Did QE Just Twist the Yield Curve?

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Abstract

If the sole effect of QE is to lower interest rates at longer maturities, it is a costly way to achieve this. I therefore argue that the effect of QE on the economy, specifically on inflation and the costs of credit, should be thought of in terms of two key channels: an interest rate effect, wherein the fall in risk-free borrowing costs leads to a secular downward movement in the general cost of borrowing, and a "pure-QE" effect, which arises through other channels. I propose a simple methodology to test for the presence of these channels, and implement it using readily available data. My results suggest that a large "pure-QE" effect exists. I discuss plausible readings of this evidence, the shortcomings of my methodology, and conclude with proposals for further research.

1 Introduction

A key component of the "unconventional" policy regime advanced economy central banks have pursued since the events of September 2008 has been direct central bank interventions in markets they have traditionally not entered, including those for private assets and importantly, the market for longer term treasurys. These unprecedented interventions have been funded by a massive increase in bank reserves, a policy measure that has come to be known as Quantitative Easing (QE). How might the consequent quintupling of the Fed's Balance Sheet between 2008 and 2014 have affected the economy? In the US, the first round of QE concentrated purchases in markets where restoring liquidity was paramount, including those for Agency MBS, Federal Agency Discount Notes and other direct obligations of Fannie Mae and Freddie Mac (Federal Reserve Board, 2008)[1]. However, as Reis (2016b) points out, financial markets seemed reasonably liquid by late 2010 (Bernanke, 2010). Further, QE-II, the Maturity Extension Program started in September 2011 and QE-III all focused on expanding the Federal Reserve's holdings of longer term treasurys. The continued need for additional QE programs must have been motivated by a need to keep long term risk-free yields depressed, or to signal a continued commitment to a stabilising the still uncertain recovery[2].

QE is an expensive way to flatten a yield curve. In Reis (2016b), QE redistributes wealth from households to banks[3] and exposes the central bank's balance sheet (and by extension, the consolidated public sector budget constraint) to risk. Breedon and Turner (2016) show, using evidence from the UK's QE program, that purchasing government bonds in secondary markets imposes significant transactions costs on an economy, up to 0.5% of the value of QE in the

UK. They argue that if the key rationale behind QE was to lower longer term interest rates in an economy at the zero lower bound, the same objective could have been achieved via more inexpensive alternative mechanisms, such as active public debt management or through direct purchases of long term bonds from the treasury[4].

This essay thus asks whether the final effect of QE in the US worked through channels other than by affecting the yield curve. Section 2 briefly discusses the existing literature on QE and its effects. Section 3 discusses the theoretical channels through which the pure-QE Effect may have affected two measures of real activity, inflation and corporate borrowing costs. Section 4 describes a simple empirical strategy to decompose the effect of QE announcements into an effect that can be accounted for purely due to the shock to policy rates, and a separate "pure-QE" effect. Section 5 discusses the data I use, and Section 6 discusses my results. I estimate that the QE-only effect appears to account for well over half of the total effect of QE on the outcome measures, and that in some cases, works in a direction opposite to that implied by the change in the policy rate on the QE date. Section 7 concludes.

2 Literature Review

2.1 QE and the economy: Theory

Conventional monetary policy is conducted by setting a target range for the interest rate in the interbank market for reserves, and ensuring the interest rate remains within this target range by affecting their supply, which the central bank controls. In the presence of nominal rigidities, a lower nominal interest rate typically reduces inflation expectations less than proportionately, implying a reduction in real interest rates; these induce additional consumption by households and investment by firms. Lower interest rates imply higher asset prices, generating a wealth effect for households, and also depreciate exchange rates, boosting export demand. Higher asset prices can support balance sheets, reducing agency costs of raising external capital, and improving credit supply (Fawley and Neely, 2013).

A limit to conventional policy is placed by the "zero lower bound" on nominal interest rates - since individuals always have the option of holding wealth in the form of a physical asset, namely currency, which earns a nominal return of 0 and may also provide liquidity services[5], they will only hold riskless short-term assets if the interest rate on these assets is above a lower bound not (far) below 0. Well before the current crisis in the US and Europe, a significant literature pointed out that this need not imply that central banks were powerless to achieve their policy objectives. Bernanke et al. (2004) discussed three channels through which outright asset purchases by a central bank financed by an issue of reserves might work: a channel via financial market imperfections rendering assets imperfect substitutes for one another, a fiscal channel where the issuance of reserves might allow the central bank to substitute seignorage for tax revenue and permit the government to relax its consolidated resource constraint, and a signaling channel to complement forward-guidance like policies. The relaxation of the budget constraint was further discussed in in the Japanese context by Auerbach and Obstfeld (2005). However, in the aftermath of the 2008 crisis and the roll-out of the first round of QE, Bernanke (2009a) argued that the design of the US program revolved around reducing credit spreads and unfreezing trading in illiquid markets, allowing for a fourth "liquidity" channel.

A rigorous model of how QE reduces interest rates and spreads in a ZLB setting is hard to motivate in environments featuring frictionless and complete asset markets where arbitrage prevails. Intuitively, in models involving consumption-based stochastic discount factors, consumers only care about consumption in different states of the world; this implies that they are indifferent between assets with identical payoff structures and between assets of different maturities as long as their yields obey the expectations hypothesis (Gürkaynak et al., 2010). Thus, if the interest rate paid on reserves and the short term nominal interest rate are equal, a reserve-financed purchase of assets merely exchanges one type of government liability for another[6]. In such economies, Wallace (1981) showed that the maturity structure of public debt is irrelevant for the price of debt, a result that echoes the Modigliani-Miller Theorem. Eggertsson and Woodford (2003) proved that this continues to hold in a more general model, under the assumptions that assets are valued purely for pecuniary returns and that the asset purchases do not change expectations about the future conduct of monetary policy. Cúrdia and Woodford (2011) show that this "irrelevance" result continues to hold in a New Keynesian Model with financial intermediation, under the additional assumption that the increase in reserves finances central bank purchases of treasurys (instead of representing a loan to private agents).

Relaxing the above assumptions has recently become the subject of an active literature. Reis (2016b) shows that introducing the possibility of government default breaks the neutrality result, since issuing nominally default-free reserves to purchase risky government bonds now reduces the riskiness of private portfolios (i.e. reserves and government bonds are no longer perceived as identical). Models of preferred habitat consider the existence of investors which prefer to invest in specific maturities only. Vayanos and Vila (2009) construct a theoretical model of these effects and show that interactions between maturity-specific investor clienteles and arbitrageurs with mean-variance utility can generate a term structure which is arbitrage-free and yet responds to demand or supply shocks *local* to specific maturities. Bauer and Rudebusch (2014) discuss the consequences if QE reveals new information to market participants, either about the central bank's assessment of the economy or about the central bank's reaction function[7].

The theoretical literature on the pass-through from twists in the yield curve to yields on private assets is smaller. A key contribution is Krishnamurthy and Vissing-Jorgensen (2011), who discuss and test for the presence of six channels for the effects of QE on risky yields and, by extension, on private borrowing costs. These include a portfolio balance channel (A transfer of risk away from private balance sheets and a reduction in term premia, which reduces yields on the purchased assets), a signaling channel, a liquidity channel, a "safety" channel (The premium on extremely safe assets over comparable riskier assets owing to the existence of specific clienteles for these asset classes), an inflation channel (insofar as QE raises (risk-adjusted) expected inflation, the inflation channel predicts an increase in nominal interest rates), and channels reflecting default risk and prepayment risk.

2.2 Empirical Approaches

There is limited consensus on the extent to which QE affects the real economy. Chen et al. (2012) estimate the effect of LSAP-II in a standard DSGE model augmented with a preferred-habitat model of bond market segmentation, and conclude that the marginal contribution of the program to inflation is small; they argue that this is due to a low degree of estimated market segmentation. By contrast, Wu and Xia (2016) use a nonlinear term structure model and show that in a VAR, the QE programs reduced unemployment by almost one percentage point over the period they were in effect.

Most empirical studies on the effects of QE have attempted to disentangle the channels through which QE affects yields on assets purchased. Gagnon et al. (2011), Swanson (2011) and Krishnamurthy and Vissing-Jorgensen (2011) all estimate, using high-frequency event-study-style approaches, that QE programs had large negative effects on these yields. The empirical strategy used by Krishnamurthy and Vissing-Jorgensen (2011) compares the behaviour of yields which are affected identically by all the channels they discuss except one, using a "differences-in-differences" style approach. While this identifies the size of the channel, it does not help decompose the *total* change in a yield into different components. Since the channels they describe may have affected both risk-free and risky asset yields, their approach does not allow us to obtain a pure-QE effect. In the treasurys market, D'Amico et al. (2012) and D'Amico and King (2013) use CUSIP - specific data to show both that there are sigificant "local supply" effects of QE on yields at similar maturities to those remaining on the specific securities purchased and that the decline in longer term yields caused by QE was due to effects on *real* term premia rather than effects on the inflation risk premium.

Turning to the effects of QE on credit conditions, Gilchrist et al. (2015) study the response of real borrowing costs, measured using yields on Treasury Inflation-Protected Securities (TIPS) and implied inflation compensation, corporate bond yields and MBS yields, to monetary policy easing, using an empirical strategy that attempts to account for "forward guidance" in policy announcements but not otherwise accounting for the effects of QE. Gilchrist and Zakrajšek (2013) explicitly study the effect of QE on an important measure of corporate credit risk, an index of credit default swaps. However, their empirical strategy does not allow for an effect of QE other than through the effect on interest rates. Hancock and Passmore (2011) study the effects of QE on MBS yields and on US Mortgage Rates. They conclude that the effect of the announcements on yields was larger than can be explained by shocks to market expectations alone since the share of MBS held by the Fed is a significant variable in explaining MBS yields, even conditional on measures of expected future interest rates. They take this as evidence for portfolio-rebalancing effects, but also argue that the Fed must hold a large share of agency MBS to significantly lower yields on them through asset purchases.

To summarize, while the literature finds that QE affected yields on assets purchased and finds evidence that it affected other risky yields, it does not identify a convincing transmission mechanism for QE that makes it different from any other policy that reduces risk-free interest rates. In this essay, I take a preliminary stab at this question and ask - suppose the central bank, possibly in coordination with the treasury, had enacted a policy that reduced yields by exactly the same amount as the QE events did. Would this policy have had the same effect as QE on inflation and on corporate borrowing costs? My study is most closely related to that of Swanson (2017), who uses a high-frequency identification approach combined with the empirical approach of Gürkaynak et al. (2005) to identify the effect of the federal funds rate shock, the "forward guidance" component and LSAP component of policy announcements, and shows that the QE had larger and more persistent effects on long-term yields and corporate bond yields than forward guidance or the fed funds rate shock. I obtain very similar results, albeit using a much simpler empirical strategy.

3 Theory

3.1 QE and Inflation

Modern theories of price level determination emphasise the role of arbitrage in financial markets in pinning down the rate of inflation in terms of the rate at which the real value of reserves[8] declines relative to the real value of other assets. Reis (2016a) argues that QE should not affect inflation once the market for reserves is saturated, since further expansions of the supply of reserves do not change the interest rate in the overnight money market (which is now at its effective lower bound, the interest rate on reserves). Announcements about the future path of the interest rate paid on reserves, which now move the overnight money market interest rate one for one, will continue to affect inflation (through a Phillips effect in the short run and a Fisher effect in the Long Run[9]). Reis (2016a) also argues that QE may have *general equilibrium* effects on inflation via its effects on other real outcomes[10].

The above argument assumes common knowledge of the policy rules the central bank is expected to follow in setting a path for reserves. We also need to consider the information revealed by a QE announcement about changes in the reaction function of the Central Bank. If private markets expect that the change in interest rates caused by QE is temporary and do not infer a change in the central bank's policy regime or reaction function, QE is inflationary only insofar as it reduces short-term borrowing costs. In this case, the effect of QE on inflation should have come about entirely through the change in nominal yields. However, if the decision by the central bank to undertake an intervention on the scale of QE is interpreted as a change in the central bank's willingness to "do whatever it takes" or as a sign of central bank pessimism[11], the effects of the announcement could go either way. In this case, we should expect a non-zero Pure-QE effect.

3.2 QE and Corporate Bond Yields

Any risky yield can be decomposed into a risk-free underlying yield and a premium reflecting various asset-specific factors. Elton et al. (2001) argue that the spread between corporate bonds and comparable maturity treasurys reflects expected default risk, a premium for local taxes and a premium for non-diversifiable risk which appears to be driven by a single underlying factor. Gilchrist and Zakrajšek (2012) use data on individual outstanding bonds to construct a measure of this risk premium and show that it has significant predictive power for economic activity[12] coming from an underlying component that is related to deviations of the asset price relative to measured default risk. They present evidence that an increase in this "excess bond premium" reflects a reduction in the ability of the financial sector to bear risk.

In general, we can thus write the yield on a corporate bond j of maturity n at time t as

$$i_t^C(j,n) = i_t + \tau_t(n) + \delta_{jt}^C + \rho_t$$

where i_t is the short term interest rate, $\tau_t(n)$ is a term premium reflecting the relatively long average maturity of corporate bonds, δ_j^C is a bond-specific default risk premium and ρ_t is the non-diversifiable excess bond premium. The effect of QE on $i_t^C(j,n)$ could have come about through a reduction in i_t, which is the only channel studied by Gilchrist and Zakrajšek (2013). A pure QE effect would work through:

- A reduction in $\tau_t(n)$, which Gagnon et al. (2011) argue is the key channel through which QE worked.
- A reduction in δ_{jt}^C, which would have occurred through supporting other forms of financing which would reduce default probabilities outright.
- Reductions in ρ_t. By boosting asset values and liquidity QE could have weakened credit market frictions, thus raising the financial sectors credit creation ability, and reducing the risk premium for a given average default risk[13].

Krishnamurthy and Vissing-Jorgensen (2011) present evidence that the effect of QE on corporate yields can be largely explained by a "signaling channel," wherein the central bank commits to keep short term rates low for an extended period, a "safety" channel which makes AAA rated yields fall by more than BAA rated yields and a "default" channel whereby QE reduced the default premium. They do not explicitly model a liquidity channel for the effect of QE on corporate yields. Since changes in interest rates could affect the premia charged on bonds as well, the pure-QE effect we estimate for bond yields may be hard to interpret. I therefore estimate the effect first for bond yields, and then for the spread on these bonds over the benchmark 10-year yield.

4 Empirical Strategy

Let t index time. Consider the change in a policy indicator, which in my case is the constant-maturity yield on a two-year on-the-run government security $i_t^{(2)}$. Let y_t be an outcome variable. I consider a model of the form

$$\Delta y_t = \phi^{iQ}\Delta i_t^{(2)} + \phi^{yQ}Q_t + z_t + \varepsilon_t^y \tag{1}$$

where Q_t is a dummy for whether a date was a QE date or not and z_t is an underlying unobserved factor uncorrelated with Q_t or ε_t^y, which affects both $\Delta i_t^{(2)}$ and Δy_t simultaneously. I assume that the policy indicator evolves according to

$$\Delta i_t^{(2)} = \alpha_0 + \alpha^Q Q_t + \gamma z_t + \nu_t^i \tag{2}$$

where γ is the size of the effect of the common factor z on $\Delta i_t^{(2)}$ relative to the effect on ΔQ. This is similar to the framework of Rigobon and Sack (2004), except I do not allow for the policy indicator to respond contemporaneously to the outcome measure.

Assumption 1. *In a sample of daily data,* $cov(Q_t, \varepsilon_t^y) = cov(\Delta i_t^{(2)}, \varepsilon_t^y) = 0$.

- *Innovations to the outcome are contemporaneously orthogonal to the change in the policy indicator due to this shock.*
- *Innovations to the outcome are contemporaneously uncorrelated with the timing of QE shocks. This holds if QE is unexpected.*

The two-equation system above suggests that estimating 1 directly by OLS will lead to a problem of what Angrist and Pischke (2009) call "bad control": The causal effect of Q_t works through a direct effect ϕ^{yQ} and an *indirect* effect through its effect on $i_t^{(2)}$[14]. Additionally, the endogeneity generated by the unobservable z_t will affect the coefficient on Q as well.

To get around this problem, I exploit the event study methodology as follows. First, I estimate equation 2 using a sample of daily data over the period when QE was in operation. I make the following assumption:

Assumption 2. *In a sufficiently small window around a QE announcement,* $cov(Q_t, \nu_t^i) = 0$.

This assumption, together with $\text{cov}(Q_t, z_t) = 0$, implies that the estimated change in i_t, say $\hat{\alpha}^Q$, consistently estimates the actual effect of QE on the policy indicator, and is the key identifying assumption made in much of the event study literature on QE. Substituting for $\Delta i_t^{(2)}$ in (1) from (2), we get

$$\Delta y_t = \alpha_0 \phi^{iQ} + (\phi^{iQ}\alpha^Q + \phi^{yQ})Q_t + (1 + \alpha^Q\gamma)z_t + \varepsilon_t^y + \phi^{iQ}\nu_t^i \tag{3}$$

Now consider the regression

$$\Delta y_t = \beta_y + \beta^Q Q_t + \nu_t^y \tag{4}$$

Estimating this equation under OLS gives us an estimator $\widehat{\beta}^Q$ which obeys

$$\begin{aligned} p\text{lim } \widehat{\beta}^Q &= \frac{\text{cov}(\Delta y_t, Q_t)}{\text{var}(Q_t)} \\ &= \phi^{iQ}\alpha^Q + \phi^{yQ} + \frac{\text{cov}((1 + \alpha^Q\gamma)z_t + \varepsilon_t^y + \phi^{iQ}\nu_t^i, Q_t)}{\text{var}(Q_t)} \\ &= \phi^{iQ}\alpha^Q + \phi^{yQ} \end{aligned}$$

where the final equality follows under assumptions 1, 2 and the assumption that z_t and Q_t are orthogonal. The coefficients β^Q and α_Q are therefore consistently estimated by running the regressions (4) and (2) respectively. This implies that as long as we have a consistent estimate of ϕ_Q, we can get a consistent estimate of ϕ^{yQ} from the relationship

$$p\text{lim } \widehat{\phi}^{yQ} = \widehat{\beta}^Q - \widehat{\alpha}^Q \widehat{\phi}^{iQ} \tag{5}$$

We cannot obtain ϕ^{yQ} by simply estimating equation (1) on a sample of non-QE dates, since the omitted variable z_t induces an endogeneity bias; in fact, it is easy to show that given the above relationships, the estimated coefficient on a sample of dates where $Q_t = 0$ satisfies

$$p\text{lim } \widehat{\phi}^{iQ} = \frac{\text{cov}(\Delta y_t, \Delta i_t^{(2)})}{\text{var}(i_t^{(2)})} = \phi^{iQ} + \frac{\gamma\sigma_z^2}{\sigma_{\nu^i}^2 + \gamma^2\sigma_z^2}$$

As Rigobon and Sack (2004) note, if we had a set of dates on which $\sigma_z << \sigma_{\nu^i}$, then the inconsistency in the above equation would vanish. A broad literature on event studies in economics notes that a convenient sample satisfying this requirement is the predetermined set of dates on which the Federal Reserve releases statements. The schedule for announcements is usually released several months in advance of actual announcements, and a disproportionate volume of economically relevant news released on these dates is related to the conduct of monetary policy. Thus, running the regression

$$\Delta y_\tau = \phi^{iQ} \Delta i_\tau^{(2)} + z_\tau + \varepsilon_\tau^y \tag{6}$$

where τ indexes the set of monetary policy release dates during a period where $Q_t = 0$ should give a consistent estimate of ϕ^{iQ}.

Assumption 3. *The parameter ϕ^{iQ} is stable across QE and Non-QE regimes.*

This means that the response of the conditional mean of any outcome considered to the size of a policy shock is a constant whether we are in a QE regime or a Non-QE regime. This is motivated by the idea that the direct effect of a 25 bps cut on a given outcome should not depend on *how* the central bank brought this about. The information content in the fact that the change in $i_t^{(2)}$ *was caused by QE in particular* is a part of the "pure-QE" effect I seek to estimate.

$\widehat{\phi}^{yQ}$ is nonlinear in 3 random variables. I construct confidence intervals under the assumption that the estimators $\hat{\alpha}^Q, \hat{\beta}^Q$ and $\hat{\phi}^{iQ}$ are orthogonal to each other[15]. Under this assumption, a first-order approximation to the variance of ϕ in the neighbourhood of its mean is given by

$$\text{var}(\widehat{\phi}^{yQ}) \simeq \sum_{x_i = \hat{\alpha}^Q, \hat{\beta}^Q, \hat{\phi}^{iQ}} \frac{\partial(\widehat{\phi}^{yQ})}{\partial x_i} \text{var}(x_i)$$

5 The Data

5.1 Choosing Dates in the Different Samples

Table 1 summarises the QE dates I choose in running my event study regressions to identify α and β. I follow Gilchrist and Zakrajšek (2013) in defining QE-announcement dates and classifying these into groups to allow for heterogeneous responses to each set of announcements. Broadly, QE-I was mainly targeted at purchases of agency MBS and other agency liabilities, whereas from QE-II onwards the main thrust of purchases shifted towards long term treasurys. Unlike Gilchrist and Zakrajšek (2013), I consider the dates September 21, 2011 and June 20, 2012 to reflect the maturity extension programme, and also consider the dates September 13, 2012 and December 12, 2012 as the event "QE-III", following Gilchrist et al. (2015). Following Krishnamurthy and Vissing-Jorgensen (2011), I do not include the announcement made on 3 November 2010 in my QE-II variable, since inference using this date is complicated by the fact that it was on a date around which other important macroeconomic news was made available.

5.2 The Policy Shock

My measure of the policy shock is the one-day change in the 2-year constant-maturity yield released by the Fed in its H.15 release. The H.15 smoothed yield curve is constructed using data on the most recently issued bonds at each maturity. Note that this measure of the policy shock also captures the effects of forward guidance (Gertler and Karadi, 2015), which operates at horizons of around 24 months. My results only change slightly when I use the active treasury yield curve estimated by Bloomberg daily. However, they do differ from the estimates relying on the off-the-run yield curves measured by Gürkaynak et al. (2007).

5.3 Inflation

Following much of the literature, I use one day changes in inflation compensation, given by the difference between the yields on the smoothed zero-coupon yield curve in Gürkaynak et al. (2007) and the smoothed zero-coupon TIPS yield curve in Gürkaynak et al. (2010). We know that

$$y_t(n) - y_t^r(n) = -\frac{1}{n}\log \mathbb{E}^Q\Bigg(\exp\bigg(-\int_0^n \pi_{t+s}ds\bigg)\Bigg)$$

where $\mathbb{E}^Q(\cdot)$ represents expectations taken under the risk-neutral measure. Inflation compensation is the (risk-adjusted) average level of inflation that is expected to prevail over the entire horizon under consideration. I also use a measure of inflation compensation derived from instantaneous forward yield curves, which gives us the instantaneous inflation rate that is likely to prevail n periods from now; this measure satisfies

$$f_t(n,0) - f_t^r(n,0) = -\frac{1}{n}\log \mathbb{E}^Q\Bigg(\exp\big(-\pi_{t+n}\big)\Bigg)$$

If agents are risk averse, the estimated inflation compensation will differ from actual expected inflation computed using a physical probability measure due to the existence of an inflation risk premium. Given that QE can potentially affect both inflation at various horizons and rotate the risk-neutral measure[16], it is unclear which channel ought to dominate *a priori.*

5.4 Corporate Bonds

I collect data on the Moody's Corporate Bond indices for AAA and BAA-rated bonds from the St. Louis Federal Reserve's FRED database, and compute the spreads on this index over the 10-year yield in the Fed's H.15. Given the lower liquidity of corporate bonds, I construct series of 2 day changes $\Delta y_t = y_{t+1} - y_{t-1}$, following Krishnamurthy and Vissing-Jorgensen (2011). I also measure effects on rates on non-financial commercial paper (NFCP), another major channel for external financing used by firms. The NFCP market froze in the aftermath of the crisis in Money Market Mutual Funds (MMMFs) in 2008, and was restored to normalcy only once the Fed began the AMLF[17] program, allowing MMMFs to obtain loans from the Fed against illiquid (but high-grade) Asset-backed commercial paper. The pure-QE effects on the commercial paper market borrowing rates are thus a good measure of whether QE successfully affected markets through liquidity infusion. To check for effects on perceived risk, I calculate effects on the TED Spread[18], a measure of counterparty risk in overnight money markets which is closely related to the excess risk premium on corporate bonds.

6 Results

6.1 The Response of On-The-Run Yields to QE Events

I run regression (2) on daily data from 2008 to 2013[19]. My estimates are tabulated in table 2. In line with most estimates relying on daily data, I estimate that QE-I announcements lowered the two-year constant maturity yield by around 11 percentage points on average, whereas the effect of QE-II was significantly smaller. My estimates differ slightly from those of Gilchrist and Zakrajšek (2013) because I use constant-maturity on-the-run securities, while they use Gürkaynak et al. (2007)'s smoothed yield curve for off-the-run securities. Following much of the literature, I use the smoothed on-the-run yield, since this better reflects the risk-free rate of return in the economy[20]. Off-the-run securities are noticeably less liquid than the on-the run treasury, and hence trade at a discount.

6.2 Inflation

Table 3 describes the response of inflation compensation at various maturities to QE events. Inflation compensation responds weakly to announcements in the QE-I regime, but responds strongly to QE-II, rising on average by 5 percentage points. Since QE-II marked a shift in stance towards purchases of longer maturity treasurys, it is unsurprising that the effects were larger for the longer maturities.

The maturity extension program and QE-III barely affected expected inflation. This is in line with the findings of Reis (2016a) - once the market for reserves was saturated, further movements in the yield curve did not affect inflation expectations. Table 4 shows that even in normal times, inflation compensation is only weakly responsive to shocks to the 2-year nominal interest rate. While it is possible that the effects of interest rate changes affect inflation only at lower frequencies, this result could also be due to the low power of the estimator, given the small time series we have and the extra noise introduced by the use of daily data.

Table 5 shows the QE-only effect, alongside the total QE effect for comparison. Most of the estimated effects for QE-I, while apparently large, are not statistically significant. I estimate that QE-2 raised inflation compensation inferred from instant forward yields by 5 percentage points at a 5 year horizon, and nearly all of this change can be explained by the pure-QE effect. The effect was smaller for the 10-year horizon (around 3 percentage points), but still significant.

In conclusion, QE-II had a substantial pure-QE effect on inflation compensation, but not the other rounds; in particular, the maturity extension program barely affected inflation. This is consistent with later rounds of QE having been expected by markets and also with the later rounds of asset purchases not having any effect on the interest rate[21].

6.3 Corporate Borrowing Costs

Table 6 suggests that most measures of borrowing costs responded strongly to QE-I announcements, with the yield on 90-day commmercial paper falling by almost 9 percentage points on average. This is possibly because QE as announced was sufficiently complementary to other initiatives to support the commercial paper market, including the AMLF. The pure-QE effect of QE-I on corporate bond yields was weaker - although I estimate large reductions in the yields on these days, the volatility in 2-day changes in corporate borrowing costs is too large to obtain significance.

QE-II led to large and statistically significant declines in the yields on corporate bonds, by around 9 percentage points for both AAA and BBB rated bonds. However, I estimate that both the AAA and BAA spreads both rose around 6 percentage points on QE-I dates and 5 percentage points on QE-II dates. This is in line with the results of Krishnamurthy and Vissing-Jorgensen (2011) who show that corporate bond yields fell by less than the yields on treasurys, and matches almost exactly the results of Swanson (2017), who identifies a similar "pure-QE" effect of around 5 percentage points using a very different methodology. However, Table 7 shows that on average, spreads on corporate bonds *fall* in response to a monetary policy shock, and corporate bond yields actually rise. Table 8 shows that around 90% of the rise in the spread due to QE-II is driven by the pure QE effect. Gilchrist and Zakrajšek (2013) show, using a different methodology, that the effect of the interest rate change on corporate credit risk on QE dates was statistically insignificant.

The pure QE-induced fall in the yields on corporate bonds accompanied by a rise in their spread over treasurys is thus puzzling. My results show that the majority of the increase in the spread cannot be explained by the change in interest rates. This is consistent with the existence of portfolio balance effects might have reduced the yields on the assets purchased (long term treasurys) by more than the yields on other assets which were close substitutes (corporate bonds), since the reduction in the latter were only through an indirect portfolio rebalancing effect. One possible explanation for this is that the pure-QE effect on term premia may be heterogeneous: term premia on purchased assets may have fallen by more than term premia for assets which were not purchased (Gagnon et al., 2011; D'Amico et al., 2012)[22].

The pure QE effect is also strong for 60 day and 90 day commercial paper rates, which *rose* by around 3 and 5 percentage points respectively due to QE-II. The evidence here is hard to interpret, since QE-II seems to have been associated with an *increase* in borrowing costs in commercial paper markets but a *decrease* in borrowing costs in corporate bonds. It is possible that the announcement of purchases of MBS, which are more similar to corporate bonds, had a larger local supply effect on corporate bonds than on commercial paper markets[23]. The insignificant response of the TED spread in response to QE announcements suggests that there was no significant immediate improvement in liquidity or in counterparty risk around the QE dates. This does not in itself imply that QE had no effect on liquidity or on risk. For example, QE may have raised stock prices significantly, reducing the reliance of corporations on the commercial paper and bond markets (Note that I do not test for effects on the cost of equity financing). Also, the liquidity effects of QE may have only appeared once purchases actually began.

Both the Maturity Extension Programme and QE-III led to statistically significant *reductions* in the BAA Spread, and over 80% of this effect was through the pure QE effect. These declines are consistent with a decline in the aggregate risk and also in corporate credit risk, since the

BAA spread falls by much more than the AAA Spread, especially in QE-III.

7 Conclusion and Future Research

My results suggest that over half of the total effect of QE on inflation and corporate borrowing costs came about through channels other than the direct effect of a lower interest rate. The effects for inflation are small and in general statistically insignificant. The effects on corporate borrowing costs are more significant: It appears that while the pure-QE effects of QE-I and QE-II reduced corporate bond yields, they also widened bond spreads. However, QE-II raised corporate bond yields and narrowed the spreads. The narrowing of the BAA Spread relative to the AAA Spread indicates that QE-III reduced credit risk significantly; no such effect was present in QE-I and QE-II.

The key question for future research is to ask what explains the pure QE Effect for corporate bonds. The fact that effects on inflation compensation are small while those on bonds are larger may imply that the effect of QE is through the effect of improved liquidity on term premia and through localised purchases, and that the signaling channel is weak. A change in expectations of the future would affect both yields and inflation compensation; a channel working through improved liquidity in asset markets and portfolio balance effects would affect bonds more than inflation compensation. Identifying a pure-QE effect on expectations is tricky. Reis (2016a) uses options data to construct the risk-neutral distribution of inflation at various horizons in the future, and calculates expected values of this distribution. A similar empirical strategy for S&P 500 options, for instance, could reveal whether QE shifted expected future profitability at various horizons, from which we can infer whether QE boosted optimism or pessimism. The second channel could be investigated by studying the buying behaviour of agents in the corporate bond market, exploiting variation in the quantity of reserves received from MBS Sales[24], and testing whether post QE, corporate bond issues by less creditworthy firms were well-received relative to the period before QE.

I now discuss some important caveats of my methodology. First, the assumption that $\sigma_z << \sigma_{\nu^i}$ for the sample of Non-QE dates is impossible to test empirically, and easy to challenge, particularly in daily data. Recent papers using high-frequency identification argue that one-day changes in the on-the-run treasury are likely to include substantial background noise, rendering estimation using one-day changes less powerful and possibly inconsistent[25]. A necessary robustness check for my results would involve replicating them using intraday data[26]. Intraday data would also allow for identification using heteroskedasticity as in Rigobon and Sack (2004)[27].

Second, I estimate my standard errors under the assumption that the three coefficient estimators are orthogonal. In general, the sign of the covariance of the estimators depends on the sign of the covariance between their policy shocks, which we do not directly observe. A consistent approach to calculating standard errors could have been to construct Bootstrap confidence intervals, which was beyond the scope of this essay.

Third, the validity of assumption 3 can be questioned. While it is noncontroversial that the response of an outcome to an interest rate change should be stable, a nonlinearity in this response renders extrapolating ϕ^{iQ} invalid. While OLS will remain the best linear predictor of the conditional expectation of the response of the outcome, this result in general will only hold asymptotically - my sample size is 84 events[28].

Fourth, associating the change in outcome variables on the day of a QE announcement need not fully reflect the effects of QE on markets once the asset purchases actually begin, a constraint that applies to all research conducted via event studies. Research by Hancock and Passmore (2014) suggests that the effects on the real costs of household borrowing, such as mortgage rates, took up to a week after the announcement to actually decline. They show that the key mechanism for this decline was a portfolio rebalancing effect, allowing firms which sold MBS to the Fed to search for other assets to satisfy their appetite for risk and therefore freeing up credit markets. Swanson (2017) argues that the effect of the QE component of an FOMC announcement were more persistent than the effects of the forward guidance component. It is reasonable to expect that QE led to improved liquidity only slowly, implying that the decline in agency costs that would have reduced yields only occurred slowly. This may be behind the weak estimated response to QE-III I estimate, since QE-III was conducted in a more phased out and open-ended manner with purchases of only $40 billion a month, as compared to the QE-II commitment to purchase $600 billion in treasury securities within two quarters.

Notes

[1] "... The principal goals of our recent security purchases are to lower the cost and improve the availability of credit for households and businesses. ..."(Bernanke, 2009b). Bernanke (2009a) referred to the programme as a form of "credit" easing, to be distinguished from "quantitative" easing.

[2]Bernanke (2010) pointed out that while financial markets had stabilised, the effects on the real economy persisted in the form of excessive unemployment.

[3]In this model, QE constitutes a purchase of risky long-term debt from the holders of public debt, paying for this with an equivalent volume of risk-free reserves. This can be thought of as a redistribution from households to banks since only banks are allowed to hold reserves.

[4]A similar point was discussed by Tobin (1963).

[5]Microfoundations for such a demand for money can be motivated, for example, by "shopping time" models (Saving, 1971), cash-in-advance constraints (Lucas and Stokey, 1987) or search models (Lagos and Wright, 2005).

[6]In other words, as long as a central bank's balance sheet possesses implicit fiscal backing, a purchase of assets from private agents financed by an issue of reserves does not change the outstanding amount of risk in the economy(Woodford, 2012). Equivalently, as Hamilton and Wu (2012) note, a change in the time path of government debt must be offset by a change in taxes that leaves state-contingent consumption unaffected, in line with the results of Barro (1974).

[7]An example of this is the "signaling" channel in Clouse et al. (2003) and Krishnamurthy and Vissing-Jorgensen (2011), where the central bank can augment the credibility of forward guidance by purchasing longer dated assets, due to the large losses it would undertake on its balance sheet if it were to raise short term rates before the average maturity of their long term debt was up.

[8]Note that this is just the inverse of the price level.

[9]It can be shown that given an economy characterised by a Taylor Rule of the form $i_t = \bar{\pi} + \hat{r}_t + \chi(\pi_t - \bar{\pi})$ and a Fisher equation of the form $i_t = r_t + \mathbb{E}_t(\pi_{t+1})$, inflation is pinned down by arbitrage in financial markets as being equal to $\pi_t = \bar{\pi} + \mathbb{E}_t\big(\sum_{s=0}^{\infty} \chi^{-(s+1)}[r_{t+s} - \hat{r}_{t+s}]\big)$. A permanent rise in i is interpreted by markets as an increase in $\bar{\pi}$, which raises current inflation via the Fisher relation, whereas a short-term increase in i is interpreted as an increase in $\hat{r}$, reducing inflation.

[10]First, QE could prevent deflationary outcomes during financial crises when the value of liquidity rises. Second, in the presence of financial frictions, QE could change the effective cost of capital in different sectors of the economy through targeted purchases of certain assets. Third, in the case of fiscal crises, as mentioned above, QE reduces the riskiness of private portfolios by replacing sovereign risk-bearing government bonds by nominally default-free reserves. Fourth, by altering the maturity structure of debt, QE affects the amount of surprise inflation that occurs in a fiscal crisis.

[11]That is, whether the information content of QE is "Odyssean", or "Delphic".

[12]They construct the Bond-level premium by comparing the price of an existing bond with the price of a hypothetical risk-free bond which exactly matches the payment pattern of the existing bond, and then average over all firms in their sample.

[13]The boost to liquidity offered by QE might reduce the importance of frictions in corporate bond markets related to information asymmetries by raising the net worth of firms in the market. This channel is described as the "financial accelerator" in the literature on the "credit channel" for conventional monetary policy (Bernanke and Gertler, 1995).

[14]I derive this inconsistency more formally in the Appendix in Section 8.

[15]The covariance between the estimators depends on the covariance of the error terms of their respective

regressions. Since $\hat{\phi}^{iQ}$ is estimated on a different sample than $\hat{\beta}^{Q}$ and $\hat{\alpha}^{Q}$, it is probably uncorrelated with either one. The covariance between $\hat{\beta}^{Q}$ and $\hat{\alpha}^{Q}$ can be shown to depend on the covariance between ν_t^y and ν_t^i on dates where $Q_t = 1$; thus we require the idiosyncratic shocks to the outcome and the policy indicator on QE dates to be approximately uncorrelated.

[16]In a model with a consumption-based stochastic discount factor, the effect of QE on future output will affect the expected MRS between current and future consumption, and hence affect the constructed risk neutral measure.

[17]Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility

[18]The Spread between the 3-month LIBOR and the 3-month T-Bill rate.

[19]Running this regression on data from 1995 to 2017 does not change these results significantly

[20]This has implications: for instance, the Maturity Extension Program lowers the off-the-run smoothed 2-year yield by around 6.5 percentage points, but it reduces the on-the run yield estimated by the treasury by only around 3 percentage points.

[21]It is possible that my results are an artifact of using a measure of inflation derived from the difference in nominal and smoothed TIPS yields, and hence reflects changes in the illiquidity premium that TIPS yields maintain over ordinary bonds which may be attenuating measured changes in inflation compensation.

[22]Another possibility is that QE-II may have revealed details regarding the Fed's pessimism regarding future economic developments. The Fed's statement on August 10, 2010 includes the text "... the Committee anticipates a gradual return to higher levels of resource utilization in a context of price stability, although the pace of economic recovery is likely to be more modest in the near term than had been anticipated." To the extent that the Fed coordinated everyone's information on the sub-par state of the recovery, it may have generated greater pessimism in the economy than was warranted given every market participant's private information. However, this is inconsistent with QE-II *raising* risk-adjusted inflation expectations

[23]That is, purchases of Agency MBS may have driven sellers of these Agencies into other high yield markets, including that for corporate bonds.

[24]Similar research using bank-level microdata shows that QE in the UK did not lead to a large increase in lending (where effects are statistically significant, they are still small) (Butt et al., 2015)

[25] High-frequency approaches including Nakamura and Steinsson (2016) and Swanson (2017) calculate a set of principal components underlying shocks to a set of variables from 10 minutes prior to 20 minutes after an event, and interpret these as corresponding to different "policy shocks" after a suitable rotation.Note that the estimators are inconsistent only if the background noise is caused by underlying factors that affect both the regressor and regressand of an equation like (6).

[26]The data providers I had access to, including Bloomberg and Thomson Reuters Eikon, only provide intraday data on most yields from 2011 onwards. Note that while the high-frequency identification approach solves the problem of correlated noise, it suffers at least two shortcomings. First, financial markets are likely to take longer than 20 minutes to digest the effect of an intervention that is as unprecedented and unexpected as an LSAP announcement. Second, these approaches suffer from a problem of low power due to small variation in their policy indicators.

[27]The Rigobon and Sack estimator derives ϕ from the difference in the variance-covariance matrix of the regressors on Policy and Non-Policy dates. The estimator is highly sensitive to the linear functional form

assumption, the choice of "policy" and "non-policy" sample dates, and often produces unreliable results due to a weak instrument problem, especially when the effect of QE is small relative to normal variation in the regressand. I estimate the Rigobon-and-Sack estimator of ϕ for all variables here and obtain unreasonably large estimate values, with massive standard errors, which are clearly inappropriate for the exercise I consider here.

[28]I run all of my regressions to obtain $\widehat{\phi}^{iQ}$ on a sample of FOMC announcement dates including both the pre-2008 and post-2008 data. I reject the null hypothesis of equality of coefficients for all variables except the non-financial commercial paper rates. Note that this is a crude approach, since in the post-2008 period, the identifying assumption $\sigma_z << \sigma_{\nu^i}$ is even less likely to be valid, given the global economic turmoil. However, it does suggest the need for better identifying assumptions.

References

Ang, Alfredo H-S. and Wilson H. Tang, *Probability Concepts in Engineering: Emphasis on Applications to Civil and Environmental Engineering*, Vol. 1, Wiley and Sons, 2007.

Angrist, Joshua D. and Jörn-Steffen Pischke, *Mostly Harmless Econometrics*, Princeton University Press, 2009.

Auerbach, Alan J. and Maurice Obstfeld, "The Case for Open-Market Purchases in a Liquidity Trap," *The American Economic Review*, 2005, *95* (1), 110–137.

Barro, Robert, "Are Government Bonds Net Wealth?," *Journal of Political Economy*, 1974, *82* (6), 1095–1117.

Bauer, Michael D. and Glenn D. Rudebusch, "The Signaling Channel for Federal Reserve Bond Purchases," *International Journal of Central Banking*, September 2014, *10* (3), 233–289.

Bernanke, Ben S., "The Crisis and the Policy Response," Speech Delivered at the Stamp Lecture, LSE January 2009.

_ , "The Federal Reserve's Balance Sheet: An Update," Speech Delivered at the Federal Reserve Board Conference on Key Developments in Monetary Policy, Washington, D.C. January 2009.

_ , "Implications of the Financial Crisis for Economics," Speech Delivered at the Conference Co-sponsored by the Center for Economic Policy Studies and the Bendheim Center for Finance, Princeton University, Princeton, New Jersey September 2010.

_ **and Mark Gertler**, "Inside the Black Box: The Credit Channel of Monetary Policy Transmission," *The Journal of Economic Perspectives*, 1995, *9* (4), 27–48.

– , **Vincent R. Reinhart, and Brian P. Sack**, "Monetary Policy Alternatives at the Zero Bound: An Empirical Assessment," *Brookings Papers on Economic Activity*, 2004, *35* (2), 1–100.

Breedon, Francis and Phillip Turner, "On the Transactions Costs of Quantitative Easing," BIS Working Paper 571, Bank for International Settlements Monetary and Economic Department July 2016.

Butt, Nick, Rohan Churm, Michael McMahon, Arpad Morotz, and Jochen Schanz, "QE and the Bank Lending Channel in the United Kingdom," Discussion Papers 1523, Centre for Macroeconomics (CFM) October 2015.

Chen, Han, Vasco Cúrdia, and Andrea Ferrero, "The Macroeconomic Effects of Large-scale Asset Purchase Programmes," *The Economic Journal*, 2012, *122* (564), F289–F315.

Clouse, James, Dale Henderson, Athanasios Orphanides, David H. Small, and P.A. Tinsley, "Monetary Policy When the Nominal Short-Term Interest Rate is Zero," *The B.E. Journal of Macroeconomics*, September 2003, *3* (1), 1–65.

Cúrdia, Vasco and Michael Woodford, "The Central-bank Balance Sheet as an Instrument of Monetary Policy," *Journal of Monetary Economics*, 2011, *58* (1), 54 – 79. Carnegie-Rochester Conference Series on Public Policy: The Future of Central Banking April 16-17, 2010.

D'Amico, Stefania and Thomas B. King, "Flow and stock effects of large-scale treasury purchases: Evidence on the importance of local supply," *Journal of Financial Economics*, 2013, *108* (2), 425–448.

– , **William English, David López-Salido, and Edward Nelson**, "The Federal Reserve's Large-scale Asset Purchase Programmes: Rationale and Effects," *Economic Journal*, November 2012, *122* (564), 415–446.

Eggertsson, Gauti B. and Michael Woodford, "The Zero Bound on Interest Rates and Optimal Monetary Policy," *Brookings Papers on Economic Activity*, 2003, *34* (1), 139–235.

Elton, Edwin J., Martin J. Gruber, Deepak Agrawal, and Christopher Mann, "Explaining the Rate Spread on Corporate Bonds," *The Journal of Finance*, February 2001, *LVI* (1).

Fawley, Brett W. and Christopher Neely, "Four stories of quantitative easing," *Review*, 2013, (Jan), 51–88.

Federal Reserve Board, "Monetary Policy Press Release, November 25, 2008," Technical Report, Federal Reserve November 2008.

Gagnon, Joseph, Matthew Raskin, Julie Remache, and Brian Sack, "The Financial Market Effects of the Federal Reserve's Large-Scale Asset Purchases," *International Journal of Central Banking*, March 2011, *7* (1), 3–43.

Gertler, Mark and Peter Karadi, "Monetary Policy Surprises, Credit Costs, and Economic Activity," *American Economic Journal: Macroeconomics*, January 2015, *7* (1), 44–76.

Gilchrist, Simon and Egon Zakrajšek, "Credit Spreads and Business Cycle Fluctuations," *American Economic Review*, June 2012, *102* (4), 1692–1720.

_ and _ , "The Impact of the Federal Reserve's Large-Scale Asset Purchase Programs on Corporate Credit Risk," *Journal of Money, Credit and Banking*, December 2013, *45* (s2), 29–57.

_ , David López-Salido, and Egon Zakrajšek, "Monetary Policy and Real Borrowing Costs at the Zero Lower Bound," *American Economic Journal: Macroeconomics*, January 2015, *7* (1), 77–109.

Gürkaynak, Refet S, Brian Sack, and Eric Swanson, "Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements," *International Journal of Central Banking*, May 2005, *1* (1).

Gürkaynak, Refet S., Brian Sack, and Jonathan H. Wright, "The U.S. Treasury yield curve: 1961 to the present," *Journal of Monetary Economics*, 2007, *54* (8), 2291 – 2304.

_ , _ , and _ , "The TIPS Yield Curve and Inflation Compensation," *American Economic Journal: Macroeconomics*, January 2010, *2* (1), 70–92.

Hamilton, James D. and Jing Cynthia Wu, "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment," *Journal of Money, Credit and Banking*, 02 2012, *44*, 3–46.

Hancock, Diana and Wayne Passmore, "Did the Federal Reserve's MBS purchase program lower mortgage rates?," *Journal of Monetary Economics*, 2011, *58* (5), 498 – 514. Carnegie-Rochester Conference on public policy: Normalizing Central Bank Practice in Light of the credit Turmoi, 1213 November 2010.

_ **and** _ , "How the Federal Reserves Large-Scale Asset Purchases (LSAPs) Influence Mortgage-Backed Securities (MBS) Yields and U.S. Mortgage Rates," Finance and Economics Discussion Series 2014-12, Federal Reserve Board 2014.

Krishnamurthy, Arvind and Annette Vissing-Jorgensen, "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy," *Brookings Papers on Economic Activity*, Fall 2011, pp. 215–265.

Lagos, Ricardo and Randall Wright, "A Unified Framework for Monetary Theory and Policy Analysis," *Journal of Political Economy*, 2005, *113* (3), 463–484.

Lucas, Robert E. and Nancy L. Stokey, "Money and Interest in a Cash-in-Advance Economy," *Econometrica*, 1987, *55* (3), 491–513.

Nakamura, Emi and Jón Steinsson, "High Frequency Identification of Monetary Non-Neutrality: The Information Effect," Working Paper, Columbia University October 2016.

Reis, Ricardo, "Funding Quantitative Easing to Target Inflation," CEPR Discussion Papers 11505, C.E.P.R. Discussion Papers September 2016.

_ , "QE in the Future: the Central Bank's Balance Sheet in a Fiscal Crisis," Working Paper 22415, National Bureau of Economic Research July 2016.

Rigobon, Roberto and Brian Sack, "The impact of monetary policy on asset prices," *Journal of Monetary Economics*, 2004, *51* (8), 1553 – 1575.

Saving, Thomas R, "Transactions Costs and the Demand for Money," *American Economic Review*, June 1971, *61* (3), 407–420.

Swanson, Eric T., "Let's Twist Again: A High-Frequency Event-study Analysis of Operation Twist and Its Implications for QE2," *Brookings Papers on Economic Activity*, 2011, *42* (1 (Spring), 151–207.

— , "Measuring the Effects of Federal Reserve Forward Guidance and Asset Purchases on Financial Markets," Working Paper 23311, National Bureau of Economic Research April 2017.

Tobin, J., *An Essay on the Principles of Debt Management* Cowles Foundation paper, Cowles Foundation for Research in Economics at Yale University, 1963.

Vayanos, Dimitri and Jean-Luc Vila, "A Preferred-Habitat Model of the Term Structure of Interest Rates," Working Paper 15487, National Bureau of Economic Research November 2009.

Wallace, Neil, "A Modigliani-Miller Theorem for Open-Market Operations," *The American Economic Review*, June 1981, *71* (3), 267–274.

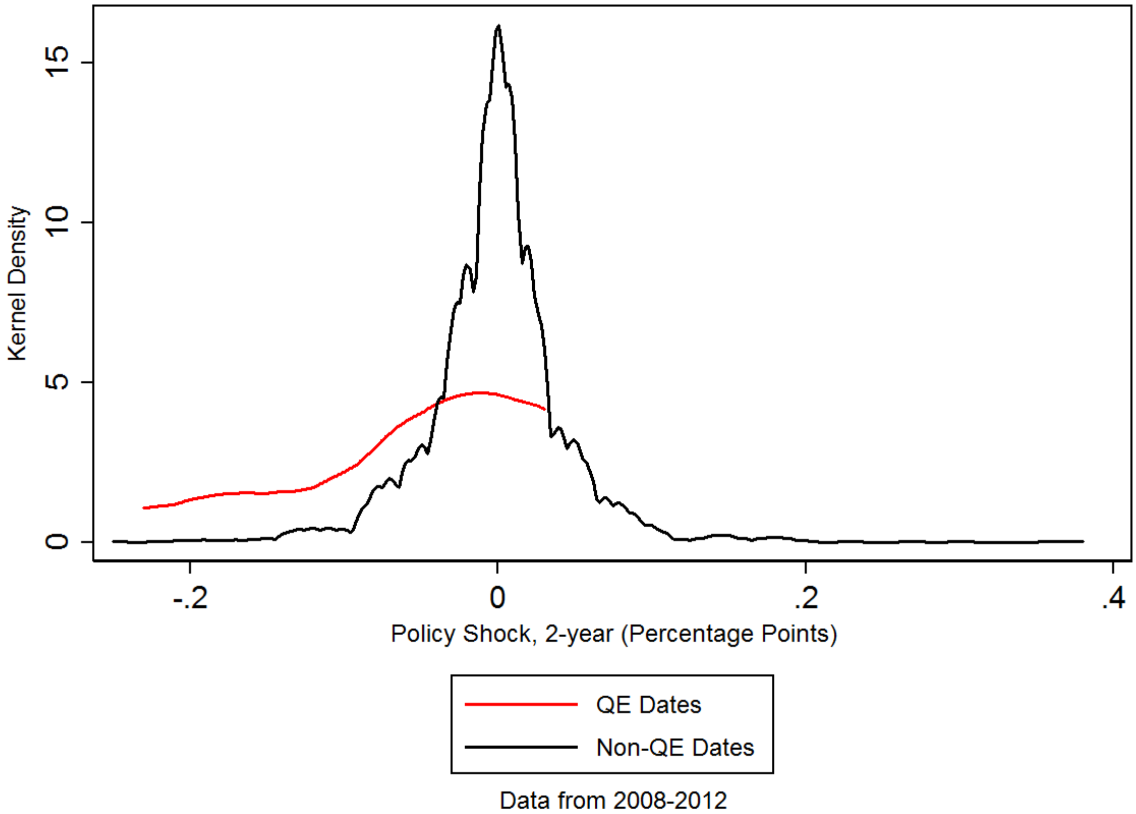
Woodford, Michael, "Methods of policy accommodation at the interest-rate lower bound," *Proceedings - Economic Policy Symposium - Jackson Hole*, 2012, pp. 185–288.

Wu, Jing Cynthia and Fan Dora Xia, "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound," *Journal of Money, Credit and Banking*, 2016, *48* (2-3), 253–291.

8 Appendix

8.1 Inconsistency of OLS under Bad Control

Figure 1: Kernel Densities of the Policy Shock on QE and Non-QE Dates



The following relies heavily on Angrist and Pischke (2009). To illustrate the inconsistency generated by bad control, first assume that z_t is constant. Let $F(\Delta i|Q)$ denote the Probability Function of the policy shock conditional on the realisation of the dummy variable Q. Denote variables valued on dates when $Q = 1$ with a subscript 1, and variables valued on dates when $Q = 0$ with a subscript 0. Note that at most one of Δy_{0t} and Δy_{t1} will be observed, and the other is a counterfactual outcome. The OLS estimator of ϕ^{yQ} in regression (1) can be written as

$$
\begin{aligned}
\widehat{\phi}^{yQ} &= \mathbb{E}(\Delta y_t|\Delta i, Q=1) - \mathbb{E}(\Delta y_t|\Delta i, Q=0) \\
&= \int \Delta y_{t1} dF(\Delta i|Q=1) - \int \Delta y_{t0} dF(\Delta i|Q=0) \\
&= \int \big(\Delta y_{t1} - \Delta y_{t0}\big) dF(\Delta i|Q=1) + \int \Delta y_{t0} dF(\Delta i|Q=1) - \int \Delta y_{t0} dF(i|Q=0) \\
&= \underbrace{\mathbb{E}(y_{t1} - y_{t0}|\Delta i, Q=1)}_{\substack{\text{Effect of QE on Dates} \\ \text{when QE occurred}}} + \underbrace{\mathbb{E}(y_{t0}|\Delta i, Q=1) - \mathbb{E}(y_{t0}|\Delta i, Q=0)}_{\substack{\text{A Selection Effect:} \\ \text{The conditional density of } i \\ \text{may differ between QE and Non-QE dates.}}}
\end{aligned}
$$

Thus, as long as the conditional densities of the size of the policy shock *in the counterfactual absence of QE* differ on QE and non-QE dates, the above estimator contains a selection bias. However, we know that given equation (2) holds, the conditional expectations of $\Delta i_t^{(2)}$ on QE and Non-QE dates differ by α^Q. Illustrating this visually, Figure 1 plots the kernel density estimates of the probability mass functions $f(\cdot)$ of the policy shock on QE and non-QE dates. As is clear, the kernel density for QE dates has significantly more mass on negative values than the distribution on Non-QE dates. This result holds even if we restrict attention to a sample of dates just prior to QE announcements.

8.2 The Variance of ϕ

The following proof follows the notation of Ang and Tang (2007). Let $Y = g(\mathbf{X})$ be a continuous and differentiable function of some random variables $\mathbf{X} = X_1, X_2, \ldots, X_n$, and let $f_i(x) : \text{supp}(X_i) \to \mathbb{R}$ be the Probability density function for each x. Assume that all the distributions f_i have finite first and second moments, with expectation μ_i and variance σ_i^2. A first-order Taylor approximation to g around the point $\mathbf{X} = (\mu_1, \mu_2, \ldots, \mu_n) = \mu$ is

$$
y \approx g(\mu) + \sum_{i=1}^{n} (X_i - \mu) \frac{\partial g(\mathbf{X})}{\partial X_i}\bigg|_{\mathbf{X}=\mu}
$$

Taking expectations and noting the linearity of the expectations operator,

$$
\begin{aligned}
\mathbb{E}(y) &\approx g(\mu) \\
\text{var}(y) &\approx \sum_{i=1}^{n} \sigma_i^2 \left(\frac{\partial g(\mathbf{X})}{\partial X_i}\right)^2 \bigg|_{\mathbf{X}=\mu} + \sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} 2\text{cov}(X_i, X_j) \frac{\partial g(\mathbf{X})}{\partial X_i} \frac{\partial g(\mathbf{X})}{\partial X_j}\bigg|_{\mathbf{X}=\mu}
\end{aligned}
$$

If we assume all the variables to be uncorrelated, then the second term above drops out.

8.3 Choosing Dates

Table 1 below shows the dates I choose for running my regression. These are based on the dates in Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), Gilchrist et al. (2015) and Reis (2016a).

For running the regressions on the Policy Sample mentioned in the text, I choose the set of all FOMC announcements between 1995 and 2004, a period during which monetary policy was largely conducted through conventional channels. I add to this data using announcements and important speeches delivered by Federal Reserve Officials and the dates of the Fed's semiannual testimony before Congress. A key benefit of this sample is that the dates for these events are predetermined, with the Fed's calendar typically being released up to 6 months in advance, which raises confidence that the choice of dates does not introduce endogeneity.

Table 1: QE Dates Considered

QE-1	25 November, 2008	Announcement that starts LSAP-I: Fed announces purchase of direct obligations of agencies (up to 100 bn) and also MBS (up to 500 bn). TALF created.
	1 December, 2008	Chairman Bernanke's speech to Austin Chamber of Commerce, and an announcement indicating potential purchases of Treasuries.
	16 December, 2008	Target federal funds is lowered to its effective lower bound. Interest on Excess and Required Reserves is set at 0.25%. Statement indicates that the Fed is considering using its balance sheet to further stimulate the economy. First reference to forward guidance: "... economic conditions are likely to warrant exceptionally low levels of the federal funds rate for some time."
	28 January, 2008	"Disappointing" FOMC statement because of its lack of concrete language.
	18 March, 2009	Announcement to purchase Treasuries and increase the size of purchases of agency debt and agency MBS. First reference to extended period: " interest rates are likely to remain low for an extended period...".
QE-II	10 August, 2010	Announcement that starts LSAP-II
	21 September, 2010	Announcement reaffirming the existing reinvestment policy.
MEP	21 September, 2011	Announcement of the Maturity Extension Program (MEP). Expansion of QE to a further $400 billion of long term treasurys, by selling equivalent amounts of short term securities (less than or equal to 3yrs). Fed announces reinvestment of principal payments from holdings of agency debt and agency MBS and a rollover of maturing treasurys at auction. Explicit Forward Guidance: "...likely to warrant exceptionally low levels for the fed funds rate at least through mid 2013".
QE-III	20 June, 2012	Announcement that the MEP will continue through the end of 2012.
	13 September, 2012	Third "Calendar-based" forward guidance: "... likely maintain the federal funds rate near zero atleast through mid-2015." First forward guidance regarding the pace ofinterest rates after lift-off: " likely maintain low rates for a considerable time after the economic recovery strengthens," and announcement of LSAP-III(flow-based; Purchases of Agency MBS at 40bn a month, through reinvestment of principal repayments). $85 billion a month increase in long term bond holdings.
	12 December, 2012	Announcement of an increase in LSAP-III (from $40 billion to $85 billion per month); first "threshold-based" forward guidance.

Sources: Gilchrist and Zakrajšek (2013), Gilchrist et al. (2015), Nakamura and Steinsson (2016) and Reis (2016a)

8.4 Results

Table 2: Shocks to On-the-run Yields on QE Dates, 2008-2013

	1 Year	2 Year	5 Year	10 Year	20 Year	30 Year
QE-I Events	-0.0299	-0.1168*	-0.1736	-0.1989	-0.1191	-0.0890
	(0.020)	(0.046)	(0.101)	(0.113)	(0.090)	(0.082)
QE-II Events	-0.0024	-0.0293***	-0.0861***	-0.0914***	-0.0566**	-0.0465
	(0.004)	(0.007)	(0.004)	(0.014)	(0.018)	(0.025)
Maturity Extension Programme	0.0226***	0.0257***	0.0289***	-0.0314	-0.0616	-0.0915
	(0.001)	(0.004)	(0.002)	(0.028)	(0.050)	(0.057)
QE-III Events	-0.0124***	0.0007	-0.0161	0.0186	0.0384	0.0485***
	(0.004)	(0.007)	(0.025)	(0.028)	(0.021)	(0.014)

HAC Standard errors in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Coefficients from a Regression of daily changes in the Yield of the maturity given on a dummy for each QE-event, defined in Table 1.

Table 3: β for Inflation Compensation at Various Maturities

	QE-I	QE-II	MEP	QE-III
2-year Cumulative	0.0627	0.0429*	0.0086**	0.0803*
	(0.049)	(0.020)	(0.003)	(0.035)
5-year Cumulative	0.0299	0.0479**	-0.0004	0.0676*
	(0.025)	(0.017)	(0.002)	(0.030)
10-year Cumulative	0.0147	0.0380***	-0.0129	0.0353
	(0.014)	(0.007)	(0.010)	(0.023)
2-year Instantaneous	0.0094	0.0101	-0.0050	0.0890*
	(0.025)	(0.007)	(0.003)	(0.040)
5-year Instantaneous	-0.0028	0.0521***	-0.0101*	0.0227
	(0.019)	(0.010)	(0.005)	(0.015)
10-year Instantaneous	0.0055	0.0291***	-0.0422	0.0211
	(0.044)	(0.008)	(0.036)	(0.019)

HAC Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Each cell represents a coefficient on a certain maturity of inflation compensation in a regression of that cost on a constant and dummies for individual QE dates.

Table 4: $\hat{\phi}^{iQ}$: Response of Inflation Compensation at various maturities to the Policy Shock

	$\widehat{\phi}^{iQ}$
2-year Cumulative	-0.0021
	(0.140)
5-year Cumulative	0.1596
	(0.082)
10-year Cumulative	0.0711
	(0.057)
2-year Instantaneous	0.2048*
	(0.101)
5-year Instantaneous	0.0242
	(0.065)
10-year Instantaneous	-0.0152
	(0.045)

HAC Standard errors in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Each cell represents a coefficient from a regression of daily changes in inflation compensation at a certain maturity on shocks to the policy indicator, on dates corresponding to FOMC announcements from 1995 to 2007.

Table 5: The Pure QE Effect on Inflation Compensation, Absolute Magnitudes and Fractions of Total Effects

	QE-I: $\widehat{\phi}^{yQ}$	QE-I: β	Fraction	QE-II: $\widehat{\phi}^{yQ}$	QE-II: β	Fraction
2-year Cumulative	0.0625	0.0627	0.9961	0.0429*	0.0429	0.9986
	(0.051)			(0.020)		
5-year Cumulative	0.0486	0.0299	1.6228	0.0526**	0.0479	1.0975
	(0.028)			(0.017)		
10-year Cumulative	0.0230	0.0147	1.5642	0.0401***	0.0380	1.0548
	(0.016)			(0.008)		
2-year Instantaneous	0.0333	0.0094	3.5417	0.0161*	0.0101	1.5931
	(0.029)			(0.007)		
5-year Instantaneous	0.0001	-0.0028	-0.0261	0.0528***	0.0521	1.0136
	(0.021)			(0.010)		
10-year Instantaneous	0.0037	0.0055	0.6776	0.0286***	0.0291	0.9847
	(0.044)			(0.008)		

	MEP: $\widehat{\phi}^{yQ}$	MEP: β	Fraction	QE-III: $\widehat{\phi}^{yQ}$	QE-III: β	Fraction
2-year Cumulative	0.0087	0.0086	1.0062	0.0804*	0.0803	1.0000
	(0.005)			(0.035)		
5-year Cumulative	-0.0045	-0.0004	10.7891	0.0675*	0.0676	0.9983
	(0.003)			(0.030)		
10-year Cumulative	-0.0147	-0.0129	1.1420	0.0353	0.0353	0.9985
	(0.010)			(0.023)		
2-year Instantaneous	-0.0103*	-0.0050	2.0455	0.0889*	0.0890	0.9983
	(0.004)			(0.040)		
5-year Instantaneous	-0.0107*	-0.0101	1.0619	0.0227	0.0227	0.9992
	(0.005)			(0.015)		
10-year Instantaneous	-0.0418	-0.0422	0.9907	0.0211	0.0211	1.0005
	(0.036)			(0.019)		

Estimated Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Total Changes in Borrowing Costs at Various Maturities on QE Dates

	QE-I	QE-II	MEP	QE-III
BAA Yields	-0.1498	-0.0928***	-0.1628*	0.0672***
	(0.093)	(0.025)	(0.067)	(0.011)
BAA Spread	0.0627	0.0557**	-0.0443***	-0.0293***
	(0.060)	(0.018)	(0.011)	(0.001)
AAA Yields	-0.1505	-0.0935***	-0.1335*	0.0915***
	(0.098)	(0.004)	(0.053)	(0.014)
AAA Spread	0.0619	0.0549***	-0.0151	-0.0051
	(0.046)	(0.004)	(0.025)	(0.004)
30-Day NFCP	0.0071	-0.0204	-0.0054***	-0.0104
	(0.021)	(0.011)	(0.001)	(0.011)
60-Day NFCP	-0.0821**	0.0295***	0.0045	-0.0005
	(0.028)	(0.004)	(0.014)	(0.004)
90-Day NFCP	-0.1025***	0.0525***	0.0025	-0.0075
	(0.025)	(0.002)	(0.014)	(0.007)
TED Spread	-9.5358	-1.5358	0.9142***	0.5042
	(4.992)	(0.928)	(0.261)	(0.673)

HAC Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Each cell represents a coefficient on a certain measure of real borrowing costs in a regression of that cost on a constant and dummies for individual QE dates.

Table 7: $\hat{\phi}^{iQ}$: Response of Borrowing Costs to Policy Shock

	$\widehat{\phi}^{iQ}$
BAA Yields	0.2811**
	(0.094)
BAA Spread	-0.2069***
	(0.053)
AAA Yields	0.3093**
	(0.101)
AAA Spread	-0.1787***
	(0.050)
30-Day NFCP	0.1645
	(0.109)
60-Day NFCP	0.1450
	(0.223)
90-Day NFCP	0.1234
	(0.133)
TED Spread	29.7679
	(31.837)

HAC Standard errors in parentheses.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Each coefficient above is from a regression of daily changes in a borrowing cost on shocks to the policy indicator, on dates corresponding to FOMC announcements from 1995 to 2007.

Table 8: The Pure QE Effect on Corporate Borrowing Costs, Absolute Magnitudes and Fractions of Total Effects

	QE-I: $\widehat{\phi}^{yQ}$	QE-I: β	Fraction	QE-II: $\widehat{\phi}^{yQ}$	QE-II: β	Fraction
BAA Yields	0.0625	-0.1498	0.7808	0.0429	-0.0928	0.9113
	(0.094)			(0.025)		
BAA Spread	0.0486	0.0627	0.6145	0.0526**	0.0557	0.8912
	(0.061)			(0.018)		
AAA Yields	0.0230	-0.1505	0.7600	0.0401***	-0.0935	0.9031
	(0.100)			(0.006)		
AAA Spread	0.0333	0.0619	0.6632	0.0161***	0.0549	0.9048
	(0.047)			(0.004)		
30-day NFCP	0.0001	0.0071	3.6887	0.0528***	-0.0204	0.7633
	(0.026)			(0.011)		
60-Day NFCP	0.0037	-0.0821	0.7939	0.0286***	0.0295	1.1438
	(0.039)			(0.008)		
90-Day NFCP	-0.1169***	-0.1025	0.8595	-0.0845***	0.0525	1.0688
	(0.030)			(0.004)		
TED Spread	0.0385	-9.5358	0.6355	0.0496	-1.5358	0.4325
	(6.373)			(1.333)		

	MEP: $\widehat{\phi}^{yQ}$	MEP: β	Fraction	QE-III: $\widehat{\phi}^{yQ}$	QE-III: β	Fraction
BAA Yields	0.0087	-0.1628	1.0444	0.0804***	0.0672	0.9970
	(0.067)			(0.011)		
BAA Spread	-0.0045	-0.0443	0.8800	0.0675***	-0.0293	0.9949
	(0.011)			(0.002)		
AAA Yields	-0.0147	-0.1335	1.0596	0.0353*	0.0915	0.9976
	(0.053)			(0.015)		
AAA Spread	-0.0103	-0.0151	0.6947	0.0889***	-0.0051	0.9744
	(0.025)			(0.004)		
30-Day NFCP	-0.0107***	-0.0054	1.7906	0.0227*	-0.0104	1.0115
	(0.003)			(0.011)		
60-Day NFCP	-0.0418**	0.0045	0.1746	0.0211***	-0.0005	1.2176
	(0.015)			(0.004)		
90-Day NFCP	-0.1700***	0.0025	-0.2845	0.0670***	-0.0075	1.0119
	(0.015)			(0.007)		
TED Spread	-0.0390	0.9142	0.1624	-0.0292	0.5042	0.9573
	(0.867)			(0.707)		

Estimated Standard errors in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$