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The impact of unconventional monetary policy on the market for collateral: The case of the French bond market*

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Abstract

We consider the channel consisting in transferring the credit risk associated with refinancing operations between financial institutions to market participants. In particular, we analyze liquidity and volatility premia on the French government debt securities market, since these assets are used as collateral both in the open market operations of the ECB and on the interbank market. In our time-varying transition probability Markov-switching (TVTP-MS) model, we highlight the existence of two regimes. In one of them, which we refer to as the conventional regime, monetary policy neutrality is verified; in the other, which we dub the unconventional regime, monetary policy operations lead to volatility and liquidity premia on the collateral market. The existence of these conventional and unconventional regimes highlights some asymmetries in the conduct of monetary policy.

Keywords: Monetary policy; Collateral; Liquidity; Volatility; French bond market.

JEL classification: G10; C22; C53.

Résumé

Nous étudions les canaux de transmission de risque de crédit associés aux opérations de refinancement entre institutions financières et participants au marché. Nous analysons en particulier les effets des primes de liquidité et de volatilité sur le marché des titres publics français. Ceux-ci sont utilisés comme collatéral dans les OMO's de la BCE et sur le marché inter bancaire. A l'aide d'un modèle de Markov à probabilité de transition variable, nous mettons en évidence deux régimes : le premier, le régime conventionnel, est caractérisé par la neutralité de la politique monétaire ; dans le deuxième régime, les opérations de politique monétaire conduisent à la mise en évidence d'effets de volatilité et de prime de liquidité sur le marché du collatéral. De plus, l'existence de ces deux régimes entraîne une implémentation asymétrique de la politique monétaire.

Mots clés : Politique monétaire, collatéral, liquidité, volatilité, Marché français des titres d'États

Codes JEL: G10; C22; C53

1. Introduction

This paper provides an empirical analysis of the impact of unconventional monetary policy on the market for collateral, taking the case of the French government debt securities market. This asset class is used both in the open market operations (OMOs) conducted by the central bank and on the secured interbank market. Open market operations and repo operations are subject to credit risk (Stiglitz and Weiss, 1981), so that collateral is provided to insure the lender against any default. The value of collateral is marked to market such that it is not constant throughout the duration of the loan. Market liquidity therefore becomes a key factor in determining the value of collateral. The aim of the paper is to examine whether tensions in the refinancing process of the banking system and the unconventional monetary policy implemented during the crisis have turned credit risk into market liquidity risk via the extensive use of some types of collateral.

Green (2005), for example, shows that the assets eligible as collateral provide lower rates of return than those not eligible by incurring an opportunity cost to owners. In the context of the recent financial crisis, we have observed several adverse phenomena. First, the increased risk associated with interbank refinancing created a concentration on the highest quality eligible collateral, such as government bonds. Second, higher counterparty risk increased the required haircuts on the value of collateral so that larger amounts of collateral became necessary. Third, increased refinancing via the central bank raised the amount of deposited collateral. Fourth, the stepping-up of numerous refinancing operations resulted in more frequent aggressive trading of collateral. Finally, the preference for longer-term operations also required larger amounts of collateral: for example, in 2006, collateral deposited amounted to EUR 959 billion, versus EUR 1,585 billion in September 2008. Given these specific circumstances, market neutrality may not always be achieved in the monetary policy stance, especially vis-à-vis the market for collateral. A large body of the literature has focused on the market for public debt securities. Diaz et al. (2006), among others, examine the impact of European Monetary Union (EMU) on the liquidity of Treasury bonds and market volatility. They conclude that EMU led to sharp falls in volatility and improved efficiency in the Spanish Treasury bond market. In the same vein, Dunne et al. (2007) compare the different European bond segments and show that, contrary to the prevailing market belief, the 10-year segment of the French bond market is a benchmark asset for the European bond market as a whole. Goldreich et al. (2005) and Fleming (2003) also focus, precisely, on the liquidity of US Treasuries and its impact on interest rates, as do Chakravarty and Saskar (1999), who also compare the different bond segments in terms of bid-ask spreads.

Our approach is different from previous papers since we explicitly relate French bond market dynamics to the ECB's unconventional monetary policy. This is also quite different from that of some recent work that develops interesting, promising and coherent macroeconomic models of the unconventional monetary policy of central banks. This research, some of which is an extension of New Keynesian general equilibrium models, is clear and computationally tractable (see among others, Gertler and Karadi, 2011; Curdia and Woodford, 2010). We do not construct a micro founded model for analysing the effects of unconventional monetary policy on the market for collateral, but rather adopt a reduced empirical assessment of unconventional monetary policy. More specifically, in our paper, we analyze the impact of unconventional monetary policy on the liquidity (bid-ask spreads) and volatility (realized bipower variation from Barndorff-Nielsen and Shephard, 2004) of the market for collateral during these unconventional periods. This analysis is based on high-frequency data identifying all quotes for on-the-run 3-month and 10-year French debt securities between 2003 and 2009. We selected on-the-run 3-month and 10-year securities for their representativeness of the short and the long segments of the French market respectively. We consider a time-varying transition probability Markov-switching vector autoregressive (TVTP-MS-VAR) model (Filardo and Gordon, 1998). In our case, the transition probabilities are governed both by the cycle of monetary policy operations and the cycle of French Treasury auctions of 10-year notes and 3-month bills.

Our main findings are as follows. First, the stepping-up of special refinancing operations with high bid-to-cover ratios makes more probable the emergence of an unconventional regime in which liquidity and volatility premia appear with, in parallel, the segmentation of the bond market. Second, regime identification shows the potential asymmetry in the monetary policy stance between conventional and unconventional regimes, where the same decision (for example more frequent open market operations (OMOs) and loose liquidity provision) may have positive or negative effects depending on the regime markets are in.

The paper is organized as follows. In the next section, we propose a brief review of the implementation of unconventional monetary policy and of developments in the French sovereign bond market. In the third section, we define indicators of liquidity and volatility and present the models. The fourth section discusses the empirical results and sheds light on their monetary policy implications. Section 5 concludes.

2. Unconventional monetary policy and the French bond market

In this paper we distinguish between three types of liquidity: central bank liquidity provided through open market operations; funding liquidity, defined by the BIS (2008) as the ability of banks to meet their liabilities, and unwind or settle their positions as they become due; and market liquidity, defined by the IMF (2004) as the ability of investors to trade quickly, at a fair price and low cost, a large amount of shares with a small impact on prices. In 2007-2008, we observed in the financial system: (i) a shortage of funding liquidity; (ii) a shortage of market liquidity in the funding market; (iii) a shortage of market liquidity in some other markets. Given this unprecedented context, the ECB, like the other major central banks, experimented with unconventional monetary policy.

2.1. A brief review of the ECB's unconventional monetary policy

The recent crisis seriously undermined the interbank market so that the ECB decided to provide huge amounts of liquidity to the banking system through regular and special

OMOs.[1] With respect to regular open market operations, the ECB first increased the levels of allotments to meet liquidity needs through main refinancing operations (MROs) and long-term refinancing operations (LTROs). Due to the strong demand for liquidity, the ECB also decided (i) to use fixed-rate tenders with full allotment in order to completely satisfy banks' liquidity needs; (ii) to introduce very long-term refinancing operations with one-year maturity; (iii) and to conduct several one-off fine-tuning and FX swap operations (Figure 1).

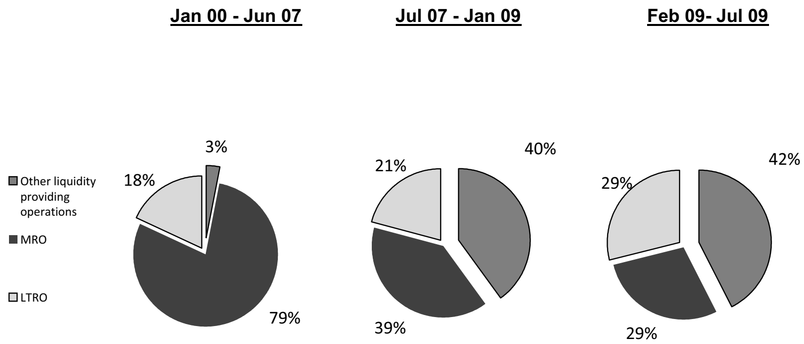

Figure 1: Proportion of ECB liquidity operations by type
(Source: ECB)

The proportion of operations outside the regular monetary policy framework has dramat-

[1] A detailed description of the regular monetary policy framework is discussed in Idier and Nardelli (2011). Curdia and Woodford (2010) provide a summary of the effects of the unconventional monetary policy implemented by the Federal Reserve for the United States. We can use this for the purposes of comparison.

ically increased during the recent period from 3 to 40%.[2] Moreover, from January 2000 to July 2007 the mean amount of allotted liquidity per operation in special operations was around EUR 17 billion, compared with around EUR 40 billion between August 2007 and October 2008. Finally, no exit strategies were put in place afterwards. Looking at the bid-to-cover ratio[3] before the implementation of unconventional monetary policy, it jumped from 1.51 in 2006 to 1.82 in 2007 (i.e. from 51% to 82% excess liquidity demand in open market operations) and plummeted to 1.03 in 2009 following the implementation of the full allotment procedure (Figure 2).

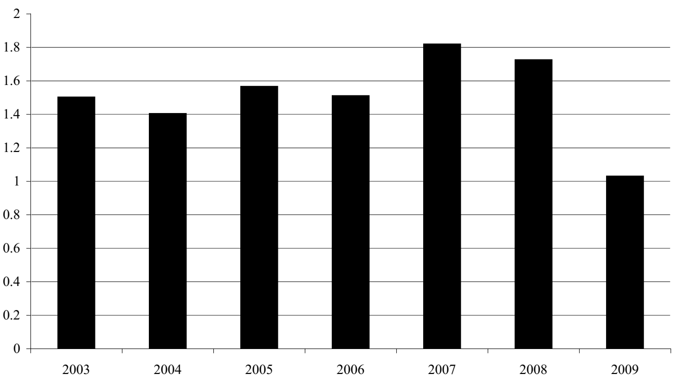

Figure 2: Bid-to-cover ratios for ECB OMOs, mean per year
(Source: ECB)

All of these operations conducted by the central bank lead to some collateral immobilization: to protect the ECB from losses due to open market operations, collateral is deposited

[2] Here, we only include liquidity-providing operations.

[3] This is defined as the supply-demand ratio for liquidity. It sums up some of the tensions relating to refinancing operations.

by banks. In the event of default, this collateral may be liquidated by the central bank to get its money back. The assets used as collateral must meet certain criteria to be eligible by the ECB (ECB "The implementation of monetary policy in the euro area", November 2008) mainly because their value is marked to market. As a consequence, the ECB, which is exposed to downward variations in the value of the collateral, uses some additional measures. First, a haircut, as a percentage discount, is applied to the value of the collateral.[4] Second, margin calls consist in counterparties (banks) providing additional cash to maintain the value of the collateral. This creates interactions between the collateral market and the central bank's refinancing operations when unconventional monetary policy undermines the principle of market neutrality. Here, we focus on the French government debt market.

2.2. The market for collateral: The case of French debt market securities

The amount of the French government's negotiable debt almost doubled between 1998 and 2008, reaching EUR 988 billion at the end of September 2008.[5] This upward trend was made possible by the introduction of marketable products with a continuum of maturities. After regular pre-scheduled auctions, securities are actively traded on the secondary market, where transactions are not centralized. This secondary market is an over-the-counter market and bilateral transaction details are partially known. It should be noted that we directly

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4 The level of the haircut is based on an asset liquidity classification: the lower the liquidity, the higher the haircut (see Avouyi-Dovi and Idier, 2010).

5 Curdia and Woodford (2010), Gertler and Karadi (2011), among others, provide figures regarding the United States.

analyze rates, not prices. This is chosen rationally for the purposes of comparison because we consider several maturities which can be differently compounded according to their issuance: the actuarial rate is less sensitive to the coupon process than the price of the bonds. Moreover some differences between rates may be directly related to the organization of the market since prices are also impacted by the wealth of market intermediaries, or their inventory risks (Fontaine and Garcia, 2010). While the quoted short-term rate is anchored to the ECB's minimum bid rate, 10-year rates are more autonomous. As a consequence, the bond spread shrank up till spring 2008. Following the financial crisis and the ECB's decisions to cut interest rates, this bond spread increased, mainly due to the sharp drop in short-term maturity rates (Figure 3).

On the European market as a whole, high volatility on bond yields for short and long-term maturities has been observed since August 2007. Due to governments' fiscal commitments aimed at tackling the effects of the crisis and to a general rise in credit risk premia, risk aversion on bonds over the long term has increased. However, this has not occurred for all government bonds within the euro area. On the one hand, bonds are suffering from a flight to quality whereby investors shift trading to the traditionally strong government debt securities (typically German or French ones). On the other hand, there are also flight to liquidity issues, with investors wishing to invest in liquid markets. In a period where refinancing is difficult on the interbank market, it is clear that banks are mitigating their risk by investing in markets where funds may be withdrawn rapidly. This preference for liquid and strong collateral during the turmoil, coupled with the change in the conduct of monetary policy, may create some adverse phenomena. In particular, when market participants focus on certain types of collateral and the central bank deposit of collateral surges, liquidity and volatility premia may appear on the market for collateral. In this context, a negative spiral between the market value of the collateral and the conduct of monetary policy may occur. This is what we attempt to assess in the following section.

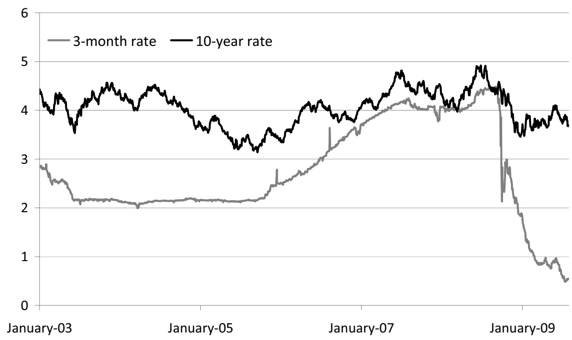

Figure 3: 3-month and 10-year rates for French bonds, 2003- 2009. (Source: Thomson Reuters)

3. The collateral channel

3.1. Dataset and market indicators

Our dataset consists in high-frequency on-the-run quotes for French debt securities with

3-month and 10-year maturities from Reuters Data Tick History; the sample period goes from January 1, 2003 to July 31, 2009. We have around 3.5 million quotes for these bonds. Some public holidays were removed from the sample due to lack of trading (Christmas, New Year's Eve, Easter, France's national holiday, etc.). Due to the greater dispersion of 3-month contracts, with more frequent auctions, the number of quotes is lower than for 10-year notes, in the case of on-the-run contracts.

3.1.1. Liquidity indicators

Following Fleming (2003), we consider that quoted spreads are efficient measures for tracking liquidity on this market. This measure is used in many markets and allows for comparisons such as in Chordia et al. (2003). In practice, the larger the spread, the higher the transaction costs. Assuming that the true value of the asset is between the bid and ask prices, the larger the spread, the greater the potential gap between this true value and the price investors have to pay for buying or selling it. We construct an average daily bid-ask spread for each rate. Since we are looking at the bid-ask spread for rates, which are inversely related to prices, the spread is defined as:

$$S_{i,t} = r_{i,t}^{bid} - r_{i,t}^{ask} \tag{1}$$

for the i^{th} transaction of day t. The daily liquidity indicator S_t is the mean over the day of all N_t spreads:[6]

$$S_t = \frac{1}{N_t}\sum_{i=1}^{N_t} S_{i,t}$$

Due to the partial information available in our dataset (e.g. no details about transaction volumes), we restrict our analysis to this standard indicator as suggested by Fleming (2003). Figure 4 presents the bid-ask spread for the two maturities between January 2003 and July 2009. The short-term maturity bond is less liquid than the longer-term one over the sample. The average bid-ask spread for 3-month maturity rates is about 4 bp, while it falls to 1.1 bp for the 10-year one.[7] Broadly on the sample, the bid-ask spread for the short-term maturity fell except during the crisis of 2008 where it jumped twice in September and October.

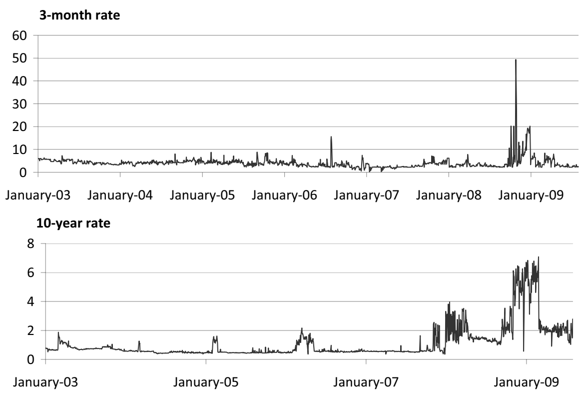

Figure 4 : Quoted bid-ask spreads for 3 month French bond rate (upper panel) and 10-year French Bond rate (lower panel), basis point.
(Sources: Thomson Reuters Tick History, authors' calculations)

[6] We also defined the daily spread as the median of spreads over a given day. This does not affect the results. See Krishnamurthy (2010) for a brief review of measures of liquidity.

[7] This is also confirmed by the relative bid-ask spreads.

3.1.2. Volatility measures

Realized volatility uses the intraday returns on an asset to calculate daily volatility measures by approximation of the quadratic variation. There are several realized volatility estimators (Wright and Zhou, 2009). This class of non-parametric volatility estimators is particularly well-suited to our analysis since our dataset consists of high-frequency data. In particular, realized volatility estimators take into account some specific characteristics of financial markets such as the presence of microstructure noise which stems from the frictions observed on the market when high frequency data are considered. For example, transactions are not continuous on the market; there is a bid-ask spread so that at least two prices are available; the size of this spread depends on the size of the tick; or market liquidity influences the price discovery process. All of this makes the true price process unobservable and estimators of volatility have to deal with these sources of noise to obtain unbiased estimates of the variance.

For on-the-run bond data, the bipower variation from Barndorff-Nielsen and Shephard (2004) is particularly well-suited since the changes in bond contracts when a new auction occurs (since we are looking at on-the-run contracts) may produce jumps in the price process. However, bipower variation is robust to these jumps such that we can also compare on-the-run rate volatilites at different maturities even if auctions are not synchronous.[8] This

[8] Barndorff-Nielsen and Shephard (2004) show, for instance, that realized power variation, realized bipower variation and realized variance are general measures for the quadratic variation process. However, only realized power variation and realized bipower variation are robust to rare jumps.

consistency even in the presence of jumps does not apply in the case of the standard realized volatility estimator defined as the daily sum of squared returns.

Let us consider a partition θ of the day using the last transaction into equal sub-intervals of time (15 minutes in our case study). Then, the day t bipower variations is defined as:

$$\sigma^2_{m,t} = \sum_{i \in \theta} |r_{m,i} r_{m,i^-}| \tag{2}$$

where $r_{m,i}$ and r_{m,i^-} are subsequent returns for the considered sub-intervals of day t, for maturity m. Realized volatility (reported in Figure 5) also surged during the crisis episodes.[9] We note that the impact is greater for the 3-month maturity than for 10-year bonds. Indeed, volatility for long-term bonds rose but did not soar.

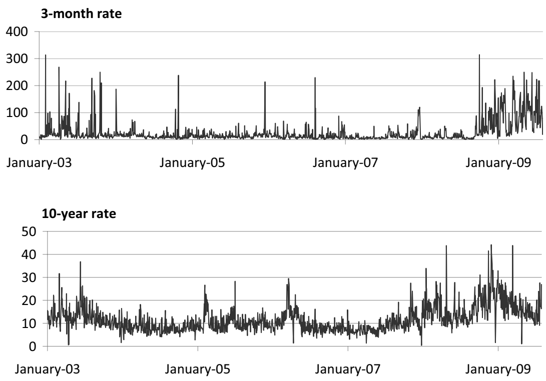

Figure 5 : Realized Volatility estimators for 3 month French bond rate (upper panel) and 10-year French Bond rate (lower panel), annualized %.
(Sources: Thomson Reuters Tick History, authors' calculations)

[9] For the sake of convenience, three huge peaks in Fig. 5 (in October 2008 with levels around 2800) have been left out of the graph.

3.1.3. Bond issuance indicators

The French bond market offers assets grouped into three categories based on their initial maturities. The first category comprises the short-term bond class with maturities less than one year. In this category, 3-month maturity bonds are typically issued weekly and respond to short-term financing needs. The second category includes bonds with 2- or 5-year maturities with a new auction per month. The last category consists of long-term bonds with maturity from 7 to 50 years, also with one auction per month. It is widely accepted that a 10-year bond is a good representative of long-term bonds on French markets. One main development in this market is its internationalization. An increasing share of negotiable French debt is held by foreign investors: by mid-2008, this share represented 62%, compared with 18.8% at the end of 1998. This internationalization has been a vector of increasing liquidity on the market with a wider pool of market participants. In the euro area, this confers on the French market a benchmark status (Dunne et al., 2007). Moreover, during crisis episodes, unlike the German market, its intermediate status vis-a-vis peripheral countries guarantees its liquidity.

Since our dataset consists of real-time quotations of on-the-run bonds we need to control for new auctions by using dummy variables when the bond contract changes for a given maturity. We thus define a dummy variable, noted $AFT_{m,t}$, which is equal to one when new bonds for maturity m are issued by the French Treasury, and zero otherwise. Moreover, we take the bid-to-cover ratio of these auctions noted $AFT\_cover_{m,t}$ to illustrate the intensity of demand.[10]

3.1.4. Unconventional monetary policy indicators

To investigate monetary policy, we construct several indicators representing the ECB's operational framework: a set of dummy variables for OMOs (noted OMO_t, which have the value of 1 on OMO announcement days and zero otherwise[11]) and the associated bid-to-cover ratio (noted OMO_cover_t). The choice of these two variables is motivated by the fact that:

- the dummy variables OMO_t account both for the usual open market operations regularly scheduled and the ability of the ECB to increase the frequency of liquidity-providing operations in the event of a perceived liquidity shortage;
- the bid-to-cover ratio both summarizes the ability of monetary authorities to structurally increase the benchmark allotments (loose monetary policy) and the intensity of demand from financial institutions. This is one main difference compared with some other indicators. For example, the use of allotted amounts, since it only captures the supply of liquidity by the ECB does not a priori represent the demand intensity in the event of inefficient demand (e.g. higher than the benchmark allotment in the event of overbidding). The same comment applies to the number of bidders, which only concerns increasing demand without considering the reluctance of the ECB to increase the benchmark or not.

10 All these data are publicly available on the French Treasury's website (http://www.aft.gouv.fr)
11 For a detailed description of the open market announcement process, see Appendix 1.

In other words, the bid-to-cover ratio associated with open market operation dummies gives good insight into both demand for and supply of central bank liquidity. All these indicators measure the intensity with which market participants are seeking refinancing from the central bank and how the monetary authorities comply with this demand for money. The descriptive statistics performed on stationary variables (Appendix 2) and presented in Table 1 genuinely give us a good intuition of the links between market volatility and collateral liquidity and the conduct of monetary policy. We report the mean and standard error of our indicators (volatility and liquidity) depending on whether an open market operation is announced or not, and divide the sample into pre- and post-2007.

Table 1 shows that bond volatility tends to increase when OMOs are announced, especially during tensions (here broadly speaking after 2007). On the liquidity side, different effects appear depending on the maturity of the bond. On the one hand, quoted spreads increase when an OMO is announced for the 10-year rate ($OMO_t = 1$). On the other hand, the spread of the 3-month rate decreases when $OMO_t = 1$ before August 2007 and increases after august 2007. These features of bonds markets first argue for an econometric model with regime switching since crisis episodes tend to change the dynamics of liquidity and volatility on the market (as in Krishnamurthy, 2010). Second these regimes seem to be highly influenced by the conduct of monetary policy so that the transition probabilities of the models depend on monetary policy indicators as previously defined.

		OMO_t	$\sigma_{120,t}$	$\sigma_{3,t}$	$\Delta S_{120,t}$	$\Delta S_{3,t}$
All Sample	Mean	0	10.2790	12.5177	-0.0004	0.0229
		1	11.1742	18.2558	0.0040	-0.0449
	Standard deviation	0	1.5067	2.6286	0.2985	0.9170
		1	1.6887	3.3190	0.5564	2.5578
before August 2007	Mean	0	9.8229	12.7131	-0.0021	0.0422
		1	9.1177	13.6214	0.0050	-0.1271
	Standard deviation	0	1.4603	2.3136	0.1058	0.8738
		1	1.5233	2.4235	0.1216	1.0665
After August 2007	Mean	0	11.4086	12.0801	0.0036	-0.0213
		1	13.1754	23.1425	0.0031	0.0216
	Standard deviation	0	1.5807	3.3552	0.5183	1.0091
		1	1.7188	3.8939	0.7410	3.3056

Table 1: Descriptive statistics for annualized volatilities and spread variations after and before August 2007. In the event of an ECB open market operation (OMO_t=1) or not (OMO_t=0)

3.2. Model specification

We now provide a brief description of the model used to evaluate the impact of unconventional monetary policy on this particular market for collateral, based on the foregoing analysis.

3.2.1. A time-varying transition probability Markov-switching model

Let us consider the Markov-switching vector autoregressive (MS-VAR) model. Thus, conditional on $\{X_k\}_{k=1:t}$, the history of past variables up to and including t. We separately implement the two following MS-VAR models (Chan et al., 2011) for 10-year (eq. 3) and 3-month (eq. 4) dynamics respectively:[12]

[12] In order to ensure convergence properties, we do not consider a unified model for the two maturities. Moreover, to limit the number of parameters to be estimated, we confine our analysis to two states. Therefore, for each maturity, the model allows for two states indexed by a latent non-observable variable which takes the value of 1 (regime 1) or 2 (regime 2).

$$\begin{pmatrix} \Delta r_{120,t} \\ \ln(\sigma_{120,t}) \\ \Delta S_{120,t} \\ \Delta r_{3,t} \end{pmatrix} = \sum_{p=1}^{P} \Phi_p(s_t) \begin{pmatrix} \Delta r_{120,t-p} \\ \ln(\sigma_{120,t-p}) \\ \Delta S_{120,t-p} \\ \Delta r_{3,t-p} \end{pmatrix} + \mu(s_t) + \varepsilon_t, \tag{3}$$

and

$$\begin{pmatrix} \Delta r_{3,t} \\ \ln(\sigma_{3,t}) \\ \Delta S_{3,t} \\ \Delta r_{120,t} \end{pmatrix} = \sum_{p=1}^{P} \Psi_p(s_t) \begin{pmatrix} \Delta r_{3,t-p} \\ \ln(\sigma_{3,t-p}) \\ \Delta S_{3,t-p} \\ \Delta r_{120,t-p} \end{pmatrix} + \eta(s_t) + u_t, \tag{4}$$

with s_t a latent non-observable variable (if we assume that there are two states then $s_t = 1, 2$ for instance) and with ε_t and u_t following a Gaussian distribution with zero mean and state dependent variance-covariance matrices $\Sigma_\varepsilon(s_t)$ and $\Sigma_u(s_t)$ respectively. Note that considering the state dependent variances allows for a mixture of Gaussian distributions that replicates the skewed and leptokurtotic distribution of bond yield variations. Following Filardo and Gordon (1998) or Henry (2009), we propose a time-varying transition probability model to explicitly identify factors which can drive changes in the transition probabilities. More precisely, the transition matrix depends on both the monetary policy cycle and the French government bond auction cycle. The choice of these variables results from several constraints. First, the model's frequency and the daily market dynamics do not make it possible to include macroeconomic variables. Second, for institutional reasons, monetary and bond cycles are highly influenced by their auction processes. Finally, given the issue of the impact of monetary policy on some alternative markets, the liquidity of the funding process and of the bond market needs to be controlled for these substantial institutional features. We thus consider both dummy variables and the bid-to-cover ratios resulting from the corresponding auctions to disentangle two possible effects:

1. We assume that the frequency of open market operations responds to refinancing demand from banks. In the same vein, the scheduled debt market cycle is assumed to provide liquidity to the corresponding bond market segment.

2. However, if the greater frequency of OMOs is combined with higher bid-to-cover ratios it reveals difficulties for banks in obtaining refinancing. For the same reasons, high bid-to-cover ratios for debt auctions may reveal excess demand for this class of assets.

In this context, the time-varying transition matrix A for the rate with maturity $m = \{3; 120\}$ is

$$A_m(t) = \begin{bmatrix} p_{m,11}(t) & 1 - p_{m,22}(t) \\ 1 - p_{m,11}(t) & p_{m,22}(t) \end{bmatrix}, \tag{5}$$

with

$$\begin{aligned} p_{m,ii}(t) &= \Phi(\delta_i + \alpha_i.OMO(t-1) + \beta_i.AFT_m(t-1) + \\ &\quad \lambda_i.OMO\_cover(t-1) + \gamma_i.AFT\_cover_m(t-1)), \end{aligned}$$

and Φ being the cumulative normal density function (Kim et al., 2008).[13] The transition probabilities $p_{m,ii}, i = 1, 2$ are non-negative and range from 0 to 1. Note that we include lagged explanatory variables to remove any endogeneity issues. The set of unknown parameters Ω comprises the mean equation parameters, the parameters of variance-covariance matrices and the parameters used in the time-varying transition probability equations. These parameters are estimated by maximizing the log-likelihood based on a sample of T obser-

[13] The results presented below are robust to some other transition probability functions which guarantee a well-defined likelihood function. For example, Henry (2009) suggests the logistic functional form for describing the state probabilities.

vations such as:

$$l(x_{1 \ldots} x_T; \Omega) = \sum_{t=1}^{T} \ln(f(x_t \mid \{X_k\}_{k=1:t-1})). \tag{6}$$

The Gaussian density $f(x_t \mid \{X_k\}_{k=1:t-1})$ considers the two states of the Markov-switching process as:

$$f(x_t \mid \{X_k\}_{k=1:t-1}) = \sum_{\bar{s}=1}^{2} f(x_t \mid s_t = \bar{s}) \Pr(s_t = \bar{s} \mid \{X_k\}_{k=1:t-1}),$$

with $f(x_t \mid s_t = \bar{s})$ the density conditional on state $\bar{s}$ ($\bar{s}$ = 1 or 2) and $\Pr(s_t = \bar{s} \mid \{X_k\}_{k=1:t-1})$ the filtered probabilities, with elements of the (1×2) Π_t vector updated for each date as:

$$\Pi_t = \frac{f(x_t) * \Pi_{t-1} A_m(t)}{[f(x_t) * \Pi_{t-1} A_m(t)]\, \iota},$$

with $*$ the Hadamard product, ι a (2×1) vector of ones, $A_m(t)$ the transition matrix defined in equation (5) and $f(x_t)$ a (1×2) vector with elements $f(x_t \mid s_t = \bar{s})$. For the robustness checks, we further apply likelihood-based tests and the Regime Classification Measure (RCM). These tests are detailed in Appendix 3. More precisely, we compare multi-regime models (the FTP-VAR model and TVTP-VAR model) with a single model (VAR model) in terms of the likelihood ratio and RCM statistics. Clearly, the FTP-VAR model performs better than the VAR model whereas the TVTP-VAR outperforms over the FTP-VAR one (the detailed results of these robustness checks are reported in Appendix 3). Model estimations are presented and discussed in the next section.

4. The asymmetric impact of monetary policy

4.1. The monetary policy cycle and regime identification

The filtered probabilities for the two regimes are presented in Figure 6 and estimated coefficients of transition probabilities in Table 2. As mentioned above, the debt market cycle and monetary policy cycle are used to identify these two regimes. The coefficients of transition probabilities of the unconventional regime (regime 1) are significant for both the 10-year and the 3-month rates at the 5% level of confidence, except for the bid-to-cover ratio in the case of the long-term maturity. However, the magnitudes and signs of the coefficients depend on the maturity. Indeed, in absolute value, the coefficients of the 3-month equation are higher than those relating to the one for the 10-year rate. Therefore, the reaction of the short-term maturity to bond issuance indicators or to unconventional policy indicators is more aggressive. For the conventional regime, the variable representing OMOs does not impact the probability of transition of the 10-year rate, whereas it has a significant effect on this probability for the 3-month rate at the 5% confidence level. On the other hand, the effects of bond issuance on the transition probabilities for both the short and long-term rates are quite similar. Furthermore, it is worth noting that there are some discrepancies between the probabilities of regimes 1 and 2: the estimated coefficients show the differences in their sign and magnititude regardless of the maturity.

How can we interpret these results? As reported in Figure 6, regime 1 concerns the

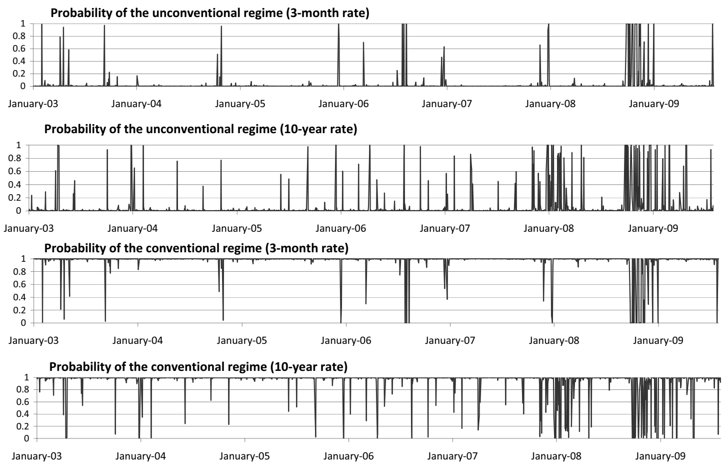

Figure 6 : Filtered probabilities for each regime (conventional and unconventional) extracted from TVTP-VAR models

2007/2008 period of turmoil but it also encompasses early 2005 and 2006, when special OMOs on the interbank market were conducted by the ECB,[14] and when monetary cycles reversed in response to increases in policy interest rates.

The impact of the frequency of OMOs may be considered in different ways. On the one hand, the frequency of OMOs is supposed to respond to the funding needs of the banking system so that their frequency smooths possible disruptions to the financial system. On the other hand, if these operations are combined with a high bid-to-cover ratio, two effects may be expected (Jordan and Jordan, 1997; Krishnamurthy, 2002): (i) a high bid-to-cover ratio may reveal a lack of funding liquidity and the fact that the ECB is not responding

[14] This followed implementation of the new operational framework in March 2004 (Idier and Nardelli, 2011).

	Model for $\Delta r_{120,t}$				Model for $\Delta r_{3,t}$	
	Unconventional	Conventional			Unconventional	Conventional
	$Pr(s_{t+1}=1\|s_t=1)$	$Pr(s_{t+1}=2\|s_t=2)$			$Pr(s_{t+1}=1\|s_t=1)$	$Pr(s_{t+1}=2\|s_t=2)$
δ	0.335**	1.15**		**δ**	-2.35**	1.167**
OMO_t	-1.33**	0.218		**OMO_t**	-11.05**	-0.697**
AFT_t	-3.93**	4.86**		**AFT_t**	-2.88**	3.01**
$OMOcover_t$	1.16**	-0.388		**$OMOcover_t$**	13.07**	0.652**
$AFTcover_t$	-0.076	-3.33**		**$AFTcover_t$**	6.12**	-0.479**

Table 2: Transition probability estimates for Δr120 and Δr3.
(**) denotes significance at the 5% level confidence and (*) at the 10% level

sufficiently to liquidity needs; (ii) however, it may also reveal that the central bank is only meeting efficient demand ('efficient' would mean what is calculated as benchmark supply by the central bank), without replacing the interbank market.

Looking at the impact of monetary and bond cycles in these regimes in Table 2, the impact of OMOs is twofold. In regime 2, which is the conventional one, the impact of the frequency of OMOs and the bid-to-cover ratio of these operations are insignificant for the 10-year rate, thus preserving the market neutrality of monetary policy implementation. However, this is not true for the 3-month rate: the more frequent the OMOs, the lower the probability of staying in the conventional regime (coefficient equal to -0.697). Moreover, when the bid-to-cover ratio is low in these more frequent OMOs (i.e. the ECB satisfies all bids posted by banks during the auction), the conventional regime is also less persistent (coefficient equal to 0.652). This tends to bear out the hypothesis mentioned in the early part of the paper: By stepping up OMOs and ensuring higher allotment, the central bank may encourage the switch from a conventional regime to an unconventional one by affecting the market used for collateral and triggering market inefficiencies. However, our findings concerning the impact of monetary policy on bond markets indicate some asymmetric results in the unconventional regime. When this regime occurs, more frequent OMOs combined with low bid-to-cover ratios (i.e. a loose liquidity policy) make the unconventional regime less persistent. This result is crucial since it introduces an asymmetry in the conduct of monetary policy: on the one hand, policy-makers should limit OMOs and supply limited liquidity to prevent a switch from the conventional to the unconventional regime. On the other hand, if a crisis occurs, by stepping up OMOs and minimizing the bid-to-cover ratio of these operations, they reduce the persistence of the crisis regime.

To sum up, regime identification via transition probabilities highlights the difficulty of managing monetary policy since identical measures may have "good" or "bad" effects depending on the regime markets are in. To limit the switch from a conventional to an unconventional regime, OMOs should not be increased and the supply of liquidity should be limited. However, to limit the persistence of the crisis regime, OMOs should be stepped up and satisfy demand for funding liquidity.

Regarding bond market cycles (i.e. the effects of AFT_t and AFT_cover_t), the effects are less ambiguous than for the monetary policy cycle (see sections above). This is certainly due to the fact that the auction schedule is very rigid both in terms of frequency and the auction process used. As a consequence, when an auction is held, the persistence of the unconventional regime decreases and the persistence of the conventional regime increases for both rates. Lower bid-to-cover ratios for these operations also have the positive effect of limiting the probability of a switch from the conventional to the unconventional regime and of shortening the unconventional regime in the case of the 3-month rate.

4.2. Market inefficiencies, volatility and liquidity premia in the two regimes

The detailed comments on the estimated TVTP-MS-VAR model only relate to the equations of the 10-year and the 3-month rates (Table 3, columns 3 and 8). In each regime, conventional and unconventional, collateral market dynamics are statistically different, as shown in the robustness checks reported in Appendix 3.

If we look at the 10-year rate in Table 3, we observe in the unconventional regimes the emergence of a liquidity premium (the estimated coefficients are significant with values of 0.797 and 1.112) indicating a higher rate when liquidity becomes scarce. This is in line with Longstaff (2002), who shows that flight-to-liquidity phenomena in bond markets may affect yield levels. In the conventional regime, we do not observe this premium (null or significant but negligible effect). However, a volatility premium is significant for this regime at the 5% level of confidence (1.14). This persistent volatility premium in the conventional regime can be compared to some extent to a GARCH in mean effect, with an increase in the rate stemming from a rise in volatility.

	Regime 1: unconventional					Regime 2: conventional				
Model for $\Delta r_{120,t}$		$\Delta r_{120,t}$	$\ln(\sigma_{120,t})$	$\Delta S_{120,t}$	$\Delta r_{3,t}$		$\Delta r_{120,t}$	$\ln(\sigma_{120,t})$	$\Delta S_{120,t}$	$\Delta r_{3,t}$
	$\Delta r_{120,t-1}$	0.327^{**}	-0.032^{**}	-0.034^{**}	0.237	$\Delta r_{120,t-1}$	0.183^{**}	0.004^{**}	0.001	0.007^{*}
	$\Delta r_{120,t-2}$	-0.190^{**}	0.039^{**}	-0.024^{*}	0.341^{**}	$\Delta r_{120,t-2}$	-0.096^{**}	-0.008^{**}	0.0001	-0.01
	$\ln(\sigma_{120,t-1})$	-0.454	0.251	-0.21^{**}	-1.44	$\ln(\sigma_{120,t-1})$	1.14^{**}	0.501^{**}	0.029^{**}	-0.135
	$\ln(\sigma_{120,t-2})$	-0.132	0.449^{**}	-0.03	-1.59	$\ln(\sigma_{120,t-2})$	0.105	0.219^{**}	-0.011	-0.285^{*}
	$\Delta S_{120,t-1}$	0.797^{**}	-0.075	-0.472^{**}	0.289	$\Delta S_{120,t-1}$	-0.028	0.066^{**}	-0.308^{**}	0.071
	$\Delta S_{120,t-2}$	1.112^{**}	0.016	-0.420^{**}	2.58^{**}	$\Delta S_{120,t-2}$	-0.078^{**}	-0.021	-0.174^{**}	0.28^{*}
	$\Delta r_{3,t-1}$	0.007	-0.004	-0.005	-0.03	$\Delta r_{3,t-1}$	-0.077^{**}	-0.004^{*}	0.008^{**}	-0.136^{**}
	$\Delta r_{3,t-2}$	-0.005	-0.005	-0.003	-0.347^{**}	$\Delta r_{3,t-2}$	0.085^{**}	0.001	-0.002	-0.361^{**}
	μ	-0.371^{*}	0.727^{*}	0.563^{**}	6.58^{**}	μ	-2.46^{**}	0.649^{**}	-0.04	1.06^{**}
	R^2	0.14	0.14	0.37	0.35	R^2	0.08	0.54	0.25	0.42
Model for $\Delta r_{3,t}$		$\Delta r_{3,t}$			$\Delta r_{120,t}$		$\Delta r_{3,t}$	$\ln(\sigma_{3,t})$	$\Delta S_{3,t}$	$\Delta r_{120,t}$
	$\Delta r_{3,t-1}$	-0.063	-0.017^{**}	0.022	0.003	$\Delta r_{3,t-1}$	-0.13^{**}	-0.006	0.008	-0.029
	$\Delta r_{3,t-2}$	-0.31^{**}	-0.022^{**}	0.095^{**}	0.036	$\Delta r_{3,t-2}$	-0.354^{**}	-0.007	-0.005	0.041
	$\ln(\sigma_{3,t-1})$	-1.25	0.12	1.25^{**}	-0.407	$\ln(\sigma_{3,t-1})$	-0.19^{**}	0.477^{**}	-0.021	0.138
	$\ln(\sigma_{3,t-2})$	-1.75	0.102	-1.32^{**}	-0.94^{**}	$\ln(\sigma_{3,t-2})$	-0.131^{**}	0.290^{**}	0.032	0.091
	$\Delta S_{3,t-1}$	0.086	-0.005	0.207^{**}	0.033	$\Delta S_{3,t-1}$	-0.192^{**}	-0.01	-0.138^{**}	-0.006
	$\Delta S_{3,t-2}$	-0.34	-0.011	-0.37^{**}	0.241^{**}	$\Delta S_{3,t-2}$	-0.174^{**}	-0.011	-0.063^{**}	-0.128^{*}
	$\Delta r_{120,t-1}$	1.08^{**}	-0.033	0.304^{**}	0.350^{**}	$\Delta r_{120,t-1}$	0.007	0.003	-0.001	0.221^{**}
	$\Delta r_{120,t-2}$	0.032	-0.057	-0.239^{**}	0.055	$\Delta r_{120,t-2}$	0.023	0.002	-0.004	-0.13^{**}
	μ	8.62^{**}	3.05^{**}	0.347	3.18^{**}	μ	0.769^{**}	0.554^{**}	-0.04	-0.54^{**}
	R^2	0.14	0.14	0.19	0.21	R^2	0.34	0.54	0.05	0.07

Table 3: Vector autoregressive models estimates under each regimes, (conventional and unconventional) for Δr_{120} and Δr_3.
(**) denotes significance at the 5% level confidence and (*) at the 10% level

In the case of the 3-month segment, premia in conventional regimes are positive on prices (negative on rates with coefficients estimated at -0.192 and -0.174): when liquidity is abundant (narrow bid-ask spread), investors are willing to pay higher prices for these assets. This is in line with the standard liquidity premium documented for on-the-run bonds as in Garcia and Fontaine (2010) for example.[15] We also note a weak but significant effect of volatility in this case. In the unconventional regime, liquidity seems less of a concern for investors maybe because they are closer to the liquidation of their contracts. To some extent, the distinct effect between regime 1 and regime 2 can be related to the findings of Jordan and

15 The liquidity premium is a factor that has proved to be of interest for bond prices (Amihud and Mendelson, 1991; Chakravarty and Saskar, 1999; Elton and Green, 1998).

Jordan (1997).

Regarding market comovements, the two rates seem to be segmented during unconventional regimes (for instance there is no effect of the 3-month rate on the 10-year rate equation), while market comovements are significant in the conventional one (coefficient estimated at -0.077 and 0.085 in the conventional regime). Comovements in this regime are significant and positive, both from long to short-term rates and vice versa. This illustrates French sovereign bond market dynamics as whole. Therefore, bond market segmentation may be a signal that reveals the emergence of an unconventional regime.

These comments are valid under a ceteris paribus hypothesis, since VAR results should be interpreted by taking into account all variable interactions. Finally, in order to complete and reinforce our empirical results, we perform the regime dependent impulse response functions (IRF). Here, we follow the methodology implemented by Ehrmann, Ellisson and Valla (2003) using within impulse response functions "à la " Pesaran and Shin (1998). The results are reported in Appendix 4. It confirms our previous results with

- market segmentation when the unconventional regime occurs;
- the appearance of liquidity premium for long-term bonds, while this premium disappears for short-term bonds

In addition, IRF reveal a strong interaction between liquidity and volatility dynamics during the unconventional regime. Higher volatility leads to higher spreads: these liquidity and volatility feedbacks are strongly reinforced in the unconventional regime and accentuate the premia observed in rates. In particular, the fact that market illiquidity leads to higher volatility for the 10-year rate, and vice-versa, is crucial since the use of French bonds as collateral for refinancing operations may expose borrowers to more frequent margin calls and undermine their financial soundness along the lines described in the Brunnermeier and Pedersen (2009) model.

5. Conclusion

This paper considers the impact of unconventional monetary policy on the market for collateral, in particular the market for French government debt securities. We focus on 3-month and 10-year rates in terms of price, volatility and liquidity linked to monetary policy cycles and bond auction cycles. This is made possible by the analysis of all quotes of on-the-run bonds between 2003 and 2009 in order to compute the bipower variation of the rate dynamics and the market liquidity of the two debt securities via bid-ask spreads. The interactions between these different indicators are (i) captured via the specification of transition probabilities and the estimation of a TVTP-VAR model and (ii) interpreted via the impulse response functions.

The TVTP-VAR detects two regimes in the data: an unconventional regime and a conventional one. The unconventional regime is characterized by the non-neutrality of monetary policy conduct with respect to the market for collateral. This regime is characterized by higher liquidity-volatility feedback and market segmentation between the 3-month rate and the 10-year rate. However, the persistence of this unconventional regime may be reduced by stepping up OMOs and ensuring a low bid-to-cover ratio (i.e. a loose liquidity policy). This policy issue is however asymmetric since the same monetary policy stance, i.e. more OMOs and loose liquidity, in the conventional regime increases the probability of switching from the conventional to the unconventional regime. In particular, the fact that the monetary policy stance is based on the market neutrality assumption poses a new risk in the refinancing process when the unconventional regime occurs. There is, in this regime, the potential for monetary policy to impact on some markets whose assets are used as collateral. Banks are therefore exposed to higher risk with collateralized loans if margin calls are required or if haircuts increase.

This highlights the difficulty for central banks in implementing an optimal liquidity policy due to these asymmetries in expected effects. The detection of which regime is prevailing in order to determine the appropriate monetary policy stance is challenging. It is even more challenging now, since the question remains as to whether the prevailing regime is a conventional or unconventional one. A return to market neutrality may however constitute an exit strategy for monetary policy.

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6. Appendices

Appendix 1: Open market announcements, timing and definition.

The ECB and the national central banks announce open market operations publicly one day before the deadline for bid submissions by eligible counterparties (banks). This public announcement is then followed by 5 subsequent steps:

1. tender announcement: (a) announcement by the ECB through public wire services and (b) announcement by national central banks through national wire services and directly to individual counterparties (if deemed necessary);
2. counterparties' preparation and submission of bids;
3. compilation of bids by the Eurosystem;
4. tender allotment and announcement of tender results: (a) ECB allotment decision and (b) announcement of the allotment result;
5. certification of individual allotment results and settlement of the transactions.

In particular, the ECB's announcement provides publicly the following information: the reference number of the operation, the date of the operation, the type of operation, the maturity of the operation, the type of auction, the allotment method, the intended operation volume, the fixed rate (only for fixed-rate tenders), the min/max interest rate, the currency of the operation, the exchange rate (in the case of foreign exchange swaps), the maximum bid limit, the minimum individual allotment (if any), the minimum allotment ratio, and the time schedule of the submission.

Appendix 2: Stationary tests

Augmented Dickey Fuller tests and Kwiatkowski, Phillips, Schmidt and Shin tests are performed (Table A.1).

The stationary results are confirmed with trend and intercept in the two test procedures.

	ADF	KPSS
$\Delta r_{120,t}$	-27.7*	0.143*
$\Delta r_{3,t}$	-12.91*	0.737*
$ln(\sigma_{120,t})$	-4.47*	2.49
$ln(\sigma_{3,t})$	-7.38*	1.56
$\Delta S_{120,t}$	-25.8*	0.019*
$\Delta S_{3,t}$	-14.7*	0.089*

$Table$ A.1: ADF and KPSS test statistics
(*) Validates the stationary hypothesis at the 5% level.

Appendix 3: Robustness checks

For robustness, we can test (i) that the TVTP-model performs better than a fixed transition probability (FTP) model or a standard VAR model[16] and (ii) that our restriction for a two-state Markov chain is robust. On the basis of the estimated likelihoods, we consider Vuong's (1989) model selection tests. Let us consider two competing models with densities f and $f\prime$ with sets of parameters Ω and Ω' respectively. The test is defined as:

$$\begin{aligned}\frac{1}{\sqrt{T}}LR_T(\Omega;\Omega') &= L_T(\Omega) - L_T^{'}(\Omega') \\ &= \frac{1}{\sqrt{T}}\sum_{t=1}^{T}\ln\left[\frac{f(x_t \mid \{X_k\}_{k=1:t-1},\Omega)}{f'(x_t \mid \{X_k\}_{k=1:t-1},\Omega')}\right]\end{aligned}$$

such that

$$\frac{1}{\sqrt{T}}LR_T(\Omega;\Omega')\tilde{}N(0,\hat{\sigma}_T).$$

$\hat{\sigma}_T$ is the heteroskedastic and autocorrelated adjusted variance of the test defined as:

$$\hat{\sigma}_T = \Gamma_0 + 2\sum_{j=1}^{J}\left(1-\frac{j}{J+1}\right)\Gamma_j$$

with

$$\Gamma_j = \frac{1}{T}\sum_{t=j+1}^{T}\ln\left[\frac{f(x_t \mid \{X_k\}_{k=1:t-1},\Omega)}{f'(x_t \mid \{X_k\}_{k=1:t-1},\Omega')}\right].\ln\left[\frac{f(x_{t-j} \mid \{X_k\}_{k=1:t-j-1},\Omega)}{f'(x_{t-j} \mid \{X_k\}_{k=1:t-j-1},\Omega')}\right]$$

similar to a Newey and West (1987) correction with autocorrelation of order J.

model for maturity	$m=3$	$m=120$
VAR vs. FTP-VAR	0.90* 0.996	1.01* 0.998
FTP-VAR vs. TVTP-VAR	0.026 0.724	0.176* 0.987

Table A.2: Vuong (1989) selection model test results, (*) indicates rejection of the null: "models are equivalent"

The Vuong test (Table A.2) shows that regime-switching VAR models are better than

[16] The VAR and FTP-VAR model estimates are not reported in this paper but are available on request.

simple VAR models[17] . It also shows that time-varying transition probability VAR models, in particular for the 10-year rate, perform better than fixed transition probability models. In addition, we also apply the RCM statistics from Ang and Bekeart (2002) to check if the two regimes in the TVTP-VAR models are clearly identified compared to a FTP-VAR. This statistic is defined for two states as:

$$RCM = \frac{400}{T}\sum_{t=1}^{T} p_t(1 - p_t)$$

so that it is bounded between 0 and 100 and indicates that the lower the statistics, the better identification for the regimes we have.

model for maturity	$m = 3$	$m = 120$
RCM for FTP-VAR	2.42	5.69
RCM for TVTP-VAR	2.25	3.74

Table A.3: RCM statistics for regime identification

The results in Table A.3 indicate better regime identification for both rates using time-varying transition probability models.

[17] Due to the presence of unidentified nuisance parameters under the null hypothesis (a single regime), we cannot use the Chi2 distribution to determine the significance of the likelihood ratio tests (see for instance, Cho and White, 2007). Therefore, these results should be interpreted with cautious. However given the support obtained by the RCM tests, the rejection of the VAR model in favour of a MS-VAR or a TVTP-MS-VAR seems robust.

Appendix 4: Within regime impulse response functions

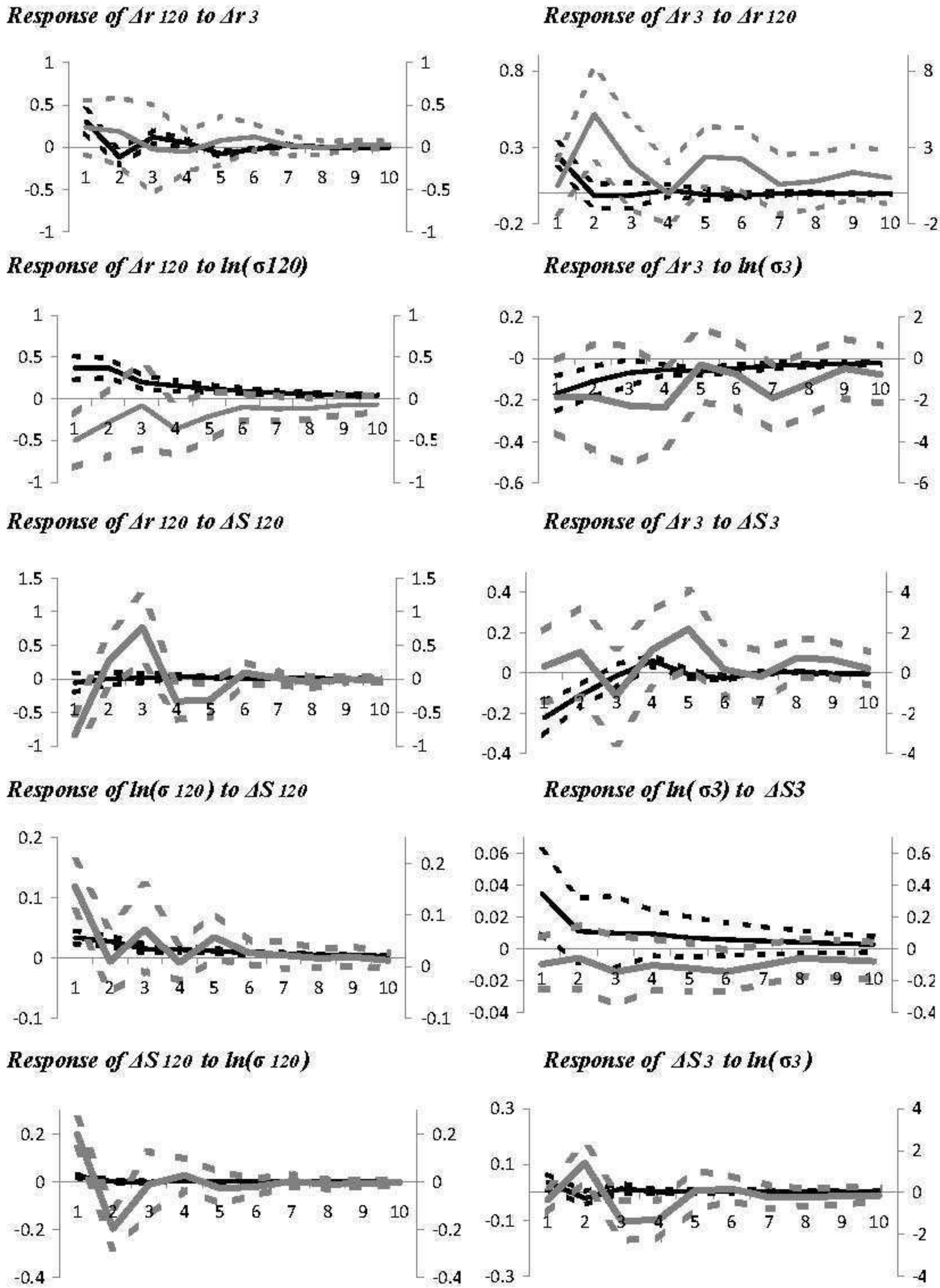

Figure 7: The conventional regime is in black (left-hand scale) and the unconventional regime in grey (right-hand scale), with the 5% confidence interval

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