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BACHELOR'S THESIS

Evaluating the Effects of Quantitative Easing in the UK Using the Synthetic Control Method

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Declaration of Authorship

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Prague, 18th May 2017

Signature

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Abstract

The thesis deals with quantitative easing (QE)—unconventional monetary policy, which was conducted by several central banks in the aftermath of recent financial crisis. Its goal is to boost the economy and to reach inflation target with key interest rates being already close to zero. The United Kingdom was one of the countries involved: Bank of England was conducting the policy in 2009-2012. The first part of the thesis focuses on quantitative easing in more detail; the policy is described in general, but special emphasis is put on Bank of England. The second part uses synthetic control method to estimate effect of the policy on real GDP and inflation of the United Kingdom. The method does not lead to construction of appropriate control unit for GDP of the UK under unusual circumstances of the financial crisis. Positive effect of quantitative easing on inflation is found, but its magnitude is surrounded by large uncertainty.

JEL Classification	E31, E37, E44, E52, E58
Keywords	quantitative easing, unconventional monetary policy, synthetic control method, Bank of England

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Abstrakt

Tato práce se zabývá kvantitativním uvolňováním—nekonvenční měnovou politikou, kterou provádělo po nedávné finanční krizi několik centrálních bank. Cílem této politiky je povzbudit ekonomiku a dosáhnout inflačního cíle s již téměř nulovými klíčovými úrokovými sazbami. Spojené království bylo jedním ze zúčastněných států: Bank of England prováděla tuto politiku v letech 2009-2012. První část práce se podrobněji zaměřuje na kvantitativní uvolňování, které je popsáno z obecného pohledu, ovšem s důrazem zejména na Bank of England. Ve druhé části je využita syntetická kontrolní metoda k odhadu dopadů této politiky na reálné HDP a inflaci Spojeného království. Metoda nevede ke konstrukci vhodné kontrolní jednotky pro britské HDP za neobvyklých podmínek finanční krize. Je nalezen pozitivní efekt kvantitativního uvolňování na inflaci, ovšem jeho velikost je obklopena značnou mírou nejistoty.

Klasifikace JEL	E31, E37, E44, E52, E58
Klíčová slova	kvantitativní uvolňování, nekonvenční měnová politika, syntetická kontrolní metoda, Bank of England

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Acronyms

bp	basis points
APF	Asset Purchase Facility
BoE	Bank of England
BoJ	Bank of Japan
CHF	Swiss franc
ECB	European Central Bank
FDI	foreign direct investment
Fed	Federal Reserve System
FLS	Funding for Lending Scheme
GDP	gross domestic product
LSAP	Large-Scale Asset Purchases
MBS	mortgage-backed securities
MPC	Monetary Policy Committee
MSPE	mean squared prediction error
OECD	Organisation for Economic Co-operation and Development
pp	percentage points
QE	quantitative easing
SNB	Swiss National Bank
SCM	synthetic control method
UK	United Kingdom
US	United States
VAR	vector autoregression

Bachelor's Thesis Proposal

Author	Vojtěch Molnár
Supervisor	doc. PhDr. Tomáš Havránek, Ph.D.
Proposed topic	Evaluating the Effects of Quantitative Easing in the UK Using the Synthetic Control Method

Research question and motivation During recent financial crisis and subsequent global recession, conventional tools of monetary policy have been exhausted rapidly and central banks began to seek another ways how to boost economic growth. Some of them implemented so-called quantitative easing (QE)—they extended their balance sheets by buying financial assets in order to decrease their yields, which should in the end stimulate the economy. Since QE had been used only rarely before the crisis, but became crucial tool within its duration, it is now very important to evaluate its effects and then consider whether its usage would be appropriate during some possible future crises. Bank of England was one of the central banks which implemented QE, specifically from 2009 to 2012. In my bachelor thesis, I am going to study quantitative easing, focusing mainly on empirical estimation of its impact on GDP of the United Kingdom.

Contribution Despite growing literature focused on quantitative easing, to my knowledge there is no study of this unconventional policy using synthetic control method. Hence my thesis should offer new approach into estimating the effects of QE.

Methodology Synthetic control method is a technique which allows to estimate development of given variable of interest if there had been no intervention and hence, by its comparison to real values of the variable, it enables to evaluate the intervention. In the core part of my thesis, I will use this method with British GDP as the variable of my interest and evaluate QE as the intervention. I will use donor pool based on countries of the EU and OECD. Then I will construct synthetic GDP of the UK as a combination of countries from the donor pool which is most similar to real

British GDP before the intervention (i.e. the announcement of implementation of quantitative easing by Bank of England). After that I will compare synthetic GDP to real GDP after the intervention and evaluate the impact of QE, discussing as well its length and significance.

Outline

1. Introduction
2. Economic background: situation after outbreak of the financial crisis
3. Quantitative easing: description, transmission mechanisms, literature review
4. Synthetic control method: description of the methodology
5. Empirical study: evaluation of QE in the United Kingdom using synthetic control method
6. Conclusion

Core bibliography

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Amendment: Two changes were made in the final version of the thesis as compared with the proposal. Firstly, empirical part of the thesis examines effects of quantitative easing not only on GDP, but also on inflation, as boost in inflation is an important objective of the policy. Secondly, detailed description of overall conditions of financial crisis is beyond scope of the thesis, so chapter about economic background would be redundant. Hence the chapter is not part of the thesis, and only basic facts relevant for quantitative easing were included in the Introduction.

Author

Supervisor

Chapter 1

Introduction

After outbreak of financial crisis in 2007 and its deterioration following bankruptcy of Lehman Brothers in September 2008, major central banks loosened their monetary policies and took other measures in order to prevent output collapse, ensure financial stability, and fight threatening deflation. Bank of England (BoE) reduced official bank rate—its key conventional monetary policy tool—from 5.5% at the beginning of 2008 to 0.5% in March 2009. Also European Central Bank (ECB), Federal Reserve System (Fed) in the United States (US), and other central banks decreased their key interest rates close to zero. Other short-term actions aimed at improving stability of stressed financial markets were taken as well.

Nevertheless, adopted measures turned out not to be enough. The economies fell into recession and were not recovering well, threat of deflation persisted, and predictions suggested that inflation targets (2% in the United Kingdom (UK)) would not be met in medium-term. Standard Taylor rules for determining optimal level of interest rate called for negative interest rates in many countries (Joyce *et al.* 2012b), which was unfeasible—although negative interest rates are not impossible, the rates cannot go much below zero, as people can hold cash. Central banks were restricted by so-called zero lower bound, they needed to loosen monetary policy even more, and their conventional policy tools were exhausted. Therefore, they resorted to unconventional tools. Most importantly, they began purchasing assets of medium to long-term maturities in large scale—policy usually referred to as quantitative easing (QE). It is supposed to depress asset yields and long-term interest rates, consequently decrease cost of borrowing and boost spending, output, and inflation. The policy was adopted by Fed, BoE, ECB, Bank of Japan (BoJ), and Swedish Riksbank.

Because of relative novelty of QE (before recent financial crisis it was used only in Japan) and its potential to substantially influence the economy (positively, but also negatively), it is now important to assess its effectiveness and risks in order to decide about appropriateness of its usage at some point in the future. Evaluation of the policy ultimately depends on effects of QE on macroeconomic variables, in particular on output and inflation. Despite growing literature focused on quantifying the effects, all macroeconomic estimates are by nature highly uncertain due to unusual economic circumstances, under which QE was launched. Hence it may be useful to supplement currently available research with another estimate obtained by a different methodology. That is the main objective of this thesis, which uses synthetic control method (SCM) to estimate impact of BoE's QE on the UK's economy, specifically on real gross domestic product (GDP) per capita and inflation. The method provides data-driven procedure of construction of control unit, which serves as a counterfactual of the UK. Values of dependent variables in the UK and in the control unit are then compared with each other to estimate effect of the policy. It turns out that the SCM is not able to construct appropriate counterfactual of UK's GDP in unusual conditions of the crisis. Results suggest positive impact of QE on British inflation, but its magnitude is highly uncertain.

The thesis is structured as follows: Chapter 2 focuses on quantitative easing in more detail; it summarizes basic facts, describes potential transmission mechanisms of QE, discusses its drawbacks and risks, and presents review of empirical literature concerned with effects of QE. Since empirical part of the thesis deals with QE in the United Kingdom, the chapter is focused especially on facts relevant for Bank of England, but it contains theoretical basis common for all relevant central banks and takes into account experiences of other central banks than BoE as well. Chapter 3 deals with methodology of the empirical analysis. At first the SCM is described in general; then specific issues related to its application on QE are discussed (including details about data). Chapter 4 presents results of the analysis. Chapter 5 concludes.

Chapter 2

Quantitative Easing

Quantitative easing is an unconventional monetary policy firstly conducted by Bank of Japan in early 2000s to fight deflation, and became an important tool of major central banks during and after financial crisis of 2007–2009. QE consists of large scale purchases of assets financed by central bank reserves. In general, central banks were purchasing many different types of assets—most importantly government and corporate bonds and mortgage-backed securities (MBS). Purchased assets substantially varied by maturity as well. At first, QE is supposed to lower long-term asset yields, which means increase of asset prices; this is equivalent to decrease in long-term interest rates. Consequently, it should boost aggregate demand and nominal spending, increase output, and ultimately help central banks to meet their inflation targets (next section provides more detailed description of transmission mechanisms).

As a first central bank after the outbreak of financial crisis, Fed introduced at the end of 2008 programme of Large-Scale Asset Purchases (LSAP), which is its official name for QE.[1] Three rounds of QE were eventually conducted in the US; during the first (QE1) and the third (QE3) round, Fed was purchasing mainly agency MBS, reflecting high importance of housing market in the US economy; in the second round (QE2), Treasuries, i.e. US government bonds, played more important role (Treasuries were being purchased in other rounds too, but in smaller amount than during QE2). The policy of QE was abandoned in October 2014 (Fawley & Neely (2013) and Ihrig *et al.* (2015)).

[1]Bernanke (2009), at that time governor of Fed, distinguished pure *quantitative easing* conducted in Japan in pre-crisis period from Fed's first phase of asset purchases, which he considered *credit easing*. Although central bank's balance sheet is enlarged in both cases, QE is concerned by quantity of bank reserves, i.e. its liabilities, but Fed was focused more on composition of its assets in order to support credit markets. Nevertheless, the term *quantitative easing* is widely used even for Fed's asset purchases in this period.

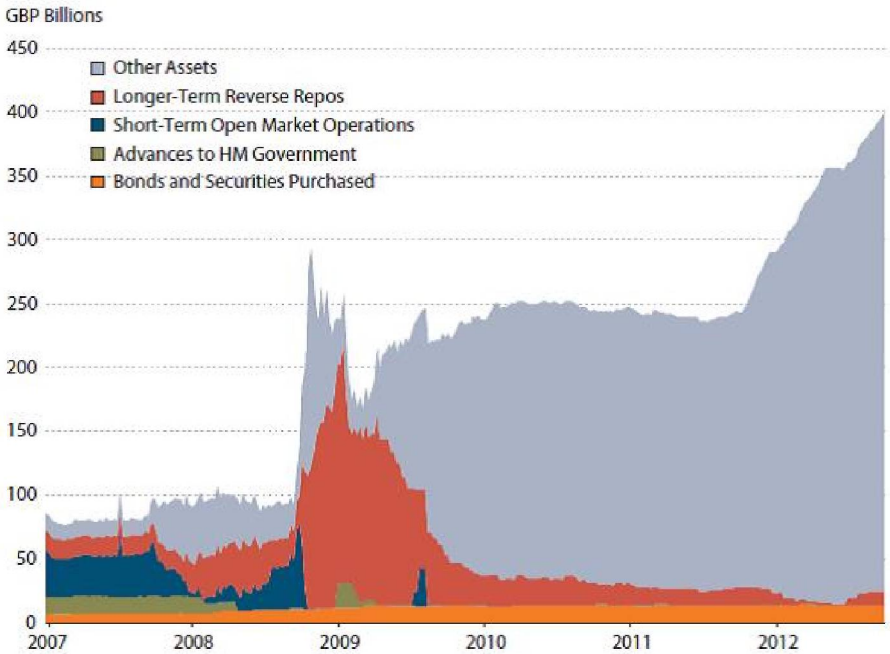
Bank of England joined Fed soon—in January 2009 it set up Asset Purchase Facility (APF) to buy high quality assets financed by Treasury bills in order to improve liquidity on credit markets. In March 2009, Monetary Policy Committee (MPC), BoE's authority responsible for conducting monetary policy, began to use the APF as a monetary tool, when newly created central bank reserves started to finance asset purchases—this was the beginning of QE in the United Kingdom. Contrary to Fed, BoE was buying almost exclusively gilts (UK's government bonds) with maturity higher than 3 years. Corporate bonds were being purchased as well in order to improve functioning of a few specific markets, but their quantity was negligible compared with gilts. Assets worth £200 were bought until the beginning of 2010 in the first phase of the programme (QE1). Additional £125 billion in assets were purchased during the second phase (QE2) from June 2011 to July 2012. Then stock of assets bought in the QE programme was maintained at the level of £375 billion—no additional purchases were conducted, but cash flows from repaid debt were reinvested (Bank of England 2012a). This lasted until August 2016, when stock of bought assets was extended to £435 billion together with decrease of bank rate from 0.5% to 0.25%, both as a reaction to worsened growth outlook—at least partly caused by the UK's decision in referendum to leave the European Union (Bank of England 2016a).

To put these figures into context, total assets of BoE increased from a little less than £100 billion in 2008 to more than £400 billion in 2016 (see Figure 2.1 for period 2007-2012), so Bank's balance sheet approximately quadrupled (Bank of England (2008) and Bank of England (2016b)). Relative amounts of asset purchases by BoE and Fed were about 20-25% of national GDP in both countries, although Fed's programme was obviously much larger in absolute value—more than $3000 billion (Fawley & Neely 2013).

One other BoE's measure complementary to QE should be mentioned: Funding for Lending Scheme (FLS). It was launched in 2012 in order to improve credit conditions and boost lending by banks and building societies. Both QE and FLS are supposed to reduce funding costs, but while QE reacts to generally weak aggregate demand and to some extent bypasses banking sector, FLS is directed specifically at banking sector (Churm & Radia 2012).

Regarding other central banks, Bank of Japan re-introduced QE in October 2010. ECB launched programmes which were to some extent similar to QE and meant extension of ECB's balance sheet as well, the programmes however comprised mostly of repurchase agreements and were aimed at providing liquidity

Figure 2.1: BoE's total assets



Note: Assets purchased by QE programme are included in Other Assets

Source: Fawley & Neely (2013)

into the banking sector—rather then monetary policies, they were lender of last resort operations (Haldane *et al.* 2016). ECB launched QE as such only in March 2015, extended it in March and December 2016, and expects it to last at least until end of 2017 (European Central Bank 2016). The Riksbank, Swedish central bank, started its own programme of QE in February 2015 (Sveriges Riksbank 2011).

2.1 Transmission Mechanisms

The literature recognizes various possible channels through which QE might influence asset prices and the economy. The most frequently mentioned are so-called *portfolio balance*, *signalling*, and *liquidity* channels (see for example Bowdler & Radia (2012) or Joyce *et al.* (2011)).

Portfolio balance channel depends crucially on imperfect substitutability of money and purchased assets for investors (pension funds, insurance companies, banks, etc.). When private investors sell gilts (or other assets) to the central bank, their money holding increases, and gilts holding decreases. If money and gilts are not perfect substitutes, relative amount of money and other assets in investors' portfolios becomes unbalanced. Therefore, investors use excessive

money to buy assets which they consider closer substitutes for gilts than money (e.g. corporate bonds)—investors rebalance their portfolios. But then sellers of these assets hold excessive money, so they use the same reasoning and buy other assets as well. Higher demand for assets increases their prices, and the process continues until prices of assets reach such level, for which overall market money holding and value of non-money assets are again balanced. Purchase of gilts by central bank hence increases prices and lowers yields of both gilts and other assets.

Joyce *et al.* (2012a) or Bowdler & Radia (2012) distinguish two sub-effects within *portfolio balance* channel. *Local supply* effect is based on an idea that some investors (especially pension funds because of their long-term liabilities) have so-called *preferred habitat* for some part of yield curve—they strongly prefer to hold assets of certain maturity, riskiness, or liquidity. When central bank buys gilts, usually long-term assets with very low credit risk, it causes scarcity of bonds with characteristics desired by some investors, and price of gilts increases.

Secondly, future development of interest rates influences future prices of long-term assets—there is interest rate risk (or duration risk). To bear the risk, investors require compensation—term premium. When central bank purchases long-maturity gilts, it reduces total amount of duration risk in private market, and hence reduces required term premium for holding remaining assets. It results in decrease in longer-term interest rates and increase in asset prices. This is called *duration* effect.

Policy signalling channel relates to information which central bank reveals to economic agents about likely future monetary policy. By asset purchases, central bank signals determination to meet inflation target. This leads to increase in inflation expectations closer to level of the target. With low nominal interest rates, higher inflation expectations decrease real interest rates.

Liquidity channel is presumed to work only when financial markets are stressed—then investors are concerned that if they need to sell assets quickly to obtain liquidity, they will be unable to find a buyer unless they accept substantial price discount. To bear this risk, investors require liquidity premium. When central bank purchases assets, it puts itself to position of the buyer. Investors know that they will be able to sell assets to the central bank in case of need, liquidity in the market increases, and liquidity premium decreases, lowering the yields.

As a result, *liquidity* channel can function only while central bank is still conducting asset purchases; and the channel is not considered very relevant for relatively liquid gilt market. Nonetheless, the effect may be present when central bank purchases assets such as corporate bonds and commercial papers. Amount of these assets purchased by BoE was low compared with gilts, but even that may have sufficed to strengthen investors' confidence and to decrease liquidity premium—just because BoE was ready buyer present in the market.

Besides these three main channels, Joyce *et al.* (2011) identify also *confidence* effects: if the policy improves perceived state of the economy, it may lead to higher confidence of consumers and to increase in spending beyond direct effects of asset purchases. Lastly, when assets are purchased from non-banks, it may encourage banks to provide more loans, which would then increase spending (since sellers of the assets would deposit obtained money in banks, amount of liquid assets held by banks as well as willingness of banks to lend would increase). Nevertheless, the MPC did not expect significant effect through this *bank lending* channel because of strained conditions in financial markets (Bank of England 2009). The presumption is empirically confirmed by Butt *et al.* (2015), who find no evidence of *bank lending* channel in the UK.

Haldane *et al.* (2016) point out that just as conventional monetary policy relies on frictions in wages and prices of goods, all described channels of QE also depend on some frictions. Information frictions, i.e. economic agents having incomplete information about future monetary policy and state of the economy, underlie *signalling* and *confidence* effects, while *portfolio balance*, *liquidity*, and *bank lending* channels rely on market frictions, for example investors having *preferred habitat* for bonds of particular characteristics, which causes imperfect substitutability of different types of assets. Effectiveness of QE depends on existence and strength of the frictions and can be expected to vary over time and across different economic conditions.

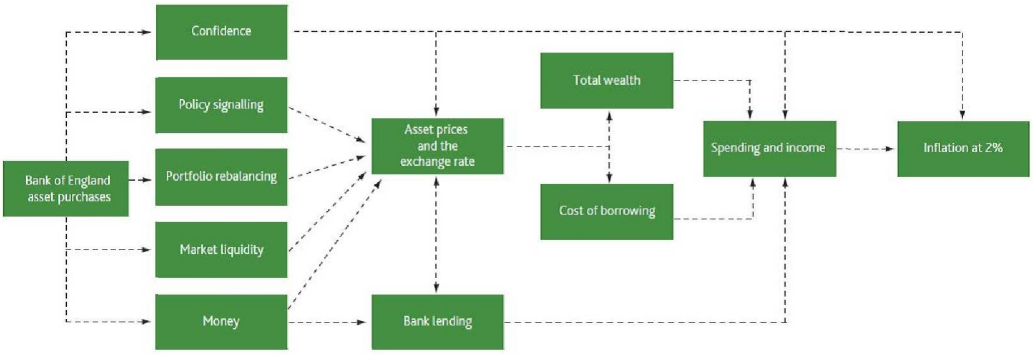
Described transmission channels creates by various ways upward pressure on asset prices. Higher asset prices may boost spending and consequently output and inflation in two main ways. Firstly, asset holders observe increase in their wealth and may decide to spend a part of the gain. Secondly, similarly to conventional monetary policy, lower yield curve transforms into lower interest rates faced by households and firms, which means lower borrowing costs leading to boost in consumption and investment. As Bowdler & Radia (2012) point out, the process is undermined when banking sector is stressed at time of crisis, but companies with access to capital markets can raise capital more cheaply even

without banking sector because of higher asset prices and investors' portfolio rebalancing towards corporate bonds.

Additionally, QE creates downward pressure on the exchange rate, which helps exporting sector.

To summarize, there are a few identified transmission channels through which QE may influence asset prices and two main ways transforming higher asset prices into increased spending, which leads to output growth and helps to reach the inflation target (see Figure 2.2 for graphical illustration of the whole process). The mechanism may be weakened or interrupted under some conditions or assumptions—it remains rather empirical question, whether assumptions needed for functioning of QE are met and whether QE can influence the economy in the intended way.

Figure 2.2: Scheme of transmission mechanisms



Source: Joyce *et al.* (2011).

2.2 Drawbacks and Risks

Quantitative easing may boost the economy at time of crisis, but it is not a miraculous cure—it is associated with costs and dangers which have to be taken into account when QE is considered.

Mortimer-Lee (2012) claims that QE distorts market, price signals may be misleading, and market does not correctly price risks. Combined with search for yield by investors in low interest rate environment, this may lead to excessive risk taking and creation of market bubbles. Allocation of resources is ineffective since unproductive companies, which should go out of business, may be able to raise funds and stay in operation thanks to low borrowing costs.

QE could be seen as buying time for implementation of time demanding structural reforms, but at the same time it may cause the reforms to seem unnecessary. QE then covers problems in real economy and makes timely implementation of needed reforms less likely (Gern *et al.* 2015).

As is admitted even by Bank of England (2012b), QE has significant distributional impact. Increase in asset prices directly benefits owners of those assets—but the ownership is distributed unevenly across population, with top 5% of households holding 40% of the financial assets of the household sector in the UK (pension wealth excluded). Two main consequences follow. Firstly, there are social considerations: QE may contribute to higher social inequality and to potential resulting social tensions; secondly, as Bossone (2013) points out, more affluent households, which benefit from QE the most, have low propensity to consume, so likely they will not spend much of newly acquired wealth, which undermines transmission of higher asset prices to increased spending described in previous section.

Lastly, Mortimer-Lee (2012) argues that exit from the policy may contain set of risks. With respect to lack of experience with unconventional policies in the past, it is unclear when exactly should the exit occur, what should be its sequencing (i.e. coordination of exit from QE with increases of interest rates), or how quickly should the exit be conducted. Too slow exit could generate substantial inflationary pressures resulting in inflation exceeding the target; too fast exit could cause return of recession and deflationary pressures.

Overall criticism of quantitative easing can be divided into two groups. First group consists of arguments impairing transmission mechanisms of QE; it can be resolved empirically whether the policy functions despite them—discussed low propensity to consume of the largest beneficiaries of higher asset prices may be an example. Second group consists of risks, which may materialize even if QE is successful in boosting spending, growth, and inflation. The risks are usually longer-term; QE might help the economy after it is implemented, and at the same time it could harm the economy in the long-run. On the other hand, long-term nature of the risks enables policymakers to adopt policies aimed at their mitigation (for example macroprudential policies). In the end, weighing of gains against costs is necessary for assessment about appropriateness of QE. Nevertheless, complete assessment is still not possible, as monetary policy has not been normalized yet and some of the risks may materialize in the future; moreover, it will never be clear-cut, because potential negative consequences of QE (such as impact of higher social inequality) are not easily measurable.

2.3 Literature Review

Since quantitative easing had not been used before financial crisis (except for Japan), but it became an important policy tool after that, there is fast-growing number of relatively new empirical studies examining its effects. Two main focuses of the literature are on direct effects on financial markets (with a few of the studies also trying to distinguish importance of different transmission channels) and on overall macroeconomic impact of QE.

2.3.1 Impact on Financial Markets

Joyce *et al.* (2010) provide one of the first studies of QE's effect on financial markets in the UK. They perform an event study of impact of distinct announcements regarding QE1.[2] Their results suggest that QE lowered yields of gilts with maturity of 5–25 years on average by around 100 basis points (bp); the reduction was mostly driven by *portfolio balance* channel. Effect on prices of corporate bonds and equities is found as well, but it is surrounded by much larger uncertainty—since portfolio rebalancing from gilts towards these assets may last some time, effect of QE is not immediate; thus, it is difficult to isolate the effect from external factors.

QE1 is examined also by Daines *et al.* (2012), who use intraday data and find significant impact on yields varying across maturities, with the largest estimated decrease in yields of 120 bp for gilts with maturity of 15–20 years. Authors also explore longer-term impacts and conclude that the effect of QE on gilt yields is persistent. Evidence of *portfolio balance* channel is found.

Joyce *et al.* (2012a) extend the analysis to QE2. For QE1, both approach and results are similar to those of Joyce *et al.* (2010) (estimated reduction in gilt yields of approximately 100 bp); for QE2 the authors argue that markets already anticipated QE, so its announcement did not contain much new information, and event study is not appropriate anymore. Instead, they use announcements of changes in structure of asset purchases (such as change in maturities of purchased gilts) to capture at least *local supply* effect. *Local supply* channel is found to have accounted for around a half of the impact of QE on gilt yields

[2]The authors implicitly assume that markets efficiently incorporate all available information; hence asset prices adjust immediately after announcement of asset purchases—before purchases really begin. Change in asset prices within two days around the announcement is used to capture the effect of QE—this relatively short time period allows to isolate the effect of QE from other factors. Similar approach is used often in studies of financial markets impact of QE.

during QE1, and its strength did not diminish during QE2 (but overall effect of QE2 is not quantified). Decrease in corporate bond yields and increase in equity prices are estimated for both QE1 and QE2, but again with high uncertainty of magnitude of the effects.

Concerning other central banks, Gagnon *et al.* (2011) analyse the first round of Fed's LSAP, i.e. QE1. In an event study they use approach similar to Joyce *et al.* (2010) and find that around announcements regarding LSAP, longer-term interest rates decreased by up to 150 bp. The most important factor is decline of term premium (between 50 and 100 bp). An alternative methodology with pre-crisis time-series data suggests decrease in ten-year term premium caused by LSAP around 38-82 bp, which brings result consistent with the event study.

D'Amico & King (2013) focus on *local supply* effect of $300 billion of US Treasury purchases during QE1. They find that the purchases caused persistent decline in yields of about 30 bp through *local supply* channel (on average for different maturities).

Transmission channels of Fed's QE1 and QE2 are examined in detail by Krishnamurthy & Vissing-Jorgensen (2011). Authors define the channels differently than this thesis and most of the literature—most importantly, they distinguish several sub-channels within *portfolio balance* channel. Using event-study approach, Krishnamurthy & Vissing-Jorgensen (2011) find importance of effects belonging to *portfolio balance* channel and of *signalling* channel; for QE1, *liquidity* channel is significant as well.[3] The study thus provides empirical evidence that QE indeed functions through various ways at the same time.

For the euro area, De Santis (2016) estimate that up to October 2015 QE reduced GDP-weighted average 10-year government bond yields in the eurozone countries by 63 bp. Most of the impact occurred before asset purchases actually began, as markets anticipated the programme and efficiently incorporated the expectations into prices.

2.3.2 Macroeconomic Impact

Ultimately, QE is presumed to increase output and inflation, and its effect on these variables is what matters in the end; the effect on financial markets is just part of the transmission. Unfortunately, since QE influences the economy

[3] QE2 was focused more on US government bonds compared with QE1, and as is discussed in section 2.1 of this thesis, *liquidity* channel is considered less relevant for purchases of government bonds. Hence it is not surprising that *liquidity* channel is found significant only for QE1.

gradually throughout period of several years, it was launched at unusual time of market stress, and there is usually need for counterfactual to asses its impact, all estimates of QE's effects on macroeconomic variables are necessarily very uncertain. For example, Williams (2013) suggests that estimates of macroeconomic effects of asset purchases are surrounded by at least twice as large uncertainty compared with effects of conventional monetary policy.

Kapetanios *et al.* (2012) assume that QE1 in the UK decreased medium and long-term gilt yields by 100 bp (based on estimate of Joyce *et al.* (2010)) and use three versions of vector autoregression (VAR) model to analyse the macroeconomic effect of the decline in yields. Their results are sensitive to the model used and its exact specification, but estimated peak effects averaged across models are increase in real GDP by about 1.5% and increase in inflation by about 1.25 percentage points (pp).

Macroeconomic effects of QE1 are estimated also by Joyce *et al.* (2011), who build on estimated changes in asset prices as well. The authors use the changes to calculate increase in households' wealth, and through wealth elasticity of consumption they conclude that peak impact of QE on real GDP was between 1.5% and 2.5%. Phillips curve relationship is then used to estimate boost to inflation between 0.75 and 2.5 pp.

Bridges & Thomas (2012) use money supply and demand framework. They estimate that £200 billion of asset purchases increased stock of broad money by about £122 billion. After that, the authors examine how other economic variables react to such money supply shock in order to return to monetary equilibrium. QE1 is estimated to increase real GDP by 2% in peak in the middle of 2011, with peak effect on inflation of 1 pp a year later.

Lower level of success of QE is suggested by Pesaran & Smith (2012) and Lyonnet & Werner (2012). The first of the studies concludes that 100 bp decrease in long-term interest rate caused by QE1 had impact on output around 1%, but the impact became insignificant after one year. Lyonnet & Werner (2012) find no significant effect of QE at all and suggest that BoE should instead focus more directly on boost to bank credit.

QE2 is examined together with the FLS by Churm *et al.* (2015). The authors estimate with Bayesian VAR model that QE2 raised GDP by 0.6% and inflation by 0.6 pp; similar effects are found also for the FLS (0.8% for GDP and 0.6 pp for inflation).

Macroeconomic impact of QE on the US economy is estimated for example by Chung *et al.* (2012), who find peak effect on GDP of about 3% and on

inflation of about 1 pp (the estimates are based only on Fed's QE1 and QE2). Announcement of ECB's QE (or expanded asset purchase programme, as it is called in the euro area) in January 2015 was estimated to increase GDP at peak by about 1.1% and inflation by about 40 bp (Andrade *et al.* 2016).

2.3.3 Overall Assessment

Papers presented in this section—especially those concerning other central banks than BoE—are just representatives of larger amount of literature dealing with effects of quantitative easing.[4] Nonetheless, they show that QE likely had significant and desired impact on the economy.

Estimates of the effects on financial markets are consistent with each other; e.g. conclusion that BoE's QE1 depressed gilt yields on average by about 100 bp, firstly presented by Joyce *et al.* (2010), is widely accepted by other researchers. Effects of comparable magnitude were found also for other rounds of QE and for other countries. Decrease in corporate bond yields and raise in equity prices were estimated too, although with lower certainty. Importance of *portfolio balance* channel was confirmed, with other transmission channels also being relevant.

Positive influence on output and inflation is found by many researchers as well, but magnitude of the effects differs, and high uncertainty of the estimates is emphasized by most of the authors. There exist also studies suggesting ineffectiveness of QE.

It should be noted that majority of empirical studies regarding effects of QE is either published by central banks or at least co-authored by their researchers. As central banks are major promoters of QE, it might lead to potential publication bias in favour of success of QE.

Finally, even if QE was successful in boosting output and bringing inflation closer to target, it does not automatically mean that it was the best available policy, or that possible risks will not materialize in the future, reversing short-term success of QE.

[4]Detailed overview of studies and estimates of financial markets impact of QE for all relevant central banks (including Bank of Japan) can be found in Appendix B of Andrade *et al.* (2016). For macroeconomic impact, a few more early studies regarding Fed's and ECB's actions can be found in Table 6 of Cecioni *et al.* (2011).

Chapter 3

Methodological Approach

3.1 Synthetic Control Method

The SCM can be useful in comparative case studies, where the researcher wants to evaluate effect of a policy, intervention, or other event, usually at aggregate level such as country, region, or city. After choice of appropriate control unit, policies can be evaluated for example by usual difference-in-differences approach, but the choice of control group can be troublesome, as there may not be single one suitable unit. The SCM provides more systematic way to choose such control unit (or more precisely, it synthetically constructs it). As Abadie *et al.* (2010) p. 494 claim,

> The idea behind the synthetic control approach is that a combination of units often provides a better comparison for the unit exposed to the intervention than any single unit alone.

The method was firstly introduced by Abadie & Gardeazabal (2003) who applied it to estimate the effect of terrorism in the Basque country.

Suppose there are $J+1$ countries (or different entities), where the first one underwent an intervention, and remaining J countries are potential control units, so-called donor pool. We have data for T time periods, and T_0 is the last period before the intervention, $1 \leq T_0 < T$, i.e. there is at least one time period before and one after the intervention. If the intervention was anticipated, and hence it could influence variable of interest even before it was launched, we can just set its start to time where it began to influence the variable of interest. Let us denote Y_{it}^N outcome of the variable of interest that would be observed without the intervention in country i at time t, for $i = 1, \ldots, J+1$ and $t = 1, \ldots, T$. Let Y_{it}^I be outcome of the variable of interest that would

be observed in country i at time t if there was the intervention in country i in periods from $T_0 + 1$ to T. Hence $Y_{it}^N = Y_{it}^I$ for $t = 1, \ldots, T_0$ for all i. The effect of the intervention in the first country at time t is then $Y_{1t}^I - Y_{1t}^N$. Y_{1t}^I is observed, and Y_{1t}^N for $t \in \{T_0 + 1, \ldots, T\}$ has to be estimated (Abadie *et al.* 2010).

Now let $\mathbf{W} = (w_2, \ldots, w_{J+1})^\top$ be $(J \times 1)$ vector of weights, where $w_2 + \cdots + w_{J+1} = 1$ and $w_j \geq 0$ for $j = 2, \ldots, J + 1$. These are respective weights of J countries in the donor pool for construction of synthetic control unit—any different value of $\mathbf{W}$ represents different control unit. Abadie *et al.* (2015) suggest selecting such $\mathbf{W}^*$, for which characteristics of the synthetic unit are the most similar to characteristics of the treated country in the pre-intervention period. Values of the dependent variable at times $T_0+1, \ldots, T$ in countries in the donor pool then can be weighted by $\mathbf{W}^*$, and the results serve as estimators for Y_{1t}^N, where $t = T_0 + 1, \ldots, T$. To put it differently, the effect of the intervention on variable Y at time t is estimated as

$$Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt}. \tag{3.1}$$

Abadie *et al.* (2010) prove unbiasedness of the estimator.

Building on Abadie & Gardeazabal (2003), let us denote $\mathbf{X_1}$ as $(k \times 1)$ vector containing pre-intervention values of k variables in the treated country (variables which may somehow predict values of the dependent variable Y should be included in $\mathbf{X_1}$; usually pre-intervention values of Y are among these variables as well). Let $\mathbf{X_0}$ be $(k \times J)$ matrix containing pre-intervention values of same k variables in J countries in the donor pool. Let $\mathbf{V}$ be $(k \times k)$ diagonal positive semidefinite matrix. Elements on the diagonal of $\mathbf{V}$, $(v_1, \ldots, v_k)$, are weights of k predictor variables in $\mathbf{X_1}$ and $\mathbf{X_0}$, i.e. they represent relative importance of the variables in predicting the outcome variable. Weights of countries in the donor pool $\mathbf{W}^*$ are then chosen to minimize

$$(\mathbf{X_1} - \mathbf{X_0}\mathbf{W})^\top \mathbf{V} (\mathbf{X_1} - \mathbf{X_0}\mathbf{W}). \tag{3.2}$$

Lastly, it remains to say how $\mathbf{V}$ is determined. Reflecting some prior knowledge about importance of predictor variables, it can be theoretically set by the researcher, but Abadie & Gardeazabal (2003) or Abadie *et al.* (2010) prefer more data-driven procedure—they choose such $\mathbf{V}^*$ which most closely matches pre-intervention values of the outcome variable in resulting synthetic control

region and in the treated country. Formally, $\mathbf{V}^*$ is chosen to minimize mean squared prediction error (MSPE), which is defined as

$$MSPE = \frac{1}{T_0} \sum_{t=1}^{T_0} (Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt})^2 \tag{3.3}$$

and the minimization is solved as a nested optimization because w_j^* is function of $\mathbf{V}^*$.[1]

To summarize, for each $\mathbf{V}$ we have $\mathbf{W}$ given by equation 3.2, where each value of $\mathbf{W}$ represents different synthetic control; from all possible synthetic controls, one which resembles the treated country the most in terms of pre-intervention values of the dependent variable is chosen. Post-intervention values of this variable in the treated country and in the synthetic control region are then compared with each other to determine effect of the intervention.

The final determination of the intervention's effect is based on a few assumptions. The synthetic control region is an estimate of the dependent variable in the treated country if there were no intervention; therefore, countries included to the donor pool should not have been influenced by the intervention in the treated country through some spillovers, they should not have launched any policy or intervention similar to that in the treated country, and they should not have been exposed to any other shocks which might influence the outcome variable unless the treated country would have probably been exposed to the same shocks in absence of the intervention (Abadie *et al.* 2015). If a country violating some of these assumptions was included in the donor pool, it would cause biased results—but only if the country obtained non-zero weight w.

Abadie *et al.* (2010) claim that the donor pool should not include countries with too different characteristics, which would just average out to create synthetic control unit. Based on this argument, Abadie *et al.* (2015) in their analysis of impact of German reunification on GDP of West Germany use only Organisation for Economic Co-operation and Development (OECD) countries as potential controls for West Germany.

Combination of a few countries may create better control unit for the treated country than any single one of them, and the SCM offers data-driven procedure of choice of the control unit. As Abadie *et al.* (2015) point out, restriction of weights of countries to be non-negative and sum up to one prevents extra-

[1] The optimization has infinitely many solutions—$\mathbf{W}^*$ does not depend on scale of $\mathbf{V}^*$; hence elements of $\mathbf{V}^*$ can be normalized to sum up to one (Abadie & Gardeazabal 2003).

polation. Another advantage is that the method explicitly shows contribution of each country to resulting control unit. On the other hand, ability of the method to approximate pre-intervention values of the outcome variable in the treated country closely enough is not automatically guaranteed in advance and depends on particular application. When the outcome variable in the treated country is the largest or the smallest of all countries considered, no combination of the donor pool can approximate it (usage of time differences or growth rates may be a solution). The SCM hinges on the assumption that the dependent variable in the treated country would develop in the same way as in the control unit if there were no intervention—in case of spillover effects to the donor pool, of other events which could influence the dependent variable asymmetrically across countries, or simply of poor pre-intervention fit, usage of the synthetic control method becomes problematic.

3.1.1 Inference

Significance of results in context of the SCM is not usually assessed based on classical standard errors and confidence intervals, but it can be evaluated by so-called placebo studies instead.

The intervention can be artificially reassigned to each country in the donor pool, for which synthetic control is created and effect of the artificial intervention is measured. Hence we get a distribution of placebo effects, which can be compared with the effect estimated for real intervention in the treated country. If the estimated effect in the treated country seems large at first, but it is well inside the distribution of placebo effects, it undermines credibility of the result. These tests are called *in-space placebos* (Abadie *et al.* 2015).

Placebo effects can be simply plotted on one graph with the effect estimated for the treated country, and the effects can be compared with each other, but Abadie *et al.* (2010) present another possible method of evaluation of real and placebo effects (which is applied in this thesis in section 4.3). After synthetic control unit is one by one created for each country, MSPE for the pre-intervention period and MSPE for the post-intervention period is computed in each instance (post-intervention MSPE is defined equivalently to equation 3.3 as mean of squared discrepancies between values of the outcome variable in actual region and in its synthetic counterpart). Then ratio of post/pre-intervention MSPE is computed. This may be useful when there is a country in the donor pool, for which post-intervention gap is large (which would itself undermine

effectiveness of the intervention in the treated country), but it is large just because the SCM is unable to create any appropriate control unit for the country, for example because the outcome variable in the country is the largest or the smallest in the donor pool. Then pre-intervention gap is large as well, and ratio of post/pre-intervention MSPE can be relatively small. If the treated country has large MSPE ratio compared with other countries, it confirms significance of estimated effects of the intervention, and vice versa.

Alternatively, Abadie *et al.* (2015) also propose *in-time placebos*: the intervention can be reassigned for the treated country to different date, where it did not actually happen.[2] Lastly, the intervention can be assigned to the treated country to date of its actual occurrence, but a variable which should not be anyhow influenced by the intervention can play role of the dependent variable. Again, if the estimated effect of the real intervention is not anyhow unusual compared with the placebo effects, it suggests that the synthetic control region does not provide good approximation for the treated country, and the results are not very reliable.

3.2 Application of the SCM to Evaluation of QE

The previous section described the SCM in general; now let us focus more specifically on its application on estimating impact of QE in the treated country, i.e. in the UK. Real GDP per capita and inflation are two dependent variables in two different analyses. This section discusses composition of the donor pool, used variables, and other issues. Results of the analysis are presented in the next chapter.

Based on set of growth predictors used by Abadie & Gardeazabal (2003) and Abadie *et al.* (2015) and supplemented by a few other variables, $\mathbf{X_0}$ and $\mathbf{X_1}$ contain real GDP per capita, inflation, unemployment, share of secondary and tertiary educated workers in labor force, gross capital formation, trade openness, population density, final consumption, fertility, net inflows of foreign direct investment (FDI), government expenditures, broad money, real effective exchange rate, and employment in industry and services (see Appendix A for exact definition of the variables, time period for which data on them are available, and other details). Annual data from the World Bank database are used in most cases, but it is desirable to have data for period shorter than one year

[2]Usually some date before real intervention is chosen; and high enough number of pre-intervention periods in the data set is necessary to conduct this type of placebo study.

for variables which serve also as dependent variables; hence quarterly data for GDP and quarterly and monthly data for inflation extracted from OECD database are used as well. Real GDP per capita is measured in 2010 US dollars with fixed purchasing power parity, it is seasonally adjusted and annualized. Inflation is measured as percentage change in consumer prices on the same period of the previous year.

For each country in the donor pool and the UK, arithmetic average of every variable over the pre-intervention period is put in $\mathbf{X_0}$ and $\mathbf{X_1}$. Beginning of the pre-intervention period is set to 2000 for most of the variables, but data availability requires later year for a few of them—see Appendix A. Also data from 1990s (where possible) are included in the analysis in Appendix B as a robustness check. QE was adopted in March 2009, so only data preceding this date are used in the pre-intervention period (i.e. data up to February 2009 for analysis with monthly inflation, and up to the end of 2008 otherwise).

As a basis for the donor pool, OECD countries are taken. Then the US, Japan, and the euro area countries have to be excluded, as they also launched QE (in the eurozone it was not before 2015, but even preceding policies of the ECB were too similar to QE). Also non-OECD and non-eurozone countries belonging to the European Union (i.e. Bulgaria, Croatia, and Romania) were considered at first, but their inclusion would require usage of only annual data on dependent variables because of worse data availability for these countries, they do not seem like very promising control units for the UK, and when they are part of the donor pool with annual data used, they obtain zero weight anyway.

Switzerland is excluded as well. Swiss franc (CHF) has been widely considered to be a safe currency; therefore, investors began buying it in large amounts at difficult time of financial crisis. This caused significant upward pressure on franc and subsequently created deflationary pressures in Swiss economy. The Swiss National Bank reacted by introduction of minimum exchange rate of 1.2 CHF per euro in September 2011 and enforced it by purchases of foreign currencies until 2015. Hence in the first period, before the peg to euro, inclusion of Switzerland to the donor pool could cause upward bias on estimates of effects of UK's QE because of strong deflationary pressures, and at the same time in the second period Switzerland conducted policy to some extent similar to QE: it was unusually loose monetary policy, and the peg was defensed by purchases of assets—foreign currencies in this case (Swiss National Bank 2011).

Exchange rate commitment of the Czech National Bank had the same characteristics similar to QE as the Swiss one. But the Czech commitment began in November 2013, more than four years after the start of BoE's QE—until then, there was no violation of the assumption of no similar intervention. Thus, the Czech Republic can be included to the donor pool, but we need to keep in mind that if it obtains non-zero weight, the estimate based on the synthetic control region will not be reliable for dates after November 2013.

For the same reason three other countries do not have to be excluded from the donor pool: Estonia and Latvia entered the eurozone after the beginning of BoE's QE, in 2011 and 2014 respectively. Sweden launched its programme of QE in February 2015. Therefore, these countries can be part of the donor pool, but if some of them obtain non-zero weight, the resulting estimate will be valid only until mentioned corresponding date.

Hence the donor pool consists of 17 countries; of them the Czech Republic, Estonia, Latvia, and Sweden need to be treated with special caution. It should be also noted that financial crisis led to generally loose monetary policy across developed economies. Countries obviously violating assumption of no similar intervention were excluded from the donor pool, but unusually loose policy even in countries remaining in the donor pool may narrow potential gap between actual and synthetic UK and underestimate effect of QE. In general, exceptional and unstable conditions of financial crisis and its aftermath make it difficult to isolate effect of QE. This is significant drawback of applied methodology, which must be taken into account in interpretation of results.

As was discussed in section 3.1, the SCM requires no spillovers from the treated country to countries in the donor pool, which may be also problematic in its application on QE. Haldane *et al.* (2016) identifies two main possible effects of QE on other countries. On one hand, QE creates downward pressure on domestic currency, which means upward pressure on other currencies. This helps British competitiveness at the expense of other countries. On the other hand, investors may rebalance their portfolios not only from gilts to other domestic assets, but also to foreign assets. Consequently, QE leads to increase in asset prices at home as well as abroad and provides boost to both UK's and other countries' economies. Haldane *et al.* (2016) show on the example of US QE that the second effect more than offset the first one, so overall spillover effect is expected to be positive (in a sense of boost to inflation and output).

Although existence of spillovers poses difficulties, it does not make the SCM inapplicable. Firstly, Haldane *et al.* (2016) claim that spillovers are significant

especially for large countries such as the US. Usage of the SCM for evaluation of QE in the US would be much less appropriate because it might lead to large bias (as the outcome variables in countries comprising the synthetic control region would be influenced by the examined policy); but for smaller British economy, the problem is less serious. There still may be bias, but its size should be much smaller. Secondly, we are able to identify direction of the potential bias. Positive spillover effects of QE imply that output and inflation in countries in the donor pool are higher than in absence of QE, which narrows the gap (if any) between real and synthetic British output and inflation, i.e. estimated effect of the intervention will be biased downwards. Hence the SCM still can be used, but it has to be kept in mind that resulting estimates will be rather conservative—the method provides us with lower bound of size of QE's impact (this argument is also in compliance with previous remark about generally unusually loose monetary policy, which could lead to downward bias as well).

The SCM computations are conducted in R with usage of Synth package described by Abadie *et al.* (2011).

Chapter 4

Empirical Results

4.1 GDP per capita

For real GDP per capita, the most important predictor variable is real GDP per capita itself with weight of almost 80%; remaining 20% is distributed across other variables (see table 4.1). The SCM approximates the UK by combination of New Zealand, Canada, Sweden, and Norway, as table 4.6 presents.

Variable	Weight
GDP per capita	0.78
inflation	0.02
unemployment	0.05
trade openness	0.02
FDI net inflows	0
final consumption	0
government expenditures	0.03
gross capital formation	0.01
real effective exchange rate	0
secondary education	0.01
tertiary education	0.01
population density	0
fertility	0
employment in industry	0.02
employment in services	0.04
broad money	0.02

Table 4.1: Weights of predictor variables in vector $\mathbf{V}$[1]

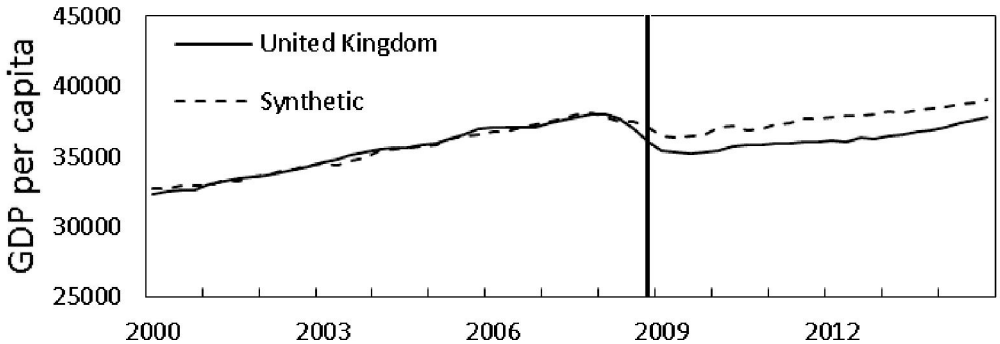
Country	Weight
Australia	0
Canada	0.26
Chile	0
Czech Republic	0
Denmark	0
Estonia	0
Hungary	0
Iceland	0
Israel	0
Korea	0
Latvia	0
Mexico	0
New Zealand	0.52
Norway	0.08
Poland	0
Sweden	0.14
Turkey	0

Table 4.2: Synthetic control unit

[1]Weights in this and following tables may not add up exactly to one due to rounding.

Figure 4.1 shows that synthetic GDP of the control unit leads to relatively precise pre-intervention fit to UK's GDP. After the intervention, British real GDP per capita is persistently below its synthetic counterpart, in peak in the second quarter of 2012 by a little less than 2000$, which is about 5% of GDP per capita at that time (remember that data on GDP are quarterly but annualized). This seems surprising and contradicting assumptions of QE's functioning. Nevertheless, mentioned good pre-intervention fit does not hold in a few last periods before the intervention; as can be seen from the figure 4.2, size of the gap was already cca 900$ (i.e. almost half of the peak gap) when QE was introduced. This suggests that the synthetic control unit serves as a good approximation for the UK only for period from 2000 to the beginning of 2008, but financial crisis affected the UK more negatively than control countries; as far as real GDP is concerned, the SCM is not able to provide appropriate control unit under exceptional circumstances of financial crisis, which causes negative gap between GDP of the UK and of the control region. The gap arose in the second half of 2008 and continued to widen both before and after QE was launched. Hence the negative gap is not attributable to QE; on the other hand, there is no evidence of positive effect of QE on GDP per capita either.

Figure 4.1: Actual and synthetic GDP pc of the UK



Note: Vertical line in this and following figures marks the last pre-intervention period. Labels on years correspond to data for the first period of given year.

Previous results are based on data from 2000 onwards, but when also all available data from 1990s are included in the analysis, weights of countries in the synthetic unit change only slightly—there are a few more countries which obtain non-zero, but still very low, weight. Resulting path of synthetic GDP does not change noticeably (see Appendix B for details).

Figure 4.2: Gap between actual and synthetic GDP of the UK

4.2 Inflation

Regarding inflation, there is a trade-off between usage of monthly and quarterly data. Monthly data can be useful to capture short-term variation in inflation as dependent variable, but it prevents inclusion of Australia and New Zealand as potential control countries because of data unavailability—quarterly data enable usage of larger donor pool (and as it turns out, New Zealand obtains non-zero weight).

With quarterly data, the most important predictor variable is again dependent variable itself, inflation in this case, but it obtains much lower weight (35%) than GDP per capita in previous analysis. Share of employment in services and GDP per capita follow in importance with a little more than 10% (see table 4.3 for details). The synthetic control unit then consists of Sweden and New Zealand, with a slight contribution of Canada (table 4.4).

As figure 4.3 and figure 4.4 show, the pre-intervention fit of the control unit is significantly worse than previously for GDP, but still the gap is in absolute value lower than 1 pp for most of the time before the intervention. In the post-intervention period, the gap rises up to 2.3 pp in the second quarter of 2010, and then declines below 0.4 pp a year later. After QE2 was launched in the middle of 2011, the gap rises again up to 2.3 pp at the end of 2011, and it peaks at 2.6 pp in the second quarter of 2013.[2] The final increase up to 2.6 pp occurred only after the Funding for Lending Scheme was adopted in July 2012, when the gap was at 1.7 pp, so part of the remaining increase up to the peak could be effect of the FLS. Because Sweden is part of the synthetic control unit, results may not be valid after 2015, when Sweden introduced its own quantitative easing.

[2]But the method does not allow to isolate the effect of QE2 from potential longer-term effects of QE1; the equation 3.2 is minimized only until the beginning of 2009, not until 2011.

Variable	Weight
inflation	0.35
GDP per capita	0.12
unemployment	0.06
trade openness	0.03
FDI net inflows	0
final consumption	0
government expenditures	0.05
gross capital formation	0.05
real effective exchange rate	0.03
secondary education	0.06
tertiary education	0.02
population density	0
fertility	0.02
employment in industry	0.02
employment in services	0.15
broad money	0.04

Table 4.3: Weights of predictor variables (quarterly data)

Country	Weight
Australia	0
Canada	0.01
Chile	0
Czech Republic	0
Denmark	0
Estonia	0
Hungary	0
Iceland	0
Israel	0
Korea	0
Latvia	0
Mexico	0
New Zealand	0.39
Norway	0
Poland	0
Sweden	0.60
Turkey	0

Table 4.4: Synthetic control unit (quarterly data)

Nonetheless, this is already long after the beginning of QE in the UK, and as the gap is approaching zero by then anyway, it does not cause any troubles.

Results suggest positive effect of QE on inflation; nevertheless, the estimates must be interpreted with caution, mainly for two related reasons—firstly because of imperfect fit during the pre-intervention period, secondly because the gap is already positive at the intervention time, with level of 1 pp. Hence at minimum this part of the gap cannot be attributed to QE.

In analyses of both GDP and inflation, there is a gap already at the intervention time (so it obviously cannot be attributed to the intervention), which widens after that. Hence it is necessary to justify in more detail why the interpretation provided here attributes the post-intervention gap (at least partly) to QE for inflation, but not for GDP. There is a difference between these two instances, which enables such interpretation. The gap at the intervention time for GDP is almost twice as high as the largest gap in the whole preceding examined period, which suggests worsening fit for GDP under crisis conditions; and the gap approximately doubles after the intervention. Conversely, the gap for inflation at the beginning of 2009 is in magnitude similar to previous fluctuations, and it is not in absolute value the highest pre-intervention gap (which is about 1.4 pp). But the peak post-intervention gap is more than 2.5 times higher than

its level when QE was launched—difference noticeably higher than for GDP. In addition, introduction of QE2 was directly followed by increase of 1.9 pp, which is sharper change than any previous fluctuation. Still it might be true that crisis influenced inflation in the UK and in countries in the synthetic control unit asymmetrically—just as with GDP previously—and the post-intervention gap widens just because of the asymmetry rather than because of quantitative easing, on the other hand (contrary to GDP), there is no sign of the asymmetry in case of inflation. Inference in the next section provides more rationale for the interpretation provided here—it shows that UK's post-intervention gap, relative to placebo studies and after controlling for pre-intervention fit, is considerably more significant for inflation than for GDP. Hence it follows that the results indicate positive effect of QE on inflation, but magnitude of the estimates is surrounded by large uncertainty.

Figure 4.3: Actual and synthetic inflation of the UK

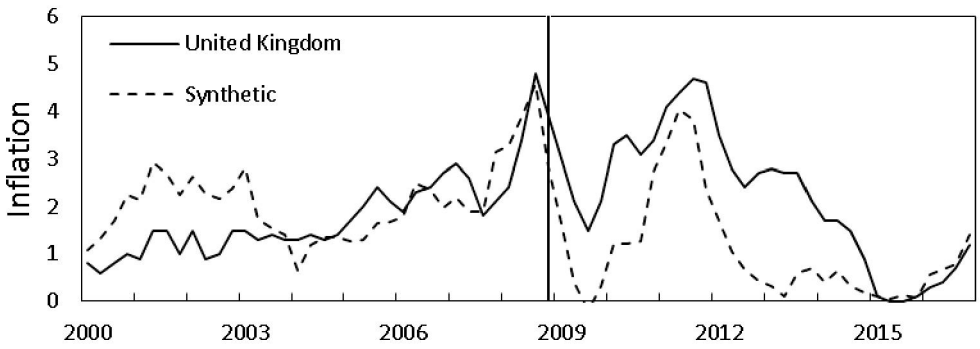
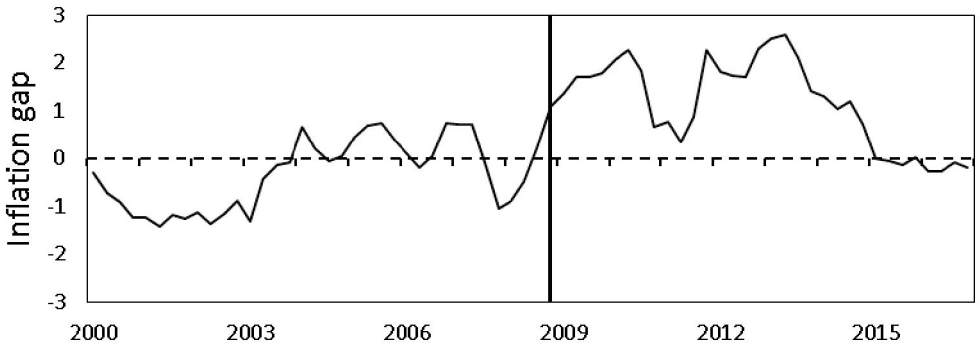


Figure 4.4: Gap between actual and synthetic inflation of the UK



Exclusion of Australia and New Zealand allows usage of monthly data for inflation. But since New Zealand played important role in the synthetic control unit with quarterly data—it accounted for almost half of it—pre-intervention

fit is expected to worsen. Without New Zealand, Sweden obtains even higher weight than before and is supplemented by South Korea and slightly by Iceland; weights of predictor variables change substantially—inflation obtains now only 5%, the most important variables with 26% are unemployment and share of secondary educated labor force.

Variable	Weight
GDP per capita	0.02
inflation	0.05
unemployment	0.26
trade openness	0.04
FDI net inflows	0.04
final consumption	0
government expenditures	0
gross capital formation	0.01
real effective exchange rate	0.04
secondary education	0.26
tertiary education	0.07
population density	0.01
fertility	0.09
employment in industry	0.01
employment in services	0.09
broad money	0

Table 4.5: Weights of predictor variables (monthly data)

Country	Weight
Canada	0
Chile	0
Czech Republic	0
Denmark	0
Estonia	0
Hungary	0
Iceland	0.04
Israel	0
Korea	0.17
Latvia	0
Mexico	0
Norway	0
Poland	0
Sweden	0.79
Turkey	0

Table 4.6: Synthetic control unit (monthly data)

Fit of actual and synthetic UK's inflation truly is worse than with quarterly data—the largest pre-intervention gap approaches -2 pp (see figure 4.5 and figure 4.6). On the other hand, post-intervention development of this altered synthetic inflation does not differ much from the one including New Zealand. The gap at the intervention time is about 1.2 pp, then it rises to 2.5, declines below 1, and after introduction of QE2 peaks at 2.7 pp. Shape of inverse W is hence the same as before; larger pre-intervention gaps also lead to a bit larger gaps after the intervention, but otherwise previous analysis with quarterly data is confirmed using monthly data and alternative synthetic control unit.

Just as with GDP, inclusion of data from 1990s in Appendix B (with quarterly data for inflation) does not change resulting synthetic path of UK's inflation by any significant way.

Figure 4.5: Actual and synthetic monthly inflation of the UK

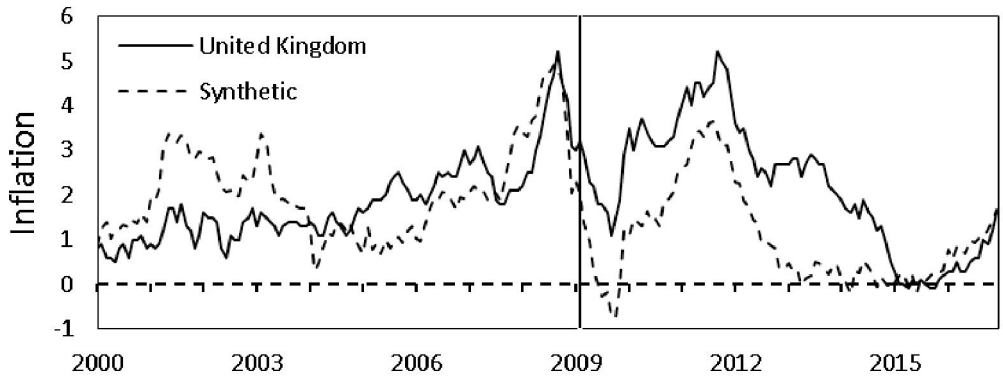


Figure 4.6: Gap between actual and synthetic monthly inflation of the UK

4.3 Inference

This section presents inference about the results based on *in-space placebos*. Synthetic counterpart is computed for each country in the donor pool separately for GDP per capita and inflation as outcome variables. Then ratio of post-intervention to pre-intervention MSPE is computed—the higher the value for the treated country compared with countries in the donor pool, the stronger the evidence of significance of the policy. Pre-intervention period lasts from 2000 to 2008. The United Kingdom is shifted to the donor pool for these computations; quarterly data are used.

Countries which participated in QE or some similar policy, but introduced it later than the UK, were in preceding analysis included in the donor pool with remark that they require special treatment if (and only if) they obtain non-zero weight—then results would be reliable only before their introduction of the policy. But inference requires different approach. Synthetic counterpart is computed for each country, and probably each country comprises part of the

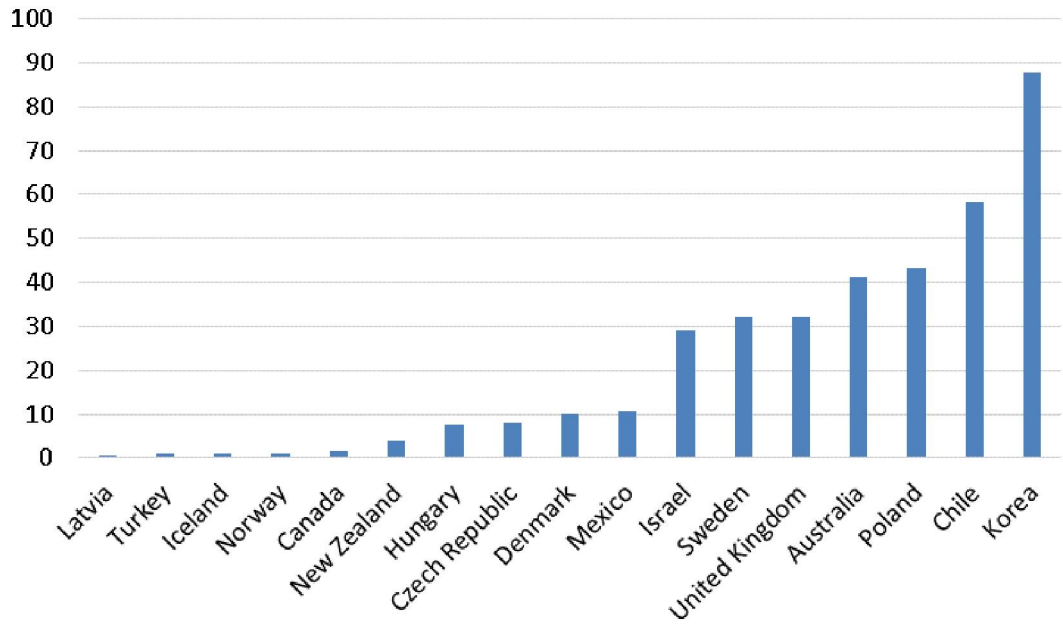
synthetic control unit for at least some other country in the donor pool. While only countries with positive weight in the synthetic counterpart of the UK were relevant for estimation of effects of QE, all included countries are now relevant for making inference about estimated effects.

Because of this reason, Estonia is excluded from the donor pool, and post-intervention MSPE is computed only based on data until the third quarter of 2013—the last quarter before introduction of the exchange rate commitment in the Czech Republic. Estonia entered into the euro area already at the beginning of 2011, so its inclusion would require computation of post-intervention MSPE with data from only two years—rather short time period. On the other hand, enlargement of post-intervention time period beyond 2013 would require exclusion of not only the Czech Republic, but also of Latvia, which entered the euro area in 2014, and of Sweden (if data from 2015 were to be included too). Therefore, exclusion of Estonia and usage of data until 2013 seems like a reasonable compromise between long enough post-intervention period (and more data for computation of MSPE ratios) and between large enough donor pool (it is preferable to have more countries available for comparison of their MSPE ratios with the ratio of the UK).

The changes in data do not influence results presented in previous sections: Estonia obtained zero weight in all cases, and synthetic control unit is computed based on pre-intervention period, while length of post-intervention period is irrelevant. The only difference is that methods applied in previous sections enabled presentation of results also for years 2014-2016, while MSPE ratios in this section take into account only data until 2013.

Figure 4.7 presents results for real GDP per capita as the dependent variable. The UK has the 5th highest MSPE ratio out of 17 countries, with two other countries obtaining only slightly lower value. Korea's MSPE ratio is almost three times higher than the UK's, and Chile's is almost twice as high. Therefore, although UK's ratio is still above average, its magnitude is not anyhow exceptional. That confirms interpretation provided in section 4.1 that the gap between synthetic and actual British GDP, at first glance surprisingly negative, is not related to quantitative easing. Financial crisis just influenced GDP of different countries asymmetrically, and the synthetic control method is not able to provide valid estimate of impact of QE on GDP under such circumstances.

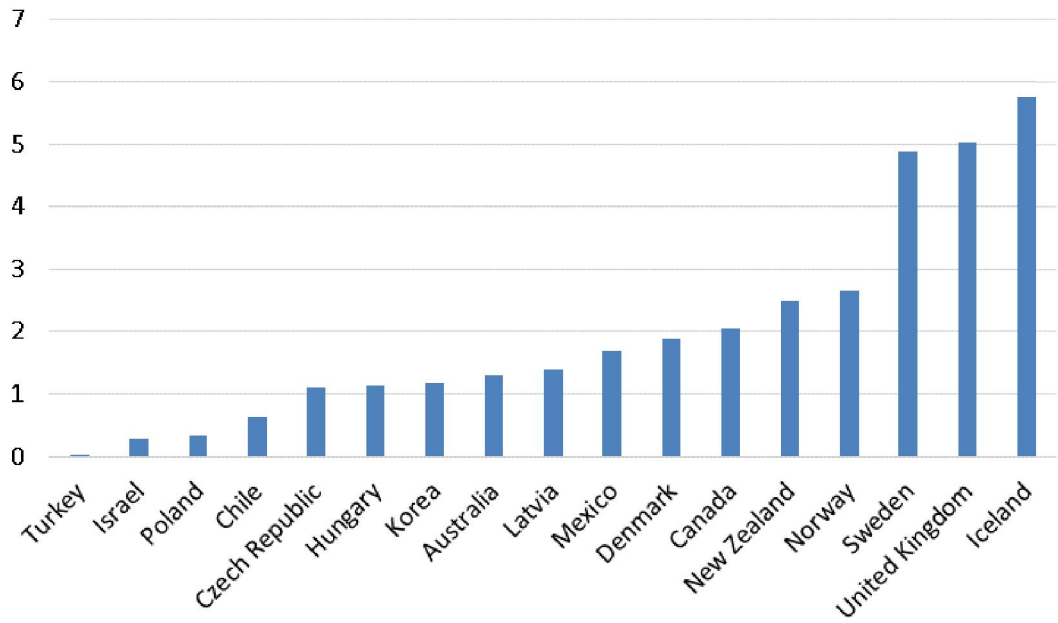
Figure 4.7: MSPE ratios—GDP per capita



Results for inflation in figure 4.8 show that 3 countries have MSPE ratio substantially higher than remaining 14, and the UK is the second of them, not far behind the first Iceland—size of the post-intervention gap in the UK is unusually large in the data set when goodness of pre-intervention fit is taken into account.[3] This is consistent with the proposition that relatively high post-intervention gap is not just result of random fluctuations, but it can be at least partly attributed to QE. Such conclusion is strengthened by potential downward bias of the results due to possible spillover effects discussed in section 3.2. Nevertheless, this does not help to resolve problem with exact quantification of QE's effect caused by the gap being already slightly positive when QE was launched.

[3]The highest MSPE ratio in case of GDP was 87.8, but here it is only 5.8. Large difference in magnitude of the ratios is caused by GDP fluctuating much less than inflation, so it can be approximated very precisely in the pre-intervention period, and then deviation of only a few hundreds dollars in GDP per capita in the post-intervention period can cause high MSPE ratio. There is not much sense in comparison of size of the ratios across variables; placings of countries and relative size of the ratios separately for each outcome variable is what matters.

Figure 4.8: MSPE ratios—inflation



Chapter 5

Conclusion

This thesis explores quantitative easing—policy of large-scale purchases of assets introduced by several central banks as a reaction to recent financial crisis and subsequent economic development. The policy is supposed to help central banks with achievement of their inflation targets when interest rates have already reached zero lower bound and threat of deflation is still present in the economy; moreover, QE should also boost real GDP.

Existing literature suggests success of QE in raising inflation and GDP, but magnitude of its estimates is surrounded by large uncertainty. Therefore, after description of QE, the thesis attempts evaluate effects of QE in the United Kingdom by the synthetic control method, which to author's knowledge has not been used in this context so far. The SCM creates control unit for the UK as a weighted average of other countries, where weights are based on pre-intervention data.

In terms of real GDP, the UK is approximated by weighted combination of New Zealand, Canada, Sweden, and Norway. Synthetic GDP of resulting control unit resembles the UK's GDP well for most of the pre-intervention period, but substantial negative gap emerges after outbreak of financial crisis—even before introduction of QE. It means that the SCM is not able to construct reliable counterfactual for the UK's GDP under exceptional circumstances of the crisis. Hence negative gap (although even larger in the post-intervention period) is not attributable to QE, but it does not allow to isolate estimate of QE's effect.

As far as inflation is concerned, Sweden and New Zealand comprises the synthetic control unit. The gap is positive here and peaks at 2.3 pp in 2010 at first, then declines below 1 pp, after QE2 rises by 1.9 pp to 2.3 pp at the end of 2011, and then peaks at 2.6 pp in 2013. Nevertheless, pre-intervention fit is

imperfect, and part of the gap is caused by the gap being already at 1 pp at the intervention time, which cannot be attributed to QE. Moreover, Bank of England introduced another tool, Funding for Lending Scheme, shortly before the peak rise up to 2.6 pp, and the method does not enable to isolate effects of QE from those of the FLS. On the other hand, estimated effects on inflation may be underestimated because of generally loose monetary policies in developed economies and because of possible spillover effects of QE, since BoE's QE could have boosted inflation also in other countries than in the UK.

The results thus suggest positive impact of QE on inflation, which is also in compliance with relatively high MSPE ratio of the United Kingdom in comparison with placebo studies; nonetheless, exact magnitude of the impact remains highly uncertain.

Mentioned results are based on quarterly data on outcome variables and on all data beginning in 2000 or later, but they are sensitive neither to inclusion of data from 1990s nor to usage of monthly data for inflation (even though monthly data require exclusion of New Zealand, which obtained non-zero weight in the analysis with quarterly data, from the donor pool).

Usage of the synthetic control method for evaluation of QE in the UK turned out to be problematic, especially regarding impact on GDP. The main reason is probably asymmetric influence of financial crisis on different countries; only few pre-intervention periods are already affected by the crisis, so the control unit is constructed mainly based on pre-crisis data. Hence, concerning the SCM in context of QE, it might be an option for future research to use the method to estimate effect of QE in Sweden, where time difference between the beginning of financial crisis and the introduction of QE (in 2015) is much larger. Therefore, there would be enough data reflecting unusual crisis and post-crisis conditions, and consequently, it could enable creation of more precise synthetic control unit. Regarding QE in general, evaluation of potential longer-term downsides and risks of the policy might be a path for future research.

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Appendix A

Data Description and Sources

Table A.1 presents description of all used variables. World Development Indicators database of the World Bank is source of all data except for following variables extracted from OECD database:

- GDP per capita (for Iceland, Mexico, South Korea, and Turkey data on real GDP in national currencies were obtained from Eurostat database and then recalculated to appropriate unit by author with usage of purchasing power parities conversion rates obtained from OECD database and with data on total population obtained from World Bank database)
- Inflation
- Real effective exchange rate (data for Latvia are from World Bank database)

Table A.1: Variables used

Variable	Description	Availability
Real GDP per capita	Quarterly data, measured in US $, in constant prices, fixed purchasing power parities, reference year 2010, seasonally adjusted, and annualized.	1998-2014
Inflation	Quarterly and monthly data, percentage change in consumer prices on the same period of the previous year.	1998-2016[1]
Unemployment (% of total labor force)	Share of the labor force that is without work but available for and seeking employment.	1996-2014
Trade (% of GDP)	Sum of exports and imports of goods and services.	1995-2014
FDI, net inflows (% of GDP)	Sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments.	1995-2015
Final consumption expenditure (% of GDP)	Sum of household final consumption expenditure (private consumption) and general government final consumption expenditure (general government consumption).	1995-2014
Government expenditures (% of GDP)	Includes all government current expenditures for purchases of goods and services (including compensation of employees). It also includes most expenditures on national defense and security, but excludes government military expenditures that are part of government capital formation.	1995-2014
Gross capital formation (% of GDP)	Consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories.	1995-2014
Real effective exchange rate index	Nominal effective exchange rate (a measure of the value of a currency against a weighted average of several foreign currencies) divided by a price deflator or index of costs. 2010 = 100.	1995-2015

[1]Time period holds for both quarterly and monthly inflation; but for monthly inflation, no data are available for Australia and New Zealand

Variable	Description	Availability
Labor force with secondary education (% of total)	Share of the total labor force that attained or completed secondary education as the highest level of education.	2006-2007
Labor force with tertiary education (% of total)	Share of the total labor force that attained or completed tertiary education as the highest level of education.	2006-2007
Population density (people per sq. km of land area)	Midyear population divided by land area in square kilometers.	1991-2015
Fertility rate (births per woman)	Number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children in accordance with age-specific fertility rates of the specified year.	1991-2014
Employment in industry (% of total employment)	The industry sector consists of mining and quarrying, manufacturing, construction, and public utilities (electricity, gas, and water).	1996-2013
Employment in services (% of total employment)	The services sector consists of wholesale and retail trade and restaurants and hotels; transport, storage, and communications; financing, insurance, real estate, and business services; and community, social, and personal services.	1996-2013
Broad money (% of GDP)	Sum of currency outside banks; demand deposits other than those of the central government; the time, savings, and foreign currency deposits of resident sectors other than the central government; bank and traveler's checks; and other securities such as certificates of deposit and commercial paper.	1995-2008

Note: Description of the variables is shortened exact definition provided by World Bank database (for the variables with World Bank database as a source). Availability is period over which data on given variable are available for *all* countries in the donor pool (and the UK).

Appendix B

Results with Longer Pre-intervention Period

Results presented in Chapter 4 were based on data from 2000 onwards. Data from 1990s are added to the analysis in this appendix. For each variable, the largest possible subset of 1991-2008, for which data on given variable are available for all countries in the donor pool, is taken; averages of values across years in the subset are computed for each country and each variable and included in the vector **V**. (The first year for which data for given variable are available for all countries differs across variables—see Appendix A). Quarterly data are used for the dependent variables—real GDP per capita and inflation—and the pre-intervention fit optimization begins in the first quarter of 1998 in both analyses (since this is the first quarter for which data on the dependent variables are available for all countries). As following tables and figures show, weights of variables and countries change slightly, but resulting synthetic UK's GDP and inflation change only negligibly compared with those presented in Chapter 4, and hence they are not sensitive to changes in particular length of pre-intervention period.

Variable	Weight
GDP per capita	0.87
inflation	0.04
unemployment	0.01
trade openness	0.02
FDI net inflows	0
final consumption	0
government expenditures	0.01
gross capital formation	0.01
real effective exchange rate	0
secondary education	0
tertiary education	0.01
population density	0
fertility	0.01
employment in industry	0.01
employment in services	0.03
broad money	0

Table B.1: Weights of predictor variables—GDP pc

Country	Weight
Australia	0.03
Canada	0.25
Chile	0
Czech Republic	0
Denmark	0.01
Estonia	0
Hungary	0
Iceland	0
Israel	0
Korea	0
Latvia	0
Mexico	0.01
New Zealand	0.44
Norway	0.07
Poland	0.01
Sweden	0.17
Turkey	0

Table B.2: Synthetic control unit—GDP pc

Figure B.1: Actual and synthetic GDP pc of the UK

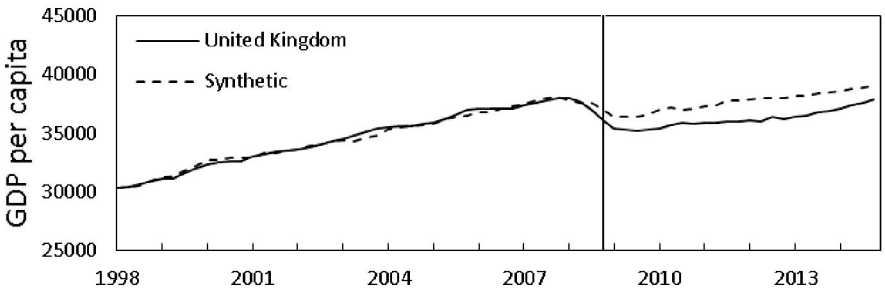
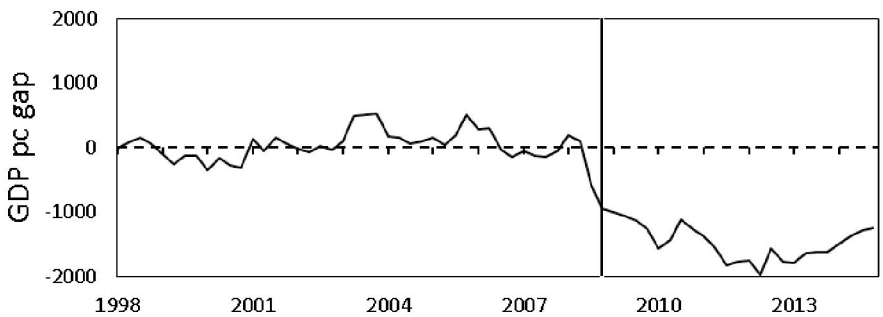


Figure B.2: Gap between actual and synthetic GDP of the UK



Variable	Weight
inflation	0.55
GDP per capita	0.06
unemployment	0.07
trade openness	0.02
FDI net inflows	0.05
final consumption	0
government expenditures	0.03
gross capital formation	0.03
real effective exchange rate	0.01
secondary education	0.03
tertiary education	0.03
population density	0.01
fertility	0
employment in industry	0.01
employment in services	0.09
broad money	0.02

Table B.3: Weights of predictor variables—inflation

Country	Weight
Australia	0
Canada	0.01
Chile	0
Czech Republic	0
Denmark	0
Estonia	0
Hungary	0
Iceland	0
Israel	0.06
Korea	0.04
Latvia	0
Mexico	0.02
New Zealand	0.31
Norway	0.04
Poland	0
Sweden	0.53
Turkey	0

Table B.4: Synthetic control unit—inflation

Figure B.3: Actual and synthetic inflation of the UK

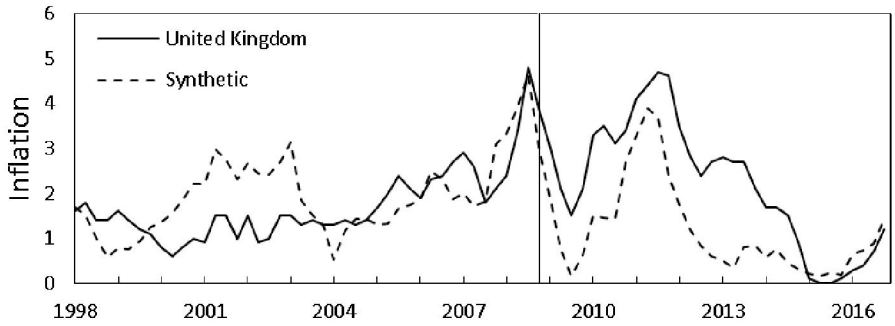


Figure B.4: Gap between actual and synthetic inflation of the UK