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Spillovers in monetary policy: The case of FED and ECB policy decisions

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Supervisor: Prof. Dr. André Alves Portela Santos

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AR	Autoregressive
ARCH	AutoRegressive Conditional Heteroskedasticity
ARJI	Autoregressive Contitional Jump Intensity
COPOM	Brazilian Monetary Policy Committee
CPI	Consumer Price Index
ECB	European Central Bank
E-GARCH	Exponential GARCH
EMU	European Monetary Union
FED	Federal Reserve Bank
FFR	Federal Funds Rate
FRED	Federal Reserve Bank of St. Louis Database
GARCH	Generalized AutoRegressive Conditional Heteroskedasticity
GDP	Gross Domestic Product
PPI	Producer Price Index
QE	Quantitative Easing

US	United States
VAR	Vector Autoregressive
VECH	Vectorization Conditional Heteroskedasticicy

Contents

Abstract:

The FED and ECB monetary policy decisions regarding the target interest rate are one of the main drivers of global financial cycles that affect both emerging and developed economies. Because of that, the investigation of how monetary policy decision announcements regarding official interest rate target made by the FED and ECB spillover in both yield curves is important for both market participants and academics. In this sense, this work extends the monetary-jump model in León and Sebestyén (2012) to a bivariate structure, which allows the analysis of four objectives: (1) Assess the extent to which not anticipated monetary policy decision contributes to the overall volatility in term structure of interest rates; (2) analyze the predictability of FED and ECB decisions and announcements; (3) assess if volatility and monetary policy spillover effects between the US and EMU yield curves exist; (4) identify two types of systematic jumps: jumps specific to one interest rate and jumps that occur to both interest rates at the same time, and assess the correlation between jumps in both markets.

The empirical evidence suggested a high level of linkage between the two markets, especially during the world financial crises, when correlated jumps appear to drive the jump arrival process of both yield curves. The jump structure is very important to explain interest rate volatility; however, unanticipated monetary policy decisions report a little contribution to the overall volatility. As for the predictability of the monetary authority, future rates do not anticipate monetary policy decisions as shorter rates, indicating market participants are more likely to change their future monetary policy expectations only after the statement has been released, implying future rates are less predictable by the market participants. Monetary policy decisions spillover effects were relevant to explain jumps in the monetary authority meeting days, since foreign monetary decisions appear to create more jumps in both yield curves than the domestic monetary policy. This suggests domestic interest rate market participants predict their domestic monetary policy better than foreign central bank decisions. Finally, regarding volatility spillover effects, it can be seen that the covariance dropped during the financial crises period, at the same time the correlated jump intensity became large and drove both markets jumps arrival processes. During the sample period analyzed both individual and correlated jumps generated in the US and EMU interest rates markets are due more to other events than to unanticipated monetary policy decisions.

Keywords: Monetary Policy Decisions; Monetary Policy Spillover; Yield Curve

Resumo:

As decisões de política monetária do FED e ECB em relação as suas respectivas metas da taxa de juros são um dos determinantes do ciclos financeiros globais que afetam as economias emergentes e desenvolvidas. Por conta disso, a investigação de como as decisões de política monetária em relação a meta oficial da taxa de juros feita pelo FED e ECB transbordam em ambas estruturas a termo da taxa de juros é importante para os participantes do mercado e acadêmicos. Neste sentido, este trabalho estende o modelo monetary-jump de León e Sebestyén (2012) para uma estrutura bivariada, permitindo a análise de quatro objetivos: (1) Avaliar a contribuição das decisões de política monetária não antecipadas para a volatilidade da estrutura a termo da taxa de juros; (2) analisar a previsibilidade das decisões do FED e ECB; (3) avaliar se o transbordamento de volatilidade e política monetária entre as estruturas a termo da taxa de juros dos Estados Unidos e União Europeia existe; (4) identificar dois tipos de saltos sistemáticos: saltos específicos a uma taxa de juros e saltos que ocorrem em ambas taxas de juros ao mesmo tempo, e avaliar a correlação entre os saltos nos dois mercados.

As evidências empíricas sugerem um alto nível de relacionamento entre os dois mercados, especialmente durante a crise financeira global, aonde os saltos correlacionados aparecem como principal determinante do processo de chegada dos saltos em ambas estruturas a termo da taxa de juros. A estrutura de saltos é muito importante para explicar a volatilidade das taxas de juros, entretanto, decisões de política monetária não antecipadas reportam uma pequena contribuição para a volatilidade total. Já em relação a previsibilidade da autoridade monetária, taxas de juros futuras não antecipam as decisões de política monetária como as taxas de juros mais curtas, indicando que os participantes do mercado estão mais propensos em mudar suas expectativas em relação ao futuro da política monetária apenas depois do anúncio ser divulgado pelo Banco Central, implicando que as taxas de juros futuras são menos previsíveis pelos participantes do mercado.

Efeitos de transbordamento de decisões de política monetária são relevantes para explicar saltos em dias de reunião da autoridade monetária, visto que as decisões de política monetária estrangeira aparentam criar mais saltos em ambas estruturas a termo da taxa de juros que as decisões de política monetária doméstica. Isto sugere que os participantes do mercado de taxa de juros doméstico prevem e antecipam melhor a política monetária doméstica do que as decisões do Banco Central estrangeiro. Finalmente, em relação aos efeitos de transbordamento de volatilidade, pode ser visto que a covariância entre os mercados de juros caiu durante o período da crise financeira global, no mesmo tempo em que a intensidade dos saltos correlacionados ficaram maiores e determinaram o processo de chegada dos saltos em ambos mercados. Durante o período amostral analisado, os saltos individuais e correlacionados gerados no mercado de taxa de juros dos Estados Unidos e da União Europeia acontecem mais por conta de outros eventos do que por conta de decisões de política monetária não antecipadas.

Keywords: Decisões de Política Monetária; Transbordamento de Política Monetária; Estrutura a Termo da Taxa de Juros

1 Introduction

León and Sebestyén (2012) state that modern monetary policy is much more than just changing a specific official interest rate. The management of monetary policy by central banks has become the art of shaping market expectations through the term structure of interest rates, affecting business and household decisions about consumption and investment and then changing the economic aggregates and the situation of the real economy.

The design of the monetary policy decision process practiced today focuses on instruments, operating targets, intermediate targets, and policy goals. Tinbergen (1956), Mishkin (2007), and Walsh (2010) describe the design as: From the goals of the monetary policy authority, to the intermediate target values needed to achieve the goals set, to the values of the operating targets consistent to reach the intermediate targets, and finally, to the instrument settings that yield the desired values of the operating targets. The present analysis has the main objective to assess the impact of a decision in one operating target (target level for official short-term interest rates) on some intermediate targets (short-term and long-term interest rates) of the monetary policy.

According to Hardy (1998), government officials, financial market participants, and economic agents know how important the target level is for an official interest rate in the conduct of the economy. Central bank imposes the official target rate as a monetary policy operating target. In most industrialized and developing countries, the monetary authority chooses the official target rate of the economy to define which size of interference and impact their decisions are driving the inter-bank sector and the market expectations. The monetary authority manages the target level for the short-term interest rates through open market operations, defining its positions regarding the future monetary policy and the economic outlook.

Roley and Sellon (1995) point out that in the standard view of the monetary transmission mechanism the monetary policy decisions are transmitted to the economy through their effect on market interest rates. A change in the target level for official short-term interest rates may affect the economic agents' expectations that are pricing long-term interest rates and the prices of assets in other markets. These changes have a great impact on economic decisions based on long-term rates, such as consumption decisions in sectors sensitive to future income, as durable goods, and influence the long-term investments, responsible for changing the supply of goods and their prices. The target level for official short-term interest rates has become the main operating target that monetary authorities rely on to affect their goals, such as economic growth, unemployment, and inflation.

However, as stated by León and Sebestyén (2012), the communication to the public regarding monetary policy decisions and visions about the future has become a key tool to achieve effective implementation of monetary policy by central banks. Communication helps manage expectations of future inflation level, economic outlook, and monetary policy decisions in modern times. Different statements made by the monetary authority can affect short and long-term interest rates at different levels, even though the decision about the official rate has been the same. Nowadays, according to León and Sebestyén (2012):

> "A monetary policy decision consists of two parts: the first is the decision itself whether or not to change the target rate, and if so, to what extent. The second part is a statement which is released with (or following) the decision and explains the rationale underlying the decision. Although the first component only affects the policy rate and very short-term market rates, it is part of the whole decision whose aim is to steer market expectation on longer horizons as well, and this objective is achieved through the statement. Hence, these two parts should not be separated, since they exert influence jointly on the markets."

Ehrmann and Fratzcher (2003) stated that, in days that monetary policy decision announcements are released to the public, parts of the decision were already expected by the market, and market prices moved prior to the announcement. Price moves that happen in those days are just the market's reaction to the surprise component in the news. Goldberg and Leonard (2003) argue that, in efficient markets, yields should be influenced only due to the surprise component of economic releases. Defining the surprise component of a monetary policy decision properly is essential to obtaining a reliable evaluation regarding the market effects, such as prices moves, volatility moves, central bank predictability, and monetary policy spillovers. As for the volatility moves, when an announcement presents heterogeneity in the interpretation, the volatility raises. If the announcement helps clarify market views, or market participants have a common understanding of the announcement, volatility should be lower.

Blinder et al. (2008) argued that, over the last two decades, communication has become an increasingly important aspect of monetary policy actions. Communication can be a powerful and important part of the central bank's toolkit since it can affect financial markets, improve the predictability of monetary policy decisions, and potentially helps central banks achieve their macroeconomic objectives. In this sense, research in the empirical literature has addressed measuring the impacts of monetary policy decisions on asset prices, especially on interest rates. The most general approach comprises regressing changes in interest rates on the surprise component of monetary policy actions on monetary meeting days. This methodology is known as "event-study" and was first applied by Cook and Hahn (1989) and followed by many others.

Cook and Hahn (1989) examined the response of the short, medium, and long-term interest rates to changes in the official interest rate of US Treasury funds during the 1970s. The evidence found by the authors suggested the expectation for future official target rate level strongly influences other market interest rates. Some examples of papers that followed the event-study approach are Thornton (1998), Bomfim and Reinhart (2000), Kuttner (2001), Cochrane and Piazzesi (2002), and Bernanke and Kuttner (2005), among others.

Since Cook and Hahn (1989), different time-series empirical approaches have been proposed to investigate the issue of measuring the reactions of monetary policy decisions on asset prices. Some researchers explore econometric models that control for the data characteristics, such as excess kurtosis and conditional heteroskedasticity. A clear advantage of this approach is to obtain more realistic estimated parameters and to assess the effects of a monetary policy decision on conditional volatility besides conditional mean. Also, this approach outperforms the event-study methodology, since the latter uses only one time-invariant coefficient to measure the unanticipated component of the monetary policy.

This more robust empirical approach is explored in the monetary-jump model proposed by León and Sebestyén (2012) to analyze the effect of monetary policy surprise in the interest rate market of the EMU (European Monetary Union). Meurer, Santos and Turatti (2015) follow the same approach to investigate this issue in Brazil. The monetary-jump model closely follows the methodology proposed by Chan (2002), Chan and Maheu (2002), Chan (2003), Maheu and McCurdy (2004), and Rangel (2011). This approach has four crucial advantages compared to the event-study methodology. First, it allows the researcher to assess the extent to which jumps contribute to the total conditional volatility of an asset, in this case, interest rates. Second, the conditional volatility is divided into two components: a jump component that characterizes abrupt variations in the asset and a GARCH component that captures smooth variations. Third, the frequency of surprises in the market regarding the monetary decision may change over time, depending on the market condition. Finally, this approach is more attractive because the excess kurtosis is treated as a systematic pattern of the model.

Empirical literature (Das, 2002; Maheu and McCurdy, 2004; Johannes, 2004; Beber and Brandt, 2010; Rangel, 2011; León and Sebestyén, 2012; Meurer, Santos and Turatti, 2015) about news being incorporated into interest rates point out that the distinction between abrupt and smooth information flows is very important in econometric modeling. They point out two main reasons for this distinction. First, the monetary authority chases the goal of shaping market expectation in a smooth way in order to be perceived as a credible institution. Second, abrupt changes in asset prices usually happen in the process of relevant news being incorporated into the market. This distinct process is treated in a parsimonious way in the monetary-jump model.

Regarding the investigation of the response of US interest rate market to FED monetary policy decisions, a large body of literature exists (Cook and Hahn, 1989; Roley and Sellon, 1995; Thornton, 1998; Bomfim and Reinhart, 2000; Kuttner, 2001; Cochrane and Piazzesi, 2002; Das, 2002). The same follows for the response of EMU yield curve to ECB monetary policy decisions (Hartmann et al., 2001; Gaspar et al., 2001; Perez-Quiros and Sicilia, 2002; León and Sebestyén, 2012). However, few analyses gauge the extent of the reaction of both markets to foreign monetary policy decisions (exceptions are Ehrmann and Fratzcher 2003; Ehrmann and Fratzcher 2005).

In this dissertation, we extend previous works on monetary policy decisions by considering a bivariate version of the monetary-jump model of León and Sebestyén (2012). The bivariate monetary-jump model proposed here is a mixture of the monetary-jump model proposed by León and Sebestyén (2012) and the bivariate GARCH-jump model proposed by Chan (2002, 2003). Besides the variance-targeting scalar VECH parametrization, this model includes a bivariate Poisson function to govern the jump component of the model, allowing the jump intensities to follow a time-varying autoregressive specification and generate correlated jumps in both series in addition to each independent jump. This model can capture smooth volatility movements, as well as abrupt changes in the rates of return of interest rates.

The bivariate monetary-jump model considered in this work has important advantages. Beyond the ability to capture financial data characteristics, such as non-normality, heteroskedasticity, excess kurtosis, and volatility clustering, the bivariate monetary-jump model allows us to assess how the monetary policy decision process affects yield curves prices and volatilities, the monetary policy decision predictability, as well as monetary policy spillover effects in order to understand how one market might influence another, that is if a monetary policy action of ECB or the FED regarding their own official target rate influences the expectations of futures interest rates in the US and EMU term structure of interest rates.

Ehrmann and Fratzcher (2003; 2005) stated the analysis of news spillovers across markets allows us to assess issues regarding markets linkage. First, the reaction of domestic asset prices to foreign news reflects the degree of financial interdependence between the two markets. Second, the analysis of news spillovers addresses the question of why financial markets are interdependent and why interdependence may evolve. Similar to these work, in 2003 the authors evaluated volatility spillover effects trough a model of the GARCH family, the exponential-GARCH specification. However, in 2005 the authors used a weighted least squares technique to make this analysis. Moreover, the bivariate monetary-jump model has another difference, that is the jump component that helps assess relevant news being incorporated to interest rate returns and volatilities.

Another reason to explore FED monetary policy comovements with other central banks' monetary policies is the important role the FED has in global financial cycles. Rey (2015) states that the picture emerging is that of a world with powerful global financial cycles characterized by large common movements in asset prices, capital flows, and leverage. Agrippino and Rey (2012) state the VIX[1] is a powerful index that explains an important part of the global financial cycle, whether for flows or for returns. In this sense, Bekaert et al. (2013), Rey (2015), and Bruno and Shin (2015) suggest one of the determinants of the VIX, and the global financial cycle, is the monetary policy decision in the US regarding the official target rate. The dollar is the main currency of global banking, so it is natural to see how important the monetary decisions regarding the official interest rate target in the US are to determinate credit conditions for the global financial system. In this sense, the US monetary policy conditions are a great determinant of risk and uncertainty and are transmitted to the world through cross-border credit flows, which affect the leverage of global banks and credit growth in the international financial system, therefore inducing sharp movements in both exchange rates and asset prices. These variables are great predictors to explain financial crises, global financial cycles, and asset moves.

León and Sebestyén (2012) argue that by studying the extent to which monetary policy is responsible for jumps in in-

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[1] The VIX is the Chicago Board Options Exchange Market Volatility Index and it is a measure of the implied volatility of S&P 500 index options.

terest rates we can analyze the predictability and effectiveness of the monetary authority over the sample period. Moreover, the jump dynamics explored here can provide a better understanding of the co-movements between US and EMU interest rates futures markets when monetary authorities release monetary policy decision announcements about the official interest rate target, which helps understand the dynamic relationship between jumps and volatilities. These issues have important implications for risk and portfolio management, such as decreasing the overall portfolio risk by lowering portfolio positions in assets with the potential rise in jump and volatility movements in days that occur monetary policy statements.

The investigation of how relevant monetary policy decision announcements, regarding official interest rate target made by the FED and ECB spillover in yield curves, is important for many market participants and academics. In this sense, this work extends the monetary-jump model in León and Sebestyén (2012) to a bivariate structure, which allows the analysis of four objectives: (1) Assess the extent to which not anticipated monetary policy decision contribute to the overall volatility in both term structure of interest rates; (2) analyze the predictability of FED and ECB decisions and announcements; (3) assess if volatility and monetary policy spillover effects between the US and EMU yield curves exist; (4) identify two types of systematic jumps: jumps specific to one interest rate and jumps that occur to both interest rates at the same time, and assess the correlation between jumps in both markets.

The interest rate data used in the empirical application for the US are Treasury constant maturity rates retrieved from FRED database. As for the EMU, the triple-A nominal government bond has been used. The data is provided by the Statistical Data Warehouse of the European central bank. The maturities used were 1, 5, and 7 years for both economic areas with daily frequency from 7 September 2004 to 6 December 2010. The number of observations is 1549. The period includes the economic turmoil of the 2007-2008 period.

This work is divided into five chapters. Chapter 2 exhibits a literature review regarding monetary authority decisions, communication, and monetary policy spillover. In chapter 3, the econometric analysis is detailed, making a brief review of the event-study approach and presenting the monetary-jump model motivation and specification. In chapter 4 the interest rate data descriptive statistics are analyzed, and it is presented the empirical results analysis. Finally, chapter 5 brings concluding remarks.

2 Literature Review

This chapter is divided into three sections. Section 2.1 make the literature review regarding monetary authority decisions. In section 2.2, the evolution and strategies of central banking communication are treated. Finally, section 2.3 brings the discussion about monetary policy spillover.

2.1 Monetary Authority Decisions

In the standard view of the monetary transmission mechanism, the monetary policy decisions are transmitted to the economy through their effect on market interest rates (Roley and Sellon, 1995). The major influence occurs in interest-sensitive sectors of the economy, such as housing, consumer durable goods, and business fixed investment. The impact on these sectors is transmitted to other sectors, affecting the total aggregate demand of the economy. However, the ability of the monetary authority to affect the economy depends on its capacity to influence market expectations, mostly regarding the future path of the term structure of interest rates and economy outlook, since most of the structural decisions are looking forward to the medium and long run.

Walsh (2010) states that central banks in the major industrialized economies implement policies by intervening in the interest rate market to achieve a target level for a short-term interest rate. However, the monetary authority does not control the variables that are likely to be most relevant to affect the aggregate spending, such as the nominal money supply, inflation, or the long-term interest rates. What is left for the monetary policymaker to take control are the reserve aggregates, such as the monetary base, or very short-term interest rates, such as the three ECB official key rates in the EMU and the official target for the FFR in the US.

The actual implementation of monetary policy is complex and involves many rules, traditions, and practices, usually referred to as operating procedures. The objective in investigating these procedures is to define what instruments are actually under the control of the central bank, what determines the optimal instrumental choice, and how this choice affects the way short-term interest rates, reserve aggregates, or the money stock might affect policy actions. Walsh (2010) synthesizes that monetary policy implementation focuses on instruments, operating targets, intermediate targets, and policy goals. Next, we detail the definition for each one of the mentioned topics.

First, instruments are the variables directly controlled by the monetary authority, such as interest rate charging banks for borrowed reserves obtained from the central bank, the reserve requirement ratios that determine the level of reserves commercial banks must hold against their deposit liabilities, and the composition of the central bank's own balance sheet. Second, operating targets are a measure of bank reserves or a very short-term interest rate the policy instruments achieve. Central bank's goals are usually defined in terms of an inflation level or deviations of unemployment from the natural rate. Finally, the intermediate target stays between operating targets and the monetary authority goals because variables such as interest rates, exchange rates, and monetary aggregates, present a higher frequency and have a strong relation with the central bank goals, so the intermediate target can be seen as proxy of the less frequent variables, such as inflation and unemployment.

The instrument choice problem is evaluated by Poole (1970). The author presented how central banks can determinate the optimal choice of monetary policy instrument in an environment where the economy presents a stochastic structure and disturbances with different types of nature and relative importance. This environment defined in the Poole (1970) analysis is remarkable since the central bank set the monetary policy instruments to achieve the operating targets before observing the central bank's goals outcome. Also, the central bank only has immediately available information regarding intermediate targets, such as moves in interest rate markets interest rates, which is not enough information to find the exact nature and relative importance of the economic disturbance in course.

The monetary policy decision process practiced today is defined by Tinbergen (1956) and confirmed by Mishkin (2007) and Walsh (2010). They describe that the decision-making process follows four steps. First, it is made the decision regarding the goals of the monetary policy authority. Second, it is defined the values of the intermediate targets needed to achieve the goals set. Third, the values of the operating targets consistent to reach the intermediate targets are decided. Finally, the choice of the instruments settings that yield the desired values of the operating targets.

Mishkin (2007) stated the Federal Reserve Bank and other major central banks focus on six basic goals when they discuss the objectives of monetary policy: (1) high employment; (2) economic growth; (3) price stability; (4) interest-rate stability; (5) stability of financial markets; (6) stability in foreign exchange markets. However, some conflicts among goals can occur and create hard choices for the central banks, especially in the short run of the economy.

Regarding the choice of target variables, Mishkin (2007) put that the monetary authority must select between two types of variables: interest rates or aggregates (monetary aggregates and reserve aggregates). Since central banks can choose only one type of target variable, some rationale was needed to define a few criteria to make this selection. The selection criteria for the target variable are: it must be measurable, controllable, and have a predictable effect on the goal.

The selection of interest rates over aggregates as target variable exists for several reasons. First, interest rates are measured more precisely and are available more quickly than the monetary aggregates (measurable criteria). Second, the central bank can set interest rates directly affecting the price of bonds through open market operations, and it cannot control the money supply (controllable criteria). And finally, as for the predictability criterion, the monetary authority wants to select the operating target with the better predictable impact in the intermediate target chosen, since the intermediate target is the goal for the operating target. Normally, the desired intermediate target is an interest rate, so the preferred operating target will also be an interest rate, such as official central bank interest rates, which makes the monetary authority select interest rate as target variables when looking for the predictability criterion.

It is a consequence of a previous choice.

To represent the monetary policy decision design used by the majority of central banks all over the most relevant economies, Mishkin (2007) point out that:

> "Suppose that the Central Bank's employment and price-level goals are consistent with a nominal GDP growth rate of 5%. If the Central Bank feels that the 5% nominal GDP growth rate will be achieved by a 4% growth rate for M2 (its intermediate target), which will in turn be achieved by a growth rate of 3.5% for the monetary base (its operating target), it will carry out open market operations (its tool) to achieve the 3.5% growth in the monetary base. After implementing this policy, the Central Bank may find that the monetary base is growing too slowly, say at a 2% rate; then it can correct this too slow growth by increasing the amount of its open market purchases. Somewhat later, the Central Bank will begin to see how its policy is affecting the growth rate of the money supply. If M2 is growing too fast, say at a 7% rate, the Central Bank may decide to reduce its open market purchases or make open market sales to reduce the M2 growth rate."

Tinbergen (1956) classifies economic policies into three structures, the quantitative policy, the qualitative policy, and reforms. The second and third structures can be exemplified as a change in the tax structure and a new social-security system, respectively. Regarding the first structure, both means and ends of a policy can be defined quantitatively and most research is focused on the analysis of the relations between this ends and means, for example, the effects of market expectations or economic aggregates of a change in tax rates or official interest rates.

The present work analysis follows the quantitative approach mentioned in the Tinbergen (1956) definition since the major objective is to assess the contribution of unanticipated monetary policy decision of the FED and ECB about official interest rates to the overall volatility in the term structure of interest rates of both economic areas. This analysis has the main objective to assess the impact of a decision in one operating target (official short-term interest rates) on some intermediate targets (short-term and long-term interest rates) of the monetary policy.

2.2 Monetary Authority Communication

Prior to the 1990s central banks were covered in mystery because they thought that was the right thing to do (Blinder et al., 2008). In that time, the conventional wisdom in central banking circles held that monetary policymakers should say little and say it cryptically. However, in the late 1990s, a new view of how central bank's communications should be has emerged, suggesting monetary policymakers should pursue a greater openness about decisions, because this strategy might improve the efficiency of monetary policy, since expectations about future central bank behavior provide the essential link between short rates and long rates. This new view believes the central bank should provide the market with more information about its own understanding of the fundamental factors guiding monetary policy. This new idea was an attempt to create a virtuous circle that allows markets to follow central bank's expectations, which eventually would turn the central bank predictions of the monetary policy goals less difficult, facilitating the monetary authority necessity to shape market expectations in a smoother way.

Blinder et al. (2008) argued that, over the last two decades, communication has become an increasingly important aspect of monetary policy actions. Communication can be a powerful and important part of the central bank's toolkit since it can move financial markets to improve the predictability of monetary policy decisions and potentially help central banks achieve their macroeconomic objectives. The authors define central bank communication as the information that the monetary authority releases to the public, regarding specific matters, such as the objectives of monetary policy, the monetary policy strategy, the economic outlook, and the outlook for future policy rates decisions.

This revolution in thinking about monetary policy communications created a new era of transparency that began in the major central banks in the world. Public announcements regarding decisions of official interest rates were released with statements that included assessments of the central bank's bias to future changes in monetary policy. As for the FED, these resolutions started in February 1994. As for the ECB, the transparency of monetary policy decisions began since it opened its doors in 1998. Another driver for increasing transparency were the theoretical arguments asking for independent central banks because this view states that the monetary authority must explain their actions and their thinking that underlie those actions.

Blinder et al. (2008) define two approaches, known as "creating news" and "reducing noise", used to evaluate how central bank communication can manage market expectations. Studies that investigate how central bank communication "create news" analyze, for example, how announcements influence asset price moves. On the other hand, research of "reducing noise" focuses, for example, on how monetary authority announcements increase the predictability of central bank actions and reduce financial markets volatility.

Another major discussion of Blinder et al. (2008) is what constitutes optimal communication strategy. There are two main strands in the literature. The first focuses on the impacts of central bank communication on financial markets. As for the second line of research, they focus on how differences in communication strategies across monetary authorities or across time reflect in different economic performance. Although this increasing look to monetary policy communication, the authors state the constitution of a consensus regarding the optimal communication strategy must emerge since many communication strategies are suggested across central banks.

Ehrmann and Fratzscher (2005) conducted research with a "reducing noise" approach. The authors analyzed how central banks should communicate. They concluded that monetary authority committee responsible for the monetary policy decision took a communication strategy more individualistic or collegiate. The collegiate communication strategy is when a conveying consensus of members is transmitted. On the other hand, the individualistic approach happens when members express a diversity of views about monetary policy and economic outlook. The purpose of their work was to analyze which communication approach is more effective in raising the predictability of markets, regarding the upcoming monetary policy and economic outlook.

The authors looked at the communication strategy of the monetary policy decision committee members of the Federal Reserve, the Bank of England, and the European central bank. The period analyzed was from January 1999 to May 2004, and fundamentally different strategies were found between the central banks in this period. FED members express personal views in the inter-meeting period of monetary policy decisions in a more individualistic approach, but the ECB and Bank of England members followed a more collegiate strategy, where statements regarding their decisions reflected the views of the committee.

Ehrmann and Fratzscher (2005) found three major results: (1) Communication that is dispersed and expresses many views about monetary policy decisions reduces the predictability of upcoming decisions of monetary policy; (2) communication dispersion about the economic outlook improve the market ability to anticipate the future path of interest rates and monetary policy; and (3) a higher frequency of communication in an inter-meeting period has helped markets better anticipate monetary policy decisions. These results suggest the monetary authority should distinguish between these two types of communication, regarding monetary policy and economic outlook, to achieve greater effectiveness in the monetary policy and implement more announcements in inter-meeting periods.

Bernoth and Hagen (2003) also used the "reducing noise" type of research to analyze the impact of ECB monetary policy announcements on three aspects of the predictability of the Euribor futures market. The first was the efficiency of the three-month Euribor interest rate futures market, the second was the effect of ECB policy announcements on the volatility of Euribor futures rates, and finally was the effect of ECB policy announcements on the prediction error in Euribor futures rates. The authors analyzed the nineteen futures contracts of three-month Euribor rates settled between March 1999 and September 2003.

The empirical results obtained by Bernoth and Hagen (2003) suggest: (1) Euribor futures rates with a forecast horizon up to four months are unbiased with efficient predictors of future spot rates; (2) futures rates changes at ECB meeting days shows most ECB policy decisions were anticipated correctly by the markets, remaining only a few surprises with low volatility; (3) the predictability of ECB policy decisions seems to have improved during the first years of the EMU; (4) market participants in the new euro interest rate markets - after EMU started - could reduce the prediction error for short-term rates.

A number of studies also followed the "creating news" approach that investigates the impact of central bank's communication in asset prices moves. Brand, Buncic and Turunen (2010) used intraday interest rate market data on monetary policy days to construct indicators of news about ECB monetary policy to study their impact on the euro area yield curve. The authors' results suggested, that during the ECB press conference, the market expectations of the path of monetary policy may change considerably. This effect can be seen on longer-term yields. Another result is that news stemming from ECB communication matters more for long-term interest rates than news about monetary policy decisions.

Perez-Quiros and Sicilia (2002) work is another example of research that followed the "creating news" approach. The authors investigate how the monetary policy decisions of the ECB affected the yield curve in the euro area on days the central bank releases the public statement regarding this information. They followed the event-study methodology and found that, in ECB decision meeting days, the yield curve presents a lower impact than in days of other monetary policy shocks.

This work focuses on the investigation of the impact the US and EMU yield curves suffer on days the FED and ECB announcements, regarding official interest rate decisions, are released to the public. Due to the empirical methodology that was chosen, it is also possible to analyze the extent to which this communication affects interest rate market prices and volatility, the monetary policy decision predictability, and monetary policy spillovers. These factors combined create an interesting analysis that mixes the "creating news" and "reducing noise" approaches.

2.2.1 Announcements and the Surprise Component of Monetary Policy Decision

Ehrmann and Fratzcher (2003) point out that on days that monetary policy decision announcements are released to the public, part of the decision is already expected by the market, and market prices moved prior to the announcement. Price movements that happen in those days are the market reaction to the surprise component in the news. Goldberg and Leonard (2003) argue that, in efficient markets, yields should be influenced only by the surprise component of economic releases. Because of that, it is fundamental to model the arrival of news information to assess how monetary policy affects interest rate markets.

Ehrmann and Fratzcher (2003) used a survey from Reuters as their expectations measure, so that the surprise component of monetary policy decision is the difference between the actual decision and the expectations measure. [1] The authors defined, if the expectations lie within an interval of 12.5 basis points above or below the decision announced, the monetary policy decision is considered anticipated by the market. The expectations data allowed the investigation regarding the predictability of the monetary policy decisions. Ehrmann and Fratzcher (2003) tested the unbiasedness and efficiency of the survey data and found the Reuters survey presents a good quality as they got good results in the tests applied.

However, Ehrmann and Fratzcher (2003) argue that the accuracy of the expectation measure may not capture the market expectations precisely. This idea surged since their estimated coefficient does not reflect a one-to-one relation between an unexpected change in the policy rate and a change in the short interest rate. One reason for this result may be because this survey was conducted prior to the announcements, and market expectations can change in the meantime. In this sense, defining the surprise component of monetary policy decision properly is essential to obtain reliable evaluation regarding the market effects, such as prices moves, volatility moves, central bank predictability, and monetary policy spillovers.

Another difference between the empirical approach adopted

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[1] Reuters survey is based on a poll of 25-30 market participants that express their expectation for the monetary policy decision. Reuters conducted this survey on Fridays before each meeting about central bank decision.

in this work and the majority of communication existing literature is the evaluation of announcements effects on the conditional volatility of interest rates. Ehrmann and Fratzcher (2003) argue that the volatility effects of announcements depend on the heterogeneity of beliefs and expectations of market participants. Volatility rises when an announcement presents heterogeneity in the interpretation. On the other hand, if the announcement helps clarify market views and market participants have a common understanding of the announcement, volatility should be lower. Ehrmann and Fratzcher (2003) results show monetary policy decision reduced the domestic volatility in the period covered, and the transatlantic volatility spillovers have also declined.

2.3 Monetary Policy Spillover

The analysis of interest rate market reactions to both domestic monetary news and foreign monetary policy decisions is presented by Ehrmann and Fratzcher (2003). Precisely, the authors investigated how interest rate markets in the US, Germany, and the Euro area react to monetary policy announcements made by the FED, Bundesbank, and ECB. They used a bivariate exponential GARCH (E-GARCH) structure to analyze the level of interdependence between interest rate markets, regarding domestic and foreign monetary policy decisions. This methodology allowed the author to measure news and spillover effects for the conditional means and the conditional variances. The period of scheduled and unscheduled meetings covered was from January 1993 to February 2002 (1993-1998 for Germany, 1999-2002 for the Euro area, and 1993-2002 for the US). The selected period made it possible to compare the situation before and after the EMU.

Ehrmann and Fratzcher (2003) stated three channels exist through which foreign announcements, regarding monetary policy decisions, may affect domestic markets; they defined this channels as:

> "First, foreign news may be relevant for domestic monetary policy authorities if these target 'external' variables, such as the exchange rate. Second, the integration of global financial markets might lead to spillover effects. A change in monetary policy in the US, for instance, will affect interest rate markets in other countries via capital flows and the elimination of arbitrage possibilities. A third channel works through real integration, namely if foreign monetary policy decisions change domestic macroeconomic conditions, for example, through effects on trade with the other country. In this sense, foreign monetary policy decisions may provide news not only about economic conditions abroad but also about the prospects of the domestic economy."

The results presented by Ehrmann and Fratzcher (2003) suggested interest rates respond strongly to domestic monetary policy. However, the effect of news, regarding the foreign monetary policy decisions, also exists but varies through the markets analyzed by the authors. FED announcements affect the German and the Euro area yield curves, whereas the US interest rate market rarely responds to ECB and Bundesbank decisions. Another major result is that only the German interest rate market presented a volatility increase when the domestic central bank released the statement. This fact may exist because monetary policy strategies and decisions of the FED and ECB became clearer to the market participants over time, generating lower volatility and less uncertainty on days around policy decisions.

Ehrmann and Fratzcher (2003) find that, after the EMU, a greater interdependence between US and Euro area yield curves[2] occurred and a much larger level of volatility were transmitted from one market to the other. Also, FED news carries over to the euro area at all maturities, but ECB statements of monetary policy decision affect the US market only at short maturities. Over time, market understanding and anticipation of domestic and foreign monetary policy decisions have improved with the general linkage of these interest rate markets.

Rigobon and Sack (2004) estimated the response of asset prices to changes in monetary policy. The authors developed a new estimator that is based on the heteroskedasticity that exists in high-frequency data, and they implemented this method using two alternative approaches - simple instrumental variables regression and generalized method of moments. The research reported that the response of market interest rates and equity prices to changes in monetary policy can be identified based on the increase in the variance of policy shocks that occurs on days of FOMC meetings and of the Chairman's semi-annual monetary policy testimony to US Congress.

Rigobon and Sack (2004) results indicated that an increase in US short-term interest rates results in a decline in stock prices and in an upward in the US and Euro yield curve that be-

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[2] The market interest rates Ehrmann and Fratzcher (2003) used were interbank rates for Germany (FIBOR) and the euro area (EURIBOR), and treasury bill rates for the USA, all of which are available at maturities of 1, 3, 6 and 12 months.

comes smaller at longer maturities. According to the estimates, a 25 basis point increase in the three-month interest rate results in a 1.7% decline in the S&P 500 index and a 2.4% decline in the Nasdaq index. As for the market interest rates, a 25 basis points increase in the three-month US rate results in an increase of more than 25 basis points in near-term Eurodollar futures rates, with similarly increases in short- and intermediate-term Treasury yields. However, for both money markets, the effect gradually diminishing as the contract horizon lengthens.

Ehrmann and Fratzcher (2005) is another example of research that looks at the interdependence between the US and the Euro area yield curves, regarding the effects of monetary policy decisions. However, the authors also analyzed the impacts of macroeconomic news. The authors found that implementing the EMU increases the interdependence between US and Euro area daily interest rates. Spillover effects from the US to the EMU are stronger than in the opposite direction. However, the developments in the Euro area markets spillover to the US. They covered the yield curves for the period 1993 to 2003.

To identify why the US and EMU interest rate markets have become more interdependent and why some US news has turned into such important determinants of EMU yield curve, Ehrmann and Fratzcher (2005) argue that some US announcements are released before Euro area news, suggesting that US news has become a leading indicator for the Euro area participants in the formation of their expectations. This hypothesis may be, in part, explained by the increased real integration of the two economies.

Another reason for the increasing interdependence between US and EMU is the role of the FED monetary policy decisions in global financial cycles. Bruno and Shin (2015) state that FED monetary policy decisions determine the leverage appetite of global banks since banks are intermediaries in the financial system and their financing costs are closely tied to the official interest rate chosen by the FED. In this sense, monetary policy may directly affect the economy through greater risk-taking by the banking sector. The authors report that a contractionary shock to FED monetary policy leads to a decrease in cross-border capital flows in the banking sector. The global financial cycle follows the FED monetary policy decision regarding the target rate and is described by Bruno and Shin (2015):

> "Lowering of bank funding costs in financial centers gives an initial impetus for greater risk-taking in cross-border banking, and any initial appreciation of the currency of the capital-recipient economy strengthens the balance sheet position of the borrowers. From the point of view of the banks that have lent to them, their loan book becomes less risky, relaxing the funding constraints for banks and creating spare capacity to lend even more. In this way, the initial impetus is amplified through a reinforcing mechanism in which greater risk-taking by banks dampens volatility, which elicits even greater risk-taking, thereby completing the circle."

This information regarding the transmission of FED monetary policy through international capital flows is important to evaluate the linkage between US and EMU interest rate market, since international capital flows affects the increase of leverage and creates a sharp, real appreciation of currencies for the recipient economies, factors that are significant predictors of financial crises, creating both assets and macroeconomic variables fluctuations (Gourinchas and Obstfeld 2012). In this sense, FED monetary policy decisions, regarding the official interest rate target, affect the EMU interest rate market through the three channels reported by Ehrmann and Fratzcher (2003).

In other words, FED monetary policy decisions became an essential external variable that influences ECB decisions (First Channel). Moreover, FED decisions have a major role determining both global financial cycles integration (Second Channel) and real integration between US and EMU economies (Third Channel). This happens because of the influence that FED decisions have in cross-border capital flows, financial markets fluctuations, and domestic macroeconomic variables.

The belief the ECB monetary policy follows the FED decisions is widely spread with market participants. However, supporting this view empirically is not an easy task. Belke and Gros (2005) investigated through Granger causality tests if the proposition that a systematic asymmetric leader-follower relationship exists between the ECB and the FED can be verified. This supposed overview it is not confirmed by the authors. They conclude the relationship between the interest rate decisions of the FED and the ECB change over time.

Belke and Gros (2005) covered the period from 1989 to 2003 and find evidence of a significant influence of the US on the EMU after September 2001. Little was found in the other direction. The author stated it is hard to determine the deeper reasons for changes in correlations over time. However, since the asymmetric leader-follower relationship appears only after a major shock that increases global risk and uncertainty, the reason for this phenomenon may be the less flexibility of the Euro area economy.

This leader-follower relationship between the FED and ECB in times that occur common shocks, especially those that increase global risk and uncertainty, may also be explained because of the "option value of waiting" strategy of the ECB. This means that the ECB reacts later to global shocks that create a large degree of uncertainty. So, during the firsts periods post shock, FED monetary policy decisions tend to drive ECB decisions.

In this section, was covered some reasons why is important to investigate the monetary policy spillover effects between the FED and ECB. It is presented the current literature that points out the existence of three channels through which foreign announcements, regarding monetary policy decisions, may affect domestic markets. Moreover, was presented some factors that put FED monetary policy decisions responsible for foreign interest rate market fluctuations.

3 Econometric Analysis of Monetary Policy Decisions

In this section, the two main methodologies used to assess monetary policy decisions will be discussed. First, the event-study approach and several works mentioned in the literature will be reviewed. Second, limitations regarding the event-study methodology and how the monetary-jump model can improve this issues will be exposed. Moreover, the importance of using the bivariate monetary-jump model to evaluate monetary decisions spillover will be addressed. Finally, the econometric model specification and the existing literature employing the monetary-jump model will be presented.

3.1 Event-Study Approach

The methodology proposed by Cook and Hahn (1989) is predominant to assess the market reaction to the monetary policy. The evidence presented supports the theory of expectations and corroborate the findings from other studies about the effect of monetary policy on market interest rates. The authors found that for the US bond market, the shorter the maturity, the greater the impact of changes in the official interest rate. In their approach, the change in market interest rate is a function of the change in the official target rate. Formally,

$$\Delta r_t^i = \alpha + \beta \Delta Target_t + \epsilon_t, \qquad (1)$$

where Δr_t^i is the change in market interest rate with maturity i, $\Delta Target_t$ is the change in the official target rate and β measure the monetary policy surprise.

Many authors followed the methodology proposed by Cook and Hahn (1989). Dale (1993) measured the response of short-term market interest rates to the Bank of England actions regarding monetary policy. The author found evidence supporting the idea that the effect of monetary policy decisions has less influence for longer maturities.

Another example in the international literature is Roley and Sellon (1995). The authors investigated the relationship of monetary policy decisions on long-term interest rates. The authors argued that the standard vision about the transmission mechanism of the monetary policy is based on a consistent relationship between monetary policy decisions and agents' expectations in the interest rate market, i.e., the monetary authority uses a policy with strong and positive effect on the level of the term structure of interest rates.

Unlike previous empirical literature showing long-term interest rates had a weak and insignificant connection to changes in monetary policy decisions, the analysis made by Roley and Sellon (1995) suggests a strong connection, in which, long rates seem to anticipate changes in monetary policy, moving in advance to the policy implemented by the monetary authority.

Following the methodology proposed by Cook and Hahn

(1989), Balduzzi, Bertola and Foresi (1994) explore the relationship between the official target rate on the overnight FED Funds[1] and long-term maturity rates. Hardy (1998) developed a technique to separate the anticipated and unanticipated components of changes in the official target rate and estimated the response of interest rates in the German market to changes in the official target rate of the German central bank.

Thornton (1998) investigated the reactions of short and long-term interest rates to changes in the FED funds official target rate. The analysis was made from October 1989 to December 1997 and focused on three points: (1) if the interest rate market reaction varies with the magnitude of target rate changes; (2) if the reaction is larger when accompanied by a discount rate[2] change; (3) if the reaction is larger when there is a policy reversal. The author reported the size of the target rate change does not appear to affect the market reaction, discount rate changes seem to matter for the inflation outlook, and finally, changes in policy increase market rate reactions.

Bomfim and Reinhart (2000) examined the effects on asset prices of greater transparency in the FED communication regarding monetary policy decisions. The authors covered the period from 1989 up to 1999 and found that, after 1994, this new strategy of openness was implemented. Bomfim and Reinhart (2000) concluded that the press releases have not been spe-

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[1] FED funds official overnight rate target is imposed by the Federal Reserve Bank itself

[2] The FED discount rate is the interest rate set by the FED on loans offered to eligible commercial banks or other depository institutions as a measure to reduce liquidity problems and the pressures of reserve requirements. The discount rate allows the FED to control the supply of money and is used to assure stability in the financial markets.

cific enough to shape market expectations in any consistent and significant manner since monetary policy announcements in that period were not generating a significant effect on financial market prices.

Kuttner (2001) also follows a similar methodology applied by Cook and Hahn (1989) and Hardy (1998) to evaluate the anticipated and unanticipated components of the decisions made by the monetary authority about the FED official target rate. Kuttner (2001) found a large and significant relationship between unanticipated components of monetary policy and market interest rates. The author argued surprise target rate changes help to explain the short end of the yield curve, however, have little effect on expectations of future monetary policy decisions.

Analyzing the equity prices reaction to changes in monetary policy decisions, Bernanke and Kuttner (2005) found a strong and consistent response of the stock market to FED unexpected monetary policy decisions. The author found that an unexpected 25-basis-point target rate cut of the FED would lead to an increase in stock prices on the order of one percent. The authors reported monetary policy surprises create different reactions across industry-based portfolios.

3.1.1 Event-Study Approach in Brazil

Following the traditional methodology introduced by Cook and Hahn (1989), many authors sought to analyze the dynamics of the market reaction to changes in the Brazilian monetary policy. Tabak (2004) and Buchholz et. al. (2012) employed a similar methodology to test market reaction to changes in official target rate by the Brazilian central bank.

Oliveira and Ramos (2011) made an adaptation of Kuttner (2001) for the Brazilian market to identify unanticipated monetary shocks to investigate how the domestic yield curve reacts to these shocks. As expected, the unanticipated component of the monetary policy generated shocks (i.e., surprise in the market) and affected the term structure of interest rates.

Unanticipated monetary shocks are defined by the authors as the difference between the average overnight rates before and after the COPOM meeting disclosure. To obtain the market reaction to these monetary surprising shocks, the authors estimated the correlation between market surprises and the term structure of interest rates, using interest rates future contracts with alternative maturities.

Focusing the analysis on the period after the introduction of Brazilian inflation targeting regime, Nunes, Holland and Silva (2011) analyzed how official target rate decisions affected the yield curve. The authors concluded that the surprise effect on the yield curve was lower than the past because the market could adjust their expectations about the COPOM decisions much earlier than before the inflation target regime was implemented. The authors found that the explanatory power of the monetary policy decisions increased after the inflation target regime used by the Brazilian central bank, and that the monetary policy surprises in Brazil affected the yield curve, although this effect diminishes for longer maturities.

3.2 Monetary-Jump Model Approach

In this section, the motivation behind the choice of not using the event-study approach in favor of the monetary-jump model to assess the market reaction to the monetary policy decision will be discussed. Moreover, the motivation for extending the monetary-jump model to a bivariate structure will be mentioned.

The decision in favor of the monetary-jump model is based on two major facts. First, the methodology introduced by Cook and Hahn (1989) presents an important limitation. The unanticipated component of monetary policy is measured by a single factor that does not vary in time. This limitation is important as it variations are expected to happen over time in the market reaction, regarding the decisions of monetary policy, due to changes in market expectations and macroeconomic conditions. So, the unanticipated component of monetary policy cannot be modeled by a time-invariant structure. Second, the interest rate data usually display features such as the characteristic of non-normality, excess kurtosis, heteroskedasticity, and volatility clustering. Note that both factors are overcome in the methodology proposed by León and Sebestyén (2012) to measure the unanticipated component of monetary policy.

The monetary-jump model used here is also known as the GARCH-jump model. Empirical literature (Das, 2002; Chan, 2002; Chan and Maheu, 2002; Chan, 2003; Maheu and McCurdy, 2004; Johannes, 2004; Matovu, 2007; Beber and Brandt, 2010; Rangel, 2011; León and Sebestyén, 2012; Meurer, Santos and Turatti, 2015) left plenty of arguments to support this modeling strategy:

(1) The monetary-jump model mixes smooth volatility movement in the GARCH structure with abrupt changes in re-

turns in the jump part. The variance[3] of the interest rate return will be driven not only by the variance of the normal disturbances but also by the jumps dynamics. This is important because central banks want to shape market expectations in a smooth way; however, sometimes, the process of news being incorporated into the market can generate abrupt movements in asset returns;

(2) ARCH and GARCH models have been mostly influential in the empirical literature that use economic and financial data. This parsimonious structure implies heteroskedasticity and volatility clustering, i.e. periods of high (low) volatility are likely to be followed by periods of high (low) volatility;

(3) The Poisson-jump structure is useful to accommodate stylized facts of the data, such as abrupt changes in interest rates. Press (1967) introduced an independent process with the arrival of jumps governed by a Poisson distribution so that excess kurtosis can be accommodated by a systematic pattern and not only by a fat tail distribution;

(4) The monetary-jump model allows for a structure with time-varying jump intensities controlling the arrival of jumps, which helps to understand the relationship between the jump dynamics and volatilities. This structure captures changes over time that may exist in market conditions and in the frequency of surprises;

Although a vast literature exists on the response of domestic interest rate markets to domestic monetary policy de-

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[3] In the bivariate structure, the covariance between two assets will be driven not only by the covariance between the normal disturbances but also by the jumps dynamics.

cisions (Cook and Hahn, 1989; Balduzzi, Bertola and Foresi, 1994; Roley and Sellon, 1995; Thornton, 1998; Gaspar et al., 2001; Kuttner, 2001; Cochrane and Piazzesi, 2002; Das, 2002; Perez-Quiros and Sicilia, 2002; Bernoth and Hagen, 2003; Brand, Buncic and Turunen, 2010; León and Sebestyén, (2012); Meurer, Santos and Turatti, 2015), relatively little is known about the reactions of yield curves to foreign monetary policy decisions (exceptions are Ehrmann and Fratzcher, 2003; Ehrmann and Fratzcher, 2005).

Ehrmann and Fratzcher (2003; 2005) stated that the reaction of domestic asset prices to foreign news reflects the degree of financial interdependence between the two markets. Rey (2015), Miranda Agrippino and Rey (2012), Bekaert et al. (2013), Gourinchas and Obstfeld (2012) and Bruno and Shin (2015) point out that FED monetary policy decisions are a great determinant of risk and uncertainty sentiment and indicate the cost of credit for global banks. These two factors are important as global banks define the quantity of loans they want to be exposed, which helps define the credit leverage ratio, gross capital flows, and exchange rates for advanced and emerging economies, all great predictors of financial crises and responsible for the global financial cycles and asset moves.

The investigation of how relevant monetary policy decision announcements - regarding official interest rate target made by the FED and ECB - spillover in both interest rate markets is important for many market participants and to the economic theory. In this sense, this work extends the monetary-jump model presented in León and Sebestyén (2012) to a multivariate structure, in particular, the bivariate parametrization, which allows the analysis of four major factors: (1) assess the extent to which unanticipated monetary policy decision contributes to the overall volatility in term structure of interest rates; (2) analyze the predictability of FED and ECB decisions and announcements; (3) assess if volatility and monetary policy spillover effects between the US and EMU yield curves exist; (4) identify two types of systematic jumps: jumps specific to one interest rate and jumps that occur to both interest rates at the same time and assess the correlation between jumps in both markets.

3.3 Econometric Specification of the Bivariate Monetary-Jump Model

The fundamental idea of the bivariate monetary-jump model is to assess how domestic monetary policy decisions spillover to a foreign interest rate market, therefore affecting the dynamics of jumps, returns, and volatilities of interest rates. The model employed in this work is a mixture of models specifications, such as the bivariate GARCH-jump model used by Chan (2002;2003), and the univariate monetary-jump model used by León and Sebestyén (2012) and Meurer, Santos and Turatti (2015).

We begin by specifying the components of returns. Given an information set at time $t-1$, which consists of the history of returns $\phi_{t-1} = (r_{t-1}, ..., r_1)$, the two stochastic innovations, $\epsilon_{1,t}$ and $\epsilon_{2,t}$, drive interest rates returns in a process of the form:

$$r_t = \mu + \epsilon_{1,t} + \epsilon_{2,t}, \tag{2}$$

where r_t is a 2 x 1 vector of returns consisting of a constant mean μ, a random disturbance $\epsilon_{1,t}$, and a jump innovation $\epsilon_{2,t}$. The impact of unobservable normal news innovations is assumed to be captured by the return innovation component $\epsilon_{1,t}$. This component of the news process drives smoothly evolving changes in the conditional variance of returns. The second component of the latent news process,$\epsilon_{2,t}$, drives infrequent large moves in returns. The impacts of these unusual news events are reffered to as jumps.

The random disturbance, $\epsilon_{1,t}$, and the jump innovation, $\epsilon_{2,t}$, follow a bivariate normal distribution with zero mean and variance covariance matrix H_t and Δ_t, respectively. The normal disturbance are assumed to be contemporaneously independent of the jump innovation.

In the monetary-jump model proposed here, it is possible to model the characteristics of the time series of interest rates and create an internal structure to assess the effect of the surprise component of the market. This component is treated as the jump structure and is defined as the days in which the ex-post probability of at least one jump is bigger than 50%.

The subsections that follow describe our parametrization for these two stochastic components of returns. Subsection 3.4.1 begin specifying the process governing jumps and the distribution of jump sizes. Subsection 3.4.2 describe the time-varying jump intensity structure. Section 3.4.3 specify the conditional variance dynamics of both components. Finally, subsection 3.4.4 threat the model estimation with the construction of the log-likelihood function and the filter that allow us to optimally infer when jumps arrive.

3.3.1 The Jump Innovation and Jump-Size Distribution

Within any single time period t, an interest rate may experience n number of jumps depending on the news content entering the market. The jump component is constructed as a sum of a series of random variables Y_i:

$$\sum_{i=1}^{n} Y_i = Y_1 + Y_2 + Y_3 + ... + Y_n, \tag{3}$$

each of these random variables can be interpreted as a jump size which is governed by a normal distribution with constant mean υ and constant variance δ^2. The jump-size distribution for the two interest rates can be characterized as,

$$Y_{1t,i} \sim N(\upsilon_1, \delta_1^2), \tag{4}$$

and

$$Y_{2t,j} \sim N(\upsilon_2, \delta_2^2), \tag{5}$$

where i and j correspond to each series of random jumps. The jump component affecting returns in the interval $[t-1,t]$ is

$$J_t = \begin{bmatrix} \sum_{i=1}^{n_{1t}} Y_{1t,i} \\ \sum_{j=1}^{n_{2t}} Y_{2t,j} \end{bmatrix}. \tag{6}$$

Therefore, the jump innovation $\epsilon_{2,t}$ in period t is expressed in a bivariate framework as,

$$\epsilon_{2,t} = J_t - E_{t-1}[J_t|\phi_{t-1}] = \begin{bmatrix} \sum_{i=1}^{n_{1t}} Y_{1t,i} - E_{t-1}(\sum_{i=1}^{n_{1t}} Y_{1t,i}) \\ \sum_{j=1}^{n_{2t}} Y_{2t,j} - E_{t-1}(\sum_{j=1}^{n_{2t}} Y_{2t,j}) \end{bmatrix}, \tag{7}$$

which is the sum of the stochastic n_{1t} and n_{2t} jumps, which arrived over the time interval $[t-1,t]$ adjusted by

$$E_{t-1}[J_t|\phi_{t-1}] = \begin{bmatrix} E_{t-1}(\sum_{i=1}^{n_{1t}} Y_{1t,i}) \\ E_{t-1}(\sum_{j=1}^{n_{2t}} Y_{2t,j}) \end{bmatrix} = \begin{bmatrix} (\lambda_{1t}+\lambda_{3t})\upsilon_1 \\ (\lambda_{2t}+\lambda_{3t})\upsilon_2 \end{bmatrix}, \tag{8}$$

so that $\epsilon_{2,t}$ is conditionally zero mean. In other words, the jump component enters the mean equation with an expected value of zero, which is achieved by subtracting the expected value from the series of random jumps $E_{t-1}[J_t|\phi_{t-1}]$.

The two discrete counting variables n_{1t} and n_{2t} governing the arrival of jumps between $[t-1,t]$ are constructed via three independent Poisson variables, namely n_{1t}^*, n_{2t}^*, and n_{3t}^*. The later Poisson variable, n_{3t}^*, is the one responsible for govern the common jumps that create correlation between n_{1t} and n_{2t}.

Each one of these variables is distributed as a Poisson random variable with parameter $\lambda_i > 0$ and probability density function given by

$$P(n_{it}^* = p|\phi_{t-1}) = \frac{e^{-\lambda_i}\lambda_i^p}{p!}. \tag{9}$$

The expected value and variance of n_{it}^* are each equal to λ_{it}, which is also referred to as the expected number of jumps or the jump intensity. $\lambda_{it} = E(n_{it}^*|\phi_{t-1})$ can be measured as the ex ante number of jumps between the period $[t-1, t]$ for the Poisson variable i. The joint probability density function for the three independent Poisson variables is

$$P(n_{1t}^* = i, n_{2t}^* = j, n_{3t}^* = k|\phi_{t-1}) = \frac{e^{-\lambda_1}\lambda_1^i}{i!}\frac{e^{-\lambda_2}\lambda_2^j}{j!}\frac{e^{-\lambda_3}\lambda_3^k}{k!}. \tag{10}$$

The correlated jump intensities are defined as a bivariate Poisson process of the form:

$$n_{1t} = n_{1t}^* + n_{3t}^* \quad \text{and} \quad n_{2t} = n_{2t}^* + n_{3t}^* \tag{11}$$

By construction, each of these counting variables, n_{1t} and n_{2t}, is capable of generating independent jumps as well as correlated jumps. The independent jumps are initiated by n_{1t}^* and n_{2t}^* in the time period t. The correlated jumps are produced by the additional Poisson variable n_{3t}^* which contributes to jumps in both series. Using the change of variables method and integrating out n_{3t}^{*} yields the joint probability density function for n_{1t} and n_{2t} as:

$$P(n_{1t} = i, n_{2t} = j|\phi_{t-1}) = \sum_{k=0}^{min(i,j)} e^{-(\lambda_1+\lambda_2+\lambda_3)} \frac{\lambda_1^{i-k}\lambda_2^{j-k}\lambda_3^{k}}{(i-k)!(j-k)!k!}, \tag{12}$$

and the expected number of jumps is equal to

$$E(n_{1t}) = \lambda_1 + \lambda_3, \tag{13}$$

and

$$E(n_{2t}) = \lambda_2 + \lambda_3. \tag{14}$$

3.3.2 Modeling Time-Varying Jump Intensity

Since the frequency and the probability of jumps may change over time depending on the market conditions and monetary policy surprises, it was allowed all three Poisson parameters to vary over time. The same time-varying jump intensity specification was used for the two independent jump and for the correlated jump. The autoregressive conditional jump intensity (ARJI) structure introduced by Chan and Maheu (2002) and used by Chan (2003) and Maheu and McCurdy (2004) was considered in this work.

The conditional jump intensity, $\lambda_{it} = E(n_{it}^{*}|\phi_{t-1})$, is the expected number of jumps conditional on the information set ϕ_{t-1}. The dynamics governing λ_{it} are parameterized in the ARJI framework as a process in the form:

$$\lambda_{it} = \lambda_0 + \sum_{p=1}^{r} \zeta_i \lambda_{it-p} + \sum_{p=1}^{s} \gamma_i \xi_{it-p}, \tag{15}$$

the conditional jump intensity for the Poisson variable n^*_{it} at time t, λ_{it}, is related to r past lags of conditional jump intensity and s past lags of the intensity residual, ξ_{it}. In the estimation process, the length of both lags is set to $r = s = 1$. A natural measure of the persistence of this process is ζ_i. The restrictions $\zeta_i = \gamma_i = 0$ yield a constant jump intensity structure. ξ_{it-p} represents the innovation to λ_{it} as measured ex post by the econometrician. This measurable shock, or jump intensity residual, is the unpredictable component affecting the inference about the conditional mean of the counting process n^*_{it}, which is defined as,

$$\xi_{it-1} = E[n^*_{it-1}|\phi_{t-1}] - \lambda_{it-1} = \sum_{j=0}^{\infty} jP(n^*_{it-1} = j|\phi_{t-1}) - \lambda_{it-1}, \tag{16}$$

where $P(n^*_{it-1} = j|\phi_{t-1})$ is called the filter and is our ex post inference on n^*_{it-1} given time $t-1$ information. $E[n^*_{it-1}|\phi_{t-1}]$ is our ex post assessment of the expected number of jumps that occurred from $t-2$ to $t-1$. λ_{it-1} is by definition the conditional expectation of n^*_{it-1} given the information set ϕ_{t-2}. Therefore, ξ_{it-1} represents the change in the econometrician conditional forecast of n^*_{it-1} as the information set is updated ($\xi_{it-1} = E[n^*_{it-1}|\phi_{t-1}] - E[n^*_{it-1}|\phi_{t-2}]$). A stationary restriction to ensure that $\lambda_{it} > 0$, for all t, can be set with the sufficient conditions $\lambda_0 > 0$, $\zeta_i \geq \gamma_i$, and $\gamma_i \geq 0$. To estimate the three equation of the ARJI model, one for each Poisson variable n^*_{1t}, n^*_{2t} and n^*_{3t}, starting values of λ_{it} must be set. We set λ_{i1} to the unconditional jump intensity value in equation (17). The unconditional jump intensity is equal to

$$E[\lambda_{it}] = \frac{\lambda_{it}}{1 - \zeta_i}. \tag{17}$$

As for the jumps size means, a constant specification for all jump arrival process was used. The time-varying jump intensity structure of this work followed the specifications set by Chan and Maheu 2002, Chan 2003, and Maheu and McCurdy 2004.

3.3.3 Conditional Variance Dynamics

The conditional variance of returns is decomposed into two separate components: a smoothly conditional variance component for the normal disturbance and the conditional variance component related to the jump innovation. The conditional variance of returns is

$$Var(r_t|\phi_{t-1}) = Var(\epsilon_{1,t}|\phi_{t-1}) + Var(\epsilon_{2,t}|\phi_{t-1}). \tag{18}$$

The first component of the conditional variance of returns, $Var(\epsilon_{1,t}|\phi_{t-1})$, is defined by the variance-covariance matrix H_t that follows a variance-targeting scalar VECH specification suggested in Engle and Mezrich (1996),

$$H_t = (1-\alpha-\beta)C + \alpha(\epsilon_{1t-1}\epsilon'_{1t-1}) + \beta H_{t-1}, \tag{19}$$

where $C = \frac{1}{T}\sum_{t=1}^{T}\epsilon_{1t}\epsilon'_{1t}$. The estimated parameters in the structure are α and β. Covariance-stationarity is obtained through the restriction $\alpha+\beta<1$.

The second component of the conditional variance of returns, $Var(\epsilon_{2,t}|\phi_{t-1})$, is defined by the variance-covariance matrix for the jump innovation, $\Delta_{ijk,t}$. This term is derived from the assumption that the correlation between the jump sizes is constant across contemporaneous equations and zero across time, i.e. $Corr(Y_{1t}, Y_{2t}) = \rho_{12}$ and $Corr(Y_{1t}, Y_{2s}) = 0$, $t \neq s$. Therefore, conditional on i and j independent jumps and k correlated jumps, the variance covariance matrix for the jump component will be

$$\Delta_{ijk,t} = \begin{bmatrix} (i+k)\delta_1^2 & \rho_{12}\sqrt{(i+k)(j+k)}\delta_1\delta_2 \\ \rho_{12}\sqrt{(i+k)(j+k)}\delta_1\delta_2 & (j+k)\delta_2^2 \end{bmatrix}. \tag{20}$$

The variance covariance matrix $H_{ijk,t}$ that represents the full monetary-jump model will always be positive definite as long as H_t is positive definite. By construction, the variance covariance matrix for the jump component $\Delta_{ijk,t}$ is well defined given i, j, and k jumps and, therefore, $H_{ijk,t}$ as the sum of two positive definite matrix will be positive definite, i.e.

$$H_{ijk,t} = H_t + \Delta_{ijk,t}. \tag{21}$$

The second moment of returns can be specified as:

$$Var(r_{1,t}|\phi_{t-1}) = \sigma_{1,t}^2 + (\lambda_{1t} + \lambda_{3t})(\upsilon_1^2 + \delta_1^2), \tag{22}$$

$$Var(r_{2,t}|\phi_{t-1}) = \sigma_{2,t}^2 + (\lambda_{2t} + \lambda_{3t})(\upsilon_2^2 + \delta_2^2), \tag{23}$$

where $\sigma_{1,t}^2$ and $\sigma_{2,t}^2$ are the main diagonal components of the variance-covariance matrix H_t, λ_{1t}, λ_{2t} and λ_{3t} are the expected number of jumps, υ_1^2 and υ_2^2 are the squared jump mean parameters, δ_1^2 and δ_2^2 are the jump variance parameters for the two Poisson processes. The second term in the right-hand side of equation (22) and (23), namely $(\lambda_{1t}+\lambda_{3t})(\upsilon_1^2+\delta_1^2)$ and $(\lambda_{2t}+\lambda_{3t})(\upsilon_2^2+\delta_2^2)$, are the jump contribution to the total conditional variance of returns.

3.3.4 Model Filter and Estimation

Having observed r_t and using Bayes rule we can infer the ex-post probability that j jumps occurred at time t, with the filter defined as,

$$P(n_{it}^* = j|\phi_{t-1}) = \frac{f(r_t|n_{it}^* = j, \phi_{t-1})P(n_{it}^* = j|\phi_{t-1})}{P(r_t|\phi_{t-1})}, \quad \text{j = 1,2,3 ...}, \tag{24}$$

where $f(r_t|n_{it}^* = j, \phi_{t-1})$ denote the conditional density of return given j jumps occur, and the information set ϕ_{t-1}. This filter is an important component because it can be used for inference on future occurrences of jumps. The probability that at least one jump occurs can be obtained from

$$P(n_{it}^{*} \geq 1|\phi_{t-1}) = 1 - P(n_{it}^{*} = 0|\phi_{t-1}), \tag{25}$$

whereas the ex-post number of jumps is

$$E(n_{it}^{*}|\phi_{t}) = \sum_{p=0}^{\infty} jP(n_{it}^{*} = j|\phi_{t}). \tag{26}$$

Combining the GARCH model with the jump process, the probability density function for r_t given i independent jumps in the first interest rate, j independent jumps in the second interest rate, and k correlated jumps in both interest rates is defined as,

$$f(r_t|n_{1t}^{*} = i, n_{2t}^{*} = j, n_{3t}^{*} = k, \phi_{t-1}) = \frac{1}{2\pi^{\frac{N}{2}}}|H_{ijk,t}|^{\frac{1}{2}} exp[-\omega_{ijk,t}^{'} H_{ijk,t}^{-1} \omega_{ijk,t}], \tag{27}$$

where $\omega_{ijk,t}$ is the usual error term with the jump component:

$$\omega_{ijk,t} = \epsilon_{it}^{*} - J_{ijk,t} = \left[\begin{array}{c} \epsilon_{1t}^{*} - (i+k)\upsilon_1 + (\lambda_{1t} + \lambda_{3t})\upsilon_1 \\ \epsilon_{2t}^{*} - (i+k)\upsilon_2 + (\lambda_{2t} + \lambda_{3t})\upsilon_2 \end{array} \right], \tag{28}$$

and $H_{ijk,t}$ is defined in (21). Finally, to complete the specification, the conditional density of returns is defined as

$$P(r_t|\phi_{t-1}) = \sum_{i=0}^{\infty}\sum_{j=0}^{\infty}\sum_{k=0}^{\infty} f(r_t|n_{1t}^* = i, n_{2t}^* = j, n_{3t}^* = k, \phi_{t-1})$$

$$\times \quad P(n_{1t}^* = i, n_{2t}^* = j, n_{3t}^* = k|\phi_{t-1}). \tag{29}$$

In the estimation process, we assume that the maximum number of jumps (i,j,k) between the period [t-1,t] is two, in order to simplify the evaluation of the sums of equation (29). The likelihood function represents the likelihood of the parameters set given the observed data set r_t. In order to facilitate the calculation it is used the log-likelihood function, that is simply the sum of the log conditional densities and can be expressed by

$$lnL = \sum_{t=1}^{N} lnP(r_t|\phi_{t-1}). \tag{30}$$

3.4 Existing Literature Employing the Monetary-Jump Model

León and Sebestyén (2012) investigated the effect of the unexpected component of ECB monetary decision announcements into the Euro bond market through different models specifications. The author's used daily observations of the Euro area interest rate market for maturities up to one year and interest rate swap contracts for maturities from one to ten years in the period of February 1999 to June 2010. The authors estimated four models with the univariate structure: (1) A model of constant volatility; (2) a GARCH model; (3) a monetary-jump model with constant volatility; (4) a monetary-jump model with constant jump intensity.

The authors found evidence that the model that better explains interest rates variations on European markets is the monetary-jump model that allows for the jumps to be time-varying and dependent on monetary policy surprises. This model has better performance than the traditional event-study framework found in the literature. León and Sebestyén (2012) concluded that the monetary-jump model outperforms specifications without the jump structure.

León and Sebestyén (2012) results suggest the ECB monetary policy decisions appear to contribute significantly to the arrival of jumps in the European interest rate market. The authors found the following results for the univariate monetary-jump model with Euro data: (1) the jump intensity parameters were insignificant only for the 10-year maturity and remain highly negatively significant for the other maturities; (2) the contribution of jumps to total volatility decreases with maturity; (3) in around a quarter of ECB meeting days occurred at least one jump in interest rate market rates, while in the 2-year yield the proportion was only 1/20; (4) the financial turmoil, such as the 2007/2008, make the identification of jumps more difficult; jumps are less likely to occur in interest rate market over crisis periods; (5) the number of jumps on ECB meetings days rise in financial distress periods but follow no clear path between maturities.

Meurer, Santos and Turatti (2015), implement a monetary-jump model similar to León and Sebestyén (2012) for the Brazilian interest rate market. The authors measured the jump contribution to the total volatility in the term structure of interest rates on the Brazilian inter-bank market and assessed the extent to which non-anticipated COPOM monetary policy decisions are driving these jumps. A major advantage of this approach is that it uses specification for jumps intensities and jumps mean that vary over time and are a function of the first two principal components of the yield curve. Jumps that contribute to measuring the total volatility of interest rates depend on the level and slope factor of the Brazilian term structure of interest rates. This specification is also useful to capture how the market expectations are changing.

Maheu and Mccurdy (2004) investigated how news arrival impact on returns and volatilities of individual stocks and indexes through a univariate GARCH-jump model. The latent news process is postulated to have two separate components, normal and unusual news events, with different impacts on returns, expected volatility, and higher-order moments of the return distribution. The authors found evidence suggesting time dependence in jump intensities for the assets analyzed, using an autoregressive conditional jump intensity parametrization. Maheu and McCurdy (2004) found that the GARCH-jump mixture model provides superior out-of-sample conditional variance forecasts than a benchmark asymmetric GARCH model with fat-tailed innovations.

Beber and Brandt (2010) reported results on jumps parameters for the US Treasury bond futures contracts with different maturities, confirming that expanding the GARCH specification with a term that allows for abrupt variations is important. For all maturities, the authors find sharp rises in jumps parameters for US macroeconomic announcements, such as the

Consumer Price Index (CPI), the Employment Report, and the Producer Price Index (PPI). They observe that jumps intensities are higher for longer maturities and decrease for shorter maturities. The authors investigated daily prices from the 1980s to 2003 and found negative values for jump mean estimates in all maturities because shorter maturities are presented with less negative values. The average jump contribution to total volatility is lower for longer maturities, and the probability of jumps occurring on the same day of a macroeconomic announcement is higher for longer maturities.

Rangel (2011) examined the effect of macroeconomic releases on stock market volatility through a univariate GARCH-jump model with time-varying jump intensity. The fundamental variables considered in the paper include measures of inflation (CPI, PPI), employment (NFP Employment and an Index of Unemployment), and short-term interest rates (FFR). The author reported that, in days of announcements, little impact was found on jump intensities, and the jump intensity responds asymmetrically to macroeconomic shocks. Rangel (2011) pointed out the relevance of incorporating heterogeneous news events to explain different volatility patterns and suggested that jumps play an important role in explaining the effects of market volatility of macroeconomic events that surprise market participants. The author stated the information of macroeconomic surprises has predictive power for jump probabilities that leads to volatility forecast improvements on event days.

Chan (2002, 2003) presented the bivariate GARCH-jump model to analyze smooth and abrupt volatility dynamics in the exchange rate returns. The author assessed the conditional correlation in the jumps dynamics between two distinct returns series. In the presence of jumps, the covariance matrix between currencies is not only driven by the covariance between the normal disturbances, but also by the characteristic of jumps correlation. The bivariate GARCH-jump model can be useful to price assets, model the risk premium in foreign exchange options, and to model the optimal hedge rate in the commodities market. This fact has important implications for risk management and hedging operations.

4 Empirical Analysis

This chapter is divided into three sections. Section 4.1 presents the interest rate data analysis and section 4.2 reports the evaluation of FED and ECB announcements regarding monetary policy decision during the sample period. Finally, section 4.3 reports the results of the bivariate monetary-jump model previously discussed.

4.1 Interest Rate Data

The interest rate data for the US are Treasury constant maturity rates retrieved from FRED which is the Federal Reserve Bank of St. Louis database. As for the EMU it is used constant maturity rates of the triple A nominal government bond. The data is provided by the Statistical Data Warehouse of the ECB. The maturities used were 1, 5 and 7 years for both economic areas with daily frequency from 7 September 2004 to 6 December 2010. The total number of observation is 1549. The period includes the economic turmoil of the 2007/2008 as well as a variety of economic and market conditions.

Ehrmann and Fratzscher (2003) put that the drawback of using daily frequency rather than intra-day or tick-by-tick data is that with a lower frequency data the noise is higher because other events are not captured as well as news that occurs during the day, thereby possibly making the measurement of announcement spillover less accurate. However, such noise occurs less in interest rate markets than in other financial markets, and the empirical literature often uses daily frequency data to capture jump movements in interest rates (Das 2002, Johannes 2004, Matovu 2007, Beber and Brandt 2010, León and Sebestyén 2012, Meurer, Santos and Turatti 2015).

Table 1 below reports summary statistics for the interest rates series both in levels and in first differences. It is also included the Jarque-Beta normality test for the percentage change data, and the Ljung-Box test for serial correlation in first differenced data and in squared first differenced data to check for AR and ARCH effects, respectively.

The Jarque-Beta test checks if the data has skewness and kurtosis of a normal distribution (null hypothesis), while the Ljung-Box tests the null hypothesis of no serial correlation in the data. These statistics give us essential information about the data characteristics that needs to be taken into consideration during the process of modeling selection.

These results in Table 1 indicate that the data shows no normality, excess kurtosis and heteroskedasticity. The critical value of the Jarque-Beta normality test is 5.9531 for all maturities. Table 1 reports that all maturities exceeded the critical value with 1% of significance. It is also reported in table 1 that all maturities have excess kurtosis with respect to that of a normal distribution.

Table 1 reports that the Ljung-Box test for ARCH effect in all maturities found the presence of heteroskedasticity. Therefore, all maturities exceeded the critical value of 31.4104 with 1% of significance. As for the Ljung-Box test for AR effect, only the 7-year Treasury rate, the 5-year and 7-year EMU government bond do not reject the null hypothesis of no serial

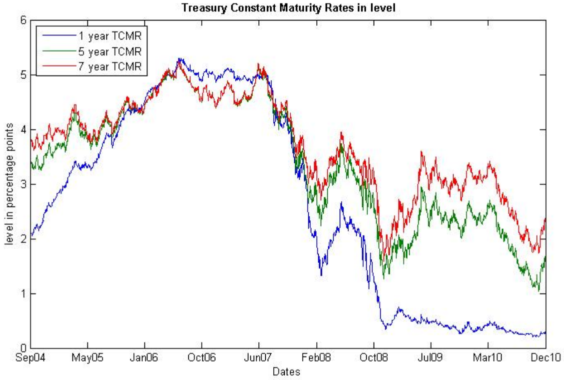

Figure 1 – United States Maturities in level

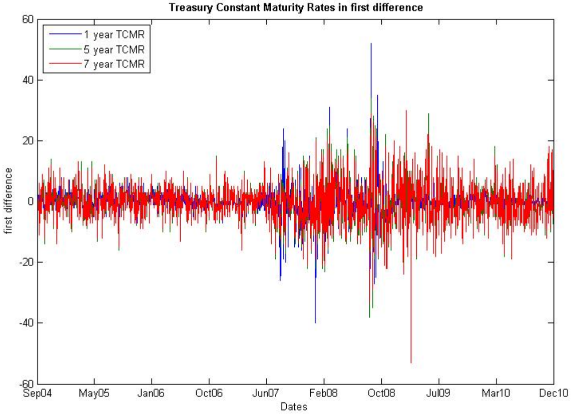

Figure 2 – United States Maturities in first difference

correlation.

Table 1 – **Descriptive statistics of interest rates in levels and in first difference.**

	US - level			**EMU - level**		
	1 year	**5 year**	**7 year**	**1 year**	**5 year**	**7 year**
Mean	2.6303	3.3784	3.6881	2.4322	3.1842	3.4696
Standard Deviation	1.8429	1.1373	0.9010	1.3125	0.7365	0.5763
Sample Variance	3.3964	1.2934	0.8118	1.7226	0.5425	0.3321
Kurtosis	1.4308	1.7703	2.1154	1.5977	2.3482	2.6885
Skewness	-0.0081	-0.2017	-0.3132	-0.1326	-0.1937	-0.2582

	US - first difference			**EMU - first difference**		
	1 year	**5 year**	**7 year**	**1 year**	**5 year**	**7 year**
Mean	-0.1207	-0.1259	-0.1052	-0.1080	-0.0931	-0.0764
Standard Deviation	4.9722	6.9728	6.9106	3.2234	4.2339	3.9628
Sample Variance	24.7225	48.6204	47.7557	10.3904	17.9262	15.7036
Kurtosis	21.2161	6.2320	6.4843	16.1436	4.0711	3.7285
Skewness	0.1131	-0.1548	-0.2421	-1.2453	0.0369	0.0756
Jarque-Beta	2141.9833*	680.3796*	798.6680*	1154.9391*	74.3919*	35.7200*
Ljung-Box (AR effect)	83.4534*	34.7790**	27.0407****	136.6791*	29.9555***	26.8951****
Ljung-Box (ARCH effect)	646.0576*	512.8975*	369.4145*	156.3873*	493.7223*	221.9370*

Note: Table 1 reports descriptive statistics of interest rates in levels and in first difference, such as the mean, standard deviation, sample variance, kurtosis, skewness, Jarque-Beta normality test, and Ljung-Box serial correlation test. *, **, *** and **** denotes significance at the 1%, 5%, 10% and 15%, respectively. Ljung-Box serial correlation critical value is 31.41 for both maturities and effects. Jarque-Beta normality test critical value is 5.95 for all maturities.

In Figures 1 and 2 it is plotted the Treasury constant maturity rates in levels and first difference. It is also plotted in Figures 3 and 4 the EMU triple A nominal government bond rates. The level of Treasury rates started to fall sharply in middle 2007 due to the financial turmoil, as well as the variance in the same period. The sharp movement in the EMU bond started later, around middle 2008. Moreover, the variance also increased in the EMU bond market during the financial crisis period.

4.2 Announcements of monetary policy decision

All publicly available statements of monetary policy meetings made by the FED in the US and by the ECB in the EMU from September 2004 to December 2010 are analyzed. It is taking into account three important factors of announcements: (1) Only official announcements of the decision-making meetings of the two central banks are analyzed; (2) FED and ECB present a different frequency of decision-making meetings; (3) the time zone between the countries define which day the market reacts to the monetary policy decision.

One point that must be noticed is when the announcement was made and the time zone between the countries. The time of the press conference about monetary policy decisions made by the FED is 2:15 p.m. in the city of Washington/DC and most statements released regarding the ECB decisions is made at 2:30 p.m. in the city of Frankfurt; however, the ECB sometimes conducts the meetings in other major cities of Europe, such as Brussels, Berlin, Madrid, Paris, Dublin, Vienna, Athens, and Luxembourg. The time zone between these cities in Europe and the east coast of the United States are 5, 6, or 7

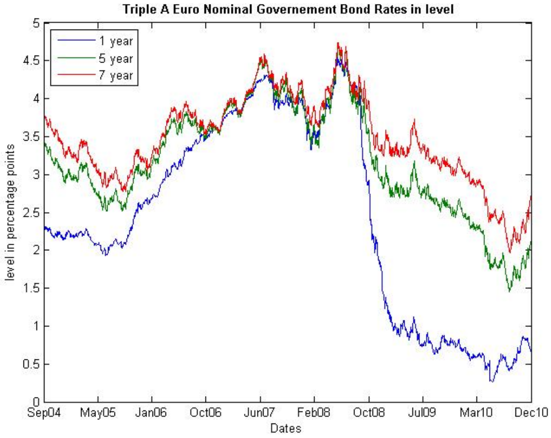

Figure 3 – EMU Maturities in level

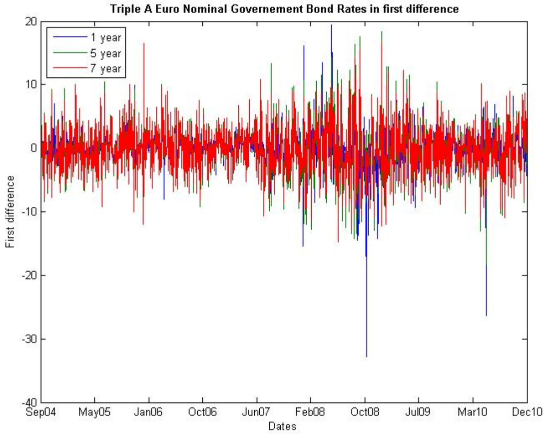

Figure 4 – EMU Maturities in first difference

Table 2 – **Summary statistics for monetary policy announcements and decisions.**

Monetary policy announcements	**Number of Meetings**	**Monetary policy decision**	**Number of decisions**
FED	52	Unchanged	27
		Increase	15
		Decrease	10
ECB	76	Unchanged	60
		Increase	9
		Decrease	7

Notes: The table reports the number of meetings that the FED and ECB performed during the sample period analyzed, and their respective decisions regarding the target rate.

hours. Therefore, the announcements made by the ECB affects the United States interest rate market in the same day. The opposite, however, is not true, since FED releases strike the European bond market in the opening of the next day. Both central bank's decisions reach their own market in the same day.

During the period analyzed, the frequency of meetings diverged between the ECB and the FED. ECB meetings take place in the first week of every month, or 12 times per year. FED meetings occur 8 times per year. Another difference between their decisions is the FED decides the official target for the federal fund's rates, whereas the ECB decides on three official key rates[1] in the same meeting. To measure how often the official rate was unchanged or changed, it has been taken into account only the marginal lending facility rate, which offers overnight credit to banks from the Eurosystem.

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[1] ECB official key rates are the interest rates on the main refinancing operations, the deposit facility rate and the marginal lending facility rate.

Table 2 reports the total number of decision-making meetings and the monetary authority decision regarding the official target rate. For the period analyzed, the ECB conducted 76 meetings, while 52 were fulfilled by the FED. Both central banks maintained the official target rate unchanged most of the time; this happened 78.94% for the ECB and 51.92% for the FED. Official target rate increased 28.84% for the FED and 11.84% for the ECB. The remaining decision of decreasing the official target rate was taken 19.23% for the FED and 9.21% of ECB decision-making meetings.

4.3 Results

This section is divided into two subsections. Subsection 4.3.1 reports the results for the bivariate monetary-jump model with constant jump intensity. After that, subsection 4.3.2 presents the results for the most sophisticated structure of the monetary-jump model that allows for time-varying jump intensity with the ARJI specification.

4.3.1 Monetary-Jump Model with Constant Jump Intensity

Table 3 reports parameter estimates of the bivariate monetary-jump model with constant jump intensity and constant jump mean along with the value of the log-likelihood function evaluated at the estimated parameters. T-statistics appear in parenthesis. It is used the same maturity of both economic areas (US and EMU) as the two variables in the estimation process of the bivariate monetary-jump model.

First, it can be seen that the three jump intensity parameters are not statistically significant for the 1-year maturity but highly significant for all jump intensity parameters in the 5-year maturity and only for the two individuals jump intensities in the 7-year maturity. For the 5-year maturity, the correlated jump intensity parameter, λ_3, exhibits a higher value than both individual parameters, suggesting that correlated jumps appear to be important in explaining the daily variations in both markets 5-year interest rate maturity.

As for the GARCH parameters, α and β, both are significant for all maturities. The jump mean and jump variance parameters, υ_1, υ_2, δ_1^2 and δ_2^2, seem to get smaller the higher is the maturity, indicating that jumps are more important in shorter maturities. The jump correlation parameter, ρ, is statistically different from zero only for the 5-year and 7-year maturity, and both are shown negative value, -0.4416 and -0.4012, respectively, implying that when jumps occur the two interest rates returns series tend to move in opposite directions. This may happen due to difference in the timezone between the markets, since FED statements are released when the EMU bond market it is already close, affecting the interest rate returns only on the next day, i.e. FED releases a surprising announcement regarding a change in the FED funds official target rate, the US interest rate market participants respond to the news moving interest rates returns on the same day of the announcement. However, due to the difference in the time zone, EMU interest rate market participants incorporate the FED news only in the next day, creating jumps in the EMU interest rate returns in a difference day that jumps occur in the US interest rate returns.

Table 4 shows the jump analysis statistics concerning

Table 3 – **Bivariate monetary-jump model with constant jump intensity.**

Maturity	1 year	5 year	7 year
λ_1	0.0001	0.1003	0.2274
	(0.0024)	(57.2589)	(2.7392)
λ_2	0.0030	0.1002	0.1788
	(0.9712)	(81.8271)	(10.6089)
λ_3	0.0224	0.3495	0.3253
	(1.6574)	(261.5267)	(1.3665)
υ_1	4.9906	0.2779	0.1763
	(0.8234)	(274.8920)	(5.2874)
υ_2	2.6120	0.0663	-0.0125
	(0.9135)	(39.8358)	(-0.1807)
α	0.0229	0.0223	0.0270
	(7.5980)	(208.1296)	(2.4713)
β	0.9315	0.9754	0.9720
	(91.7454)	(8113.9)	(31.7306)
δ_1^2	7.0017	0.6566	0.4937
	(0.7030)	(385.2311)	(6.3945)
δ_2^2	6.2775	1.6155	1.5015
	(3.0849)	(430.1428)	(2.8976)
ρ	0.0145	-0.4416	-0.4012
	(0.5975)	(-151.5145)	(-1.9224)
lnL	-874.4	-4697.4	-4683

Notes: The table 4 reports parameter estimates for the bivariate monetary-jump model with constant jump intensity and jump mean. t-Statistics appear in parentheses and lnL denotes the value of the likelihood function evaluated at the estimated parameters. The model is defined as $r_t = \mu + \epsilon_{1,t} + \epsilon_{2,t}$, where $\epsilon_{1,t} = H_t z_t$, $\epsilon_{2,t} = \begin{bmatrix} \sum_{i=1}^{n_{1t}} Y_{1t,i} - (\lambda_1 + \lambda_3)\upsilon_1 \\ \sum_{j=1}^{n_{2t}} Y_{2t,j} - (\lambda_2 + \lambda_3)\upsilon_2 \end{bmatrix}$, $z_t \sim N(0,1)$, $Y_{t,ij} \sim N(\upsilon, \delta^2)$, where $Y_{t,ij}$ is the jump-size distribution for the two interest rates. n_{1t} and n_{2t} are Poisson processes with constant jump intensities (λ_1 and λ_3) and (λ_2 and λ_3), respectively. H_t follow a variance-targeting scalar VECH specification, $H_t = (1 - \alpha - \beta)C + \alpha(\epsilon_{t-1}\epsilon_{t-1}') + \beta H_{t-1}$. It is assumed that z_t, J_t and n_t are independent.

monetary policy decisions. The number of jumps in the US and EMU are the number of days on which the sum of the ex-post probabilities of at least one jump on $(n_{1t}^{*} + n_{3t}^{*})$ and $(n_{2t}^{*} + n_{3t}^{*})$ is higher than 50%, respectively. One jump can be characterized as

$$P(n_{1t}^{*} \geq 1|\phi_{t-1}) + P(n_{3t}^{*} \geq 1|\phi_{t-1}) > 0.5, \tag{31}$$

and

$$P(n_{2t}^{*} \geq 1|\phi_{t-1}) + P(n_{3t}^{*} \geq 1|\phi_{t-1}) > 0.5, \tag{32}$$

The number of jumps on FED and ECB meeting days overall meeting days is the ratio of the number of jumps on the monetary authority meeting days to the total number of meeting days that occur in analyzed period. To calculate the cross-border statistics, the difference in the timezone between the two economic areas has been taken into consideration. ECB meeting days generate jumps in the US interest rate market in the same day. However, US meeting days generate jumps in the ECB interest rate market only in the next day. Finally, the average jump contribution to total US and EMU volatility are respectively

$$\frac{\sqrt{(\lambda_1 + \lambda_3)(\upsilon_1^2 + \delta_1^2)}}{\sqrt{\sigma_1 + (\lambda_1 + \lambda_3)(\upsilon_1^2 + \delta_1^2)}}, \tag{33}$$

and

$$\frac{\sqrt{(\lambda_2 + \lambda_3)(\upsilon_2^2 + \delta_2^2)}}{\sqrt{\sigma_2 + (\lambda_2 + \lambda_3)(\upsilon_2^2 + \delta_2^2)}}. \tag{34}$$

where σ_1 and σ_2 are the main diagonal components of the variance-covariance matrix H_t, λ_1, λ_2 and λ_3 are the expected number of jumps, υ_1^2 and υ_2^2 are the squared jump mean parameters, δ_1^2 and δ_2^2 are the jump variance parameters for the two Poisson processes.

The average jump contribution to total volatility for the US in both markets is higher for the 1-year maturity, reaching 0.9853, which implies that jumps are the main driver of the volatility for that maturity. As for the 5-year and 7-year maturities, a smaller value is obtained, but still very large contribution from jumps for the total volatility in those maturities.

The total number of jumps and the number of jumps on FED and ECB meetings days overall meeting days appear to increase with maturity. In the Treasury 7-year maturity, jumps in the US occur on 23% of FED monetary policy decision announcements and on 30% of ECB meetings. This information suggests that monetary policy surprises are more pronounced in the long term rates, implying that the FED and ECB monetary policy decisions have a higher impact in future market expectations after the announcement. This occurs because future rates do not anticipate monetary policy decision as shorter rates, indicating that agents are more likely to change their future monetary policy expectations only after the statement been released.

The EMU interest rate market appears to follow the same path in the sample period analyzed but with one important difference. This change concerns the fact that the average jump contribution to total volatility in the EMU interest rates seems to remains almost constant with maturity. The total number of jumps and the number of jumps in EMU rates on ECB and FED

Table 4 – **Jump analysis for the bivariate monetary-jump model with constant jump intensity.**

Maturity	1-year	5-year	7-year
Average jump contribution to total volatility - US	0.9853	0.8238	0.8454
Number of jumps - US	14	267	426
Number of jumps on FED meetings days overall meeting days	0.0192	0.1346	0.2308
Number of jumps in US on ECB meetings days	1	17	23
Number of jumps in US on ECB meeting days over all ECB meeting days	0.0132	0.2237	0.3026
Average jump contribution to total volatility - EMU	0.6179	0.6347	0.6358
Number of jumps - EMU	18	294	392
Number of jumps on ECB meetings days overall meeting days	0.0132	0.2105	0.25
Number of jumps in EMU on FED meetings days	1	19	21
Number of jumps in EMU on FED meeting days over all FED meeting days	0.0192	0.3654	0.4038

Notes: The table reports the jump analysis for the bivariate monetary-jump model with constant jump intensity and jump mean regarding the FED and ECB meetings about the monetary policy decision. The number of jumps in the US is the number of days on which the sum of the ex-post probabilities of at least one jump on n^*_{1t} and n^*_{3t}, $P(n^*_{1t} \geq 1|\phi_{t-1}) + P(n^*_{3t} \geq 1|\phi_{t-1})$, is higher than 50%. The average jump contribution to total US and EMU volatility are $\frac{\sqrt{(\lambda_1+\lambda_3)(\upsilon_1^2+\delta_1^2)}}{\sqrt{\sigma_1+(\lambda_1+\lambda_3)(\upsilon_1^2+\delta_1^2)}}$ and $\frac{\sqrt{(\lambda_2+\lambda_3)(\upsilon_2^2+\delta_2^2)}}{\sqrt{\sigma_2+(\lambda_2+\lambda_3)(\upsilon_2^2+\delta_2^2)}}$, respectively. The number of jumps on meeting days overall meeting days is the ratio of the number of jumps on meeting days to the total number of meeting days.

meeting days overall meeting days also increase with maturity. In the 7-year maturity, jumps occur in 25% of ECB meetings days and in 40% of FED statements days. This result suggests that EMU long-term interest rates expectations are also more likely to change after the meetings.

In both interest rate markets, the probability of jumps in the domestic market is higher when the foreign monetary authority releases a decision statement. For instance, in the 5-year and 7-year US Treasury rates, jumps occur in 13% and in 23% of FED meetings days, respectively, and in 22% and in 30% of ECB meetings days, respectively. As for the 5-year and 7-year EMU interest rates, jumps occur in 21% and in 25% of ECB meetings days, and in 36% and in 40% of FED meetings days, respectively. This may occur because domestic market participants might anticipate with higher precision their domestic central bank monetary policy.

Finally, the number of jumps in the EMU interest rate market on FED meeting days overall FED meeting days is higher than the impact of ECB decisions in terms of the number of jumps in the US Treasury rates for all maturities. These suggest that the relative importance of the FED monetary policy for the EMU interest rate market participants is higher than the ECB decisions for the US interest rate market participants. Another possibility is that US interest rate market participants anticipate ECB monetary policy decisions with higher precision than EMU interest rate market participants anticipate FED decisions regarding changes in the official target rate.

4.3.2 Monetary-Jump Model with Time-Varying Jump Intensity

Table 5 reports the estimated parameters for the bivariate monetary-jump model with time-varying jump intensity and constant jump mean for the three maturities considered. Although not all jump intensity parameters in the ARJI framework reports statistical significance, it is important to highlight that the majority are significant. For the 1-year maturity, the parameters presented the greater consistency, only the parameter ζ_1, a natural measure of the US jump intensity persistence, was not statistically significant. Next, it is reported all jump intensities equations for the 1-year maturity with their own respective parameters and t-statistics values:

$$\lambda_{1,t} = 0.0006(59.45) + 0.0001(0.002)\lambda_{1,t-1} + 0.9266(21.19)\xi_{1,t-1} \tag{30}$$

$$\lambda_{2,t} = 0.0017(25.78) + 0.1130(14.33)\lambda_{2,t-1} + 0.5861(144.0)\xi_{2,t-1} \tag{31}$$

$$\lambda_{3,t} = 0.0133(49.54) + 0.6082(77.19)\lambda_{3,t-1} + 0.0094(61.69)\xi_{3,t-1} \tag{32}$$

For the 5-year maturity, only two jump intensity parameters were statistically significant. The first was the intensity residual parameter, γ_2, for the EMU jump intensity equation, and the second was the correlated jump intensity persistence parameter, ζ_3. Moreover, for the 7-year maturity, a few parameters were reported not statistically significant, these parameters are γ_1 for the US jump intensity equation; ζ_2 for the EMU jump intensity equation; λ_{31} and γ_3 for the correlated jump intensity equation.

Figures 5 to 9 reports the time-varying jump intensity for the two individual jump processes as well as the correlated jump process in the 7-year maturity. Moreover, for the same maturity, it is also presented the time-varying jump intensity for the EMU and US interest rate[2]. Correlated jumps appear to drive the US and EMU jump intensity processes since all three figures show an increase in the jump intensities in the financial crises period. This characteristic suggests that in world financial crises the correlated jump intensity seems to be more important than individuals jump generating processes.

The process that originates correlated jumps reports the trend of growth starting close to June 2007 (observation 700), peaking nearly September 2008 (observation 1000) and returning to the original place nearly in April 2010 (observation 1400). This trend indicated that the 2008 financial turmoil presented the characteristic of contagious between the US and EMU interest rate market, reinforced what actually happened in this period. This trend can be seen in other figures presented here, such as the ex-post number of jumps and the ex-post probability of at least one jump occurring.

Table 6 reports the remain parameters estimates for the bivariate monetary-jump model with time-varying jump inten-

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[2] $\lambda_{1,t}$ and $\lambda_{2,t}$ are the individuals jump intensity processes and $\lambda_{3,t}$ is the correlated jump intensity process. US jump intensity is $\lambda_{1,t} + \lambda_{3,t}$ and EMU jump intensity is $\lambda_{2,t} + \lambda_{3,t}$.

Table 5 – **Jump intensity parameters of the bivariate monetary-jump model with variant jump intensity - ARJI structure.**

Maturity	1-year	5-year	7-year
λ_{11}	0.0006	0.1610	0.1860
	(59.4486)	(0.2734)	(99.2138)
ζ_1	0.0001	0.0001	0.3275
	(0.0022)	(0.0000)	(7.8439)
γ_1	0.9266	0.0086	0.0001
	(21.1874)	(0.1891)	(0.0028)
λ_{21}	0.0017	0.0110	0.0929
	(25.7852)	(0.4093)	(13.6472)
ζ_2	0.1130	0.8143	0.0962
	(14.3286)	(1.4717)	(1.3628)
γ_2	0.5861	2.6750	0.6682
	(144.0526)	(2.8279)	(3.2731)
λ_{31}	0.0133	0.0176	0.0099
	(49.5371)	(1.6342)	(0.7346)
ζ_3	0.6082	0.9657	0.9826
	(77.1903)	(231.6678)	(35.710)
γ_3	0.0094	0.0899	0.1442
	(61.6877)	(0.9120)	(1.8903)

Notes: The table reports parameter estimates for the ARJI time-varying jump intensity structure. t-Statistics appear in parentheses. Each one of the three Poisson variables parameters ($\lambda_{1t}, \lambda_{2t}$, and λ_{3t}) that govern the arrival of jumps between $[t-1, t]$ for the three counting process, (n^*_{1t}, n^*_{2t}, and n^*_{3t}), here represented as the US, the EMU, and the correlated counting process, are modeled in the form: $\lambda_{it} = \lambda_0 + \sum_{p=1}^{r} \zeta_i \lambda_{it-p} + \sum_{p=1}^{s} \gamma_i \xi_{it-p}$; where ξ_{it-p} represents the innovation to λ_{it} as measured ex post by the econometrician. This measurable shock, or jump intensity residual, is the unpredictable component affecting the inference about the conditional mean of the counting process n^*_{it}, which is defined as, $\xi_{it-1} = E[n^*_{it-1}|\phi_{t-1}] - \lambda_{it-1} = \sum_{j=0}^{\infty} jP(n^*_{it-1} = j|\phi_{t-1}) - \lambda_{it-1}$.

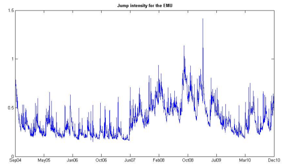

Figure 5 – 7-year maturity: Jump intensity for EMU - $\lambda_{2,t} + \lambda_{3,t}$.

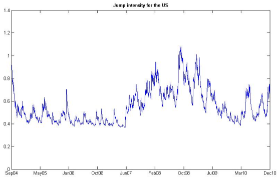

Figure 6 – 7-year maturity: Jump intensity for US - $\lambda_{1,t} + \lambda_{3,t}$.

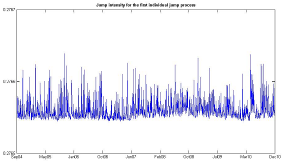

Figure 7 – 7-year maturity: Jump intensity for the first individual jump arrival process - $\lambda_{1,t}$.

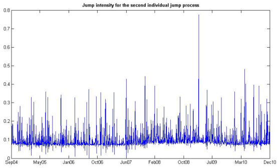

Figure 8 – 7-year maturity: Jump intensity for the second individual jump arrival process - $\lambda_{2,t}$.

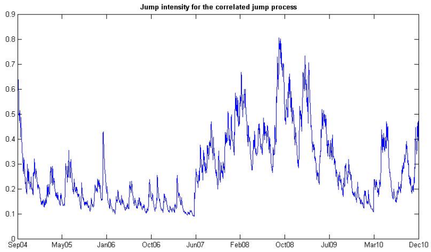

Figure 9 – 7-year maturity: Jump intensity for the correlated jump arrival process - $\lambda_{3,t}$.

sity and constant jump mean as well as the log-likelihood values for the three maturities considered. The jump mean and jump variance parameters for both countries indicate to follow the same pattern of the monetary-jump model with constant jump intensity. υ_1, υ_2, δ_1^2 and δ_2^2 decrease with higher maturities and are statistically different from zero. This demonstrates that jump movements in longer-term rates are less sharp and less variant than in short-term rates in the sample period analyzed.

Moreover, the GARCH parameters are reported in table VI. Where the parameter α shows statistical significance only for the 1-year maturity, while β is reported highly significantly for all maturities. As for the estimated jump correlation parameter, ρ, it is reported negative values for the 5-year and 7-year maturities as well as in the monetary-jump model with constant jump intensity structure, and the parameter is significantly positive for the 1-year maturity. For the two long-term maturities, the second model got similar results to the first estimated model. As in Chan (2003) investigation of currencies returns, if the jump correlation parameter (ρ) is reported negative, the correlation between interest rates returns decreases when the size of the correlated jump intensity become large. This characteristic can be seen in figure 10, that reports the covariance between both countries 7-year interest rate maturity. The covariance drop during the financial crises period, the same time that the correlated jump intensity becomes large and drive both countries jump arrival processes. This information may help diversify risk in portfolio management.

Negative jump correlation parameter on long-term maturities it is more expected since the presence of jumps it is

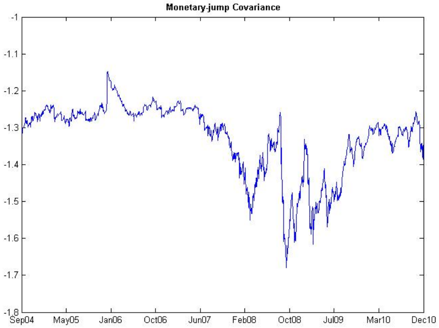

Figure 10 – 7 year maturity: monetary-jump covariance for US and EMU.

larger than the 1-year maturity on days that the monetary policy meet, suggesting that market participants change their view of long-term maturities only after the announcement been released. Beyond the timezone argument to explain the negative jump correlation parameter, another suggestion may be the difference packages of economic recovery measures implemented by the FED and ECB after the crises, and their impact on long-term interest rates. The Quantitative Easing (QE) program was launched by the FED in late November 2008, and was aggressively extended in the following years to respond to the financial and economic problems in the US after 2008. The measures taken allowed US Treasury long-term interest rates to be quickly affected after the financial turmoil, a fast drop in this assets level prices occurred after 2008. As for the ECB QE package, it was started in may 2009 with the purpose of purchasing corporate debt. Only in January 2015 that the ECB introduce a more aggressive program to purchase EMU bonds from central governments, thus affecting long-term interest rates in a stronger way after the sample period analyzed here.

Concerning the jump analysis for the second model, it is reported in table 7 similar results to the first model, however, two differences are presented. First, FED monetary policy decisions affect the EMU interest rate market participants with the same importance that the ECB meetings impact the US Treasury market agents. For the 5-year and 7-year, the number of jumps at the US Treasury rate in ECB meeting days overall ECB meeting days are 25% and 30%, respectively. As for the number of jumps in FED meeting days at the EMU market, the values are 23% for the 5-year and 30% for the 7-year maturity. Second, for the EMU rates, the number of jumps on ECB meeting days overall meeting days is higher in the 5-year maturity than in the 7-year maturity, which implies that this is the EMU rate with fewer anticipations regarding the ECB monetary decisions in the sample period analyzed, occurring jumps in 19.74% of meeting days, being that in the 7-year maturity this value drop to 18.42%. The pattern of the number of jumps on meeting days increasing with maturity does not happen only in this case.

However, the majority of the jump analysis statistics stay with the same pattern that it is reported in the monetary-jump model with constant jump intensity. Follow below the five points of the jump analysis with the same pattern.

(1) The average jump contribution to total volatility in both markets is higher for the 1-year maturity. Reaching 98% for the US Treasury and 60% for the EMU triple-A government bond.

(2) The number of jumps in both interest rate market

Table 6 – **Bivariate monetary-jump model with variant jump intensity and constant jump mean for US and EMU data.**

Maturity	1 year	5 year	7 year
υ_1	3.3260	0.2595	0.1609
	(281.7903)	(21.9472)	(3.1770)
υ_2	1.9553	0.1817	0.0867
	(102.3762)	(1.9158)	(2.5163)
α	0.0188	0.0191	0.0219
	(85.7069)	(0.5051)	(0.6643)
β	0.9350	0.9709	0.9681
	(2793.9)	(11.2504)	(13.6293)
δ_1^2	4.7129	0.6558	0.5073
	(210.8568)	(16.0125)	(23.3894)
δ_2^2	5.4068	1.9317	1.8150
	(224.2921)	(83.6535)	(11.5132)
ρ	0.6814	-0.4547	-0.3216
	(221.7433)	(-17.7286)	(-2.7937)
lnL	-860.238	-4690.2	-4677.5

Notes: The table 6 reports parameter estimates for the bivariate monetary-jump model with time-varying jump intensity. t-Statistics appear in parentheses and lnL denotes the value of the likelihood function evaluated at the estimated parameters. The model is defined as $r_t = \mu + \epsilon_{1,t} + \epsilon_{2,t}$, where $\epsilon_{1,t} = H_t z_t$, $\epsilon_{2,t} = \begin{bmatrix} \sum_{i=1}^{n_{1t}} Y_{1t,i} - (\lambda_{1t} + \lambda_{3t})\upsilon_1 \\ \sum_{j=1}^{n_{2t}} Y_{2t,j} - (\lambda_{2t} + \lambda_{3t})\upsilon_2 \end{bmatrix}$, $z_t \sim N(0,1)$, $Y_{t,ij} \sim N(\upsilon, \delta^2)$, where $Y_{t,ij}$ is the jump-size distribution for the two interest rates. n_{1t} and n_{2t} are Poisson processes with time-varying jump intensities (λ_{1t} and λ_{3t}) and (λ_{2t} and λ_{3t}), respectively. H_t follow a variance-targeting scalar VECH specification, $H_t = (1 - \alpha - \beta)C + \alpha(\epsilon_{t-1}\epsilon'_{t-1}) + \beta H_{t-1}$. It is assumed that z_t, J_t and n_t are independent.

rise with maturity. For the US market, the number of jumps goes from 20 in the 1-year maturity to 459 jumps in the 7-year maturity. Moreover, for the EMU interest rate market, the number of jumps goes from 23 in the 1-year maturity to 278 in the 7-year maturity.

(3) Foreign monetary authority decisions generate more surprise in domestic interest rate market participants than the domestic monetary authority. The only exception is 1-year EMU bond, in which the ECB has more effect than the FED. For example, for the 7-year US Treasury maturity, the number of jumps on FED meeting days overall meeting days reaches 23% while this ratio for the ECB meetings reaches 30%. As for the 7-year EMU bond, the number of jumps on ECB meeting days overall meeting days is 18%, and for the FED meetings affect the ratio is 30%. This information indicates that market participants predict their own monetary policy better than the foreign monetary policy.

(4) The average jump contribution to total volatility in the EMU interest rate market remains almost constant with maturity. For the 1-year, 5-year and 7-year EMU triple A government bond the values are 60%, 59%, and 58%, respectively.

(5) The number of jumps on ECB and FED meeting days overall meeting days is higher for 5-year and 7-year maturities than for the 1-year maturity, indicating that market participants change more their expectations regarding long-term rates after the announcement. In the US Treasury market, the 1-year average jumps on FED and ECB meeting days overall meeting days is close to 3%, increasing respectively to nearly 23% and 26% for the 5-year and 7-year maturity. Very similar values are

also obtained in the EMU market.

Regarding the results reported by León and Sebestyén (2012) and by Beber and Brandt (2010), some of them are different than those found here. First, the jump contribution to the total volatility shows higher values for all maturities than those reported in León and Sebestyén (2012) for EMU bond returns and in Beber and Brandt (2010) for US market. Second, the contribution of jumps to the total volatility do not follow a clear decreasing path for the maturities analyzed, in the US Treasury interest rates the jump contribution to total volatility are reported higher in the 7-year than in the 5-year maturity, and for the EMU interest rates the jump contribution to total volatility remains almost constant with maturity. This trend is different from those found in León and Sebestyén (2012) and in Beber and Brandt (2010). Third, all estimated jump intensity parameters are reported positive, indicating that in this sample period jumps are always likely to occur and happen more on longer maturities. Four, the number of jumps on meeting days overall meeting days increase with maturity for US rates on FED and ECB statements and for EMU rates on FED announcements. Only the number of jumps on ECB meeting days overall meeting days decrease for the EMU rates, going in the same direction of the results reported by León and Sebestyén (2012).

In the sense of comparing the goodness of fit of both models, it is conducted the likelihood-ratio test, which expresses how many times more likely the data are under one model than the other. The statistical value of 28.32, 14.40 and 11 was obtained for 1-year, 5-year, and 7-year, respectively. The critical value for all maturities is 7.81. For all maturities, the null hy-

Table 7 – **Jump analysis for the bivariate monetary-jump model with time-variant jump intensity and constant jump mean.**

Maturity	1-year	5-year	7-year
Average jump contribution to total volatility - US	0.980	0.8298	0.8455
Number of jumps - US	20	330	459
Number of jumps on FED meetings days overall meeting days	0.0192	0.2115	0.2308
Number of jumps in US on ECB meetings days	3	19	23
Number of jumps in US on ECB meeting days over all ECB meeting days	0.0395	0.25	0.3026
Average jump contribution to total volatility - EMU	0.6068	0.5930	0.5812
Number of jumps - EMU	23	228	278
Number of jumps on ECB meetings days overall meeting days	0.0263	0.1974	0.1842
Number of jumps in EMU on FED meetings days	1	12	16
Number of jumps in EMU on FED meeting days over all FED meeting days	0.0192	0.2308	0.3077

Notes: The table reports the jump analysis for the bivariate monetary-jump model with time-varying jump intensity and constant jump mean regarding the FED and ECB meetings about the monetary policy decision. The number of jumps in the EMU is the number of days on which the sum of the ex-post probabilities of at least one jump on n^*_{2t} and n^*_{3t}, $P(n^*_{2t} \geq 1|\phi_{t-1}) + P(n^*_{3t} \geq 1|\phi_{t-1})$, is higher than 50%. The average jump contribution to total US and EMU volatility are $\frac{\sqrt{(\lambda_{1t}+\lambda_{3t})(\upsilon_1^2+\delta_1^2)}}{\sqrt{\sigma_1+(\lambda_{1t}+\lambda_{3t})(\upsilon_1^2+\delta_1^2)}}$ and $\frac{\sqrt{(\lambda_{2t}+\lambda_{3t})(\upsilon_2^2+\delta_2^2)}}{\sqrt{\sigma_2+(\lambda_{2t}+\lambda_{3t})(\upsilon_2^2+\delta_2^2)}}$, respectively. The number of jumps on meeting days overall meeting days is the ratio of the number of jumps on meeting days to the total number of meeting days.

pothesis is rejected with 5% level of significance in favor of the alternative model, that is, in favor of the bivariate monetary-jump model with time-varying jump intensity specification.

5 Conclusion

This work investigates how relevant monetary policy decision announcements, regarding official target rate made by the FED and ECB, spillover in both yield curves. The bivariate monetary-jump model proposed here is a mixture of the monetary-jump model proposed by León and Sebestyén (2012) and the bivariate GARCH-jump model proposed by Chan (2002, 2003). Besides the variance-targeting scalar VECH parametrization, this model includes a bivariate Poisson function to govern the jump component of the model, allowing the jump intensities to follow a time-varying autoregressive specification and generate correlated jumps in both series in addition to each independent jump. This model can capture smooth volatility movements and abrupt changes in the rates of return of interest rates.

The bivariate monetary-jump model allows us to assess how the monetary policy decision process affects both yield curves prices and volatilities, the monetary policy decision predictability and effectiveness, and monetary policy spillover effects in a quest for understanding how one market might influence another. In this sense, the analysis focuses on four objectives: (1) Assess the extent to which not anticipated monetary policy decision contribute to the overall volatility in both term structure of interest rates; (2) analyze the predictability and effectiveness of FED and ECB decisions and announcements; (3) assess if volatility and monetary policy spillover effects between the US and EMU yield curves exist; (4) identify two types of systematic jumps: jumps specific to one interest rate and jumps that occur to both interest rates at the same time and assess the correlation between jumps in both markets.

Regarding the first objective, the average jump contribution to total volatility in both yield curves suggests the jumps structure is very important in the process of measuring volatility in interest rate returns. For all US maturities, the jump contribution to total volatility stays higher than 82%, and for the EMU maturities, the jumps contribute closely to 60% of the total volatility. However, the contribution of an unanticipated monetary policy decision to overall volatility is not that significant; in both yield curves and for all maturities, the monetary surprise component corresponds closely to only 5% of the total number of jumps. Meaning that jumps from different natures occur in the interest rates returns more often than the surprise component of monetary policy decision.

The second objective can be analyzed through the number of jumps on ECB and FED meeting days overall meeting days. In the US Treasury market, the 1-year average jumps on FED and ECB meeting days overall meeting days is close to 3%, increasing respectively to nearly 23% and 26% for the 5-year and 7-year maturity. Very similar values are also obtained in the EMU market. This suggests the predictability of both central banks are lower for the 5-year and 7-year maturities than for the 1-year maturity, implying the FED and ECB monetary policy decisions have a greater impact in future market expectations after the announcement. This occurs because future rates do not anticipate monetary policy decision as shorter rates, indicating agents are more likely to change their future monetary policy expectations only after the statement has been released. Foreign monetary authority decisions generate more surprise in domestic interest rate market participants than the domestic monetary authority. This information indicates the US and EMU interest rate market participants anticipate their own monetary policy decisions better than the foreign monetary policy. This information is also related to monetary policy spillover effects, which is part of our third objective.

Concerning volatility and monetary policy spillover effects between US and EMU yield curves, the monetary-jump model with constant jump intensity shows a different result than the model with time-varying specification. For the model with time-varying jump intensity, FED monetary policy decisions affect the EMU bond market participants with the same importance that the ECB meetings impact the US Treasury market participants. As for the model with constant structure, FED monetary policy decisions report a higher monetary surprise ratio, suggesting FED decisions for the EMU bond market are more important than ECB decisions for the US Treasury interest rate market. Regarding volatility spillover effects, it can be seen in the covariance chart between those two assets that the covariance drop during the financial crises period, the same time the correlated jump intensity becomes large and drives both countries' jump arrival processes.

Finally, the monetary-jump model could identify two types of jumps and reports that correlated jumps appear to drive the US and EMU jump intensity processes in the financial crises period. This characteristic suggests that, in world financial crises, the correlated jump intensity seems more important than individual jump generating processes. This trend reinforced that the 2008 financial turmoil presented the characteristic of contagious between the US and EMU yield curves. The jump correlation parameter was reported negative on long-term maturities, which suggests jumps move interest rate returns in opposite directions due to the time zone between the markets since FED decision statements affect the EMU interest rate market only on the next day. Beyond the time zone argument to explain the negative jump correlation parameter, another suggestion may be the difference packages of economic recovery measures implemented by the FED and ECB after the crises and their impact on long-term interest rates.

The empirical evidence suggested a high level of linkage between the two markets, especially in the world financial crises when correlated jumps appear to drive the jump arrival process of both countries. Also, monetary policy decisions spillover effects were very relevant to explain jumps in the monetary authority meeting days since foreign monetary decisions appear to create more jumps than the domestic monetary policy in the interest rate returns. The jump structure is very important to explain interest rate volatility; however, the monetary policy surprise component reports little contribution to the overall volatility. Since FED monetary policy decisions, regarding the target rate, are main drivers of global financial cycles that affect developed and emerging economies, further work can focus in the linkage of FED monetary policy with other central bank decisions and yield curves to evaluate if an interdependence exists that affects asset moves.

Apendix

Figures

Figures 11 to 20 reports the ex-post number of jumps and the ex-post probability of at least one jump occur for both individual jump arrival processes and for the correlated jump arrival process in both economic areas. The charts show the rising pattern of the correlated jump arrival process during the financial crises period. The monetary-jump model was able to report this contagious feature of the 2008 financial and economic crises. This increasing trend can also be verified in figures 21 and 22 for the monetary-jump measure of volatility for both countries in the period of the financial turmoil, an expected movement since volatility is a proxy of risk and uncertainty. As for figures 23 and 24, both charts show a decreasing contribution of jumps to total volatility in the crises period, however, the initial level shows a quick recovery after this period, remaining at a very similar level of jump contribution when compared the started and end point.

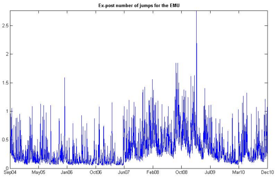

Figure 11 – 7 year maturity: Ex-post number of jumps for the EMU.

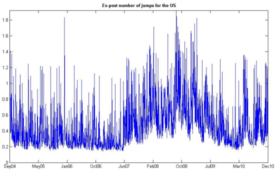

Figure 12 – 7 year maturity: Ex-post number of jumps for the US.

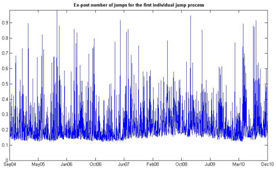

Figure 13 – 7 year maturity: Ex-post number of jumps for the first individual jump process.

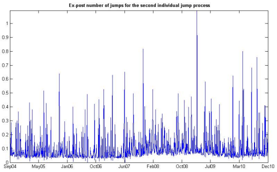

Figure 14 – 7 year maturity: Ex-post number of jumps for the second individual jump process.

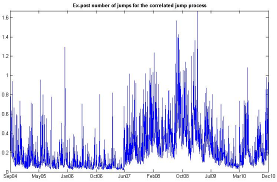

Figure 15 – 7 year maturity: Ex-post number of jumps for the correlated jump process.

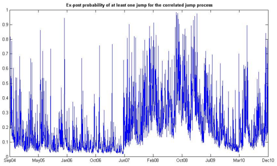

Figure 16 – 7 year maturity: Ex-post probability of at least one jump for the correlated jump process.

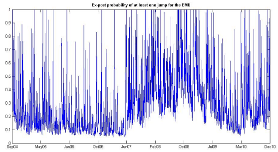

Figure 17 – 7 year maturity: Ex-post probability of at least one jump for the EMU.

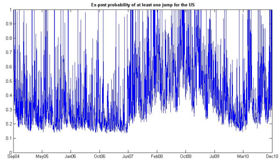

Figure 18 – 7 year maturity: Ex-post probability of at least one jump for the US.

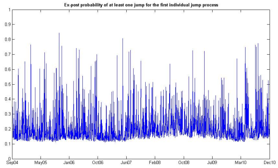

Figure 19 – 7 year maturity: Ex-post probability of at least one jump for the first individual jump process.

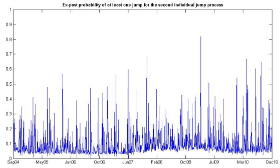

Figure 20 – 7 year maturity: Ex-post probability of at least one jump for the second individual jump process.

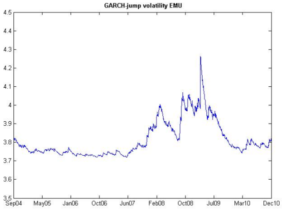

Figure 21 – 7 year maturity: Monetary-jump volatility for the EMU.

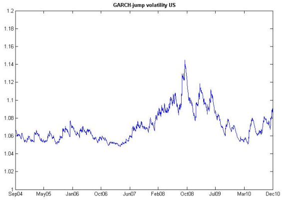

Figure 22 – 7 year maturity: Monetary-jump volatility for the US.

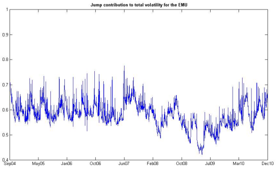

Figure 23 – 7 year maturity: jump contribution to total volatility for the EMU.

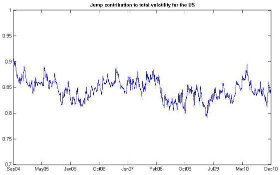

Figure 24 – 7 year maturity: jump contribution to total volatility for the US.

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