups. When *Brexit_Prob* is used as an indicator, we find no effect on AAA countries. On the opposite, Brexit likelihood has a significant effect on riskier countries. As presented, an increase in the Brexit probability increases the CDS by around 0.1 percent. However, the results have to be interpreted with caution because our estimations explain only a small fraction of the variation in our data as indicated by the (pseudo) R^2 values.

Regarding our SUR estimation results, we observe a strong decrease in long-term interest rates for the UK by around 0.6 basis points. Similar results for the UK yield are presented by BoE (2016). With respect to the other countries, we observe the same pattern as indicated by our panel estimation results with large increases for "riskier" countries and decreases for "risk-free" countries. For the remaining countries which can neither be considered "risk-free" nor high-risk (according to our classification), we observe mainly insignificant results which further supports our argument of a safe haven effect. For Greece, we observe a very strong effect as a one percentage point increase in the Brexit probability increases the Greek yield by 2 basis points. This does not come as a surprise as Greece has the worst rating in our sample (CCC).

The results for the sovereign credit risk reveal significant positive effects for the GIIPS countries, the UK, Germany and Belgium. While the effect on German CDS is significant it is very small as it increases by 0.05 percent when Brexit probability increases by one percentage point. The largest effects are found for Italy, Spain, Greece and Portugal. Putting these results into perspective, the increases in yields appear to be driven by increases in sovereign credit risk. For the UK, we find the largest increase in CDS spreads indicating that markets assume that Brexit might have an effect on the creditworthiness of the UK.

Table 4.7 – *Effects on interest rates $IR10_t^i$ and sovereign credit risk (CDS_t^i); SUR estimation*

	Specification						
	10-Year Interest Yield				CDS		
	(1)	(2)	(3)	(4)	(1)	(2)	(3)
	$Brexit\_Prob$	$Brexit\_Prob$ $Future3x6_t^i$	$Brexit\_Prob_t$ (weighted estimation)	$Brexit\_Poll_t$	$Brexit\_Prob$	$Brexit\_Prob$ $Comm_t$	$Brexit\_Poll_t$
Austria	-0.0496 (0.583)	-0.0534 (0.568)	-0.0428 (0.002)	0.6360 (0.141)	0.0355 (0.107)	0.0331 (0.114)	0.1091 (0.240)
Belgium	-0.0566 (0.591)	-0.0558 (0.596)	-0.0465 (0.0082)	-0.0036 (0.991)	0.0673 (0.000)	0.0620 (0.000)	0.2258 (0.126)
Canada	-0.5540 (0.0050)	-0.5540 (0.0050)	-0.4596 (0.0000)	-1.2151 (0.009)	0.0001 (0.452)	0.0002 (0.379)	-0.0006 (0.546)
Denmark	-0.3125 (0.0010)	-0.2505 (0.030)	-0.2595 (0.0000)	-0.4096 (0.601)	-0.0114 (0.177)	-0.0143 (0.121)	0.0084 (0.761)
Finland	-0.1609 (0.0731)	-0.1385 (0.120)	-0.0288 (0.0057)	0.3705 (0.368)	-0.0126 (0.093)	-0.0132 (0.097)	0.0938 (0.216)
France	-0.0553 (0.5614)	-0.0588 (0.544)	0.0138 (0.4286)	0.5724 (0.230)	0.0301 (0.541)	0.0245 (0.607)	0.0244 (0.814)
Germany	-0.3151 (0.0002)	-0.3125 (0.0003)	-0.2636 (0.0000)	-0.2350 (0.683)	0.0495 (0.014)	0.0499 (0.012)	0.1547 (0.339)
Greece	2.0558 (0.0427)	2.1477 (0.0480)	1.4181 (0.0000)	2.0897 (0.725)	0.1662 (0.058)	0.1635 (0.059)	0.6272 (0.322)
Netherlands	-0.1500 (0.0758)	-0.1386 (0.132)	-0.1137 (0.0000)	0.2526 (0.573)	0.0142 (0.516)	0.0100 (0.606)	0.1727 (0.474)
Norway	-0.3544 (0.0008)	-0.1647 (0.0247)	-0.3332 (0.0000)	-0.7217 (0.408)	-0.0144 (0.382)	-0.0159 (0.330)	-0.0408 (0.161)
Ireland	0.0955 (0.5931)	0.0346 (0.875)	0.3306 (0.0000)	1.0348 (0.058)	0.0488 (0.014)	0.0408 (0.092)	-0.2553 (0.561)
Italy	0.3450 (0.0851)	0.3324 (0.118)	0.6338 (0.0000)	1.0200 (0.076)	0.1982 (0.009)	0.1832 (0.006)	0.9263 (0.235)
Japan	-0.1334 (0.0722)	-0.2013 (0.0211)	-0.0567 (0.0000)	-0.3063 (0.020)	0.1730 (0.221)	0.1670 (0.235)	0.2501 (0.645)
Portugal	0.8974 (0.0084)	0.8931 (0.011)	1.4330 (0.0000)	2.4518 (0.055)	0.1561 (0.039)	0.1444 (0.046)	0.2880 (0.674)
Spain	0.3989 (0.0261)	0.4053 (0.033)	0.6732 (0.0000)	1.3719 (0.060)	0.1578 (0.000)	0.1489 (0.000)	0.1983 (0.630)
Sweden	-0.3199 (0.0070)	-0.3265 (0.004)	-0.3153 (0.0000)	-0.5805 (0.275)	-0.0028 (0.742)	-0.0049 (0.502)	0.0319 (0.614)
Switzerland	-0.2456 (0.0270)	-0.2458 (0.028)	-0.3398 (0.0000)	-0.8675 (0.200)	-0.0008 (0.339)	-0.0005 (0.475)	-0.0067 (0.146)
UK	-0.6039 (0.0000)	-0.5047 (0.0000)	-0.7194 (0.0000)	-1.5587 (0.067)	0.2109 (0.031)	0.2135 (0.027)	0.9386 (0.060)
United States	-0.4241 (0.001)	-0.2093 (0.0149)	-0.4281 (0.0015)	-1.0500 (0.026)	0.1303 (0.326)	0.1456 (0.300)	0.7226 (0.287)
Average R^2	0.0645	0.2224	0.3521	0.0098	0.0143	0.0254	0.0253

Note: The reported values present the coefficient of the Brexit variable. The Newey-West estimator is used for the calculation of the covariance matrix.

4.3.3 Impact on the external value of the British pound

Because Brexit can be linked to uncertainty and the possibility of an economic decline in the UK in the future, an increase in the Brexit likelihood should cause a depreciation of the British Pound. This hypothesis is supported by large losses of the pound vis-à-vis other currencies on the day after the referendum.

However, the exchange value is not only linked with expectations about the development of real economic variables and the level of uncertainty but also with interest rate differentials and expectations about (national) monetary policies.[28] In order to account for these aspects, we calculate the difference between the 3-month future of country i and the value for the UK ($\mathrm{Future3x6}_t^i - \mathrm{Future3x6}_t^{UK}$). We follow the same approach to calculate the (long-term) interest rate differential.

Table 4.8 – *Effects on the external value of the British Pound ExR_t^i; panel estimations*

	Random Effects					
	(i)	(ii)	(iii)	(iv)	(v)	(ii)
$Brexit\_Prob_t$	-0.1217 (0.000)	-0.1183 (0.000)	-0.1118 (0.000)			
$Brexit\_Poll_t$				-0.2306 (0.000)	-0.2100 (0.000)	-0.2063 (0.000)
$Diff\_Future3x6_t^i$		-0.0557 (0.000)			-0.0551 (0.000)	
$Diff\_IR10_t^i$			-0.0331 (0.000)			-0.0342 (0.000)
Pseudo R^2	0.1731	0.1788	0.1862	0.0148	0.0314	0.0517
Hausman-test p-value		0.4998	0.5062		0.7213	0.7009

Note: Constants are included. P-values are presented in brackets. Newey-West estimator is used for the calculation of the covariance matrix. Individual and time effects are included.

According to our panel estimation results, a one percentage point increase of the Brexit probability decreases the value of the pound by around 0.12 percent. When we focus our analysis on poll survey data (*Brexit_Poll*), the effect is about 0.23 percent. For our control variables, we find the expected impact of the interest rate differentials.

[28] In case of the Euro, we take German 10y yields as a proxy of the „European“ interest rate. However, we do not find different results when Dutch, French or Finnish Yields are used.

Table 4.9 - *Effects on the external value of the British Pound ExR_t^i; SUR estimations*

	Specification				
Exogenous Variables:	(1) $Brexit\_Prob_t$	(2) $Brexit\_Prob_t$ $Diff\_Future3x6_t^i$	(3) $Brexit\_Prob_t$ $Diff\_IR10_t^i$	(4) $Brexit\_Prob_t$ (weighted estimation)	(4) $Brexit\_Poll_t$
Canadian Dollar	-0.1115 (0.001)	-0.1108 (0.001)	-0.1115 (0.001)	-0.1451 (0.000)	-0.2007 (0.209)
Danish Krone	-0.1057 (0.000)	-0.1032 (0.000)	-0.1059 (0.000)	-0.1370 (0.000)	-0.2115 (0.157)
Euro	-0.1055 (0.000)	-0.1021 (0.001)	-0.1051 (0.000)	-0.1367 (0.000)	-0.2082 (0.166)
Norwegian Krone	-0.0543 (0.109)	-0.0522 (0.119)	-0.0605 (0.069)	-0.0664 (0.000)	-0.1045 (0.421)
Japanese Yen	-0.1584 (0.000)	-0.1381 (0.000)	-0.1434 (0.002)	-0.2006 (0.000)	-0.1728 (0.581)
Swedish Krone	-0.0865 (0.005)	-0.0918 (0.005)	-0.0797 (0.016)	-0.1233 (0.000)	-0.2995 (0.035)
Swiss Franc	-0.1316 (0.000)	-0.1285 (0.001)	-0.1297 (0.000)	-0.1784 (0.000)	-0.3629 (0.041)
US Dollar	-0.1228 (0.001)	-0.1220 (0.001)	-0.1283 (0.000)	-0.1772 (0.000)	-0.2848 (0.159)
Average R^2	0.3321	0.2356	0.2252	0.3542	0.0142

Notes: The reported values present the coefficient of the Brexit variable. The Newey-West estimator is used for the calculation of the covariance matrix.

Regarding the effect on the value of the British pound, we find similar results across currencies. The weakest and sometimes insignificant effect is found for the Norwegian Krone. Again, when we account for the timing for the probability increase by weighting the observations, we find larger and very significant results. For the Euro, we find an appreciation of up to 0.14 percent against the British pound. For the USD, we find even stronger effects of up to 0.1772 percent.

Comparing our results to the exchange rate development immediately after Brexit on Friday, the 24th of June, the British pound depreciated against the USD (Euro) by around 8 (6.3) percent. The probability of Brexit on the 23rd of June was about 17 percent. Calculating 83 * 0.1021 = 8.476 for the Euro and 83 * 0.1220 = 10.126 for the USD, we obtain estimates which are quite close to the observed developments.

In order to check for robustness of our results, we perform several addition estimations. We estimate (G)ARCH models in order to correct for potential volatility cluster which can be frequently observed in financial markets. However, our models do not find evidence of (G)ARCH effects. For the estimation of the stock market impacts, we use a different sample based on MSCI data. We find nearly identical results. We also use 6-month and 9-month futures instead of the 3-month interest rate and obtain nearly identical results.

Comparing our results with those presented by Krause et al. (2016), we find qualitatively similar results. Although results cannot be compared quantitatively due to differences in the variables used to measure the Brexit probability[29], it is worth to mention that Krause et al. (2016) find strong effects on stock prices, government bond yields and the British pound. However, while the authors find significant effects for the UK, impacts on German, European and US variables are significantly smaller and in most cases insignificant. Another study by Arnorsson and Zoega (2016) finds a (very) strong effect on the British pound. Based on their results, a one percentage point increase in Brexit Polls lowers the external value of the pound vis-à-vis the Euro by 1.1 percent. As both studies are based on poll data, the differences might be caused by differences in the exogenous variables. However, the results suffer from a weak amount of explanatory power as indicated by the R^2 of their estimations.

Gerlach and Di Giamberardino (2016) use an approach which is related to ours; but they restrict their estimations on the effects on the British pound (we include more countries and their exchange rates) and do not correct for expectations of future monetary policy, as we do. They find that an increase of one percentage point in the Brexit probability depreciates the Pound against the USD by about 0.21%. Our results point in the same direction but are somewhat smaller (around 0.12%). Regarding the effects on stock prices, Raddant (2016) focuses on the immediate impact after the referendum. While he also observes strong negative effects on European stock markets, he concludes that the Italian stock market is highly affected by Brexit, despite a relatively low connection between both markets. His result is corroborated by our estimations. However, we observe a similar pattern for Portugal and Spain as well.

Regarding the most recent developments in equity markets in Europe, we have observed a relatively strong recovery after the EU-referendum in the UK. For example, the Stoxx Europe 600 was priced at around 346 points before Brexit and subsequently decreased by about 11%. On 22nd of September 2016, the index was again at 347 points. Some authors evaluate the development by stating that the effects of Brexit have already vanished. We argue that the recovery of prices does not indicate that Brexit had only a little or no effect. First of all, stock prices are assumed to follow a random walk. Therefore, past shocks – like Brexit – still have an effect on current prices. Furthermore, stock prices are highly information-efficient. As new information are priced in, the new (good) news might (over-)compensate the effects of past news. As we do

[29] The authors use poll results from whatukthinks.org and in order to construct a dummy variable for time periods when the support for “leave” surpasses the support for “remain”.

not know the counterfactual i.e. the equity price development without Brexit, we cannot state that Brexit effects have already vanished by simply observing recent price developments.

5. Conclusions

In this paper, we have assessed the impact of Brexit uncertainty on the UK and also on international financial markets, for the first and the second statistical moments. Firstly, we estimated the time-varying interactions between UK policy uncertainty, which can to a large extent be attributed to Brexit uncertainty, and UK financial market volatilities (second statistical moment) and identified the substantial role of policy uncertainty for financial market volatilities. The policy uncertainty induced by the Brexit referendum resulted in huge spillovers to financial markets, with magnitudes that were never observed before. Moreover, the policy uncertainty spillovers remained strong since then, suggesting that political uncertainty concerning the development of the relationship between the United Kingdom and the EU causes turbulences on financial markets even 3 months after the vote. This can further weaken investment and hiring in the UK (and Europe). Seen on the whole, thus, we feel legitimized to corroborate the view of IMF (2016) and others that Brexit-caused policy uncertainty will continuously cause instability in key financial markets and has the potential to do damage to the British (and, as shown in section 4, also other European countries') real economy as well, even in the medium run.

Secondly, we used two other measures of the perceived probability of Brexit, namely daily data between 1st of April to the 23rd of June 2016 of probabilities released by Betfair as well as (aggregated) results of polls published by Bloomberg. Based on these datasets, we analyzed the Brexit effect on the levels of stock returns, sovereign CDS, ten-year interest rates of 19 different countries predominantly from Europe as well as the British pound and the euro (first statistical moment). Here, we find evidence that an increase in Brexit probability has especially strong effects on European stock markets. Regarding the effect on long-term interest rates and CDS, we observe a large heterogeneity across countries which can be related to the differences in sovereign credit risk. The main cause of this pattern might be related to an expected decrease in economic activity which might further jeopardize the sustainability of government debt. As Brexit might have unforeseeable effects on the stability of the entire EU, the effects may simply be generated by an increase in the, according to our view, still low probability of a breakup of the Euro area or the EU. Regarding the effect on the exchange rate, we find that an increase in the Brexit probability leads to a depreciation of the British pound. Based on the results gained in our paper, the main losers outside of the UK appear to be the GIIPS economies which are already struggling with the still ongoing sovereign debt crisis. So, how to explain the current lack of an even bigger (real economic) impact? It may just be because Brexit has not happened yet.

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Appendix

Table A1 - *VAR model specification tests*

VAR Lag Order Selection Criteria
Included observations: 4096

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-5628.419	NA	0.003139	2.749716	2.754344	2.751355
1	13690.21	38599.53	2.52e-07	-6.678814	-6.660304*	-6.672260
2	13725.84	71.13829	2.49e-07	-6.691817	-6.659426	-6.680349*
3	13735.18	18.62615	2.49e-07	-6.691981	-6.645708	-6.675598
4	13754.55	38.61553	2.48e-07	-6.697044	-6.636889	-6.675746
5	13767.38	25.56895*	2.47e-07*	-6.698916*	-6.624880	-6.672704
6	13772.96	11.11774	2.48e-07	-6.697248	-6.609330	-6.666121
7	13779.73	13.45019	2.48e-07	-6.696155	-6.594355	-6.660113
8	13787.36	15.17536	2.48e-07	-6.695488	-6.579807	-6.654532

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Roots of Characteristic Polynomial
Lag specification: 1 5

Root	Modulus
0.990123	0.990123
0.983251	0.983251
0.958368	0.958368
0.348462 - 0.447724i	0.567346
0.348462 + 0.447724i	0.567346
0.289396 - 0.381579i	0.478908
0.289396 + 0.381579i	0.478908
-0.336782 - 0.271603i	0.432655
-0.336782 + 0.271603i	0.432655
-0.415378	0.415378
0.055904 - 0.393290i	0.397244
0.055904 + 0.393290i	0.397244
-0.290021 - 0.259796i	0.389366
-0.290021 + 0.259796i	0.389366
0.349733	0.349733

No root lies outside the unit circle.
VAR satisfies the stability condition.

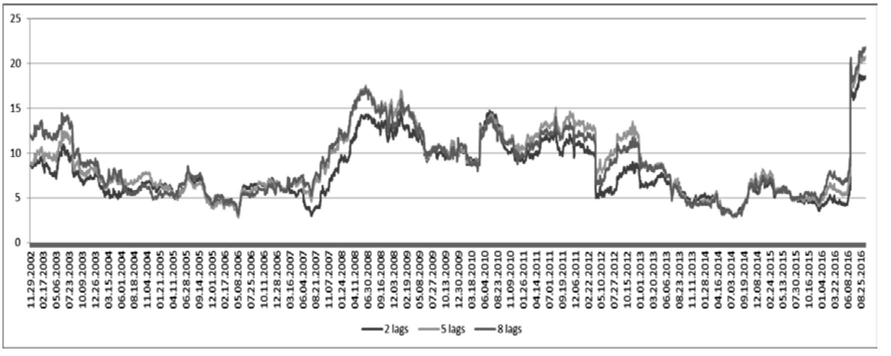
VAR Residual Serial Correlation LM Tests
Included observations: 4099

Lags	LM-Stat	Prob
1	6.356161	0.7038
2	5.070791	0.8281
3	9.175463	0.4212

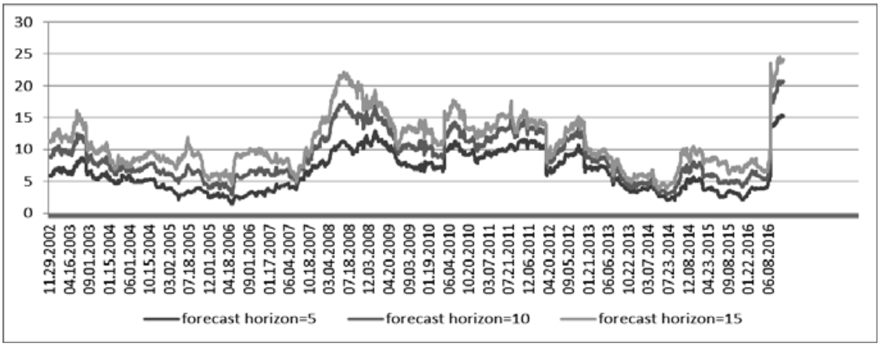
Probs from chi-square with 9 df.

Figure A1 - *Robustness Check*[30]

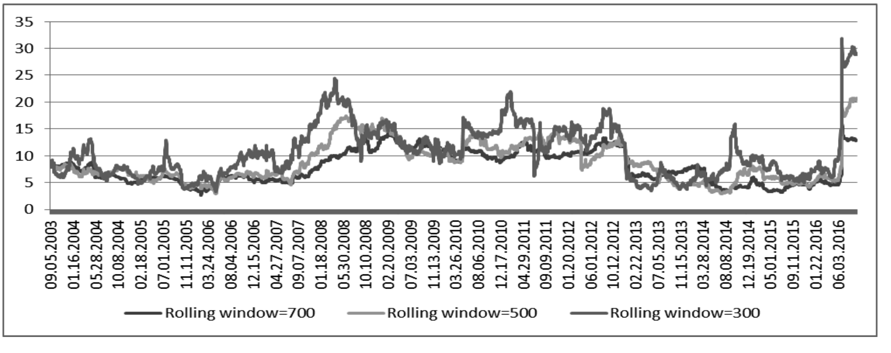
a) Total Spillover Index for different lag choices



b) Total Spillover Index for different forecast horizon choices



c) Total Spillover Index for different rolling window choices



[30] Additional robustness check results for other spillover indices are available upon request.