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$$\frac{n!}{(n-1)!} p^{m-1} (1-p)^{n-m} = p \sum_{\ell=0}^{n-1} \frac{\ell+1}{n} \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell} = p \frac{n-1}{n} \sum_{\ell=0}^{n-1} \left[\frac{\ell}{n-1} + \frac{1}{n-1} \right] \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell} = p^2 \frac{n-1}{n} +$$

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The Impact of the Brexit Vote on UK Financial Markets: A Synthetic Control Method Approach

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Abstract:

We estimate how the UK financial markets would have evolved if the Remain camp had won the referendum. To construct the counterfactual, we use the synthetic control method. Our results suggest that there would not have been any significant change in the development of the FTSE 100 Index in the medium to long term if there had not been a referendum. On the other hand, we find a significantly negative effect of 1.2 percentage points on the 10-year bond yield. Given the geopolitical circumstances in mid 2016, financial agents investing in the pound could have sought safer investment options represented by longer-term government bonds, which consequently could result in lower bond yields.

JEL: C10, Q10, Q18

Keywords: Brexit, financial markets, macroeconomic indicators, synthetic control method

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1 Introduction

Economists and social scientists are often interested in the impact of events or interventions at an aggregate level on entities such as countries, regions or firms. The unexpected result of the Brexit vote on June 23, 2016 provides a unique opportunity to study the impact of this idiosyncratic event on selected financial indices. Moreover, the unpredictability of the vote allows us to use the synthetic control method (SCM) introduced by (Abadie & Gardeazabal, 2003), which provides a data driven approach in which control units are systematically chosen as a weighted average of all relevant units that best fit the characteristics of the treatment unit. Using the weighted average approach precludes the extrapolation that is the typical basis of regression models (King & Zeng, 2006).

There is limited literature related to the impact of the Brexit vote on the British economy. Born, Müller, Schularick, & Sedláček (2017) use the SCM to evaluate the effect of the vote on the change in future expectations about the UK economy. They find that a large part of the cost of Brexit could be attributed to the gloomier average expectations of economic agents about the British economic future. Another contribution by Ramiah, Pham, & Moosa (2017) using the event study methodology shows that the banking, travel and leisure sectors were negatively affected, with cumulative abnormal returns of -15.37% for the banking sector. The consequences of the Brexit vote on living standards was studied by Breinlich, Leromain, Novy, & Sampson (2017), who suggest that the referendum increased aggregate UK inflation by 1.7 percentage points within one year. Moreover, they find that the cost of inflation is evenly shared across the income distribution, but not across regions, with London the least affected and Scotland, Wales and Northern Ireland impacted the most. The effect of the Brexit vote on corporate loan origination was estimated by Berg, Saunders, Schäfer, & Steffen (2016). They propose a new matching strategy called Siamese twins matching, which is used to find appropriate counterfactuals for the UK market. The results show that the UK syndicated loan market dropped by 25% after the Brexit vote.

Deploying the SCM, we build a counterfactual world that shows how selected variables would have developed if the Brexit vote had not occurred. In this paper, we estimate the impact on the UK stock exchange, long-term government bonds and exchange rate. We approximate the aforementioned variables by long-term treasury yield

(10-year gilt yield), Financial Times Stock Exchange 100 Index (FTSE 100 Index) and the real effective exchange rate (REER). We use monthly data from the OECD database to establish the donor pool of countries that best resembles the economic development of the UK before the vote. We contribute to the current literature on the economic impact of the Brexit vote by analysing the development of stock and bond markets and the real effective exchange rate. As far as we know, this paper is first to analyse the impact of the Brexit vote on UK financial market using SCM. Our paper relates to the analysis of macroeconomic experiments at the aggregate level Billmeier & Nannicini (2013), Gathani, Santini, & Stoelinga (2013) and Hosny (2012) and the literature on employing the synthetic control method. From the outset, we would like to stress that we are not testing a model of the UK economy. Instead, we attempt to establish a possible path of selected variables and the magnitude of the effect of the Brexit vote.

The results based on monthly data show that there would not have been any significant change in the development of the FTSE 100 Index if the referendum had not occurred. Since that companies listed on the FTSE 100 derive 76% of their revenue outside the UK, financial agents could take advantage of British currency depreciation and implement a wait-and-see approach (FTSE Russell, 2017). As the Bank of England in their Quarterly Bulletin from 2016 Q3 points out (p.146): *‘On 23 June UK-focused equity prices fell sharply. However since then, expectations for a broadly more accommodative stance of monetary policy from major central banks helped to reverse some of these moves. Equities performed strongly, credit spreads decreased, and volatility fell to record lows’* Manning (2016). This corresponds with the result for REER, which would not have declined in the case of no referendum. Finally, we find a significant effect on the 10 year bond yield, which would have been higher had there not been any referendum. In their study, Born, Müller, Schularick, & Sedláček (2017) show that macroeconomic uncertainty explains close to half of the observed output loss in the UK after the Brexit vote. Adding the geopolitical circumstances in mid 2016, financial agents investing in GBP could seek safer options represented by longer term government bonds, which results in lower bond yields.¹ Moreover, as Manning (2016) reports in Quarterly Bulletin 2016 Q3 (p.147) : *‘At longer maturities, contacts attributed some of the moves to changes in hedging activities of liability-driven investors such as insurers and pension funds.’* In conclusion, the unexpected result of the Brexit vote helped

¹The presidential election in the USA, the Syria crisis and the EU immigration policy discussion.

to decrease long-term government yield and triggered a strong decline in REER. On the other hand, the equity market stayed relatively unaffected in the mid to long term thanks to the accommodative monetary policy of the Bank of England following the referendum.

2 Synthetic Control Method

The SCM was introduced by Abadie & Gardeazabal (2003), Abadie, Diamond, & Hainmueller (2010) and Abadie, Diamond, & Hainmueller (2015) to address the difficulty in finding the counterfactual development of a treated unit. In general, the SCM assigns weights to control units so that these units best fit the pre-treatment characteristics of the treated unit. The SCM has been used in many fields, including international finance (Jinjarak, Noy, & Zheng (2013), Sanso-Navarro (2011)), financial policy (Aregger, Leutert *et al.* (2017), (Bruha & Tonner, 2017) and Opatrny (2017)), trade liberalization (Billmeier & Nannicini (2013), Gathani, Santini, & Stoelinga (2013) and Hosny (2012)) and taxation (Kleven, Landais, & Saez (2013)).² Since the introduction of the SCM, there have been several articles that extend the SCM. For example, Acemoglu, Johnson, Kermani, Kwak, & Mitton (2016) and Cavallo, Galiani, Noy, & Pantano (2013) modify the SCM in such a way that more than one treated unit can be used to assess the intervention effect.

Another extension was proposed by Wong (2015), where the SCM is applied to a cross sectional setting and the synthetic control asymptotic distribution is derived as the number of individuals in the sample goes to infinity. Kreif, Grieve, Hangartner, Turner, Nikolova, & Sutton (2016) examine the SCM in contrast with the difference-in-differences method in the health policy context. They find that in contrast to the DiD method, for the incentivised condition, the SCM reports that a pay-for-performance (P4P) initiative did not significantly reduce mortality. Recently, Amjad, Shah, & Shen (2018), reviewed by Alberto Abadie, present a robust generalization of the synthetic control method for comparative case studies that automatically identifies a good subset of donors for the synthetic control, overcomes the challenges of missing data, and continues to work well in settings where covariate information may not be provided.

The extent of inference procedures, originally developed by Abadie, Diamond, &

²See Firpo & Possebom (2017) for a rich list of studies using the SCM.

Hainmueller (2010) and Abadie, Diamond, & Hainmueller (2015), represent an important research topic. Their inference procedures consist of estimating p-values through permutation tests. Using this procedure, they test the null hypothesis of no effect of the intervention. Ando & Ando (2015) design two new test statistics that have more power when applied to test the null hypothesis than those introduced by Abadie, Diamond, & Hainmueller (2010) and Abadie, Diamond, & Hainmueller (2015).

Another inference procedure that uses confidence intervals was proposed by Gobillon & Magnac (2016). They use a bootstrap technique to compute confidence intervals for the policy effect on more than one treated unit. To obtain valid results, a large number of treated and control regions is necessary. The issue with the validity of confidence intervals for a small number of control units was solved by Firpo & Possebom (2017). They extend the original inference procedures in a way that allows for different treatment assignment probabilities across units – any region could have a different probability of facing the intervention of interest. Moreover, their modified inference procedure allows for testing any type of sharp null hypothesis – any other than the null hypothesis of no effect proposed by Abadie, Diamond, & Hainmueller (2010) and Abadie, Diamond, & Hainmueller (2015). Finally, their inference procedure allows for the construction of confidence intervals for the post-intervention outcome as a function of time. We use the modified inference method of Firpo & Possebom (2017) to show the effect of the Brexit vote on long-term treasury yield (10-year gilt yield), Financial Times Stock Exchange 100 Index (FTSE 100 Index) and the real effective exchange rate (REER).

The following section is subdivided into three parts. The first presents the data used for the analysis, while the second and third describe the synthetic control method and its inference procedure, respectively. The notation and ideas mainly follow those of Abadie, Diamond, & Hainmueller (2010), Abadie, Diamond, & Hainmueller (2015) and, for the extended inference procedure, those of Firpo & Possebom (2017).

2.1 Non EU OECD Countries as Control Units

The data set used to analyse the impact of the Brexit vote on the selected variables is based on the OECD database. We use monthly data starting in April 2008 and ending in November 2018.³ The donor pool of countries consists from 9 non-OECD members

³The start period was chosen due to missing data.

– Australia, Canada, Chile, Israel, Japan, South Korea, Mexico, New Zealand, and the United States. As Abadie, Diamond, & Hainmueller (2015) suggest, countries that may be affected by intervention in the ‘treated’ country should be excluded from the sample. Therefore, we exclude from the donor pool European countries that could be affected the most by currency depreciation after the Brexit vote.

We select long-term treasury yield (10-year gilt yield), Financial Times Stock Exchange 100 Index (FTSE 100 Index) and the real effective exchange rate (REER) as our outcome variables. Covariates include short-term treasury yield (2-year bond yield), 3-month interbank rate, overnight interbank rate (these variables help us to cover the short-term market perception of the current state), adjusted leading indicator, GDP ratio to trend, industrial production index, import and export indices, relative consumer price index, and harmonised unemployment (these variables explain the current state of economies in each country in the donor pool).⁴ Finally, the selected covariates reasonably reflect the national monetary and financial sector, as well as the macroeconomic development of the economy.

2.2 Methodology

Suppose that the data set consists of information about $J + 1$ countries. Without loss of generality, we assume that only the first country continuously faces the intervention of interest from period $t_0 \in \{1, \dots, T\}$ Abadie, Diamond, & Hainmueller (2010). As a consequence, there are J countries remaining as eventual control units that are not influenced by the intervention. Let Y_{it}^N denote the potential outcome of interest in the absence of the intervention for country i in period t , where $i \in \{1, \dots, J + 1\}$ and $t \in \{1, \dots, T\}$. Let T_0 , where $1 \leq T_0 \leq T$, be the number of pre-intervention periods. Depending on the anticipation effect, we can reset T_0 to the period when the first effect of the intervention is assumed to appear Abadie, Diamond, & Hainmueller (2015). Let Y_{it}^I denote the outcome of interest affected by the intervention for country i in period $t \in \{1, \dots, T\}$. Naturally, we assume that the intervention has no effect on the outcome in the pre-intervention periods; therefore, $Y_{it}^N = Y_{it}^I$ for $t \in \{1, \dots, T_0\}$ (Opatrny, 2017).

The effect of the intervention with $t > T_0$ is represented as follows:

$$v_{it} = Y_{it}^I - Y_{it}^N \tag{1}$$

⁴See Table 1 for descriptive statistics of the variables.

Because Y_{it}^I is observed in equation (1), we must estimate Y_{it}^N . Abadie & Gardeazabal (2003) defined the weighted average of the control units with weights $w = \{w_2, \dots, w_{J+1}\}$ with $0 \leq w_j \leq 1$ for $j = 2, \dots, J + 1$ and

$$\sum_{j=2}^{J+1} w_j = 1$$

. These restrictions are made to avoid an extrapolation. By means of the given weights $\{w_2, \dots, w_{J+1}\}$, the synthetic control estimators of Y_{it}^N and v_{it} are:⁵

$$\hat{Y}_{it}^N = w_2 Y_{2t} + \dots + w_{J+1} Y_{J+1,t}$$

$$\hat{v}_{it} = Y_{it}^I - \hat{Y}_{it}^N$$

The next step is to choose the weights $\{w_2, \dots, w_{J+1}\}$ that best reflect the pre-intervention characteristics of the treated unit. Abadie, Diamond, & Hainmueller (2010) choose $w^* = \{w_2^*, \dots, w_{J+1}^*\}$, which minimizes:

$$v_1(X_{11} - w_2 X_{12} - \dots - w_{J+1} X_{1,J+1})^2 + \dots + v_k(X_{k1} - w_2 X_{k2} - \dots - w_{J+1} X_{k,J+1})^2 \quad (2)$$

where $\{v_1, \dots, v_k\}$ represents the relative importance of the synthetic control assigned to predictors $\{X_{11}, \dots, X_{k,J+1}\}$. Consequently, the procedure comes down to choosing $\{v_1, \dots, v_k\}$.⁶ As in most empirical studies using the SCM, we choose the weights $\{v_1, \dots, v_k\}$ to minimize the size of the prediction error, $Y_{it}^I - \hat{Y}_{it}^N$, in a selected pre-intervention period (Opatrny, 2017).⁷ This can be done by solving a nested optimization problem with v selected such that w minimizes the root mean square predicted error (RMSPE) during a selected period.⁸ Therefore, each choice of v results in a different country weight $w(v)$, which then gives a value for the RMSPE.

To precisely minimize the RMSPE, the following conditions must be fulfilled. First, countries that faced similar intervention should be excluded from the data set to avoid potential bias in the output. Second, to ensure a good fit of the counterfactual outcome, the control units must have similar economic performance to that of the unit exposed

⁵See Abadie, Diamond, & Hainmueller (2010), where it is proved that \hat{v}_{it} is an unbiased estimator of v_{it} .

⁶See Table 5 in Appendix for the relative importance of our covariates.

⁷See Abadie *et al.* (2011), which describes other approaches for choosing the weights $\{v_1, \dots, v_k\}$

⁸The RMSPE has the following formula: $RMSPE = \left(\frac{1}{T_0} \sum_{t=1}^{T_0} (Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt})^2 \right)^{\frac{1}{2}}$

to the intervention. Moreover, countries that may be affected by the intervention in the ‘treated’ country should be excluded from the sample Abadie, Diamond, & Hainmueller (2015). Taking these assumptions into account, we consider non-OECD countries as suitable comparison units. However, as Amjad, Shah, & Shen (2018) claim, for the optimal result, the method still depends on a subjectively chosen subset of donors and covariate matrix. Moreover, the SCM performs poorly in the case of missing data or strong levels of noise in the data set.

2.3 Inference Procedures

We use three inferential methods for the SCM. Two of these methods are based on the ‘placebo’ effect initially introduced by Abadie & Gardeazabal (2003). The third method, which involves constructing a confidence interval, was briefly used in Opatrny, 2017, but a later study Firpo & Possebom (2017) provides a theoretical background for constructing the confidence intervals for SCM.

The first inference method applies the synthetic control method to all control units. As a result, we obtain a synthetic control for countries not exposed to the intervention. Consequently, this allows us to evaluate the estimation of the effect between the treated unit and the units not exposed to the intervention Opatrny (2017). In other words, we would lose confidence about the results if the SCM was used to estimate a large effect on a unit where the intervention did not occur. Formally, for each country $i \in \{1, \dots, J + 1\}$ and period $t \in \{T_0, \dots, T\}$, Abadie, Diamond, & Hainmueller (2015) compare the effect of the intervention in the treated country, \hat{v}_{it} , with the effect of the intervention in the control units \hat{v}_{it} . To solve the problem that $|\hat{v}_{it}|$ could be atypically larger than $|\hat{v}_{it}|$ for some periods but not for others, they suggest using the distribution of the following statistic:

$$RMSPE_i := \frac{\sum_{t=T_0+1}^T (Y_{it} - \hat{Y}_{it}^N)^2 / (T - T_0)}{\sum_{t=1}^{T_0} (Y_{it} - \hat{Y}_{it}^N)^2 / (T_0)} \quad (3)$$

Equation 3 is then used to compute the following p-value:

$$p := \frac{\sum_{i=1}^{J+1} D_i}{J + 1}, \quad (4)$$

where D_i equals 1 if $(RMSPE_i \geq RMSPE_1)$. Therefore, Abadie, Diamond, & Hainmueller (2015) could reject the null hypothesis of no effect of the intervention if p is less than some pre-specified significance level. However, Firpo & Possebom (2017) claim that the design of the p-value in equation 4 implicitly assumes a uniform distribution of the probability of being treated. Therefore, their extension of the inference method suggests a parametric form of treatment probabilities. For $\bar{i} \in \Omega := \{(1), \dots, (J+1)\}$, such that $RMSPE_{(1)} > RMSPE_{(2)} > \dots > RMSPE_{(J+1)}$ and $RMSPE_{\bar{i}} = RMSPE^{obs}$, if there is more than one $i' \in \Omega$ with that property, Firpo & Possebom (2017) propose selecting the largest. They define the treatment probabilities as

$$\pi_{(i)}(\phi) = \frac{\exp(\phi v_{(i)})}{\sum_{i' \in \Omega} \exp(\phi v_{i'})}, \quad (5)$$

where $\phi \in R_+$ is the sensitivity parameter and $v_{i'} \in \{0, 1\}$ for each $i' \in \Omega$. This result provides an intuitive way to analyse the sensitivity of the parameter to deviations from the uniform distribution assumption. For example, the interpretation of ϕ is as follows: a unit $i_{(1)} \in \Omega$ with $v_{(i1)} = 1$ has a $\Phi := \exp(\phi)$ times higher probability to be treated than a unit $i_{(2)} \in \Omega$ with $v_{(i2)} = 0$ (Firpo & Possebom, 2017).⁹ Due to assumption 5, the authors use the following formula to compute the p-value:

$$p(\phi, v) := \sum_{(i) \in \Omega} \frac{\exp(\phi v_{(i)})}{\sum_{i' \in \Omega} \exp(\phi v_{i'})} D_i, \quad (6)$$

where D_i equals 1 if $(RMSPE_{(i)} \geq RMSPE_{\bar{i}})$ and $v := (v_1, \dots, v_{J+1})$. This formula allows us to reject the exact null hypothesis if $p(\phi, v)$ is less than some pre-specified significance level.

In the empirical section below, we use the approach of Firpo & Possebom (2017). Given the fact that $(J+1) = 10$, the probability that any control unit would receive the same treatment effect reaches a maximum of 1/10, which is equivalent to a p-value of 0.1 according to equation 4 proposed by Abadie, Diamond, & Hainmueller (2015). Our results suggest p-values equal to 1/10, 3/10 and 6/10 for the ten-year gilt yield, real effective exchange rate and FTSE 100 Index, respectively. Applying the standard rejection rule when the p-value equals 0.1, we do not reject the exact null hypothesis H_0 : There is no effect of the event $Y_{it}^N = Y_{it}^I$ for $t \in \{1, \dots, T\}$ in terms of REER and

⁹See section 3 in Firpo & Possebom (2017) for the details.

the FTSE 100 Index. Applying the sensitivity analysis proposed by Firpo & Possebom (2017) to check the robustness of the result for REER, we do not reject H_0 : There is no effect of the event is not a robust result, because we must set $\phi_{REER} = 1.35$ in order to reject it at the 10% significance level. As Firpo & Possebom (2017) suggest, when the exact null hypothesis, H_0 , is false and we do not reject it, we want the sensitivity parameter $\phi \in R_+$ to be small because a more robust result could keep us from making a type II error. We argue that $\phi_{REER} = 1.35$ is reasonably small according to section 5.2 in Firpo & Possebom (2017). On the other hand, in the case of the FTSE 100 Index, we must set $\phi_{FTSE100} = 2.6$ in order to reject H_0 at the 10% significance level. When the exact null hypothesis, H_0 , is true and we do not reject it, we want the sensitivity parameter $\phi \in R_+$ to be large because a more robust result could keep us from making a type I error. Finally, in the case of the ten-year gilt yield, we already reach a maximum p-value of 0.1, which results in $\phi_{10YBondYield} = 0.003$. As Firpo & Possebom (2017) claim, if the sensitivity parameter $\phi \in R_+$ is close to zero, the permutation test's decision is not robust to small violations of the assumption of a uniform distribution of the probability of being treated, i.e., $\phi = 0$.

In conclusion, our results indicate that H_0 : There is no effect of the intervention, $Y_{it}^N = Y_{it}^I$ for $t \in \{1, \dots, T\}$, may be true for the FTSE 100 Index but false for the REER and ten-year gilt yield. This result is confirmed by the inference method using confidence sets described in the Synthetic Outcome Section 3 below.

The second method related to the placebo study applies the synthetic control method to the period when the intervention did not occur in a treated unit. As Abadie, Diamond, & Hainmueller (2015) mention, a large placebo estimate would undermine the credibility of the result. For example, if there is a significant effect of the intervention in an earlier period, the confidence of the effect would greatly diminish.¹⁰

The third method is based on the construction of a confidence interval. As mentioned earlier, in the study conducted by Opatrny (2017), point-wise confidence intervals are used. Using the original RMSPE¹¹ computed by the SCM, we derive the respective confidence sets for the outcome Y_{it}^N in the post-intervention period $t \in \{T_0, \dots, T\}$. In this empirical research, we use the confidence sets proposed by Firpo & Possebom (2017), which provide the theoretical background for confidence sets with constant and

¹⁰We can choose random periods prior to the intervention.

¹¹The formula mentioned in the footnote in section 2.2.

linear in time intervention effects. For linear in time intervention effect, they assume

$$H'_0 : Y_{it}^I = Y_{it}^N + (\hat{c} \times (t - T_0))D_t, \quad (7)$$

for each unit $i \in \{1, \dots, J + 1\}$ and time period $t \in \{1, \dots, T\}$, where D_t equals 1 if $t \geq T_0 + 1$ and $\hat{c} \in R$.¹² Therefore, Firpo & Possebom (2017) assume constant in space effects, but linear in time intervention effects. Moreover, they suggest that we can apply the inference procedure described earlier in this section 2.3 to the empirical distribution of $RMSPE^{\hat{c}}$ as a test statistic.¹³ Consequently, the $(1 - \gamma)$ – the confidence interval for the linear in time intervention effects – becomes

$$CI_{(1-\gamma)}(\phi, v) := \left\{ \begin{array}{l} f \in R^{\{1, \dots, T\}} : f(t) = (RMPSE^{\hat{c}} \times (t - T_0)) * D_t \\ \text{and } p^{\hat{c}}(\phi) > \gamma \end{array} \right\} \subseteq CI_{(1-\gamma)}(\phi, v), \quad (8)$$

where $\gamma \in (0, 1) \subset R$. Intuitively, as Firpo & Possebom (2017) state, the confidence interval contains all linear in time intervention effects, for which H'_0 is not rejected by the inference procedure described earlier in this section 2.3.

3 Synthetic Outcome Findings

In Figure 1a, we can see that the synthetic output almost copies the path of the real output after the Brexit vote. In other words, the FTSE 100 index would not have changed had there not been a referendum, taking into account the monthly frequency of the data.¹⁴ The results are driven mainly by New Zealand, Mexico and the United States, with weights of 0.477, 0.125 and 0.103, respectively.¹⁵ All other control units receive a weight less than 0.1. As Manning (2016) comments, equity markets declined remarkably immediately after the Brexit vote; however, they rebounded strongly in the following days. He adds that this recovery was driven in part by accommodative

¹²For constant in time intervention effects, they exclude the term $(t - T_0)$ from equation 7.

¹³The inference procedure is referred to as *the first method*.

¹⁴See Table 6 in Appendix for quantitative details about the result in the period after the Brexit vote.

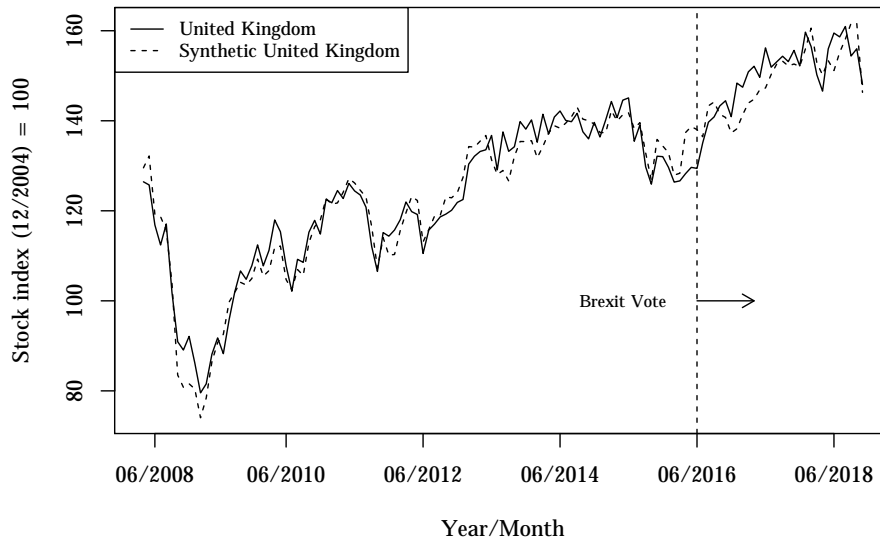
¹⁵See Table 2 in Appendix for details.

central bank policy and in part by ‘search for yield’ behaviour among market agents in an environment of low interest rates. In summary, our results suggest that the unexpected outcome of the Brexit vote had no impact on the equity market in the medium to long term.

As a robustness check of the results, we run the inference procedures described in section 2.3. In Figure 1b, we change the date of the vote to December 2014. The resulting dashed line is almost identical to that in Figure 1a. Following the idea of Abadie, Diamond, & Hainmueller (2015), if there is not a significant effect of the Brexit vote in an earlier period, the confidence of the effect is not undermined. Our results do not undermine the main finding, as shown in Figure 1b.

Figure 1: Brexit Vote Had No Impact on the Stock Index

(a) Stock Index – Intervention set to June 2016



(b) Stock Index – Intervention set to December 2014

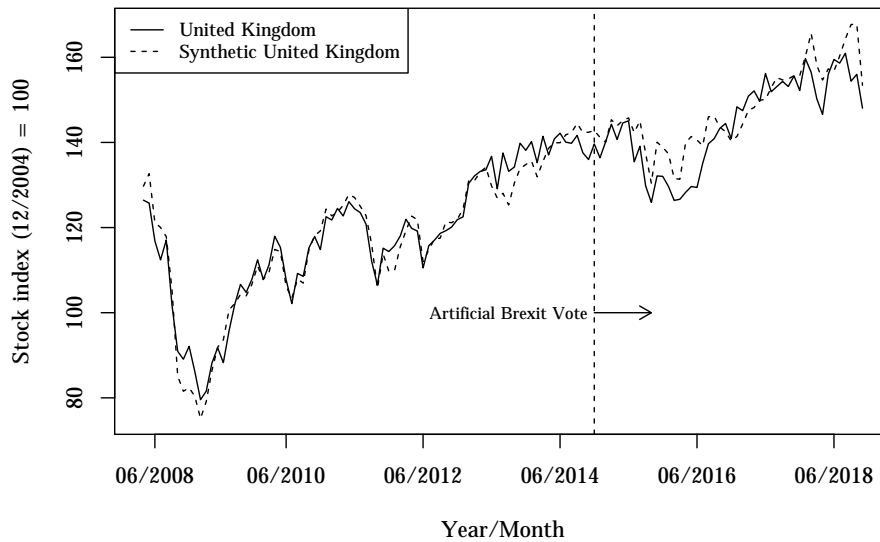


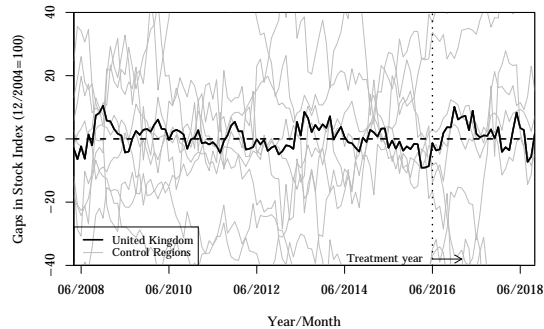
Figure 2 shows the statistical significance of the result. In Figure 2a, we can see an estimate of the effect of the Brexit vote on the UK and all control units. Moreover, the intervention effect does not abnormally differ from that of the other control units given the pre-treatment fit. Figure 2b shows the estimated 90% confidence intervals.

Intuitively, if the confidence interval includes the zero function, we do not reject the null hypothesis H'_0 : There is no effect of the Brexit vote on the Stock Index. However, immediately after the Brexit vote, the estimated result lies outside the confidence interval. This result is in line with the comments of Manning (2016) that equity markets significantly dropped after the Brexit vote but recovered quickly in the following period. In conclusion, the statistical inference procedure confirms the result that the Brexit vote had no impact on the Stock index in the medium to long term.

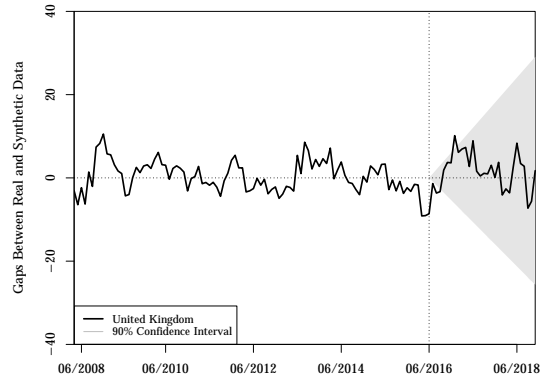
On the other hand, the impact of the Brexit vote on the 10-year gilt yield is depicted in Figure 3. The synthetic output would have been 1.2 percentage points higher had there not been a referendum (Figure 3a). The United States, Canada and South Korea compose the synthetic output with weights of 0.440, 0.332 and 0.226, respectively. Other countries receive weights of less than 0.002.¹⁶

Figure 2: Statistical Significance of the Synthetic Output for the Stock Index

(a) Stock Index – Placebo Inference Method



(b) Stock Index – Confidence Interval



In addition to the aforementioned hedging activities by pension funds and insurers, the low ten-year gilt yield after the Brexit vote was driven in part by increased expectation for an additional round of quantitative easing from the Bank of England. Consequently, on August 4, 2016, the UK Monetary Policy Committee (MPC) announced a supportive package for the UK economy consisting of (Manning (2016), pp. 147): *(i) a 25 basis points cut in Bank Rate to 0.25%, (ii) a Term Funding Scheme (TFS) to reinforce the pass-through of the cut in Bank Rate, (iii) purchases of up to £10 billion of sterling non-financial investment-grade corporate bonds (see “Corporate capital markets” section), and (iv) an increase in the stock of purchased UK government bonds,*

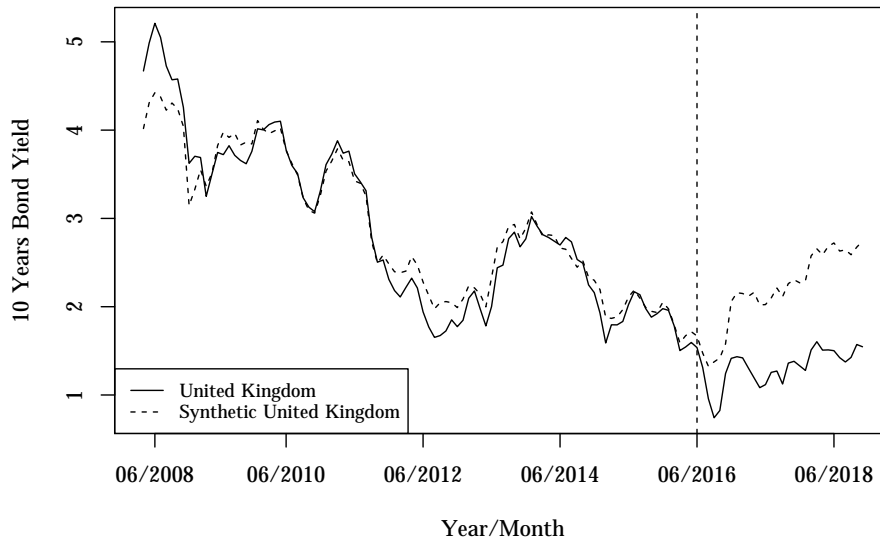
¹⁶See Table 3 in the Appendix for details.

by £60 billion over six months, to £435 billion. These measures helped to further lower the 10-year gilt yield, as noted by Bank of England (2016) in Inflation Report. Another fact that explains the significant gap between the real and synthetic output is related to increased US Treasuries yield in the period after the Brexit vote. As Manning (2016) explains (pp. 148): *‘market contacts attributes these moves to an increasing focus on domestic drivers of interest rates rather than spillovers from the United Kingdom’s referendum and the subsequent monetary policy response’*.

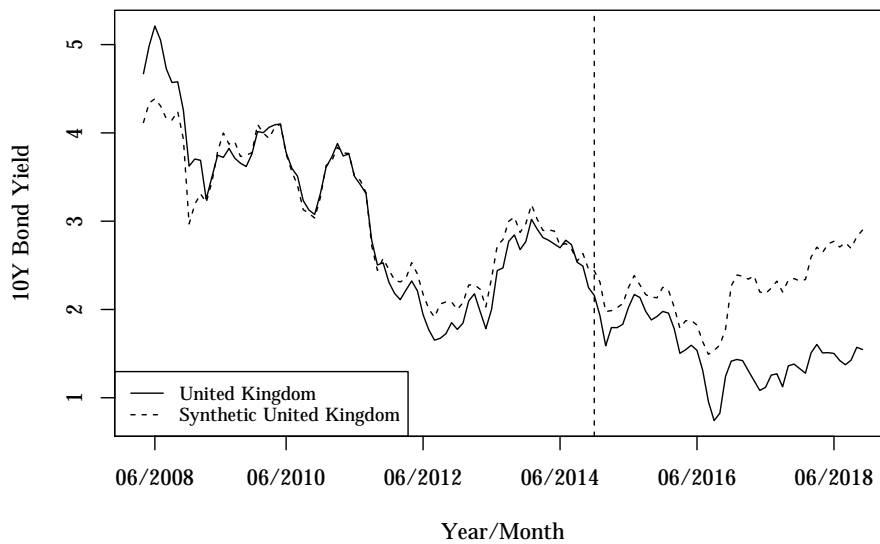
We verify the statistical significance by setting the Brexit vote to December 2014 (Figure 3b). The result closely resembles that in Figure 3a. Therefore, we believe that this statistical inference does not undermine our result. Alternatively, we run the placebo inference method (Figure 4a).

Figure 3: Synthetic 10Y Bond Yield Higher than the Real One

(a) 10-Year Bond Yield – Intervention set to June 2016



(b) 10-Year Bond Yield – Intervention set to December 2014



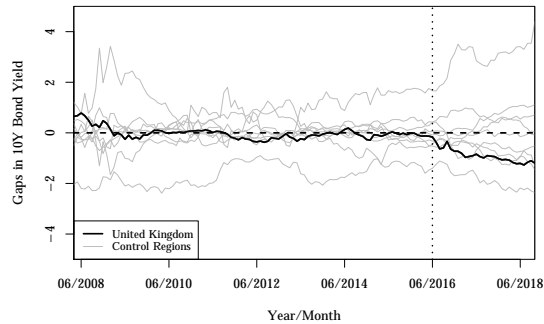
Given the result, we infer that the synthetic output does not abnormally differ from the other control units. In other words, applying the SCM on all other control units, we do not find any better pre-intervention fit. Finally, we estimate the 90% confidence interval (Figure 4b). The confidence interval does not include the zero function; therefore, we

reject the null hypothesis H_0' : There is no effect of the Brexit vote on ten-year gilt yield. To conclude, we claim that the Brexit vote had a significant negative impact on the ten-year gilt yield.

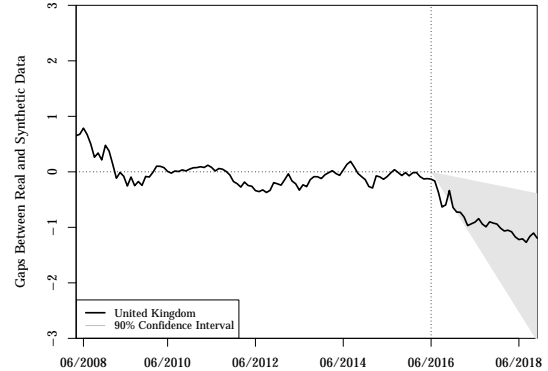
Figure 4: Statistical Significance of the Synthetic Output for Long-Term Bonds

(a) 10Y Bond Yield – Placebo Inference

Method



(b) 10Y Bond Yield – Confidence Interval



Finally, we apply the SCM to the real effective exchange rate (Figure 5a). The synthetic output would be 10.8 index points higher than the real one relative to the last period in our data set, November 2018. The result is driven primarily by the United States, New Zealand and South Korea, with weights of 0.523, 0.388 and 0.054, respectively. Other control units receive weights of less than 0.004.¹⁷ This is a rather intuitive result given the sharp depreciation in sterling right after the Brexit vote. As Manning (2016) mentions, sterling depreciated by approximately 7% on a trade-weighted basis. Moreover, he adds that the further depreciation in August could be attributed to the Bank of England’s easing monetary policy. However, since then, the currency reversed the trend and gained back part of the loss. Consequently, Manning (2016) explains (pp. 149): *‘By the end of the review period (September 2016), forward-looking measures of implied volatility had decreased, and foreign exchange (FX) options pricing also pointed to a relatively even balance of upside and downside risks for the currency. However, speculative investors look to have remained more heavily positioned for the latter. Weekly positioning data for FX futures showed a continued increase in sterling short positions despite some improvement in UK economic data towards the end of the review period’*. In conclusion, we see substantial short-term impact, which

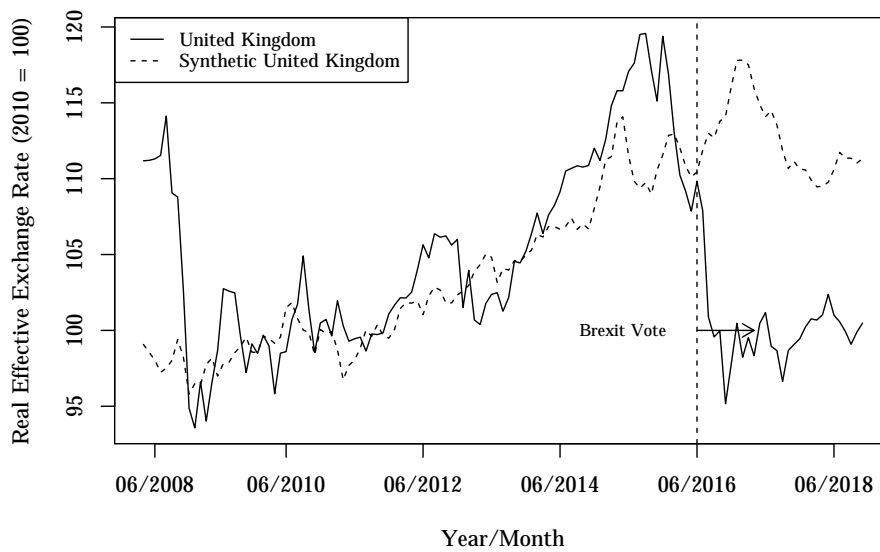
¹⁷See Table 4 in the Appendix for details.

weakens in the long term.

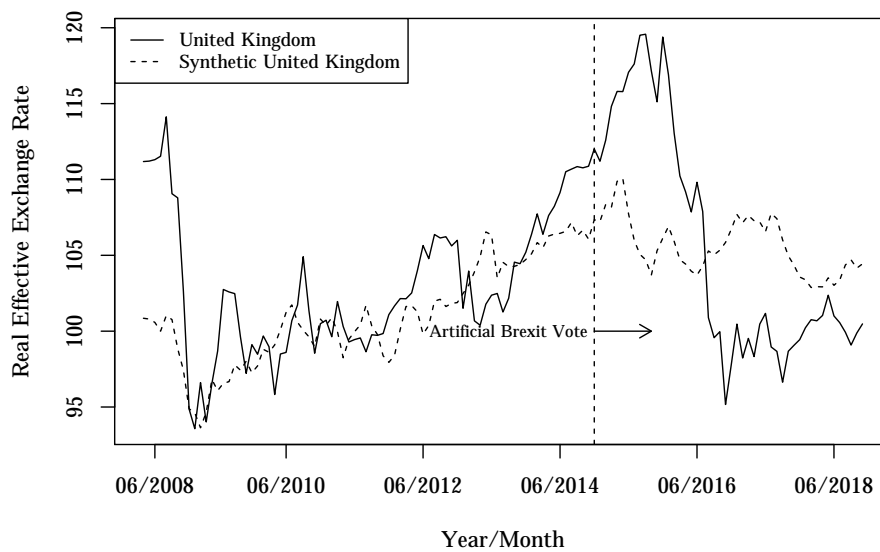
In Figure 5b, we set the Brexit vote to December 2014. The synthetic outcome follows the same trend as that in Figure 5a. Therefore, this placebo inference does not undermine the result.

Figure 5: Synthetic REER Higher than the Real One

(a) Real Effective Exchange Rate – Intervention set to June 2016



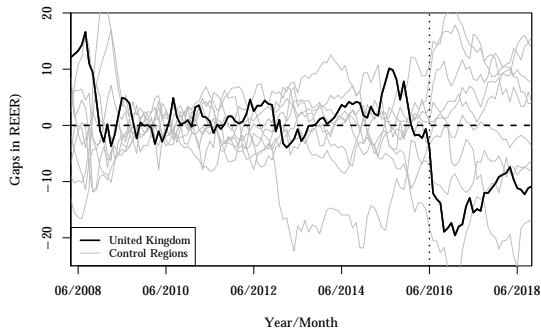
(b) Real Effective Exchange Rate – Intervention set to December 2014



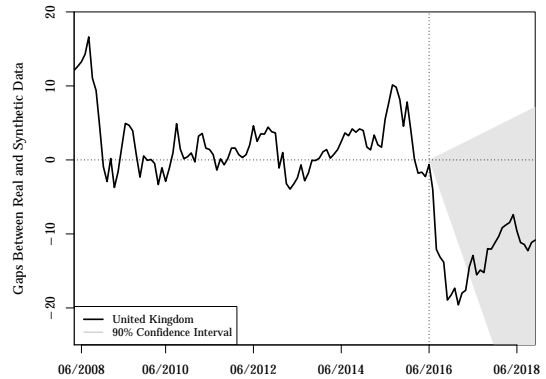
In Figure 6a, we apply the SCM to all control units. The result does not abnormally differ from all other control units. This suggests that we do not find any better pre-intervention fit among the control units. Finally, we estimate the 90% confidence interval (Figure 6b).

Figure 6: Statistical Significance of the Synthetic Output

(a) Real Effective Exchange Rate – Placebo Inference Method



(b) Real Effective Exchange Rate – Confidence Interval



The confidence interval does not include the REER result immediately after the Brexit vote. Therefore, there was a significant effect in the short term. Moreover, the confidence interval contains the zero function, which suggests that when considering a longer period, the REER would have been lower, but the result is not statistically significant.

4 Conclusion

We examine the impact of the Brexit vote on the UK stock exchange, long-term government bonds and the exchange rate. Using the synthetic control method developed by Abadie & Gardeazabal (2003), we build a counterfactual world that shows how selected variables would have developed had there not been a Brexit vote. We use Firpo & Possebom (2017)'s approach to assess the inference method from the SCM. Using well-developed quantitative analysis tools, this paper uniquely contributes to the current literature on the economic impact of the Brexit vote on the development of stock and bond markets and the real effective exchange rate.

Our results show that there would not have been any significant change in the development of the FTSE 100 Index in the mid to long term if the referendum had not

occurred. On the other hand, we find a significantly negative effect of 1.2 percentage points on the 10-years bond yield. Given the geopolitical circumstances in mid 2016, financial agents investing in GBP could seek safer investment options represented by longer-term government bonds, which consequently could result in lower bond yields. Finally, we apply the SCM to the real effective exchange rate, which would have been 10.8 index points higher than the real one if the referendum had not occurred. However, these results could suffer from the main shortcomings of the method. As Amjad, Shah, & Shen (2018) note, the shortcomings are related to the fact that the optimal result depends on a subjectively chosen subset of donors and covariate matrix. Furthermore, the SCM performs poorly in the cases of missing data or strong levels of noise in the data set.

Overall, we estimated the effect of the Brexit vote on the UK's financial variables. Because the real terms and conditions of Brexit were still being negotiated during the writing of this paper, we could not estimate the economical impact of Brexit itself, which could be the subject of a future analysis.

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Appendix

Table 1: Descriptive Statistics of the Variables Used for the SCM Computation

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
2YBonds	1,234	2.292	1.977	0.050	0.569	3.490	8.870
10YBonds	1,270	3.535	1.898	-0.230	2.126	4.958	9.820
Index	1,270	150.203	51.256	57.530	113.760	181.512	291.740
Value.3 month interbank rate	1,233	2.185	1.953	0.050	0.550	3.190	8.870
Value.Leading indicator, amplitude adjusted	1,270	99.814	1.333	93.508	99.387	100.564	103.474
Value.GDP (ratio to trend, smoothed)	1,257	99.795	1.089	94.662	99.477	100.358	103.149
Value.Industrial production, s.a.	1,246	98.219	6.438	63.959	94.994	101.967	118.358
Value.Overnight interbank rate	1,268	1.879	1.698	-0.071	0.428	2.990	8.260
Value.Relative consumer price indices	1,270	102.428	12.849	75.946	93.930	108.336	154.476
Value.Labour Force Survey - quarterly rates Harmonised unemployment - monthly rates Total All persons	1,224	5.553	1.626	2.200	4.248	6.625	10.231
Value.International Trade Imports Value (goods) Total	1,270	3.861	16.895	-44.429	-5.526	14.171	64.682
Value.International Trade Exports Value (goods) Total	1,270	3.564	16.561	-43.678	-6.528	13.166	54.423
REER	1,270	99.090	10.212	67.847	94.862	105.561	123.368

Source: Author's computation based on the OECD database.

Table 2: Country Weights Computed by SCM - Stock Index

Country	SCM Weight
Australia	0.027
Canada	0.047
Chile	0.050
Israel	0.032
Japan	0.080
Korea	0.060
Mexico	0.125
New Zealand	0.477
United States	0.103

Source: Author's computation based on SCM.

Table 3: Country Weights Computed by SCM - 10Y Bonds

Country	SCM Weight
Australia	0.000
Canada	0.332
Chile	0.000
Israel	0.000
Japan	0.002
Korea	0.226
Mexico	0.000
New Zealand	0.000
United States	0.440

Source: Author's computation based on SCM.

Table 4: Country Weights Computed by SCM - REER

Country	SCM Weight
Australia	0.002
Canada	0.003
Chile	0.002
Israel	0.003
Japan	0.004
Korea	0.054
Mexico	0.021
New Zealand	0.388
United States	0.523

Source: Author's computation based on SCM.

Table 5: Weights for Covariates Computed by SCM

Statistic	Stock Index	10Y Bonds	REER
2YBonds	0.0000	0.1176	0.0277
10YBonds	0.0001	0.0006	0.0365
Index	0.0311	0.0079	0.0450
Value.3 month interbank rate	0.0000	0.0798	0.0570
Value.Leading indicator, amplitude adjusted	0.1180	0.0676	0.0572
Value.GDP (ratio to trend, smoothed)	0.4549	0.0000	0.0450
Value.Industrial production, s.a.	0.0563	0.0000	0.0966
Value.Overnight interbank rate	0.0001	0.2003	0.1031
Value.Relative consumer price indices	0.0538	0.1707	0.1511
Value.Labour Force Survey - quarterly rates Harmonised unemployment - monthly rates Total All persons	0.0593	0.0602	0.1183
Value.International Trade Imports Value (goods) Total	0.0000	0.2508	0.0193
Value.International Trade Exports Value (goods) Total	0.0831	0.0245	0.0008
REER	0.1430	0.0198	0.2423

Table 6: Synthetic Outcome Results after the Brexit Vote

Period	Stock Index Real	Stock Index Synthetic	10YBonds Real	10YBonds Synthetic	REER Real	REER Synthetic
6/2016	135.10	136.45	1.3105	1.4742	107.8845	111.8675
8/2016	139.68	143.32	0.9569	1.3250	100.8900	112.9908
9/2016	140.86	144.17	0.7421	1.3753	99.5689	112.6990
10/2016	143.31	141.44	0.8243	1.4192	99.9646	113.7787
11/2016	144.45	140.73	1.2430	1.5796	95.1671	114.0983
12/2016	140.91	137.29	1.4150	2.0581	97.7697	116.0484
01/2017	148.37	138.22	1.4336	2.1582	100.4659	117.7966
02/2017	147.46	141.32	1.4203	2.1494	98.2316	117.8141
03/2017	150.87	143.93	1.3058	2.1185	99.5233	117.5108
04/2017	152.11	144.79	1.1940	2.1621	98.3250	115.9445
05/2017	149.64	146.89	1.0830	2.0195	100.4665	114.8947
06/2017	156.20	147.28	1.1175	2.0241	101.1733	114.0848
07/2017	151.90	150.29	1.2560	2.0985	98.9577	114.4853
08/2017	153.13	152.66	1.2713	2.2113	98.6659	113.5466
09/2017	154.34	153.23	1.1241	2.1142	96.6353	111.8598
10/2017	153.14	152.18	1.3610	2.2611	98.6765	110.6707
11/2017	155.64	152.61	1.3816	2.3050	99.0702	111.1331
12/2017	152.19	152.06	1.3299	2.2707	99.4424	110.6367
01/2018	159.69	155.95	1.2781	2.2941	100.2237	110.5804
02/2018	156.48	160.58	1.5100	2.5756	100.7577	109.9158
03/2018	150.22	152.86	1.6034	2.6555	100.6829	109.4655
04/2018	146.58	150.17	1.5080	2.5874	101.0345	109.4961
05/2018	155.98	153.35	1.5108	2.6829	102.3698	109.7645
06/2018	159.49	151.15	1.5016	2.7221	101.0042	110.6012
07/2018	158.63	155.18	1.4229	2.6300	100.5650	111.7331
08/2018	160.95	158.15	1.3739	2.6439	99.9295	111.3530
09/2018	154.38	161.66	1.4260	2.5886	99.0835	111.3530
10/2018	156.00	161.60	1.5720	2.6747	99.8739	111.0281
11/2018	148.06	146.31	1.5462	2.7412	100.4784	111.3116

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