



**How do option-implied inflation
expectations react to the announcements
of non-conventional policies from the
European Central Bank**

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Abstract

This Dissertation builds a routine to extract inflation expectations from options through the risk-neutral distribution methodology, based on the Black-Scholes pricing model. The data includes cap and floor options, equivalents of call and put options with inflation as the underlying, with some technical differences. The methodology includes extracting implied volatilities from observed prices of caps and floors, then use a cubic interpolation on implied volatilities, to be able to fit to the volatility smile. Further, taking advantage of Breeden and Litzenberger (1976), the initial density functions are calculated as the second derivative of the option price in the Black-Scholes model. For a more encapsulating approach, the cap and floor density functions were aggregated, thereby being able to compare net effects with objectives of the monetary policy. A robustness test was also performed to analyze price variations along the two days prior, and after, the announcements of each policy, using floor options and inflation-linked swaps. The results show that, the ABSPP & CBPP3 and the TLTRO I announcements registered decreases, although the variations in prices and densities are small, therefore suggesting the importance of anticipation of measures and of other transmission channels to assess the effects of these policies. This is in line with the September 2015 report by the Vice-President of the ECB, Vítor Constâncio, that acclaims the effectiveness of the non-conventional monetary policies in controlling low inflation expectations, although affirming that the below, but close to, 2% goal of inflation has not been met.

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Resumo

Esta Dissertação elabora uma rotina para extrair expectativas de inflação através de uma metodologia de distribuição neutra de risco, baseada no modelo de preços de Black-Scholes. A data utilizada inclui opções *cap* e *floor*, equivalentes às *calls* e *puts* mas com inflação subjacente, com certas diferenças técnicas. A metodologia engloba extrair volatilidades implícitas dos preços das opções observadas, procedendo uma interpolação cúbica nas volatilidades implícitas, para ser possível aplicar um *fit* ao gráfico da volatilidade. Tomando partido do trabalho realizado por Breeden e Litzenberger (1978), as funções de densidade iniciais são calculadas a partir da segunda derivada da função do preço de opções do modelo Black-Scholes. Para uma perspectiva completa, procedeu-se ao agregamento das funções de densidade dos *caps* e *floors* numa única garantindo também as comparações com objectivos da política monetária. Um teste de robustez foi também conduzido através das variações dos preços de *floors* e *swaps*, dois dias antes e depois dos anúncios das políticas. Os resultados indicam que para quantificar com sucesso os efeitos destas políticas, um período de tempo maior deve ser considerado, sugerindo ainda a importância da antecipação das medidas e outros canais de transmissão para averiguar os efeitos da mesma. Isto está em linha com o documento apresentado em Setembro de 2015 por Vítor Constâncio, VP do ECB, que enalteceu a efetividade das medidas de política monetária não convencionais no combate às expectativas de baixa inflação, acrescentado ainda que o objectivo do banco central de inflação inferior, mas perto de, 2% ainda não foi atingido.

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Title: Como é que as expectativas de inflação subentendidas nas opções financeiras, reagem ao anúncio de políticas não-convencionais do Banco Central Europeu

Palavras-chave: Função de densidade de probabilidade, distribuição neutra de risco, inflação subentendida de opções, preços de opções, política monetária, políticas não convencionais

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List of abbreviations

ABSPP – Asset-backed Securities Purchase Programme

CBPP3 – Third Covered Bond Purchase Programme

CSPP – Corporate Sector Purchase Programme

ECB – European Central Bank

PDFs – Probability Density Functions

PSPP – Public Sector Purchase Programme

SEF – Survey of External Forecasters

SPF – Survey of Professional Forecasters

TIPS – Treasury Inflation Protection Securities

US – United States

1. Introduction

In response to the economic and financial crises during the last decade, the ECB has adopted a series of non-standard measures. In particular, since 2014, measures have been implemented more directly aimed at counteracting the strong downward risks to price stability. The most relevant of these measures were the Asset Purchase Program (APP), the credit easing measures and the cut in official interest rates into negative territory. Given the clear aim of warranting price stability and the importance of expectations in policy transmission, it is of utmost importance to assess the impact of such measures in inflation expectations. Literature shows that announcement effects are the most important ones. The present Dissertation, thus, assesses the effect of the announcements on daily-frequency inflation expectations measures, by means of an event-study type of analysis. Moreover, as a complementary analysis, the option prices, specifically cap prices, were examined to determine if the effect on implied inflation was consistent with the price variation in those options.

The main source for inflation expectations used in this Dissertation will be inflation options, namely caps and floors, that behave just like call and puts would on any underlying asset, in other words, caps and floors have a payout structure identical to the commonly known one of calls and puts. The key differentiating factor between the two options, however, lies on the underlying asset value at maturity, which for caps/floors is measured as the value three months prior to the expiration of the option rather than the plain value at maturity. To that purpose, a routine was built to withdraw the probability distribution of inflation in the future, based on what has already been developed in some central banks. This is based on the known probability density functions methodology for inflation options using the Black-Scholes model, as well as the principle introduced by Breeden and Litzenberger in 1976 that stated that the second partial derivative of the asset price is proportional to the its density functions at maturity T .

On the one hand, using inflation expectations from option prices has the big advantage of assessing the entire distribution of expectations, instead of only the central point, as usually one can find using other market instruments such as inflation swaps or inflation-indexed bonds. On the other hand, the very thin market for inflation options, besides being an OTC market, can be considered a disadvantage of the analysis based on this data.

The estimated probability density functions, along with the option price analysis are compared with the objectives of the European Central Bank, both at short-term and long-term. This

Dissertation aims to evaluate the effects these measures had, against objectives stated by the ECB.

Inflation expectations, in the eyes of the central bank, have a fundamental role as a tool to understand how the market, and consequentially the investors, assess the compliance of the central bank with its mandate of price stability. The European Central Bank has, in its price stability mandate, an objective to keep inflation in the medium-term below, but close to, 2%. Anchored inflation expectations are of relevance to the central bank and could be interpreted as medium- to long-term inflation expectations below, but close to, 2%. This was the reference point to assess whether, or not, these non-conventional monetary policies were having the desired effect at the announcement.

As such, the present Dissertation is structured as follows: section 2 relates to the most important advancements made in the field of measuring inflation expectations, as well as a deeper view of how relevant inflation expectations, along with non-conventional monetary policies, are for the European Central Bank's objectives. Following, section 3 incorporates the data and methodology chapters, in which, firstly, the type of data and its description are presented, then secondly, how that data will be analyzed to yield the results that will then be compared to the set objectives. In section 4, in which the findings on policy announcements are discussed, the scrutiny of each announcement reveals that, besides the abnormal behavior displayed by the public sector purchase program, the cumulative probabilities of future inflation expectations show a positive effect, as the densities in the options with one-year maturity, suffer a shift from the strike price range above 2%, to the ranges lower than 1% and 1.5%. Also, the robustness option price analysis corroborates this effect by registering decreases in prices, both in short-term maturities of one year and long-term maturities of 5 years. Thus, one can conclude that the announced measures were effective in contributing to attain the ECB's policy objective. Lastly, section 5 presents a conclusion to this Dissertation in which all key takeaways are recalled, and future improvements to this research are discussed to the betterment of further research in parallel to this one.

2. Literature review

Extracting inflation expectations from options has been a viable alternative to estimate how the market forecasts future inflation since the 1990s, with the introduction of the Treasury Inflation Protected Securities. Nonetheless, improvements to the methodology, as well as development of new ones, are continuous, thus, to review evolutionary process, a broader division between what can be extracted from the market and how those values effect the monetary authority's decision making was necessary. It is deemed necessary due to the relevancy of inflation expectations to the major central bank, as they are the ones that set a target for inflation. Hence, it is paramount to monitor if the market participants perceive that the central bank is capable of meeting its objectives.

2.1 Different sources for inflation expectations

There are two major sources from which inflation expectations can be extracted, namely surveys and market instruments. This Dissertation will focus on eurozone instruments, thereby the analysis based on these instruments will, consequentially, emphasize eurozone effects.

2.1.1 Survey-based approaches to inflation forecasts

A survey is defined as “an examination of opinions, behaviors, among others, made by asking people questions”¹. As such, a survey can yield results in any area of expertise, if the correct participants were to be asked the correct questions, in this case, the questionnaires should be done to the investors/market. In general, surveys have the advantage of being clean of noise and volatility while struggling with the disadvantage of low frequency.

Garcia (2003) provides valuable insights to using surveys, specifically the Survey of Professional Forecasters (SPF). This survey, launched in 1968 in the United States of America, is a quarterly questionnaire whose questions can be aggregated inside three main focal points: inflation, gross domestic product (GDP), and employment. Inflation-wise, this survey yields expectations based on both, the harmonized index of consumer prices (HICP) and the same without tobacco, alcohol, food and energy. These expectations are calculated for the short-term for one, two and three years, considering any year after that as long-term. Yet, the outlined shortcomings of using these surveys come to light as it is only a quarterly questionnaire, which

¹ As per the Cambridge Dictionary: <https://dictionary.cambridge.org/dictionary/english/survey>

not only does it create scarcity of information, it also is highly dependent on the time period of the questionnaire.

From a central bank's perspective, there are some issues of relevance from the use of SPF to read inflation expectations. According to Giordani and Soderlind (2002), forecasters from the (SPF) tend to undermine inflation uncertainty. Moreover, Glas and Hartmann (2016) prove that the cross-sectional variance of point forecasts ("disagreement") from the SPF does not qualify as an appropriate representation of uncertainty. Therefore, developing a more robust and reliable measure for future inflation should bring stability, as well as empirical grounds, from which the ECB can assess the need to implement non-conventional measures.

Other central banks also use qualitative information from surveys for their regular policy analysis. The Bank of England conducts, similarly to the SPF, the Survey of External Forecasters (SEF) that yields not only point forecasts, but also density forecasts to inflation and GDP². While it differs from the SPF in terms of density forecasts and its short-term measures being for 4 years instead of 3, the SEF presents the same drawback as its ECB comparable: quarterly frequencies and, consequentially, timing problems.

Smith (2012) takes advantage of the Bank of England's SEF to establish a comparison between option-implied measures of uncertainty for UK retail price index (RPI) inflation³ and, probability distributions of measures of uncertainty for consumer price index (CPI) inflation provided by the survey. Even though comparisons between RPI and CPI are noisy at heart, it proves that SEF measures are on track with option-implied measures.

2.1.2 Inflation-linked instruments

It is possible to infer inflation expectations from financial market instruments indexed to inflation, such as bonds, swaps and options as the main data driver. These instruments provide additional information relative to survey-based expectations. They gave the advantage of having higher frequency and should provide consistent expectations in the absence of market frictions or other limits to arbitrage. In practice, the pricing for these instruments is subject to several premia, such as liquidity, risk or term, that blurs the information flow about relevant expectations for policy makers. The following paragraphs will go into further detail as to why these instruments might (or not) be useful for policy analysis.

²First 2019 SEF <https://www.bankofengland.co.uk/inflation-report/2019/february-2019/prospects-for-inflation>

³ RPI was the previous measure of inflation before the CPI, and its options' maturities range from 1-30 years. When maturity is reached, the underlying asset value is the RPI inflation two months before the maturity.

Inflation-linked bonds such as US Treasury Inflation Protected Securities (TIPS) are bonds that allow investor protection against inflation. The principal is adjusted to inflation, i.e., rises with inflation. With the inception of the first inflation-linked derivative as index-linked debt, Treasury Inflation Protected Securities (TIPS) have been continuously issued by the US Treasury dating from the late 1990s and, have been since then a vehicle from which market inflation expectations can be derived. However, as Gürkaynak, Sack and Wright (2010) proved, TIPS are not a transparent measure since they are distorted by inflation risk premium and liquidity premium effects.

Another market instrument indexed to inflation is inflation swaps. These are swaps in which one of the legs pays a fixed rate and the other pays a floating rate indexed to inflation. In the euro area, inflation-linked swaps are commonly traded and benefit from high liquidity with several maturities being traded. Inflation-linked swaps attracted the attention of researchers that thought these swaps might provide a better insight into how the market forecasts inflation. Haubrich, Pennacchi and Ritchken (2012) focused on these derivatives to extract inflation expectations, real rates, and risk premia, having found that more reliable information on real yields could be derived by the difference between nominal yields and inflation swap rates, than from inflation-linked bonds. Moreover, Fleckenstein, Longstaff and Lustig (2017) concentrate on deflation risk and how the markets react to tail risk occurrences using inflation options as well as inflation-linked swaps, yielding results to these tail risk similar to those of corporate defaults or enormous insurance losses.

More recently, inflation-indexed options have emerged in the market. These caps and floors are groups of caplets and floorlets that share the same strike and notional while the maturity is on consecutive years, thus these options protect the owner against increases – caplets – and decreases – floorlets – in inflation. For instance, in caps, the buyer acquires the option by paying a premium in the present to then, when maturity is reached, receive the difference between the realised inflation rate and the strike, multiplied by the notional. However, money only changes hands if the difference is positive much like a call option as seen in the following figure:

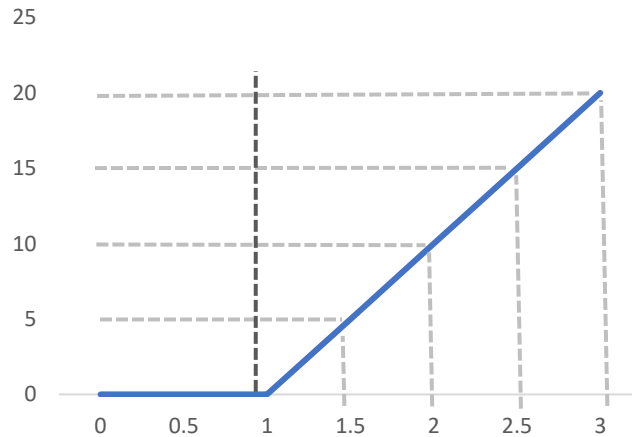


Figure 1 - Pay-out of a caplet in £000's Smith (2012)

As the market of caps and floors increased in popularity in the US and more so in Europe, so did the research regarding its possibility of yielding a new method to extract market inflation expectations. The major disadvantage of this source of information comes from the possibility to take the entire distribution of expectations instead of only the average expectation. Kitsul and Wright (2013) present the first application to extract probability density functions from inflation-linked derivatives and how those functions are affected by macroeconomic public news. This new methodology introduced a way to extract market implied inflation along a time series that resulted in the understanding that investors have high marginal utility in states of the world with the presence of tail risk.

2.1.3 Implied pdfs and implied vs underlying distributions

To understand how to determine expectations of future inflation through options, first it is important to understand the building blocks underneath it. It is possible to determine expectations about variables through options due to the Black-Scholes formulas for the prices of call and put options⁴ in the risk-neutral world. Hull, J. (2006) thoroughly proves how the term $S_0 N(d_1) e^{rT}$ is the expected stock price at time T with $N(d_2)$ being the probability of the call option being exercised, all in the risk-neutral world. While these are terms directly observable from the formulas, other relevant variables are not so easily spottable, for instance, the implied volatility. This variable is obtained via a trial-and-error procedure in order to determine the most approximate value of σ that in the Black-Scholes call option formula

$$c = S_0 N(d_1) - K e^{rT} N(d_2) \quad p = K e^{rT} N(-d_2) - S_0 N(-d_1)$$

$$d_1 = \frac{\ln\left(\frac{S_0}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)T}{\sigma\sqrt{T}} \quad d_2 = d_1 - \sigma\sqrt{T}$$

satisfies the given requirements for the outstanding variables. Implied volatility will also be of huge value in the application of the methodology of this Dissertation as it is its starting point. Maintaining in the risk-neutral world, Malz (2016) from the Federal Reserve Bank of New York, aims to reduce complexity of risk neutral distributions (RND) by facilitating a simpler method, which is in parallel with the one employed in this Dissertation.

The computation of RNDs begins with the derivation of the Black-Scholes formulas as per Breeden and Litzenberger (1978), that states that the derivative of the call option value with respect to the strike price represents adequately risk-neutral probability that the asset price at time T will not be higher than the strike price at maturity. Hull, J. (2006) shows these findings as the second derivative of the European call price formula in respect to the strike price equal to risk-neutral probability density function. This means the same as having the risk-neutral probability of the underlying price being under, or above, any target.

This methodology has been applied for other financial assets, such as in Clews, Panigirtzoglou and Proudman (2000), in which they use a technique for estimating uncertainty about interest rates at a constant horizon since 1997. In fact, there were two methods employed, the parametric and the non-parametric. This non-parametric method follows the same steps as Breeden and Litzenberger (1978) and expands by interpolating across the implied volatility smile using a cubic smoothing spline. By calculating the deltas of the options, it facilitates the interpolation in the “delta-space”, to then convert back to the original “strike-price-space”.

The main conclusions from this paper were that the non-parametric method was consistently better than the previous parametric method and, that the non-parametric method was able to construct probability density functions over a constant-maturity horizon - defined maturity horizon.

Smith (2012) also provides further conclusions that can be taken from probability density functions. Some summary statistics have different particular interpretations within the interpretation of the estimates of the probability density function, namely, the mean is seen as the price of the asset that the probability density function is linked to, the skewness relates to the balance of risks around the central expectation and, standard deviation that includes market’s uncertainty degree about the variable (Smith, 2012).

Also, the concept of implied distribution is relevant as it is, theoretically, an emulation of the underlying distributions without being an exact representation, meaning that although they are similar, the implied distribution still has important details different from the underlying

distribution. These differences include, mainly, the effect of pay-out in painful states of the world, such as deflation or high inflation, in which the pay-outs will be more valued than they would be in painless states of the world and vice-versa. This means that implied tail probabilities and standard deviation extracted from these inflation options will be necessarily higher than the underlying probabilities and, that increases in the underlying probability will be augmented in the implied probability (Smith, 2012).

2.1.4 Discrepancies between the analysis of caps and floors

Kitsul and Wright (2013), Smith (2012) and Gimeno and Ibáñez (2018) have expanded the method described above of deriving implicit probability distributions of the underlying asset, based on the Black-Scholes option pricing model, to inflation options. There are slight differences in the methods applied by each author but all of them rely on caps and floors as the data drivers to the process.

The major problem of deriving the implicit distribution of inflation expectations from options comes from the low granularity of data and the low liquidity in an OTC market that leads to frequently observed extreme prices.

Indeed, tradable caps and floors may not provide enough data points to infer a probability density function to its full extent. The before mentioned papers use different methodologies to overcome this issue, such as extrapolating cap prices to the same maturity and strikes as the effective market options.

Gimeno and Ibáñez (2018) fit the observed strikes to a multivariate Gaussian distribution based also on the inflation-linked swap prices, whereas Smith (2012) increases the dataset by expanding over maturities rather than strikes for the same maturity.

2.2 Assessment of monetary policy measures on expectations

2.2.1 Non-conventional monetary policy of the ECB

Within the scope of this thesis, I'll assess the impact of the announcement of unconventional monetary policy measures. Literature suggests that the announcement effect is highly relevant, especially when looking at high-frequency market data.

The focal non-conventional monetary policies will be the asset purchase programme (APP) and the targeted long-term refinancing operations (TLTRO) given their timespan and direct impact they were planned to have on inflation. Within the APP there are four specific programs, namely

the corporate sector purchase program (CSPP); public sector purchase program (PSPP); asset-backed securities purchase program (ABSPP) and; third covered bond purchase program (CBPP3) while the TLTRO was firstly on the fifth of June 2014, and later as TLTRO II on the tenth of March 2016.



Figure 2 - Timeline of the monetary policy announcements

The asset purchase program was created to tackle the risk of a possible lasting period of low inflation by monthly acquiring assets valued at €15 to €80 billion⁵ by providing monetary accommodation through the purchase of securities, such as, corporate sector bonds (CSPP), nominal and inflation-linked central government bonds (PSPP), asset-backed securities (ABSPP) and, covered bonds (CBPP3). The impact of these purchases on inflation can be understood under the following three driving channels⁶:

Firstly, through the direct pass-through channel, these non-conventional procedures aim to improve borrowing conditions to the private sector by creating better refinancing conditions to the banks which, in the end, will stimulate consumption and investment. This channel will be further discussed as it is the main driver to the TLTRO, both first and second, measure.

Secondly, the portfolio rebalancing channel transmits through the decrease in yields on larger sets of assets. With the acquisitions made by the central bank, the seller’s liquidity of those assets increases tenfold and, even if this increase is not a perfect substitute for the asset sold, the trade between assets might trigger a rebalancing of the portfolios in favour of different assets. Moreover, a wave of portfolio rebalancing might lead to more purchases of foreign assets in the euro area which, in consequence, augments the pressure on Euro.

Lastly, the signalling channel. The impact of this channel can be twofold, meaning that it can either exert pressure on the central bank to review market expectations regarding short-term interest rates or, it may also lead to a boost in inflation expectations. While the latter is deducted

⁵ <https://www.ecb.europa.eu/explainers/tell-me-more/html/app.en.html>
⁶ https://www.ecb.europa.eu/pub/pdf/other/eb201507_article01.en.pdf?6ab82335bdf51755798444b35ede83f5

through the lower real long-term rates that enhance consumption and investment, the pressure to review market expectations stems from the large period of liquidity derived from the maturity of the acquired assets.

On the other hand, the TLTRO are targeted operations set to boost credit institution's liquidity in the form of a loan with a fixed rate and maturing in September 2018. Even though banks are eligible to borrow 7% of a particular portion of their eligible loans in the first two operations, the following ones might increase this percentage, variable on performance of the credit's activity versus each bank's thresholds. Similarly to its predecessor, the TLTRO-II provides the same targeted operations, only here there are four operations and a borrow percentage of 30%. As for the interest rate, it is fixed at the rate equal to the main refinancing operations (MRO), however if the bank's eligible net lending surpasses their benchmark, this rate is bound to decrease.

2.2.2 Expected Inflation

Inflation expectations from the private sector are a fundamental input for central bankers when evaluating the monetary policy decisions towards their broader goal of attaining price stability (Boninghausen & Kidd & de Vincent-Humphreys 2018). Van der Crujisen and Demertzis (2005) dissect previous literature, theoretical and empirical, regarding transparency from the central bank, its policies and their expected effects. Despite the most recent empirical methods pointing to an upside of transparency, literature is not unanimous on this topic. Moreover, differences in methodologies might create different results, thus making it even harder to unanimously declare positivity. Still, it is still possible to conclude that the overall effects of transparency are desired, with the procedural transparency presenting the biggest unknown.

Circling back to inflation expectations, and given that imperfect knowledge is a characteristic associated with economic agents, policies employed by the central bank that are unable to manage these expectations tend to create a disparity between the central bank's and the market's future inflation forecasts, whereas active communication from the central bank paired with attentiveness to the market tend to anchor inflation expectations to the central bank's target (Orphanides & Williams, 2003).

Scharnagl and Stanf (2015) and Gimeno and Ibáñez (2018) reveal relevant conclusions regarding the effects on these inflation expectations from the monetary policies by the ECB. Scharnagl and Stanf (2015) focus on the period of the sovereign debt crisis between 2009 and 2013 concluding, through option-implied probability density functions, that inflation

expectations' mean decreased whereas uncertainty registered an increase since mid-2011. Near that time, the effects of monetary policy announcements sunk and the fear about extreme inflation or deflation rose consistently. Gimeno and Ibáñez (2018) opt for a risk-neutral density approach also, emphasizing tail risks, meaning probability of extreme scenarios. Using eurozone inflation options, it finds that the estimation of maturity structures of risk-neutral densities is better suited to analyse changes in inflation expectations. Also, it offers the possibility of cumulative probabilities, thus assessing inflation expectations below any threshold becomes possible. Lastly, comparisons with the RNDs extracted from the SPF can yield information about risk aversion levels at changing levels of inflation.

3. Data & Methodology

3.1 Data

The present Dissertation implements a routine that yields daily probability density functions for inflation expectations in a future date and, gathers time periods in which the central bank acts by means of non-conventional policies to evaluate whether or not these measures had the desired impact. For that to be possible, times-series data regarding inflation caps and floors, Euribor interest rate swaps and, inflation swaps were required.

The main data sources are the daily prices of caps and floors on the Harmonized Index of Consumer Prices excluding tobacco (HIPCxT) with strikes ranging from -3% and 4%, with increments of 0.5% between each other, and yearly maturities ranging from 1 year to 5, withdrawn from the Bloomberg Database⁷. Furthermore, maturity is also valued since the larger the spectrum from which inflation can be extracted, the wider the perception of market inflation expectations. However, inflation-indexed options over 5 years of maturity were considered the higher threshold, as predictions of inflation over ten years in advance are not reliable enough to act upon. Thus, caps and floors with the aforementioned strikes and frequencies were also bound to yearly maturities until 5 years. When maturity is reached, inflation-linked options have a different process than the usual one of calls and puts. In calls and puts, when maturity is reached, if the strike price is under the price of the underlying asset on that day (in calls, reverse in puts), then the option is exercised and the investor earns the difference between the two prices times the amount of option bought. In inflation-linked derivatives, when maturity is reached,

⁷ Access to The Bloomberg database was given thanks to the Bank of Portugal.

The Bloomberg label associated with caps and floors is EUIZC and EUIZF respectively. Additionally, the numbers following these letters are associated with the strike price and maturity, for example, EUIZC61 refers to a cap with 6% strike and 1-year maturity

instead of the strike price being compared to the value of inflation on that day, it is compared to the one exactly three months prior.

On the other hand, Euribor interest rate swaps in addition to inflation swaps were used to discount/compound prices and as a proxy for the spot price of the inflation asset, respectively, with both variables being obtained via DataStream. The latter includes daily values one year in advance from January 2010 until April 2019, while the daily Euribor swaps' maturities range similarly to the caps/floors, meaning, yearly until 5 years plus the 10 year.

3.2 Methodology

Previous literature often places the main methodological emphasis on the calculation of the probability density functions for extended timelines, nevertheless this Dissertation encompasses a further step, being the effect of monetary non-conventional policies on these functions. As such, with the purpose of addressing this Dissertation's research question, a two-pronged approach is necessary, firstly by attaining the combined daily probability density functions of caps and floors and then, by assessing the impact of the central bank's measures in the three daily pdfs post and prior to the announcement. The following routine was built on a previous version created by Ken Deely, whose work on the MATLAB process of using density functions in financial options is available in the MathWorks website⁸. Although this code served as a starting point, the main element, among several in-between steps, from which conclusions from this Dissertation will be drawn, is very much a deviation from his methodology, namely the aggregation of the caps and floors probability density functions into a single one that represents the full inflation-indexed options perspective.

The routine relies on calculating the implied probability density function for both caps and floors separately. All intermediate steps are thus repeated for both sets of options throughout the routine. The first step is to calculate the implied volatility, according to the Black-Scholes model (MATLAB function `bldimpv`). Using a Black-Scholes model, the required inputs of option price, spot price, strike price, risk-free rate and, maturity, can be extracted from the caps/floors⁹, maintaining implied volatility as the sole output. This process is done for both caps and floors yielding the following two graphs that plot implied volatility in respect to strike price. For illustrative purposes, all the figures in this section will be based on the observed values for a day chosen at random. It is relevant to mention that a normalization towards the strike price

⁸ <https://www.mathworks.com/company/newsletters/articles/estimating-option-implied-probability-distributions-for-asset-pricing.html>

⁹ Given that Caps/Floors have pay-out structures identical to Calls/Puts, the Black-Scholes formula is applicable.

(K) was done throughout the research, in which the strike price equal to 0% is the 100 value. This means that inflation below 0% is to be seen to the left of the strike price equal to 100.

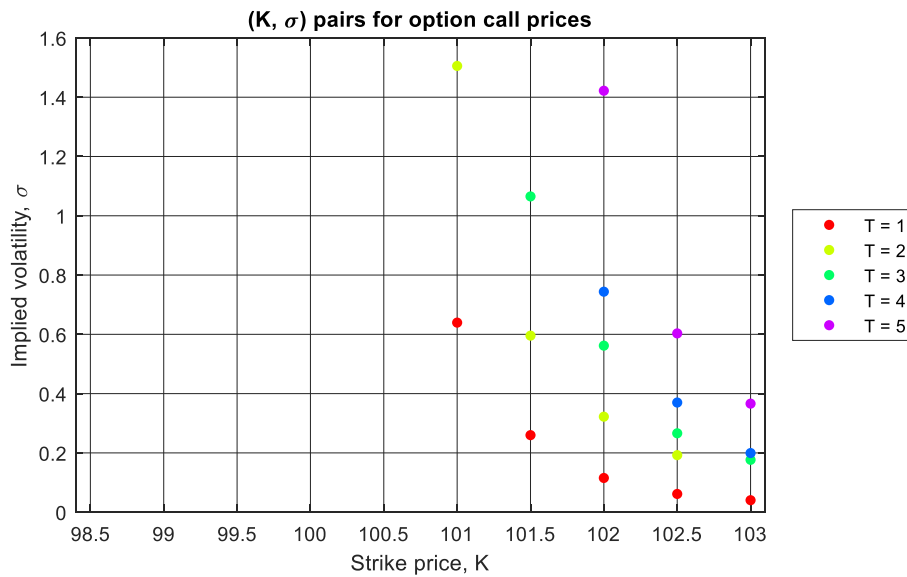


Figure 4 - (K,σ)-space observed pairs for option call prices

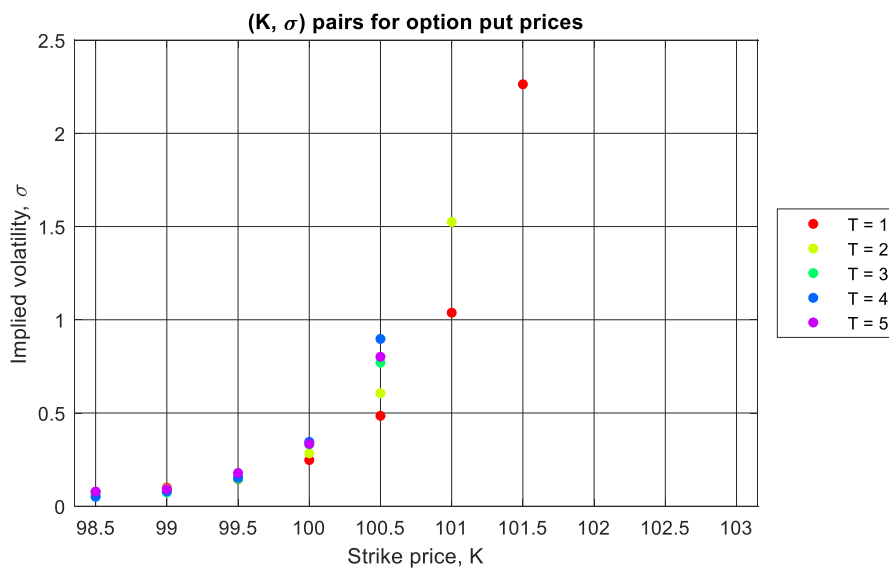


Figure 3 - (K,σ)-space observed pairs for option put prices

Figures 3 and 4 indicate that, for both caps and floors, implied volatility tends to be lowered the further the strike is from the spot price ($S=100$), in other words, in the case of caps, strikes upwards of 100 have declining implied volatilities and, in the case of floors, there is a mirrored effect starting slightly higher than 100.

Having calculated implied volatility and displayed it in the (K,σ)-space, meaning strike price and asset volatility respectively, the next step is to interpolate for additional data points in this same space. Here, different approaches can be taken, such as fitting a quadratic function for

each maturity or the SABR model (this one only attainable through a specific payable toolbox in MATLAB named Financial Instruments Toolbox, thus weighing negatively when deciding the approach), however, this Dissertation opts to interpolate using the cubic spline methodology for each maturity. In general, applications for other options, such as interest rate options, use splines to adjust the volatility smile. This is a two-step process that expands the sample of strike prices within the range of the observed values, and then extracts a value in the strike-sigma-space for each maturity by fitting to a spline function, equally expanding data points for both caps and floors. The following two figures are a result of the fit, plotting it directly on figures three and four.

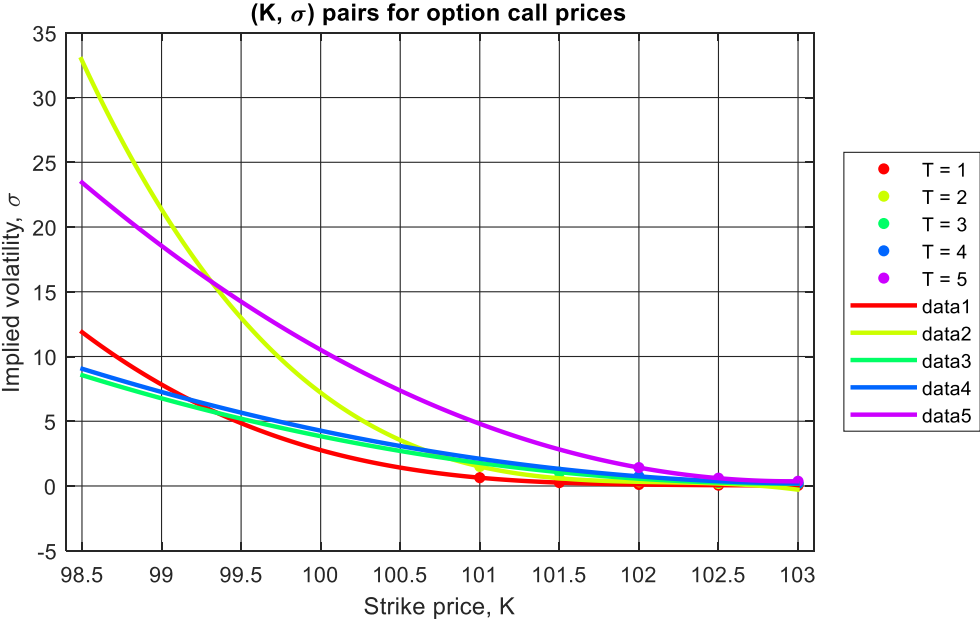


Figure 6 - (K, σ) -space interpolated implied volatilities for option call prices

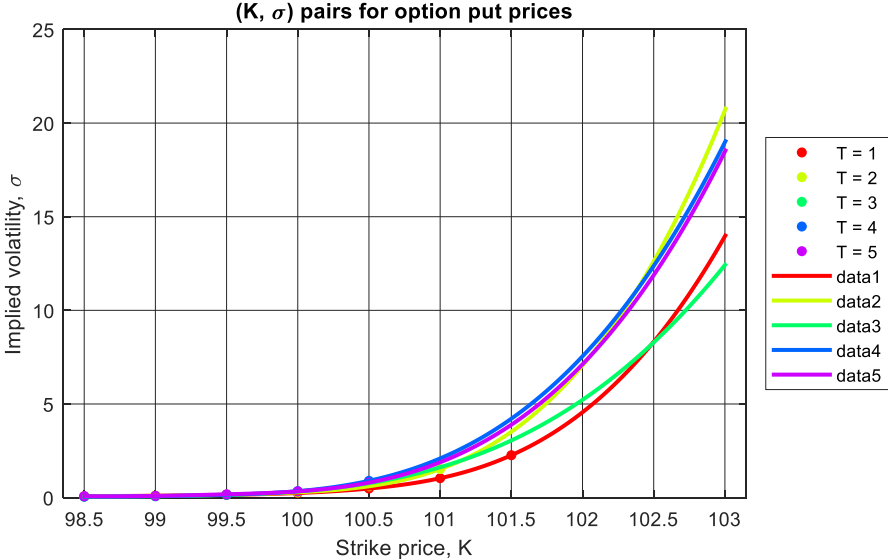


Figure 5 - (K, σ) -space interpolated implied volatilities for option put prices

Figures 5 and 6 illustrate a broader picture than the one provided in figures 3 and 4, thus it is possible to observe a stronger pattern of the implied volatility in both inflation-indexed options. Maintaining the (K, σ) -space as the frame of reference, implied volatility tends to be higher on one side of out-of-the-money strikes that, for caps, translates to being higher at strikes lower than the spot price and tending to zero post spot price, whereas in floors it shifts, tending to zero pre spot price and increasing thereafter. From these figures, one can already anticipate potential issues in computing density functions. Indeed, the volatility smile differs from what we usually find in other options, as it is not in a U-shape, rather a J- or inverted J-shape.

Having expanded the data set, the next step involves a conversion back to the (K, price) -space as it is necessary to implement the implied strike price density function (Breen and Litzenberger, 1978) implemented by MATLAB function `blsprice`. After this step, it is possible to have a function of the option price twice differentiable, i.e., one gets the second derivative of the asset's call price is proportional to its probability density function at maturity "T". Hence, by calculating both partial derivatives in respect to the strike price, after converting to the strike-call price frame, it yields the first incomplete look of the daily density functions for each maturity. In practice, occasionally the fitted volatility smile implies negative volatilities along the considered strikes vector. Whenever this occurs, I disregard such points, implying a smaller base for the density function in such cases and the possibility of a sudden break in the second derivative of the price function.

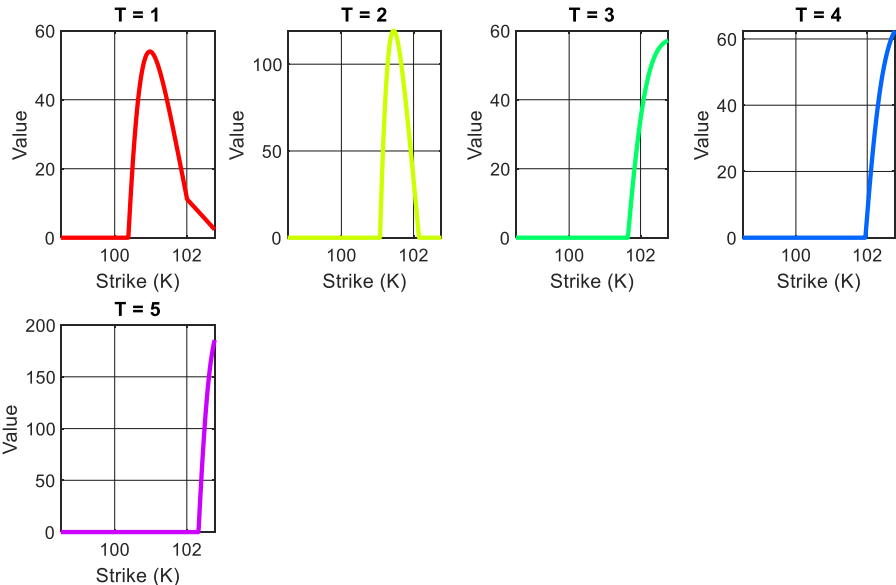


Figure 7 - Second derivative of call price for all 5 maturities in the (K, price) -space

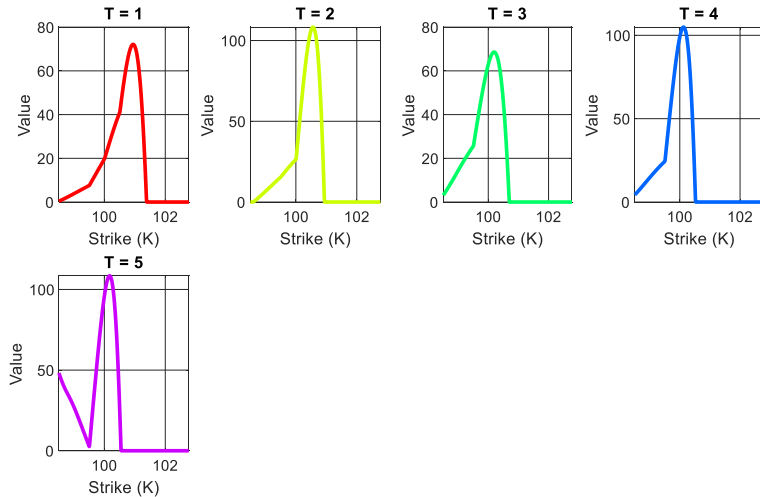


Figure 8 - Second derivative of put prices for all 5 maturities in the (K,C)-space

Figures 7 and 8 confirm that these initial density functions lack information with the progression of the strike price, mainly Figure 7 related to the cap functions, therefore, one more interpolation is required to gain information along the strike prices. By using a linear interpolant, the extrapolation and normalization under each function is made possible, ensuring that negative probabilities are not considered and that the total area sums up to one, which yields the implied density functions as seen in Figures 9 and 10.

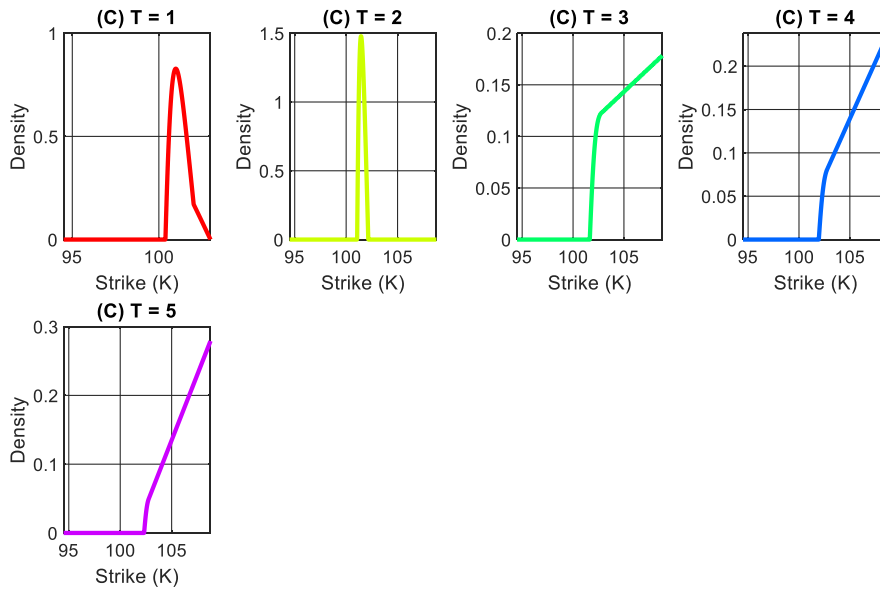


Figure 9 - Density functions over 5 maturities for option cap prices

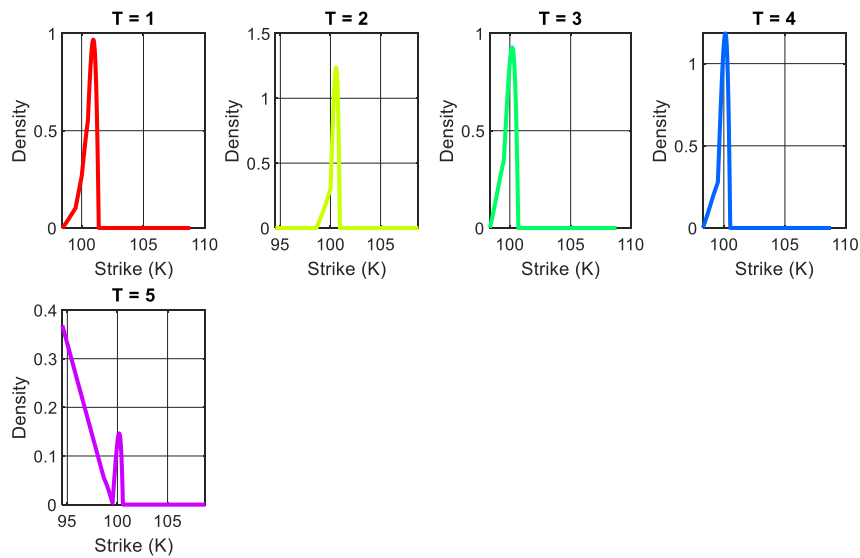


Figure 10 - Density functions over 5 maturities for option floor prices

Although having separate density functions based on both caps and floors opens an exploration avenue of divergency in expectations between caps and floors markets, I consider that by themselves, they provide incomplete information. Indeed, the available data seems to be able to provide data mostly for the out-of-the-money range of caps and floors. In this way, there is a gain from considering the information provided by both, specially considered the asymmetric shape of the volatility smile. I consider the output of the density functions of both caps and floors together as frequencies and fit a Gaussian density function to it. This makes it so that both graphs yield a single pdf that should be normalized to further smoothen its curve.

This method can be easily criticized by being ad-hoc and forcing the fit to the strict density function. On the other hand, as recognized by other authors, namely Gimeno and Ibáñez (2018), the application of a Gaussian distribution can be justified given the few strikes available. These authors have also considered a mixture of two Gaussian distribution, but this produces frequently degenerate distributions or densities difficult to interpret.

The following figure shows the final probability density functions, in respect to the strike price, in which it is possible to observe that the majority of the density falls under the range of strike prices of 0% and 1,5% with the rest being zero, or slightly higher. This method also provides some insight to the plot of both the caps and the floors data, as they are represented by the two blue lines from which the single red density function is calculated.

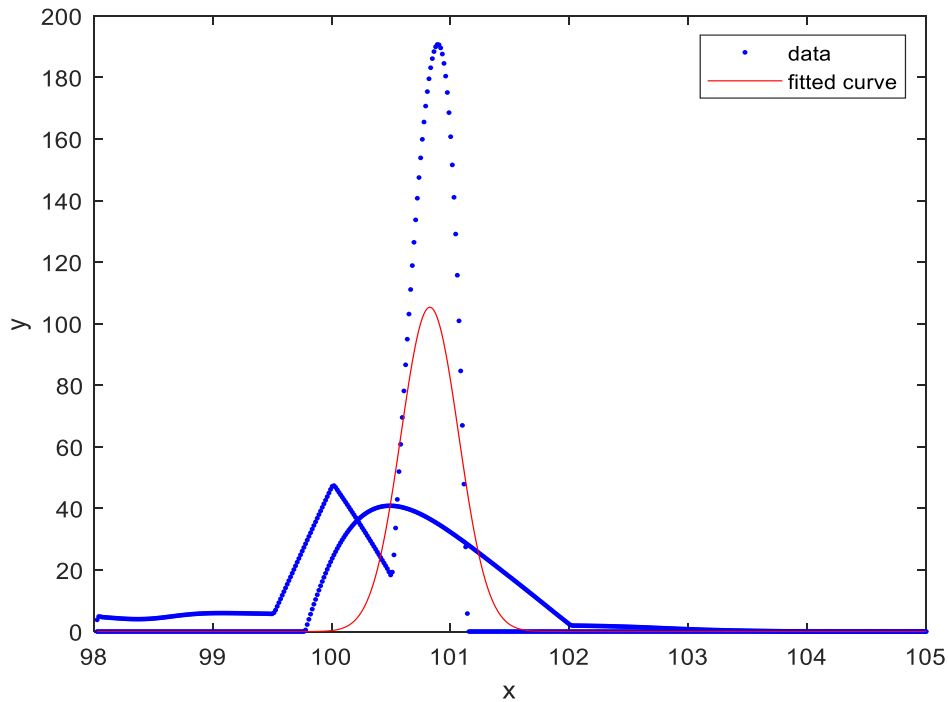


Figure 11 - Probability density function combining both caps and floors densities

Moreover, an extra step towards future evolution of the asset prices was taken. Since option prices include investor's expectations of underlying asset prices in different moments in the future according to the option contract, fan charts regarding evolution of underlying price in respect to progression of time were developed.

Based on the probability density functions, this Dissertation opts to extract random sample of values for asset prices for each future time entry, creating a matrix wherein the rows contain the future times and, the columns are dedicated for the random extracted asset prices. From this sample, that is done with floor prices, cap prices and, both together, the only other input required is a historical performance of the asset at hand, which in this case is only assumed at time 0 with a spot price of 100. The results are shown in Figure 12 in a plot using cap prices whereas Figure 13 concerns the forecasted price evolution based on the floor prices. Figure 14 shows the broader picture with the joint forecasts of both caps and floor prices in order to compensate for how both sides of the market expect future inflation to develop.

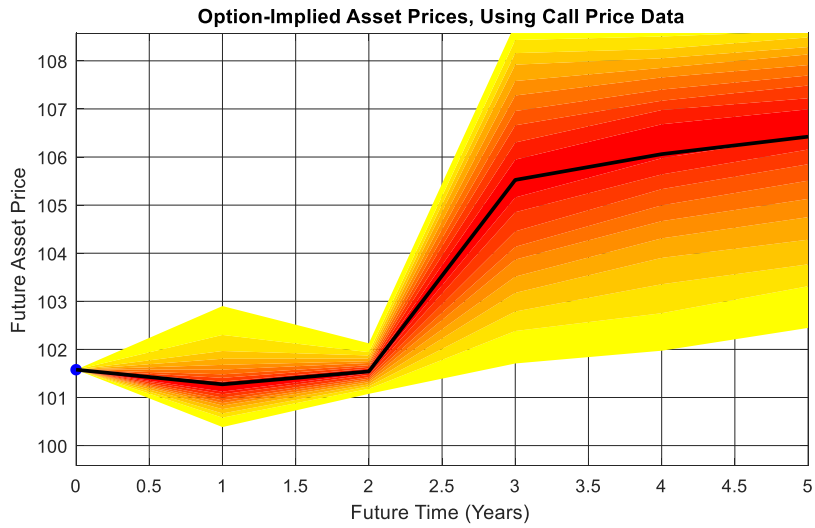


Figure 13 - Future asset price projection based on cap option prices

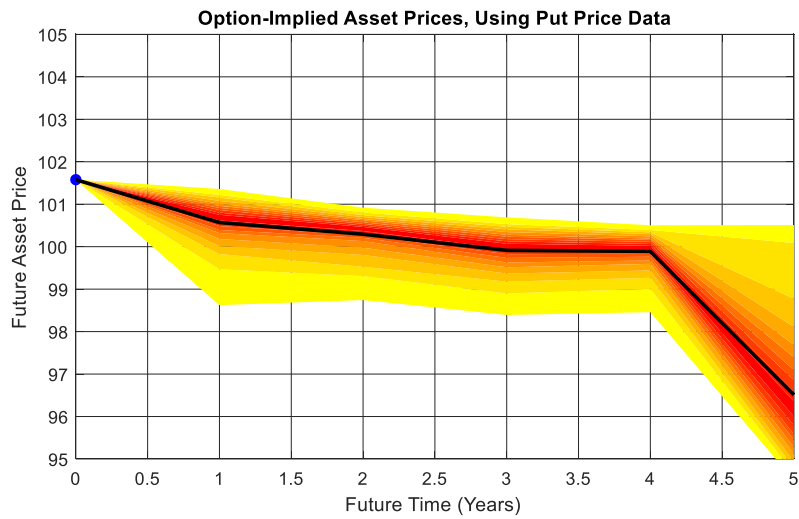


Figure 14 - Future asset price projection based on cap option prices

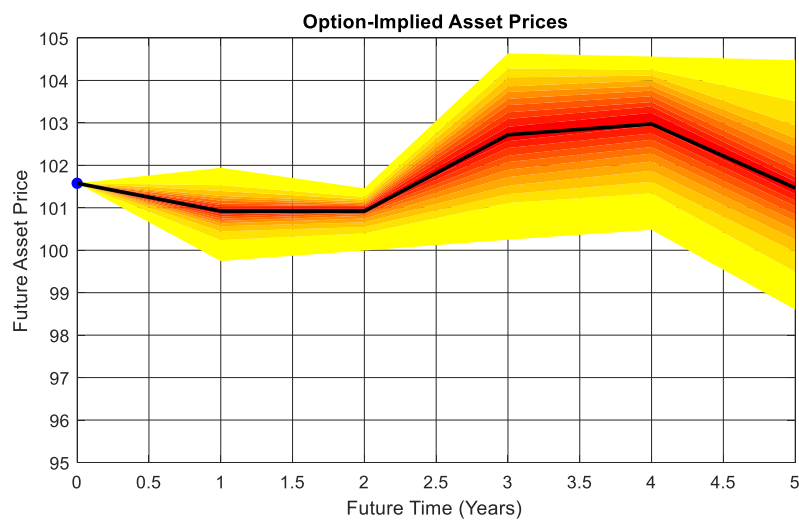


Figure 12 - Future asset price projection based on option-implied asset prices

Each change in colour represents a change in different quantiles, meaning that as the dispersion expands away from the centre, it starts to change from a vivid red to a yellow tone. This facilitates the interpretation that not only does the degree of likelihood increase conversely to the widener of the fan chart, but also the passing of time causes a consistent increase in uncertainty. Furthermore, the central line represents the median progression of the underlying asset price, thus the most expected scenario for the price of the asset, based on this randomly selected day, is to decrease slightly during the first two and a half years, recuperate and pass the initial value, to then decrease again to the approximately original state. It should be mentioned that the fan charts are calculated from two separate density functions based on caps and floors, respectively.

4. Findings on policy announcements

This section concerns the application of the routine developed in the methodological chapter as well as a complementary analysis regarding observable long- and short-term impacts of the aforementioned announcements, following other lines of study such as Scharnagl and Stapf (2015). This observable effect analysis, motivationally, stems from the implications the implied inflation has on the inflation-indexed options such as caps, meaning, the price of these options should change with inflation-impacting announcements.

The perfect window of time to capture announcement effects is still unknown as literature divides itself between ranges. However, this Dissertation will follow a short-term and long-term approach to the observable data. For that, the required data includes floor prices for strike prices of zero, one and two percent with maturities of one and five years and will be complemented with the analysis of inflation swap prices with the same maturities except they start in one- and five-years' time respectively.

To evaluate announcement impacts on the short term, daily percentage change of one year floors three days prior, and after, the announcement (inclusive), in conjunction with the daily percentage change of inflation-linked swaps with one year maturity, comprise two extra robustness analysis to the results prompted by the probability density function analysis. Adding to that, a graph of the price evolution 2 months prior, and after, of the one-year maturity floor with zero percent strike price was elaborated for each of the announcement dates.

Similarly, long term impacts are measured using daily percentage changes of floors and swaps with five-year maturities, as well as the announcement dates graph of price change of the five-year maturity floor with zero percent strike price. These maturities were chosen in parallel with

what is published by the central bank in their monthly, and yearly, bulletins as to facilitate comparisons between what was the impact the central bank expected the policies to have, versus the actual impact they did have in the inflation expectations.

4.1 Asset Purchase Program & TLTRO

4.1.1 ABSPP & CBPP3

The announcement dates for both the asset-backed securities purchase programme and the third covered bond purchase programme coincided on the second of October of 2014. As such, given that it is highly complex to separate the effects of both announcements, these programmes were analysed as one.

Regarding the observable analysis, the announcement seems to have had the desired impact with decreases in prices in the short term only on the last day of analysis, (Table 1) but also in the zero percent strike floor in the long-term. However, the long-term floors (aside the zero percent strike) seem to have their prices relatively unscathed, aside of marginal increases. One of the objectives of the programmes was to contain expectations of very low inflation, thus the long-term decreases of 16% and 7% the days after the announcement contribute to those objectives (Table 2). Swaps register short-term decreases with emphasis on the 6% brought by the second day after the announcement, whereas the long-term remain essentially the same. A broader look these effects is provided in Appendix 2 and 3 with graphs of the price variation two months prior and after the announcement in 1-year and 5-year zero percent strike floors respectively. From these, it is possible to see that the short-term remained broadly stable and increased substantially at the end of November, possibly related to other factors.

This does not necessarily weight against the effectiveness of these measures, given that I'm not controlling for other factors and given that the impact of expectations can occur via other channels as discussed before.

		Daily price change of 1-year floor				
ABSPP & CBPP3	Strikes	01/10/2014	02/10/2014	03/10/2014	06/10/2014	07/10/2014
	Floors	0%	3%	7%	2%	3%
1%		-2%	6%	1%	3%	-5%
2%		-2%	3%	0%	1%	-2%
Swaps		-8%	-2%	-2%	-6%	3%

Table 1 - Daily price change of 1-year floor for the ABSPP & CBPP3 announcement

Daily price change of 5-year floor (ND=no data)

ABSPP e CBPP3	Strikes	01/10/2014	02/10/2014	03/10/2014	06/10/2014	07/10/2014
	0%	0%	6%	3%	-16%	-7%
Floors	1%	1%	6%	ND	1%	5%
	2%	1%	3%	1%	2%	0%
Swaps		-1%	-1%	-1%	0%	0%

Table 2 - Daily price change of 5-year floor with 0% strike (ND=no data)

Proceeding to the probability density function analysis, theoretically, the impact of these non-conventional measures ought to be assessed by comparing the daily cumulative probabilities during the days prior, and after, the announcement. As such, Table 3 includes the cumulative probabilities of the options maturing in one year, the day prior to the announcement, the day of the announcement and, two days after, in which the progression through the period shows an increase post announcement day (02/10/2014) in caps whose strike prices are below 0% and relative stability thereafter. Before the announcement, the largest mass of probability (around 70%) was concentrated in an inflation bin between 0% and 1%, clearly below the price stability mandate. After the announcement, the probabilities remained broadly the same. The changes shown in the table are overall marginal suggesting the absence of any relevant announcement effects on the distribution of inflation expectations. These probabilities present in Table 3 stem from the probability density functions of each day, with the announcement day being the following Figure 15.

ABSPP & CBPP3	01/10/2014	02/10/2014	03/10/2014	06/10/2014	07/10/2014
0%	3.4%	2.6%	2.5%	3.0%	2.7%
1%	74.8%	74.8%	74.7%	74.8%	74.7%
1.5%	97.2%	97.6%	97.6%	97.4%	97.8%
2%	99.9%	99.9%	99.9%	99.9%	99.8%
2.5%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 3 - Cumulative probabilities with the strike prices as thresholds for the ABSPP & CBPP3 announcement

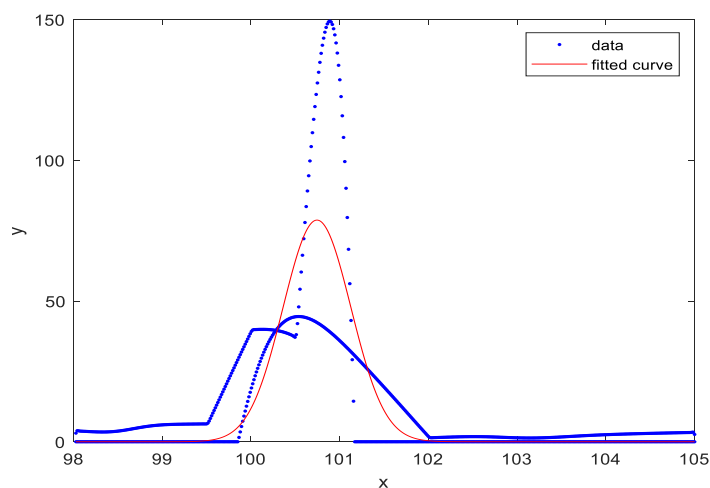


Figure 15 - Probability density function of inflation expectations in one year as of 02/10/2014

4.1.2 PSPP

While the public sector purchase program's announcement date (22/01/2015) was later than of the ABSPP & CBPP3, it was widely anticipated by market participants in advance. This likely blurs the analysis of the announcement effect, as only surprises have a material impact. As it can be seen in tables 4 and 5, the announcement of the PSPP had no visible impact on implied inflation expectations in the short-term options-wise. However, in the swaps market it was observed an increase in prices of 7% the day before the announcement, probably reflecting some anticipation to the announcement, and 12% in the announcement day, with no real changes after that. In the long-term, the roles seem reversed. While the swaps market shows no real impact of the announcement, the floor options with a zero percent strike reflect a decrease of 15% in the announcement day, and floors with one percent strike price saw their prices decrease by 23% on the following day. The appendixes 4 and 5 show the price change of 1-year and 5-year floors, two months before and after the announcement. From these graphs it is possible to see the decrease that both register after the announcement date, with the long-term one being the more significant and drastic one.

Despite some anticipation about the implementation of the PSPP, at the announcement there was still some effect on prices of these instruments in line with an increase in inflation expectations. Indeed, during the month of December of 2014 discussions about a possible programme of purchasing euro government securities were had, thus adding an extra layer of complexity to the analysis given that information is everything in financial markets. In other words, almost a full month before the official announcement, there was extra information for

the investor to act upon, leading to an effect of the announcement being possibly lower than the real one had it not been anticipated.

		Daily price change of 1-year floor				
PSPP	Strikes	21/01/2015	22/01/2015	23/01/2015	26/01/2015	27/01/2015
	0%	-2%	-3%	0%	3%	-1%
Floors	1%	-1%	-2%	0%	3%	1%
	2%	-1%	-1%	0%	2%	1%
Swaps		7%	12%	0%	0%	0%

Table 4 - Daily price change of 1-year floor for the PSPP announcement

		Daily price change of 5-year floor				
PSPP	Strikes	21/01/2015	22/01/2015	23/01/2015	26/01/2015	27/01/2015
	0%	-9%	-15%	-3%	-5%	8%
Floors	1%	ND	0%	-23%	0%	ND
	2%	-3%	-5%	-1%	1%	1%
Swaps		1%	4%	0%	0%	0%

Table 5 - Daily price change of 5-year floor for the PSPP announcement

Contrary to the price analysis, the cumulative probabilities evidenced in Table 6 show a significant change in the probabilities the days following the announcement. With a decrease of nearly 12% on the following day on the probability of deflation, contrasting with an increase of 18.4% at the start of the week after the announcement, this measure seems to be the one that caused most impact in the moment of the announcement on how the market viewed inflation expectations for the beginning of 2016. The net effect of the measure led to an increase in inflation expectations in line with the objectives of the programme¹⁰. Figure 16 shows a graphical representation of the cumulative probabilities at the day of the PSPP announcement, supporting the large density mass before the 0% percent strike.

PSPP	21/01/2015	22/01/2015	23/01/2015	26/01/2015
0%	92.4%	90.7%	78.9%	97.3%
1%	100.0%	100.0%	98.6%	100.0%
1.5%	100.0%	100.0%	99.8%	100.0%
2%	100.0%	100.0%	100.0%	100.0%
2.5%	100.0%	100.0%	100.0%	100.0%

Table 6 - Cumulative probabilities with the strike prices as thresholds for the PSPP announcement

¹⁰ However, this was quickly reversed the following days, with investors assuming that a scenario of deflation could happen with 97,3% probability in early 2016. These variations can reflect the usual volatility of the financial markets

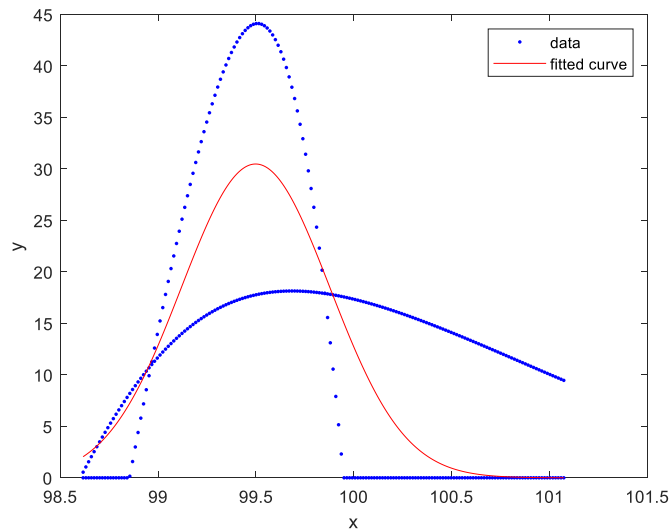


Figure 16 - Probability density function of inflation expectations in one year as of 02/10/2014

4.1.3 CSPP & TLTRO II

Similarly, to the ABSPP & CBPP3 joint announcement, the corporate sector purchase program and the second targeted long-term refinancing operations share the same announcement date, which again means that individually assessing the impact of both policies should prove troublesome, as the overlapping of effects plays its part.

The immediate joint impact of the announcement of these policies was quite contained. The daily changes on option prices (Table 8), were even slightly against the objectives of the central bank, meaning that floor options registered increases in the days following the announcement, globally, in the short-term, and marginal increases and decreases in the long-term. Regarding swaps, the movements were also quite contained; both the short- and long-term show decreases in price, however only the short-term change two days after the announcement possesses relevant weight.

Graphically, with a broader view, the effect seems much different. Appendixes 6 and 7 reveal the price change of a 1-year and a 5-year floor, respectively, two months prior, and after, the announcement. Firstly, the short-term evidences a steep decrease post announcement day that was not visible around the announcement date. Similarly, the long-term evidences a significant decrease in the price of floors roughly three weeks after the announcement and continues to lower thereafter. Hence, the evidence suggests in favor of increased inflation expectations, in line with the objectives of the central bank.

Daily price change of 1-year floor

CSPP e TLTRO II		21/01/2015	22/01/2015	23/01/2015	26/01/2015	27/01/2015
	Strikes					
	0%	8%	3%	4%	6%	7%
Floors	1%	3%	2%	2%	3%	4%
	2%	1%	1%	1%	2%	2%
Swaps		-2%	0%	2%	-8%	-2%

Table 7 - Daily price change of 1-year floor for the CSPP & TLTRO II announcement

Daily price change of 5-year floor

CSPP e TLTRO II		09/03/2016	10/03/2016	11/03/2016	14/03/2016	15/03/2016
	Strikes					
	0%	-1%	-2%	3%	-5%	3%
Floors	1%	ND	ND	ND	ND	ND
	2%	0%	-1%	1%	1%	2%
Swaps		-1%	1%	2%	-2%	-1%

Table 8 - Daily price change of 5-year floor for the CSPP & TLTRO II announcement

Through the density function analysis, the CSPP & TLTRO II joint announcement did not present the desired effect, however the daily variations are too marginal to take direct conclusions (Table 9). While the aim was to raise inflation expectations away from the current low expectations, the last day in analysis registers an increase in expectations below 0% and 1%. These increases reflect a slight increase in the expectations that inflation can, in a years' time, decrease below 1%, which is the opposite what were the ECB's objectives. Nevertheless, and as previously mentioned, these variations are too small to conclude concrete effects from, thus this change should not represent the effectiveness of this monetary policy. Figure 17 illustrates the probability density function of the day of the announcement (10/03/2016), which is the probabilities in table 9 of that day and shows the bigger than desired density of expectation below 0 (100 normalized in the graph).

CSPP e TLTRO II	08/03/2016	09/03/2016	10/03/2016	11/03/2016	14/03/2016
0%	26.7%	27.3%	26.7%	27.7%	30.5%
1%	91.2%	91.3%	91.0%	91.3%	92.9%
1.5%	99.0%	99.0%	99.0%	99.0%	99.3%
2%	100.0%	100.0%	100.0%	100.0%	100.0%
2.5%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 9 - Cumulative probabilities with the strike prices as thresholds for the CSPP & TLTRO II announcement

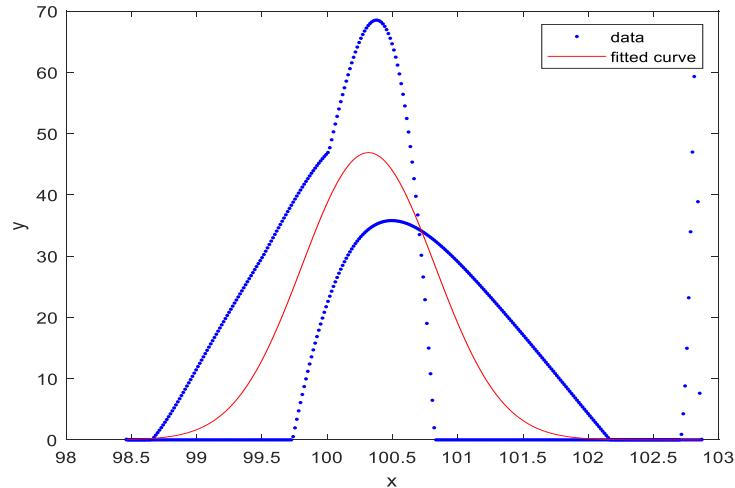


Figure 17 - Probability density function of inflation expectations in one year as of 10/03/2016

4.1.4 TLTRO I

The main objective of targeted long-term refinancing operations was to provide liquidity at low costs to the banking sector in a way that could be transmitted to the rest of economy through bank lending. But given that they were a monetary policy measure, the TLTRO could also have impact inflation expectations. Indeed, in the short-term (Table 10) it is possible to observe shrinkages in prices of floor with all three strike prices on the day of the announcement and further. The most relevant of them being a 13% decrease in prices of floors expiring in one year and at a zero percent strike price, the day after the announcement. Swap prices go up slightly with the highest variance on the day of the announcement. On the long-term, prices of floors lower just like in the short-term but with lower decreases, while the swap prices maintain unchanged.

Graphically, in Appendixes 8 and 9, the representation of the daily price change of floors with one year and 5 years maturity, respectively, and a strike price set at 0%, evidences shrinkages of approximately 1% in the short-term and of roughly 3% in the long-term. This broader picture corroborates the shrinkages shown in Tables 10 and 11.

		Daily price change of 1-year floor				
TLTRO I	Strikes	04/06/2014	05/06/2014	06/06/2014	09/06/2014	10/06/2014
Floors	0%	2%	-4%	-13%	0%	-4%
	1%	2%	1%	-1%	1%	-4%
	2%	1%	0%	-1%	0%	-1%
Swaps		1%	4%	-1%	0%	0%

Table 10 - Daily price change of 1-year floor for the TLTRO I announcement

		Daily price change of 5-year floor				
TLTRO I	Strikes	04/06/2014	05/06/2014	06/06/2014	09/06/2014	10/06/2014
	0%	-3%	0%	0%	0%	0%
Floors	1%	-1%	0%	-3%	-8%	0%
	2%	-2%	-2%	-1%	0%	1%
Swaps		1%	0%	0%	0%	0%

Table 11 - Daily price change of 5-year floor for the TLTRO I announcement

Moving to the density functions approach, the first targeted long-term refinancing operations were associated with an increase in low inflation expectations similarly to previous announcements. Following Table 12, the announcement day registered an increase in density under the 1% threshold, which translates to an increase in low inflation expectations, the exact opposite of the central bank’s objectives. However, the increases are marginal, and lower than 1% throughout the three days after the announcement, thus do not constitute enough grounds to judge the policies effectiveness.

Graphically, this low density of deflation expectations can be seen in Figure 18, in which the probability density function of the announcement day is represented.

TLTRO I	03/06/2014	04/06/2014	05/06/2014	06/06/2014	09/06/2014
0%	2.3%	2.6%	3.0%	3.4%	3.2%
1%	67.8%	68.6%	68.6%	69.3%	69.7%
1.5%	95.5%	95.5%	95.2%	95.3%	95.6%
2%	99.8%	99.8%	99.8%	99.8%	99.8%
2.5%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 12 - Cumulative probabilities with the strike prices as thresholds for the TLTRO I announcement

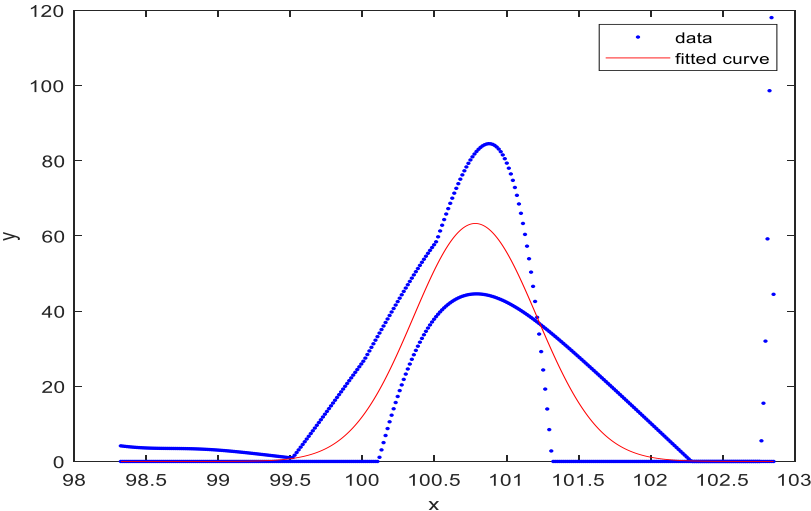


Figure 18 - Probability density function of inflation expectations in one year as of 05/06/2014

5. Conclusions

The present Dissertation's aim is twofold: (i) to build a routine to withdraw the distribution of inflation expectations implied in inflation options and (ii) to evaluate the effect in inflation expectations from the announcement of several ECB policy measures, in particular the Asset Purchase Program (APP), and its constituents, and the TLTROs. For that to be possible, a probability density function methodology was adapted from the financial options field, then the resulting functions were to be analysed based on the monetary policies announcement dates, from which the impact of these measures was extracted and compared to the objectives set-up by the central bank. Moreover, I have also assessed the direct impact of the announcements on inflation-indexed asset (options and swaps) prices.

For this two-pronged analysis to yield any results, the methodology to estimate the probability density function is important. However, there are several challenges in the specific market segment of inflation-index options that need to be considered. Firstly, there is the issue of low observable data points, related to the lack of liquidity in the inflation-indexed options market, implying few strikes with prices and very high price changes for discrete changes in strikes. The first step of the routine consists in fitting a spline to the volatility smile, and for that to be possible, a cubic interpolation based on implied volatility is required.

Secondly, taking advantage of the findings of Breeden and Litzenberger in 1976, the initial density functions are calculated using the second derivative of the option price in the Black-Scholes option model. With density functions for both caps and floors, I opted for an ad-hoc method to aggregate them in order to have a clearer picture of how both sides of the market see inflation expectations, thus being able to use that net effect to compare between the objectives and targets of the monetary authority.

The findings present in section 4 represent, not only the aggregate result previously mentioned applied to the announcements of the monetary policies, but also a complementary robustness test in which the changes of the floor prices themselves are analysed. Firstly, the joint announcement of the asset-backed securities purchase programme and the third covered bond purchase programme show that, in the density function analysis, the changes in density following the announcement were negligible, which even though they are decreases, are not large enough to warrant as an effect. Regarding the price analysis, floors with zero percent strike prices, in the short and long-term, are the most affected by the measure with reductions of 16% and 7% in the two days following the announcement.

On the other side of the spectrum, the public sector purchase program's announcement impact was contaminated by the ahead discussions about a possible programme of purchasing euro government securities. This non-regular information flow caused the short-term options' price to maintain virtually the same, with marginal changes. Nevertheless, the long-term evidenced significant decreases in the floors with zero and one percent strike prices, which goes in line with the objectives of the ECB. Swaps registered an increase of 12%, in the short-term, in the day of the announcement, but remained relatively unchanged in the long-term. Regarding the density functions, the along the same lines as the probability of inflation below 0% decreased relevantly on the day after the announcement.

In line with the ABSPP & CBPP3 joint announcement, the corporate sector purchase program and the second targeted long-term refinancing operations were announced in the second of October of 2016. Concerning the density function analysis, this announcement showed an alternative variation of increases and almost offsetting decreases, registering a net effect marginal of less than 1% increase in strike price ranges of below 1%. Option prices in the long-term maintain this almost offsetting pattern while the short-term is characterized by continuous increases in floor prices, although of minor size, whereas swaps show a meaningful decrease in the short-term, the long-term evidenced offsetting variances.

Finally, the first targeted long-term refinancing operations, announced on the 05/06/2014, shows, when it comes to the price analysis, decreases in floor option prices both in the short-term and the long-term that are in parallel with the evolution to the targets set by the central bank, while swaps remain unchanged in the long-term and increases 4% in the short-term on the announcement day. The probability function analysis shows a different side with increases, albeit below 1%, in strike price ranges below 1.5%, which, all in all, represent the low impact the announcement that the measure had.

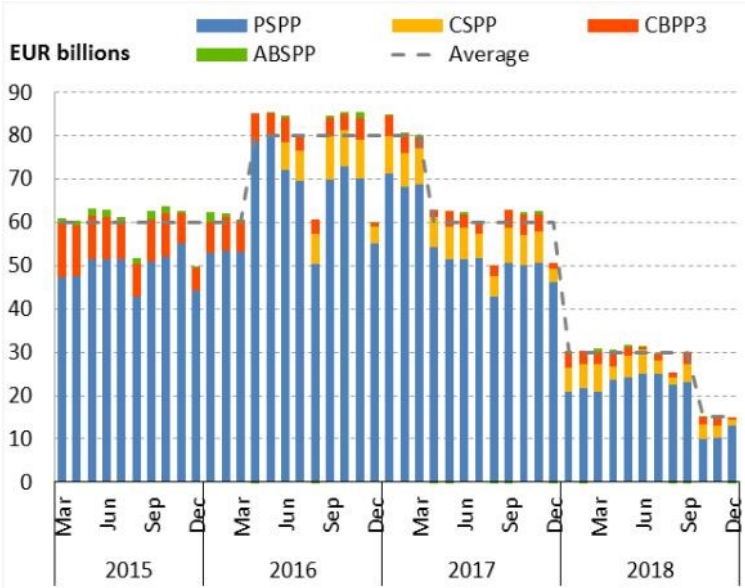
Future research on this topic might include, as a step forward, an increase in data points from observable options, as this methodology puts a large emphasis on the quantity of data available, along the lines of what it is proposed by other works (e.g., Gimeno and Ibáñez, 2018 or Smith, 2012). This would offset the main shortcoming of this research, namely the lack of liquidity and transaction volume that caps and floors markets were associated with at the times of these monetary policies, which at times prevented the interpolation process due to insufficient observable data. However, the complexity of the suggested works that allow for a better use of the available information is beyond the scope of this dissertation.

Concluding, in order to successfully quantify the effect of these announcements, a bigger time window is a necessity. On the one hand, a shorter window is not so much influenced by other factors and is thus more adequate to assess properly the announcement effects. On the other hand, the measures were already anticipated by market participants in some part, meaning some effects could already be incorporated ahead, while investors also take some time to incorporate the full extent of the details of the measures, meaning a possible extension over time of the effects. The thinner horizon used in this thesis is inadequate to fully quantify the effects that the non-conventional monetary policies had overall in reducing low inflation expectations in the markets, at least because it ignores other channels of transmission. The effectiveness of these programmes, or at least partial effectiveness, is in line with the official remarks¹¹ made by Vítor Constâncio, Vice-President of the ECB on the eleventh of September of 2015. In this publication, the Vice-President of the ECB praises the non-conventional measures employed to combat the threat of low inflation and the crisis, by stating that they were “successful to avoid the worst for the European Monetary Union” and “proved crucial to avoid deflation and foster the economy recovery”. ECB’s VP expresses also that the objectives of inflation below, but close to, 2% were not met yet, however a “sufficient degree of monetary policy accommodation” will lead to that target.

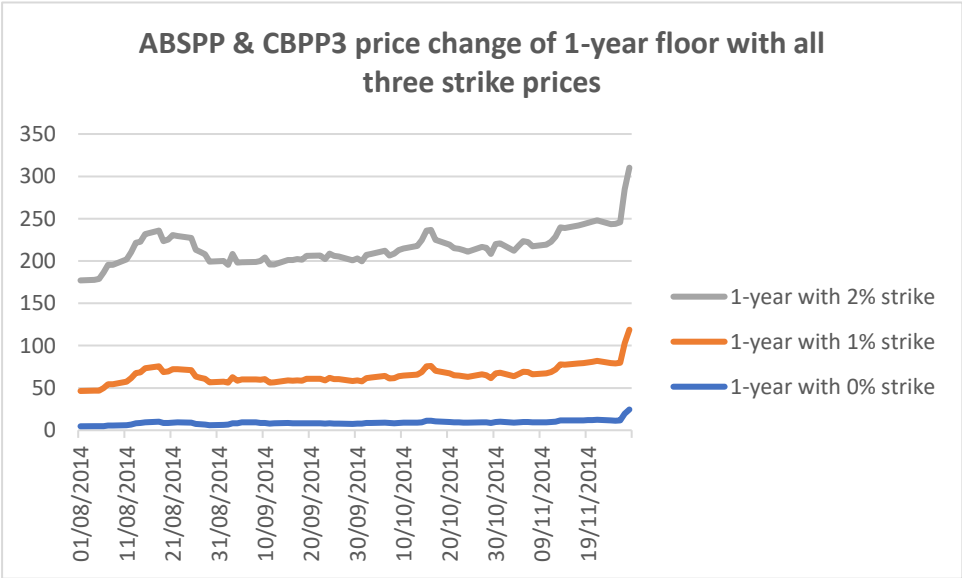
¹¹ <https://www.ecb.europa.eu/press/key/date/2017/html/ecb.sp170912.en.html>

6. Appendixes

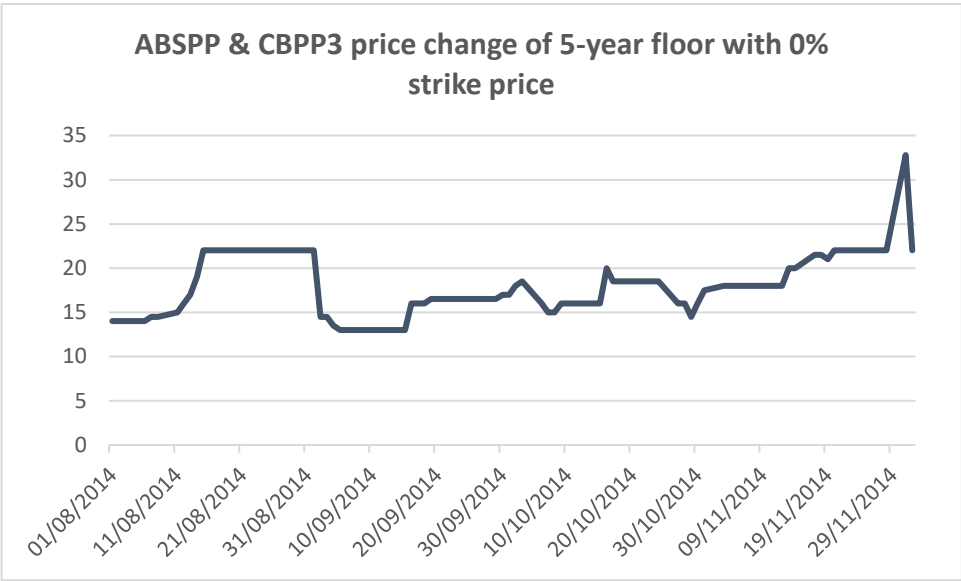
Appendix 1 – History of APP net asset purchases | Source: ECB



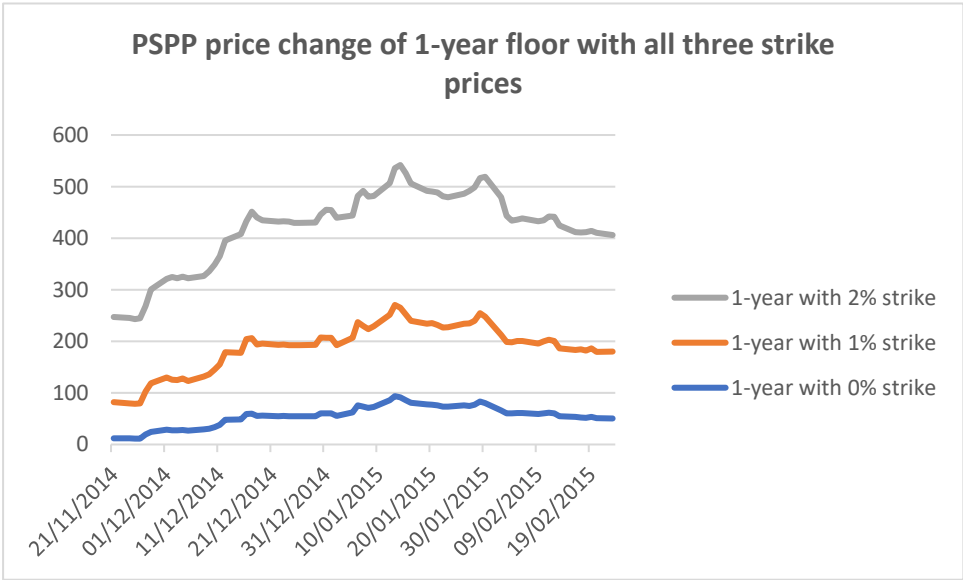
Appendix 2 – Price change around the ABSPP & CBPP3 of 1-year floor with all three strike prices



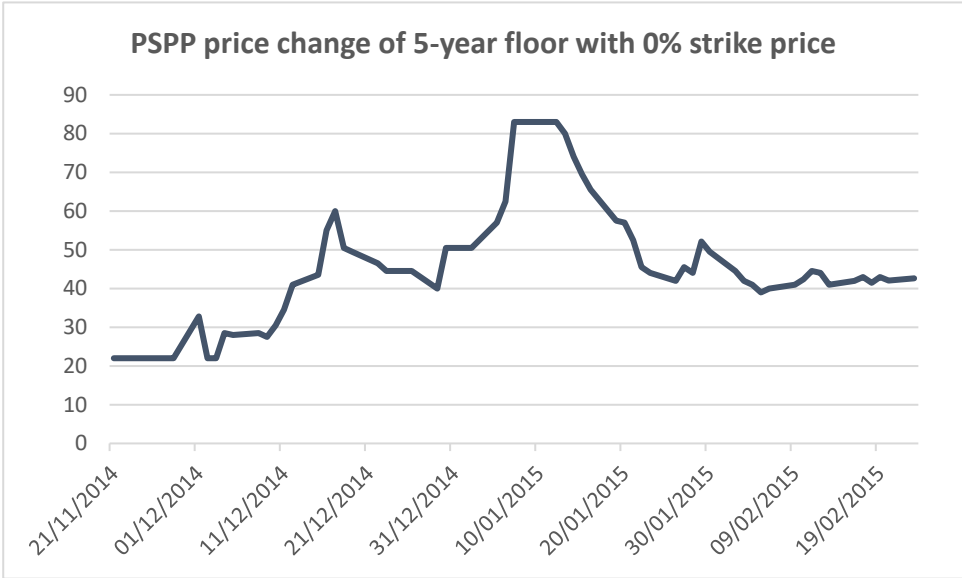
Appendix 3 - ABSPP & CBPP3 price change of 5-year floor with 0% strike price



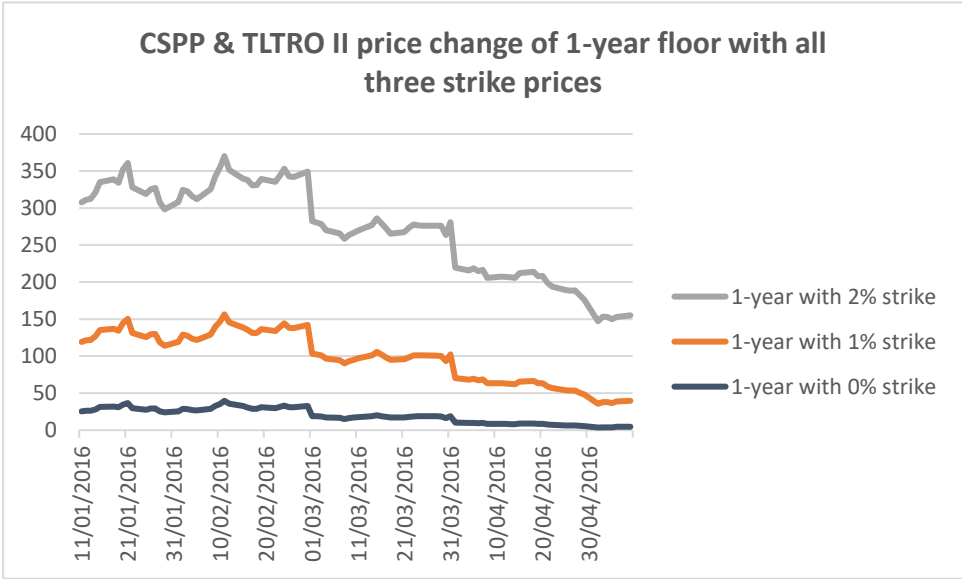
Appendix 4 – PSPP price change of 1-year floor with 0% strike price



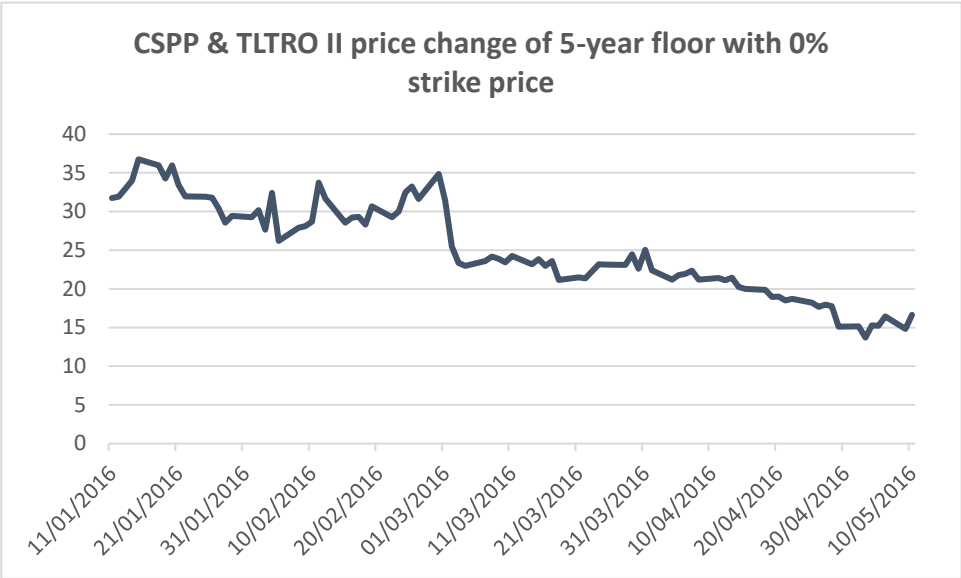
Appendix 5 – PSPP price change of 5-year floor with 0% strike price



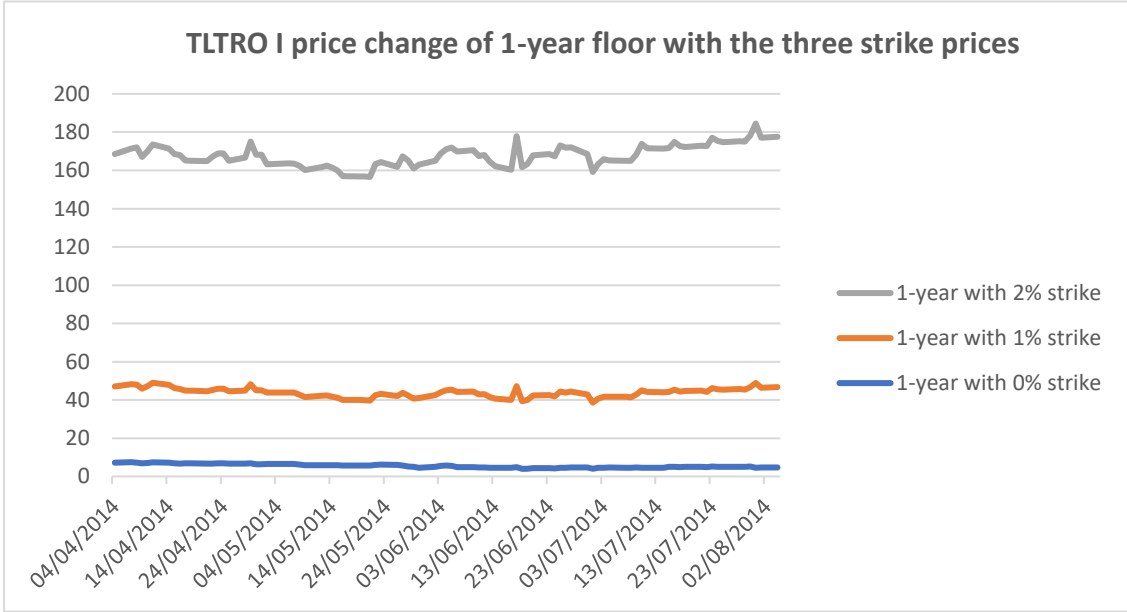
Appendix 6 – CSPP & TLTRO II price change of 1-year floor with all three strike prices



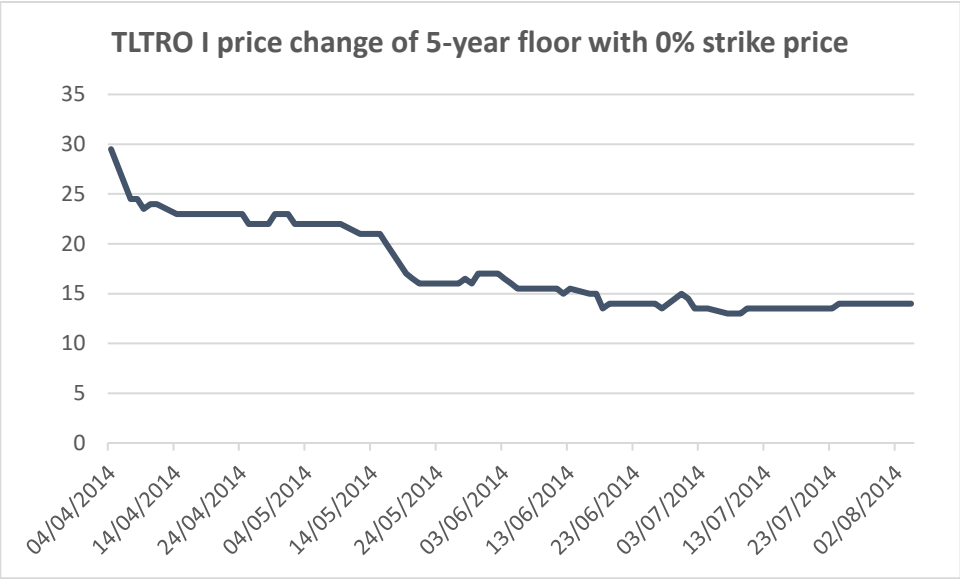
Appendix 7 – CSPP & TLTRO II price change of 5-year floor with 0% strike price



Appendix 8 – TLTRO I price change of 1-year floor with the three strike prices



Appendix 9 – TLTRO I price change of 5-year floor with 0% strike price



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