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The Effect of the U.S. Quantitative Easing on the Term Structure. A Spatial Panel Model Approach.

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Abstract

In this paper, we apply the spatial panel model that accounts for serial dynamics, cross-sectional dependence, and common factors to assess interest rate sensitivity across the term structure to changes in the policy rate. Considering the Quantitative Easing (QE) program as a breakpoint, we apply this method before and after implementing this program. First, results suggest the existence of spillovers between different maturities. Second, after QE implementation, the impact of monetary policy is influencing more time the interest rates, that is, it will be more persistent, and the influence of Federal Funds rate on Treasury Constant rates has changed, although remaining the same pattern where short-term maturities are more sensitive than long-term ones. Finally, our findings may suggest that the Fed would possess more controllability of the term structure and a more efficient transmission mechanism. These results possess important considerations to policymakers and the effectiveness of the monetary policy applied by the Fed.

1. Introduction

Since the last Great Recession, the Federal Reserve (Fed, hereafter) has pursued several less conventional monetary policies. Such policies include setting interest rates at low levels (the Federal Funds rate was set between zero and 25 basis points) to manage or influence longer-term interest rates as predicted by the Expectations Hypothesis of Term Structure (EHTS, hereafter), attending to the transmission mechanism of monetary policy (Vides et al., 2020). This could be explained by the central bank's capacity to affect longer-term interest rates which is crucial if monetary policy is effective (Busch and Nautz, 2010). Furthermore, these monetary policies have been accompanied by programs such as Quantitative Easing

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(Q.E., hereafter) to stimulate the economy through large-scale asset purchases (LSAPs) of Treasury securities (see Wright, 2012).

Although the aftermaths of the COVID-19 outbreak mainly affected the supply side, the Fed, among other Central Banks, announced several interventions with different magnitudes in response to the effects of COVID-19 (see Rebucci et al., 2022) and to stabilize the real economy. Nevertheless have these less conventional monetary policies affected the relationship between short- and long-term interest rates? In this regard, the behaviour of interest rates in response to the Fed measures is a subject of great interest to financial market participants and policymakers. In this sense, the implementation of the Q.E. program (by reducing interest rates and adopting unconventional monetary policy measures) fosters an environment of highly low-interest rates and interest rates of long-term decreases, which reflect the slow pace of economic recovery, lower inflation rates and inflation expectations, as well as accommodating monetary policy (Caporale et al., 2017) so, one could wonder: How have unconventional monetary policy measures influenced the effectiveness of conventional measures? Therefore, the main aim of this study is to analyze how unconventional monetary policies (Q.E.) have influenced the dynamic of the relationship between the Federal Funds Rate (F.F., hereafter) and each Treasury Constant rate maturity.

The literature concerning the relationship between short- and long-term interest rates is quite large. In this regard, the works of Kuttner (2001), Demiralp and Jorda (2004), Thornton (2005) or, more recently, Akram (2021) show the relationship between Fed policy rate and longer-term interest rates and states that interest rates respond differently to changes in the F.F. and the success of the Fed in the controllability of longer-term interest rates. Additionally, Cassola (2008) and Hassler and Nautz (2008), Busch and Nautz (2010) or Cömert (2012) reveal that persistence could affect the controllability of central banks on interest rates, evidencing a weak power in the term structure.

This paper applies the spatial models by attending to geographical assumptions, following Tobler's First Law (1970), i.e., “everything is related to everything else, but near things are more related than distant things". This paper uses a spatial model for non-geographical units (Beck et al., 2006) by considering the different maturities of the Treasury Constant rates (T.C., hereafter) as "locations" with distances between them, measuring how the policies or any shock may spread and how could be the spillovers behaviour between interest rates and bringing important consideration to forward guidance and the pass-through of interest rates. Thus, our empirical contribution is similar to Dalhaus et al. (2021). This paper mainly uses the simultaneous dynamic spatial panel data model with common factors proposed by Vega and Elhorst (2016) based on the model of Bailey et al. (2016). This is the first model that simultaneously considers serial dynamics, cross-sectional heterogeneity and common factors.

Although other authors have analyzed some of these dynamics with different models or sequential approaches, not performing the analysis simultaneously can potentially lead to biased results since temporal dynamics, cross-sectional dependence and common factors are more likely to be interdependent (Vega and Elhorst, 2016). In our case study, some papers have analyzed the temporal dynamics of the Treasury Constant Rates (Vides et al., 2020), the cross-sectional dependence between the different maturities (Dalhaus et al., 2021), and their relationship with the federal fund rate (Deleidi and Levrero, 2021). However, to the best of our knowledge, work has yet to be analyzed simultaneously in a model.

Furthermore, our model allows us to estimate the impact of the F.F. rate on each maturity of T.C. In this sense, our results show that the persistence of the impact of a shock on T.C. is greater after the implementation of Q.E. than before. Furthermore, although the influence between the different maturities does not change with the implementation of Q.E., the impact of the F.F. on maturities has. After the implementation of Q.E., the F.F. seems to have a more homogeneous and similar impact on all maturities, although maintaining the same pattern where the short rates are more sensitive than long rates.

The rest of the paper is organized as follows. The following section covers the literature on this topic. Section 3 describes the methodology used for the work. Section 4 discusses how different dimensions of the monetary policy spread through maturities and how they interact with each other. We identify the conclusions and policy implications in section 5.

2. Literature Review

Initially, as Demiralp and Jorda (2004) stated, the "Holy Grail", or in other words, the primary purpose of monetary policy, is to influence short-term interest rates by central banks and then to handle long-term interest rates and, finally, economic activity. A change in the aim of the monetary policy causes a move of the longer-term interest rates in unison and in a manner broadly consistent. Indeed, it is said that a monetary policy is effective when variations in short-term policy interest rates would impact long-term ones (Holmes et al., 2015). Nevertheless, the hypothetical effectiveness of monetary policy would be determined by the impact that policies might have on long-term rates.

Thus, as previously mentioned, the EHTS is the most influential theory that explains the interaction and sensibility between interest rates of different maturities, i.e., all changes in the term structure due to changes in short-term interest rates are attributed to the EHTS (see Gürkaynak and Wright (2012), for a survey), and has been used as a tool to steer the interest rates in an implicit path (see the deep explanation of the topic in the influential papers of Campbell and Shiller, 1991; Campbell, 1995; and Rudebusch, 1995). This implicit path reveals how interest rates may change if new information about the economic stance and if monetary policy requires an adjustment of the path, that is, formulating a new policy (Abassi and Linzert, 2012). When central banks (e.g., Fed) regulate their monetary policy instruments, they operate within the interest rate channel[1], by directing or changing the monetary base and the policy rates. In this sense, following the term structure of interest rates, the policy rates would similarly transfer the effects on market rates (Nguyen et al., 2021).

Moreover, the sensitivity of long-term interest rates to short-term interest

[1] Mishkin (2013) considers the interest rate channel or the interest rate pass-through as a direct monetary transmission channel which could affect the interest rate transmission mechanism.

rates.[2], such as the F.F. for the USA, which looks to decline progressively after the end of the 1980s and 1990s. In this sense, Greenspan (2005) explained the natural behaviour of the interest rates in his speech, i.e., if the monetary authority, in this case, the Fed, applies a rise of short-term interest rates, an increase typically follows them in longer-term interest rates. At this point, Greenspan's evidence that the last behaviour of the movement of long-term interest rates would be a puzzle due to the difficulty of predicting their trend. In this line, Bernanke (2006) also appeared surprised that long-term bond rates did not move with the Fed rate. Additionally, Rudebusch et al. (2006) evidenced that long-term interest rates tend to move similarly to short-term interest rates, though with different magnitudes. This could be a clue of the responsiveness of long-term interest rates given a shift of the short-term interest rates or policy rates, such as F.F., a pass-through may exist from short- or policy rates to long-term rates.

Initially, attending to the influential paper of Mankiw and Miron (1986), their results support the idea that any change in monetary policies applied to short-term interest rates would have an immediate effect on long-term interest rates, being critical in the effectiveness of monetary policy and the interest rates pass-through. More recently, Kuttner (2001) evidences the relationship between Fed policy rate and longer-term interest rates and states that interest rates respond differently to changes in F.F. Otherwise, Demiralp and Jorda (2004) find strong support that when the Fed apply a new monetary measure, the interest rates react strongly, showing the success of the Fed in the controllability on longer-term interest rates. Thornton (2005) indicates that other determinants of long-term interest rates exist besides the market's expectation of the F.F. or the monetary policy carried out. He concludes that short-term interest rates are not the exclusive determinant of long-term interest rates. Furthermore, several authors show the need to consider the nature of the persistence in the relationship between shorter- (as F.F., for instance) and longer-term interest rates.

The research by Cassola (2008) and Hassler and Nautz (2008) demonstrate how persistence affects the impact of central banks on interest rates, evidencing a weak power in the term structure. Thus, Busch and Nautz (2010) claim that monetary authorities must be concerned about the interest rates' persistence; this persistence might be crucial as the lasting impact of shocks would distort the precision of policy signals and the central banks' influence on longer-term interest rates. Similarly, Cömert (2012) employed a set of techniques and showed that the Fed has been losing its control over long-term interest rates, appearing that the interest rate channel usability has diminished with the decoupling between short-term rates, i.e., F.F. and long-term interest rates although he reveals that usually, the F.F. and bond rates shift jointly. However, they possess a less than complete pass-through from the F.F. to the long-term interest rates. For its part, Wright (2012) treats the effect of monetary policy when the policy rate is stuck at the zero lower bounds, evidencing that monetary shocks affect long-term interest rates. Regarding the power and controllability of the term structure by handling the short-term interest rates, Bauer and Rudebusch (2014) argue that variations in very short-term interest rates could

[2] For an in-depth explanation of how monetary authorities try to influence long-term interest rates, see the survey by Papadamou et al., (2020).

drive changes in near-term interest rates. Similar results were obtained by Kool and Thornton (2012), who show that central banks' measures had limited success in the effectiveness of the monetary policy. Akram and Li (2016) achieve a similar conclusion to Thornton (2005), demonstrate that long-term interest rates are driven by short-term interest rates manipulated by central banks. However, as Thornton (2005) specifies, this can occur if other variables, such as inflation or economic activity, are under control.

More recently, Guidolin and Thornton (2018) suggest that the predictability of the short-term interest rates and the success of the forward guidance policies would be possible if central banks could perform a credible path for the policy rate, the evidence since the Fed began publishing its F.F. target in the middle of '90s. Furthermore, Fullana et al. (2020) measure the effectiveness and how shocks derived from the monetary policy may affect the financial system. The work of Dalhaus et al. (2021) also emerges in the literature as a new view of how interest rate surprises might spill over to greater maturities, thus allowing us to assess the effectiveness of the monetary policy transmission mechanism. They find that short-term to longer-term interest rates pass-through is attenuated. In contrast, the pass-through related to medium and long-term maturities is stronger than in the previous case. Moreover, they value the importance of attending the spillovers since knowing the spillover structure could be suitable for monetary authorities and Bu et al. (2021) evidence that any shock to the monetary policy series selected holds effects on middle-term interest rates.

Last but not least, Akram (2021) models the term structure of interest rates and the relationship between short- and long-term interest rates, constructing his study on the Keynesian perspective concerning that short-term interest rate is a primary driver of the long-term interest rate, being an essential point in the controversy of academic and policy discussions in the assessment of the monetary policy and the monetary transmission mechanism effectiveness. Deleidi and Levrero (2021) related F.F. and long-term interest rates (the 10-Year Treasury Bond) and Moody's AAA Corporate Bond, concluding that monetary policy could affect long-term interest rates. The Fed would have a certain degree of freedom in establishing the levels of the short-term policy rate. In this regard, Akram (2022) applied a geometric Brownian motion to present a long-term interest modelling based on Keynes's conjecture that a monetary authority's action may influence long-term interest rates by steering short-term interest rates, being the policy rate crucial for this purpose.

From an empirical point of view, the econometric literature in the treatment of the term structure and the responsiveness of long-term interest rates or the pass-through from short-term to long-term interest rates has been widely based on the application of different approaches such as the VEC model (Akram and Li, 2016), Dynamic models (Kuttner, 2001; Demiralp and Jorda, 2004; Rudebusch et al., 2006; Abbassi and Linzert, 2012; Kool and Thornton, 2012; Bauer and Rudebusch, 2014), fractional integration and cointegration models (Hassler and Nautz, 2008; Busch and Nautz, 2010; Vides et al., (2019, 2020)), VAR, CVAR or SVAR model (Campbell and Shiller, 1991; Rudebusch, 1995; Wright, 2012; and Holmes et al., 2015), Diebold and Li model (Guidolin and Thornton, 2018) among others. In contrast, the empirical contribution of this paper is similar to that applied by Dalhaus et al. (2021), which is an extension of the spatial lag model. In particular, this paper uses the simultaneous dynamic spatial panel data model with common factors proposed by Vega and Elhorst (2016) based on the model of Bailey et al. (2016).

3. Methodology

3.1 Data Description

For our empirical analysis, we employ a quarterly sample of T.C. of 11 different maturities from 2002Q1 to 2021Q4 (amounting to 79 observations for each interest rate series). The data corresponds to 1-month, 3-month, 6-month, 1-year, 2-year, 3-year, 5-year, 7-year, 10-year, 20-year and 30-year constant maturity rates. Additionally, the F.F. is considered the central interest rate in the U.S. financial market. It can influence longer-term interest rates and other financial products, such as mortgages, loans, and savings, essential to consumer wealth and confidence. Furthermore, the F.F. is shown as the reference of the Fed's monetary policy proceedings in the empirical analysis. The Fed implements the monetary policy by shifting the F.F. target, which is supposed that be related to other interest rates by the market's expectation (see Atesoglu, 2003; and Sarno et al., 2005; for a deep discussion of the F.F.). The data are collected from Federal Reserve Economic Data (FRED) set by the Economic Research Division of the Federal Reserve Bank of St. Louis.

Additionally, we point to the beginning of the Q.E. implementation as a breakpoint in our sample. As it is well known, the subprime mortgage market collapsed by the middle of 2007, triggering the beginning of The Great Recession. The U.S. government faced this quarrelsome event with a fiscal stimulus package and unprecedented bank bailout, and the Fed launched the Q.E., an unconventional monetary policy to purchase assets that may affect financial markets and economic activity (Williamson, 2017). This Q.E. program was announced in the third quarter of 2008, being our breakpoint to apply our model.

As we can see in figure 1, the variables display similar behaviour in terms of volatility and report a graphical exploration of the time-series dynamics plot for all maturities. In figure 1, we can see a vertical dashed line, which corresponds to the implementation of the Q.E. program.

Table 1 shows descriptive statistics associated with each interest rate for different maturities. We can see that attending to the standard deviation, the greater the maturity, the less volatility they present.

Figure 1 Dynamics of the Variables Used

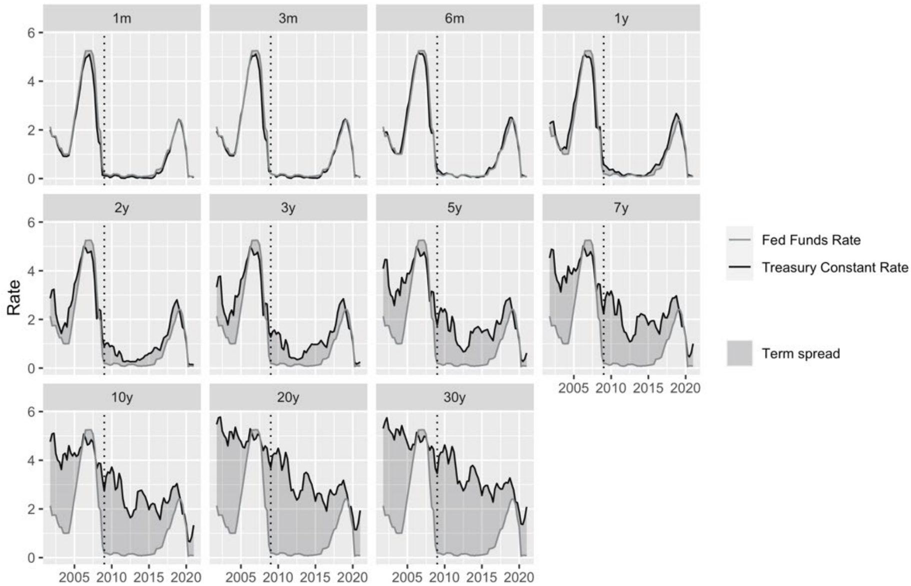


Table 1 Descriptive Statistics for the Data

	Mean	*Median*	*S.D.*	*Min*	*Max*
Fed. Funds rate	1.358	0.973	1.553	0.060	5.257
			Treasury Constant rate		
1m	1.217	0.841	1.455	0.010	5.108
3m	1.271	0.920	1.482	0.014	5.114
6m	1.378	1.010	1.516	0.049	5.173
1y	1.483	1.097	1.486	0.082	5.091
2y	1.714	1.271	1.414	0.132	4.998
3y	1.942	1.513	1.356	0.164	4.987
5y	2.392	2.147	1.268	0.271	4.993
7y	2.752	2.586	1.204	0.462	5.018
10y	3.077	2.900	1.165	0.650	5.106
20y	3.635	3.547	1.213	1.145	5.774
30y	3.775	3.703	1.102	1.363	5.744

Notes: The data spans from 2002Q1 to 2021Q4

3.2 Model

Several articles show that different maturity of the T.C. influences each other (see Campbell, 1995); Holmes et al., 2015; Akram, 2021; among others). This generates a cross-sectional correlation, which implies that part of the variations we observe in their rates are due to variations in the rates of other longer-term or shorter-term maturities. In addition, many works also find that the rates are persistent over time. Part of their variations are explained by the rates of previous periods. In this sense, any model that attempts to model variations in interest rates must consider cross-sectional dependence and persistence.

In our case study, we add the F.F. to the model to determine its influence on the different maturity types. In this line, these interest rates must be modelled as a variable that varies in each period but is the same for the different maturities of the T.C. That is, it can influence all of them. To model the dynamics found in interest rates and the influence of the F.F. on different rates at different maturities, we use a recent model developed by Vega and Elhorst (2016).

This model comes from the spatial econometrics literature and takes into account, simultaneously, the cross-sectional dependence and persistence of a variable (T.C.) observed in different places (maturities, in our case), in addition to including common factors. These variables affect all places where the analyzed variable is measured (the F.F. in our case study).

The Vega and Elhorst (2016) model, which simultaneously accounts for serial dynamics, cross-sectional dependence and common factors, an extension of the Bailey et al. (2016) two-stage method reads as follows (eq. 1):

$$TC_t = \tau TC_{t-1} + \delta WTC_t + \eta WTC_{t-1} + \Gamma_1 FF_t + \Gamma_2 FF_{t-1} + \mu + \varepsilon_t \qquad (1)$$

where TC_t is a column vector with one observation of the dependent variable (T.C.) for every maturity rate (i) at every point. TC_{t-1}, WTC_t and WTC_{t-1} are vectors of temporal, cross-sectional and cross-sectional temporal lags, respectively, with τ, δ and η autoregressive coefficients. W is the row-normalized connectivity matrix, setting the relation structure of the different maturity rates, which will be explained later. FF_t and FF_{t-1} are the F.F. at times t and t-1, and Γ_1 and Γ_2 column vectors with unit-specified coefficients of response to the common factor, that is, an individual coefficient for every maturity rate of response to the F.F. and μ represent the cross-sectional fixed effect added to the model and ε_t is the Nx1 vector independently and identically distributed error term with zero mean and constant variance σ^2.

The parameter of the sensitivity of each maturity rate (i) to the Federal Funds rate (γ) can be estimated by dividing the elements of Γ_1 by 1-δ or by dividing the elements of Γ_2 by (-τ -η) (Vega and Elhorst, 2016). This model allows us to estimate the persistence of the T.C. simultaneously, the influence between the different maturities and, finally, how changes in the F.F. affect each maturity.

3.2.1 Cross-Sectional Dependence and Weight Matrices

A significant cross-sectional dependence parameter implies that the T.C. in a certain maturity can be explained by the other maturities to which it is related. If this parameter is positive, it reflects a positive cross-sectional dependence, which implies that if the different maturities of the T.C. influence a certain maturity to grow, it will also grow. On the contrary, if this influence is negative, it implies that if the different maturities of the T.C. influence a certain maturity to grow, it will do the opposite. A positive cross-sectional dependence would imply that all maturities have similar behaviour and are aligned. Otherwise, a negative cross-sectional dependence would imply that the different maturities have an antagonistic behaviour, which could be interpreted as substitute products.

As stated above, the cross-sectional dependence will be influenced by the relationship established between the different maturities. As established in the literature, this relationship determined in the weight matrix (W) must be pre-specified and symmetrical (Dahlhaus et al., 2021). In the spatial econometrics' literature, the weight matrix can be defined by economic or geographic distance. However, in our case, we must define the relationship between different maturities of the T.C.

To determine the weight matrix in our model, we follow two different approaches by Fernandez (2011) and Asgharian et al. (2013), the latter recently used by Dahlhaus et al. (2021) in an analysis of networking in the yield curve and its implications for monetary policy. Fernandez (2011) states that the element (*i, j*) of the distance matrix is given by the Euclidean distance d_{ij}, between the elements. This distance is calculated by equation 2:

$$d_{ij} = \sqrt{2(1 - \rho_{ij})} \tag{2}$$

where ρ_{ij} is Spearman's correlation coefficient. Given that, the first weight matrix that we use in our model (W_1) is defined as

$$W_1 = \exp\left(-d_{ij}\right) \tag{3}$$

and it is row-standardized, as usual in the literature on spatial econometrics. In this matrix, more distant maturities receive smaller weights.

The second approach we take to determine our weight matrix (W_2) is the one proposed by Asgharian et al. (2013).

$$C_{ij} = 1 - \frac{F_{ij} - min_j F_{ij}}{max_j F_{ij} - min_j F_{ij}} \tag{4}$$

where F_{ij}, is the distance (in months) between maturities and W_2 is obtained by row standardization. These two alternatives will be used in our model to test its consistency.

The weight matrices are necessary for the proposed model to measure the cross-sectional correlation. Before estimating the model, we tested the presence of cross-sectional dependence in the two proposed subperiods.

We use the CD test developed by Frees (1995) to do this. This test examines whether the degree of cross-sectional dependence is zero (null hypothesis) or positive (alternative hypothesis). It follows a chi-squared distribution with T-1 degrees of freedom, and the test is independent of any pre-specified specification of W. The result yields a value of 195.609 and 332.771, with a p-value of 0.000 for the Pre-QE and Post-QE data, respectively.

This result shows the presence of cross-sectional dependence between the different maturities of T.C. rates, measured in our model through the parameters δ and η thanks to the necessary pre-specification of the weight matrix (W) that collects the relationships between the maturities.

3.2.2 Persistence

The habit of persistence is added to the model by including temporal lag TC_{t-1}, cross-sectional temporal lag WTC_{t-1} and the common factor (F.F.) lagged one period (FF_{t-1}). This makes our model dynamic. That is, it takes into account the persistence habit of interest rates. From the moment a change occurs in the variables that affect interest rates until this change is reflected in its value, more than one period may pass.

One of the main questions that arises from the persistence is the possible need to account for more lags in our model. Following Yu et al. (2012), Elhorst (2014) and Ciccarelli and Elhorst (2018), our model has to meet the condition of $\tau + \delta + \eta < 1$, which justifies that our model is stable and does not need to add more temporal lags or change the spatial dynamics.

Furthermore, as Elhorst (2021) points out, economic agents take time to gather all the relevant information. That is why, in our model, it is necessary to include the dynamics if changes in interest rates can be reflected beyond a period. From this model, we can calculate the half-life of a change explaining the T.C. This can be calculated as $h = \frac{\ln(\frac{1}{2})}{\ln(\tau)}$ and represents the average periods that a shock is impacting on T.C. is fully reflected in its value. In our case study, the calculation of the h value can tell us if the introduction of Q.E. has affected how T.C. absorb economic and financial information.

The τ parameter represents what Korniotis (2010) interprets as the coefficient of external habit persistence, which reflects the time that a given maturity of T.C. takes to pick up information from other maturities. Elhorst (2010) shows that imposing $\eta = -\tau\delta$, an empirical regularity in these models (Parent and LeSage (2010, 2011), the impact of a change will gradually diminish over space (maturities) and time, which is expected in our case study.

3.2.3 Common Factors

One of the main benefits of using this model in our case study is that it allows us to estimate the sensitivity parameter of each T.C. to changes in the F.F., which can measure the effectiveness of the monetary policy.

This parameter can be estimated by including the F.F. in the model for each period analyzed, modelled as a common factor. In our model, we include the F.F. from the same period FF_t and the previous period FF_{t-1}. The reason for including the value of the previous period is that the effect of the changes produced in the F.F. can happen beyond a period (a quarter), which makes sense, especially if the T.C. is persistent over time. To get this sensitivity parameter, it is necessary to apply a transformation to the estimated parameters in γ_1 or γ_2. Vega and Elhorst (2016) explain that the sensitivity parameter can be found in one of the following ways.[3]:

$$\gamma_1 = \frac{\Gamma_1}{1-\delta} \tag{5}$$

$$\gamma_2 = \frac{\Gamma_2}{-\tau-\eta} \tag{6}$$

The parameter γ can be interpreted as the sensitivity of each maturity of the T.C. to changes in the F.F. If $\gamma > 1$, the given maturity is identified as sensitive to changes.

4. Empirical Results

This section shows the results of applying the spatial panel model to assess interest rate sensitivity across the term structure to changes in the F.F. by accounting for persistence, cross-sectional dependence, and common factors. The application of the spatial panel model, a new procedure in this literature, is summarized in table 2. We start our econometric exercise by studying the possibility of persistence. Once this step is done, we test the cross-dependency between each interest rate with different maturities. Finally, we assess whether a change in the policy rate, i.e., the F.F., could provoke a reaction in the rest of the interest rates.

Table 2 Strategy of Empirical Research

Procedure	***Parameter***	***Hypotheses***
Persistence	τ	Is any shock persistent in the term structure? How long does a shock last?
Cross-sectional dependence	δ	Do Treasury Constant maturities influence each other?
Model stability	η	Is the estimated model stable?
Sensitivity to common factor	γ	How do changes in the Federal Funds rate affect the term structure?

As explained in the Data subsection, the effect of unconventional monetary policies in the face of the 2008 financial crisis, such as the Q.E., has been identified as a structural change in the behaviour of interest rates (see Vides et al. (2020) for instance). It is possible that unconventional monetary policies, mainly designed to stabilize the term structure, may influence the effectiveness of traditional monetary policy. For this reason, we divided our sample into two subperiods, 2002Q1-2008Q4 and 2009Q1-2021Q4. This allows us to identify possible changes in the traditional monetary policy transmission mechanism (handling the F.F.) with the inclusion of

[3] Both procedures usually produce similar results in the applied literature. However, γ_2 is used in some cases because it is based on the relative strength of both internal and external habit persistence (Korniotis, 2010).

new ways of monetary policy. Thus, once the methodology is previously explained, we apply the simultaneous dynamic spatial panel data model with common factors to assess the sensitivity of the different maturities of interest rates selected and to assess the effect of the application of the Q.E. program on the term structure, analyzing the regimes resulting before and after the Q.E. program. The results obtained from the estimation of the models for both sub-periods, i.e., before the beginning of the Q.E. program and after the beginning of the Quantitative Easing (pre-QE and post-QE), are shown below.

Table 3 shows the general information of our four estimated models. The first and second models (M1 and M2) show the results of our pre-QE estimation, with the weight matrices W1 and W2, respectively. The third and fourth models (M3 and M4) show the estimated results of the post-QE model with the weight matrices W1 and W2, respectively. As can be seen, the estimated results with both weight matrices (W1 and W2) are very similar. For reasons of simplicity, we analyze the values obtained in the models that use W2 (M2 and M4) since the log-likelihood is greater in both pre-QE and post-QE, respectively, which indicates better goodness of fit. However, the results of M1 and M3 are almost equal and also represented in table 3.

Regarding the persistence parameter τ, it shows a high persistence of the different maturities of the T.C. with $\tau > 0.75$ in all the estimated results. This parameter seems to be higher post-QE, which may indicate that after Q.E., changes are influencing more time the interest rates more. In the same way, the impact of monetary policy on interest rates would be more persistent; that is, it would have an effect for a more extended period. We could verify this by calculating the half-life of a change (h) = 2.478 for M2 and (h) = 9.276 for M4. The results show that post-QE, changes that affect the T.C., are being influenced during 6.798 more periods.

Table 3 Models Resume

	Models			
	M1	***M2***	***M3***	***M4***
τ	0.770*** (0.000)	0.756*** (0.000)	0.922*** (0.000)	0.928*** (0.000)
δ	0.810*** (0.000)	0.811*** (0.000)	0.814*** (0.000)	0.829*** (0.000)
η	-0.690*** (0.000)	-0.654*** (0.000)	-0.755*** (0.000)	-0.773*** (0.000)
Log-likelihood	139.108	149.160	307.866	346.512
Matrix	W1	W2	W1	W2
Period	Pre-QE	Pre-QE	Post-QE	Post-QE

Notes: the p-values are reported in parentheses

As for the cross-sectional dependence parameter, it measures the spillovers that occur between different maturities on average. The results show a high cross-sectional dependence $\delta > 0.80$, which may reflect that the different maturities of the T.C. influence each other and therefore they could follow a similar dynamic. The introduction of Q.E. seems to have not affected how the different maturities affect each other, with the cross-sectional dependence parameter δ practically the same before and after its introduction. The cross-sectional persistence parameter η is interpreted as the external habit of persistence.[4]. Furthermore, all our models satisfy the stability condition where $\tau + \delta + \eta < 1$.

Tables 4 and 5 show the result of the response coefficients to the common factor (Γ1 and Γ2) as well as their transformation (γ_1 and γ_2)[5]. The transformed parameter, also known as the common factor sensitivity parameter (γ), allows us to estimate the sensitivity of each T.C. maturity to changes in traditional monetary policy, that is, changes in the F.F.

The estimated results with both procedures (γ_1 and γ_2) present a similar pattern. In general, short-term rates have a greater positive sensitivity to changes in the F.F. As maturities get longer, this sensitivity decreases, becoming negative for longer pre-QE rates. This can be explained as when policy rates increase, the yield curve shows an inverse relationship due to increases in short-term or decreases in long-term rates, flattening the yield curve. As King and Yu (2018) state, when the Fed increases the F.F., a yield curve flattening is a common characteristic of monetary policy tightening. This occurs as the F.F. and other short-term interest rates move quicker than long-term rates, compressing the spread between short- and long-term rates. However, this could also be caused by major central banks' massive long-term asset purchases in the aftermath of the global financial crisis, among other issues Christensen (2018).

Furthermore, following Roley and Sellon (1995), a negative or inverse relationship between long-term rates and policy actions is consistent with the expectations theory and “can occur if investors believe a current policy action will be fully offset and ultimately reversed in the future". Following this point, our results show that pre-QE, the relationship of the F.F. with long rates was negative, becoming null (not significant) post-QE, which may indicate that unconventional monetary policy measures have achieved that inventors trust that these measures will be stable over time, an argument that is reinforced by the increase in post-QE persistence found in our model. Accordingly, Yildirim and Ivrendi (2021) explain that the use of forward guidance by the Fed holds effects on expectation and term premium components, driving the expectations of future short rates down, decreasing longer-term rates, and influencing financial conditions by diminishing uncertainty and risk. In this respect, Rudebusch (2018) suggests that forward guidance has generally been viewed as an effective policy tool to sustain economic recovery.

Finally, our results also show that post-QE, the variance of the sensitivity of the different maturities has decreased, which reflects that the effect of the F.F. on the different rates of the T.C. is more homogeneous, although maintaining the pattern where the rates at short are more sensitive than long types. These findings align with the previous literature on the topic that an expansionary monetary policy (a decline in the central bank policy rate) leads to a drop in short-term interest rates. Assuming sticky prices that the EHTS maintains, long-term interest rates also plunge, but by a

[4] For an extensive review of this parameter, see Elhorst (2021).
[5] Based on the log-likelihood result, we show the results of the models when using W2 since it outperforms the results with W1.

lesser amount than the decline in short-term interest rates, which conducts an increase in economic activity Nsafoah (2021). This could also reflect that unconventional monetary policy measures have affected the influence of traditional monetary policies on interest rates.

Table 4 Model 2. T.C. Sensitivities (γ1) to F.F. with W2 Weight Matrix

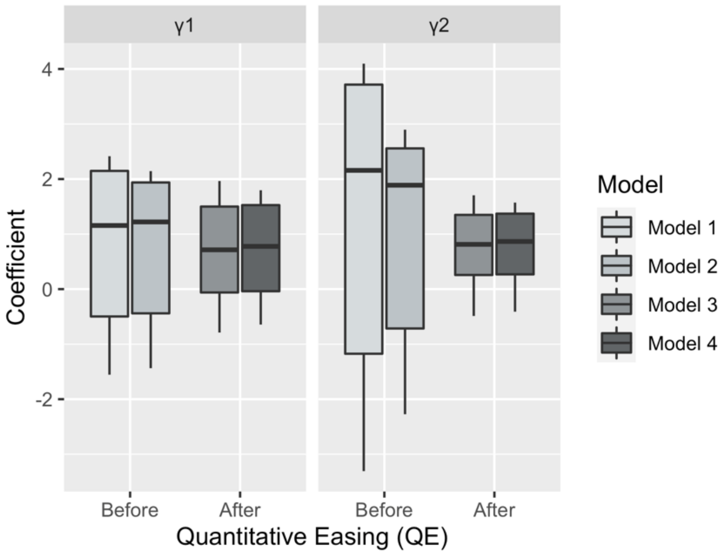
Maturity	*Pre-QE (M2)*			*Post-QE (M4)*		
	Γ_1	$\gamma_1 = \frac{\Gamma_1}{(1-\delta)}$	*p-value*	Γ_1	$\gamma_1 = \frac{\Gamma_1}{(1-\delta)}$	*p-value*
1m	0.366	1.939	0.000	0.308	1.797	0.000
3m	0.399	2.117	0.000	0.289	1.690	0.000
6m	0.404	2.144	0.000	0.280	1.634	0.000
1y	0.365	1.936	0.000	0.243	1.419	0.002
2y	0.290	1.536	0.000	0.180	1.051	0.016
3y	0.230	1.221	0.000	0.133	0.777	0.065
5y	0.058	0.309	0.223	0.050	0.291	0.422
7y	-0.025	-0.135	0.667	0.002	0.009	0.868
10y	-0.140	-0.745	0.007	-0.015	-0.085	0.937
20y	-0.271	-1.436	0.000	-0.096	-0.564	0.214
30y	-0.214	-1.136	0.000	-0.110	-0.644	0.152

Table 5 Model 4. T.C. Sensitivities (γ2) to F.F. with W2 Weight Matrix

Maturity	*Pre-QE (M2)*			*Post-QE (M4)*		
	Γ_2	$\gamma_2 = \frac{\Gamma_2}{(1-\delta)}$	*p-value*	Γ_2	$\gamma_2 = \frac{\Gamma_2}{(1-\delta)}$	*p-value*
1m	0.248	2.425	0.000	0.255	1.572	0.005
3m	0.285	2.792	0.000	0.228	1.469	0.009
6m	0.296	2.898	0.000	0.224	1.446	0.009
1y	0.275	2.690	0.000	0.201	1.297	0.016
2y	0.234	2.292	0.000	0.164	1.055	0.040
3y	0.193	1.888	0.000	0.134	0.865	0.080
5y	0.047	0.458	0.257	0.082	0.531	0.225
7y	-0.021	-0.210	0.901	0.047	0.302	0.415
10y	-0.124	-1.220	0.031	0.036	0.235	0.473
20y	-0.232	-2.273	0.000	-0.051	-0.331	0.680
30y	-0.174	-1.707	0.000	-0.064	-0.410	0.563

Furthermore, in figure 2, we can see that before the implementation of Q.E., the coefficients were less dispersed than after the implementation of Q.E. This behaviour may suggest that the Fed would possess more controllability of the term structure due to the Q.E. This may imply that any policy measure could spread with more homogeneity. The transmission mechanism could be more efficient.

Figure 2 Summary of Estimated Coefficients



Finally, table 6 summarises the findings obtained throughout the Empirical results section. In this table, we also present data that is valuable to highlight.

Table 6 Strategy of Empirical Research

Procedure	Parameter	Hypotheses
Persistence	τ	The persistence in the term structure has increased after the implementation of Q.E.
Cross-sectional dependence	δ	Treasury constant maturities influences remain similar after the implementation of Q.E.
Model stability	η	The models estimated are stable over space and time
Sensitivity to the common factor	γ	Short-term Treasury Constant maturities are more sensitive to changes in the Federal Funds rate than long-term ones. The Q.E. has changed this influence.

5. Conclusions

This paper examines the behaviour of U.S. short and long-term ex-post interest rates by employing the spatial panel model that accounts for serial dynamics, cross-sectional dependence, and common factors simultaneously Vega and Elhorst (2016). This procedure aims to analyze whether the application of unconventional monetary policies has impacted the sensitivity of interest rates in the face of variations in F.F. Thus, assess the spillovers of the monetary policy across the yield curve. Future papers may discuss how changes in other factors, such as price level or public debt, may influence the sensitivity and spillovers found in this study. Due to the Great Recession (2008), the Fed released a series of policies for struggling with such a crisis, i.e., the Q.E. program. For this reason, we apply this point as a breakpoint and analyze the two resulting regimes. As it is well known, the Q.E. is an unconventional monetary policy by which the Fed has tried to control the term structure and the possible responses to the real economy by steering the policy rate, i.e., the F.F., among other measures, such as the purchase of assets that may affect the financial markets.

Furthermore, attending to the obtained results, we find persistence in the relations amongst interest rates and hence, in the application of policies by the Fed. From a monetary policy point of view, when a policy is launched, and new information or shock is spread over the term structure (such as a Fed intervention), a given shock would hold more prolonged effects on the term structure (these results are in line with those obtained by Deleidi and Levrero (2021). This result may give us a view of how efficient the transmission mechanism is and why the new information is better transmitted through the term structure with a longer duration, making the new policies more permanent. This persistence may cause investors to be more sensitive and confident about the design and shift of the new policy. In this sense, as Roley and Sellon (1995) stated, if policy actions are seen as relatively permanent, variations in long-term interest rates might completely reflect or surpass the current change in the fund's rate target. On the other hand, if policy action is seen as transitory, investors' response and long-term rates are probably muted. Therefore, when both regimes are examined, we find more persistence after applying the Q.E. than before, which seems that there is a more efficient transmission mechanism after the application of the Q.E., so the implementation of the Q.E. seems to be justified because, with this unconventional monetary policy tool, the Fed tries to reflect a serious image of serenity and rationality in order to create an environment of confidence.

By attending to the cross-sectional dependence, we study that the selected interest rates with different maturities may influence themselves. As previously mentioned, Central banks (such as Fed) try to steer the long-term interest rates by controlling the short-term interest rates. The obtained results may be robust with the EHTS, which could be assumed as fulfilled. According to the EHTS, the long-term interest rate should reflect the current level of the very short- or short-term interest rate and its expectations over the maturity of the long-term investment. Consequently, the shortest maturity interest rate, i.e., the F.F., and the expectations on this rate establish the remaining interest rates.

Furthermore, by assessing the common-factor sensitivity, we also reveal the sensitivity to F.F. of short- and long-term interest rates, which could be in line and consistent with the expectations theory since the one goal of the monetary policy is to control the long-term interest rates by steering the short-term interest rates. In this sense, we could observe how each interest rate maturity reacts to changes in F.F. as sensitivity increases. Thus, it could be observed that the term structure would absorb the Fed's monetary policy intentions. Otherwise, we find an inverse relationship between the common factor, i.e., the F.F., and the long-term interest rates. This inverse relationship may reflect how investors' expectations might be given a change in the policy interest rate and the yield curve. In the literature, this behaviour is viewed as a flattening of the yield curve. As Estrella and Trubin (2006) state, the yield curve's slope may adversely affect real economic activity and demand for credit and inflation. Additionally, following Roley and Sellon's (1995) statement, our results suggest that the Q.E. has influenced the investor's trust in monetary policies since the non-negative relationship between F.F. and longer-term T.C. rates reflect the belief that a current policy action would be persistent over time.

Because of the above, we suggest that as the Fed only can influence the short-end of the term structure, the monetary policy would affect short-term interest rates. Thus, it could be necessary to adopt different strategies to influence longer-term interest rates and achieve a spillover structure that can be helpful for policymakers (Dahlhaus et al., 2021). In this respect, this type of program, i.e., Q.E., seems necessary to let the transmission mechanism of interest rates and joint credible forward guidance could help to understand how a policy will respond to economic conditions, which can add stimulus even when short-term rates are at the lower bound (see Bernanke (2020), for a deep explanation) and achieve to spread to all the term structure. Finally, the implementation of Q.E. has created a context of more favourable influences between rates and maturities for the effectiveness of conventional monetary policies.

APPENDIX

Table A1 Model 1. T.C. Sensitivities (γ1) to F.F. with W1 Weight Matrix

Maturity	***Pre-QE (M1)***			***Post-QE (M3)***		
	Γ_1	$\gamma_1 = \frac{\Gamma_1}{(1-\delta)}$	*p-value*	Γ_1	$\gamma_1 = \frac{\Gamma_1}{(1-\delta)}$	*p-value*
1m	0.459	2.415	0.000	0.366	1.965	0.000
3m	0.459	2.415	0.000	0.328	1.765	0.000
6m	0.437	2.302	0.000	0.303	1.627	0.000
1y	0.379	1.994	0.000	0.256	1.373	0.002
2y	0.295	1.552	0.000	0.190	1.020	0.019
3y	0.220	1.156	0.000	0.133	0.714	0.088
5y	0.057	0.299	0.266	0.054	0.291	0.426
7y	-0.032	-0.168	0.583	0.001	0.006	0.874
10y	-0.157	-0.826	0.004	-0.024	-0.128	0.870
20y	-0.295	-1.555	0.000	-0,114	-0.611	0.189
30y	-0.268	-1.414	0.000	-0.147	-0.788	0.088

Table A2 Model 3. T.C. Sensitivities (γ2) to F.F. with W1 Weight Matrix

Maturity	***Pre-QE (M1)***			***Post-QE (M3)***		
	Γ_2	$\gamma_2 = \frac{\Gamma_2}{(1-\delta)}$	*p-value*	Γ_2	$\gamma_2 = \frac{\Gamma_2}{(1-\delta)}$	*p-value*
1m	0.320	3.981	0.000	0.286	1.705	0.003
3m	0.329	4.096	0.000	0.256	1.529	0.006
6m	0.318	3.956	0.000	0.241	1.440	0.009
1y	0.279	3.476	0.000	0.211	1.258	0.019
2y	0.229	2.853	0.000	0.172	1.026	0.046
3y	0.173	2.158	0.001	0.136	0.813	0.099
5y	0.034	0.425	0.367	0.089	0.529	0.232
7y	-0.039	-0.480	0.711	0.051	0.303	0.423
10y	-0.150	-1.868	0.015	0.035	0.210	0.510
20y	-0.266	-3.307	0.000	-0.056	-0.336	0.681
30y	-0.233	-2.906	0.000	-0.082	-0.488	0.490

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