RECOVERING RISK-NEUTRAL DENSITIES FROM EXCHANGE RATE OPTIONS: EVIDENCE IN TURKEY[§]

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Abstract

This paper uses over-the-counter currency options data to investigate market expectations on Turkish Lira-U.S. Dollar exchange rate. We extract option implied density functions to examine the evolution of market sentiment over the possible values of future exhange rates. Uncertainty is well measured by option-implied probabilities. Estimated densities for selected days point out an increase in uncertainty in foreign exchange market during financial turbulence periods. We make inferences about the effectiveness of policy measures and see how the market perception changed throughout the crisis. We uncover the effectiveness of policy measures by observing shrinking densities and confidence bands.

Keywords: Options, Risk neutral density, Market expectations.

JEL Codes: G13, G19, F31

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I. Introduction

Options markets are very important for academics, market participants and policy makers. They provide a rich source of information about investors' expectations and market uncertainty about the future course of the financial asset prices. Options contracts give the right to buy or sell an asset in the future at a price (strike) set now. Options have a value since there is a chance that the options can be exercised, that is, the underlying asset price will be more/less than a particular strike price. Hence, when we look at options with different strike prices, the prices at which such contracts trade now give us information about the market's view of the chances that the price of the underlying asset will be above/below these strike prices.

The common way of dealing with the information embedded in option prices is to extract implied risk-neutral probability density function (RND), a commonly used indicator to gauge expectations about future price of a financial asset under risk neutral assumption of the preferences of the investors. The impact of monetary policy decisions on market expectations, the probability that interest rate may prevail inside a specific range or the riskiness of a currency position can be revealed through the information content of RNDs.

Recently an increasing number of studies have investigated the shape of the risk-neutral probability distribution of future asset prices using options on interest rates, equity prices and exchange rates in line with the deepening of the derivative markets. Many studies on different assets indicate the usefulness of RNDs.[1] The evidence is in favor of the interpretation that the estimates of RNDs do not help forecast the future but reveal the market sentiment that is useful for the policy stance of the central banks. Most central banks track the changes in market sentiment via the estimates of RNDs.[2]

Estimates of RND are commonly studied in the context of fundamental economic questions related to an important event or a possible change in regime or announcements of economic news that could affect expectations. For example, Bahra (1997) compares RNDs around announcements of inflation reports to test the change in market sentiment using options on three-month sterling interest rate. He provides a very informative discussion about RNDs in assessing monetary conditions and credibility of the monetary policy. He argues that the central bank credibility measured as the difference between the markets perceived distribution of the future rate of inflation and target inflation can be assessed via RNDs. Since there is no

[1] See Coutant et al. (2001), Jondeau and Rockinger (2000), Melick and Thomas (1997).

[2] See Csavas (2008), Bhar and Chiarella (2000), Syrdal (1999), Nakamura and Shiratsuka (1999).

direct instrument available to compute RND for inflation, he suggests using the RND of long-term interest rates to measure uncertainty over future inflation. Campa et al. (1999) compute RNDs on cross rates within the "Exchange Rate Mechanism" of the European Monetary System to assess the credibility of commitments to exchange rate target zones and determine whether the bandwidths are consistent with the market expectations. The RND could also be utilized in testing the rationality and measuring risk attitude of investors, which are highly important for policy makers.

This study aims to extract the risk-neutral densities embedded in over-the-counter (OTC) exchange rate options in Turkey. To the best of our knowledge, this is the first attempt to recover RND for TL/USD exchange rates. While the number of studies on RNDs for developed economies is large, there are only few studies for emerging markets due to unavailability of the options data. Growth in the derivative activities in Turkey motivates us to understand relevant information concerning market expectations contained in the prices of options.

The literature on RND estimation covers a wide range of techniques including parametric, non-parametric and structural models.[3] While some methods may not be convenient due to the lack of data for options, the others may yield distorted density functions inconsistent with empirical statistics or probability theory. For instance, models with volatility smile curve fitting as in Shimko (1993) may lead to negative probabilities. To circumvent these shortcomings, we apply Malz (1997) method, which ensures positive density. Moreover, the Malz method is analytically tractable since it requires only three observations to uncover the underlying density.

We investigated the information content of RNDs when financial markets were subject to a greater uncertainty during the period 2006 and 2008. We make inferences about the effectiveness of monetary policy measures and see how the market perception changed throughout the crisis. For both periods we observed that the estimated densities signaled more uncertainty during the crisis times and the monetary policy measures were successful in reducing the uncertainty.

The plan of the remainder of this paper is as follows. We introduce our data in section 2. In section 3 we briefly present the method employed. Section 4 describes the case studies and section 5 concludes.

[3] Studies such as Bahra (1997), Campa et al. (1998), Jondeau and Rockinger (2000), Bliss and Panigirtzoglu (2004) provide informative discussions about various RND methods.

II. Data

Derivatives are forward market instruments and their volume has exceeded the volume of spot market instruments in the global economy.[4] There are two different types of derivatives markets, distinguished by whether they are traded in an organized market or not. Exchange-traded derivatives are traded in specialized and organized markets. The other type is the OTC market where trading takes place directly between parties without an organized market or intermediary. The volume of OTC derivatives market is generally higher than that of exchange-traded derivatives market.

In Turkey, there are both organized and unorganized derivatives markets. Organized derivatives market, Turkish Derivatives Exchange (TURKDEX), is located in İzmir. The products traded in TURKDEX are future contracts on stock index, interest rates, currencies and commodities. There are no options contracts traded in TURKDEX. However, there are options contracts on exchange rates traded in OTC market.

It is worth mentioning a few words on options quotations before documenting the details of the data and the methodology we adopt. The options are traded in both exchange traded (organized) and OTC (unorganized) markets. But quotations in two markets differ from each other. In exchange traded markets, the quotations are given in terms of strike levels and option prices. Whereas in OTC markets, the quotations are given in terms of deltas[5] and implied volatilities. Using the Black-Scholes formula it is easy to reveal the strike price from delta and option price from implied volatility. The OTC quotation facilitates the scaling of the asset price movements in markets where financial assets display volatile price patterns. For example, foreign exchange rates are quickly changing in short periods of time. It is very hard to determine constant strike levels for such assets. A practical solution adapted in the market is to quote in terms of deltas instead of strike prices. Ultimately, the implied volatility takes the role of option price and delta takes the role of strike price.

There are three option combinations, which are heavily employed in currency options markets. These are at-the-money straddle (atm), risk reversal (rr) and strangle (str).[6] While at-the-money straddle options have 50 delta, risk reversals and strangles can have different delta levels. Since 25 delta is the most liquid one, we choose 25 delta risk reversal and strangle in line with the Malz (1996) approach we adopt. These option types in currency options markets enable investors to get information about the behavior of moments of expected values of the

[4] See BIS statistics for global OTC derivatives.

[5] Delta is a parameter showing how close the asset price to the strike price (i.e. moneyness of the option).

[6] See Appendix for details.

underlying exchange rate. For instance, the straddle indicates the expected volatility of the exchange rate. Similarly, risk reversal and strangle give information about the skewness and kurtosis of the distribution of future exchange rate, respectively.

The dataset consists of OTC foreign currency options, quoted in terms of implied volatility and delta. We used options on Turkish Lira against US Dollar. Maturity is taken as one month. Risk free interest rates used in the option prices are determined from USD and TL LIBOR markets at the corresponding maturities. The dataset covers the daily observations between 2006 and 2009. We used the settlement prices of options, which are determined at the close of trading day.[7]

It is important to take into account the liquidity of USD/TL options market. Unfortunately, the depth and volume of the over-the-counter market in Turkey is low. The liquidity in the options markets may be even lower during the crisis period. Therefore, the RND functions may not truly reflect all changes in market sentiment in short periods. Thus for event study purposes, it may be better to look at changes in the RND function at somewhat lower frequencies. We choose the time intervals at least as one week. The dates refer to the time periods before the financial turbulence, during the turbulence and after the policy measures taken by Central Bank of the Republic of Turkey (CBRT).

We focus on two case studies to understand how the market sentiment changed during financial turmoil experienced in the second half of 2000's, May-June 2006 and September-October 2008. For the first period, we graph RNDs for the days of May 8, May 15, June 13 and July 21 2006. The second case study deals with the global financial crisis, which was intensified by the bankruptcy of Lehman Brothers in September 2008. To investigate the effects of the crisis on the financial market, we examine the days of September 8, September 16, October 22 and October 31 2008. We make inferences about the effectiveness of policy measures and see how the market perception changed throughout the crisis.

III. Methodology

The density extracted from the traded options is called the risk neutral density (i.e. RND), which provides the set of probabilities that investors would attach to future asset prices in a world in which investors are risk-neutral. The intuition behind RND is closely linked to Arrow-Debreu prices of contingent claims. Since derivatives are contracts on future events, the prices of derivatives today reflect the possibility of the realization of those events.

[7] See Melick and Thomas (1998), Söderlind and Svensson (1997).

The pricing of contingent claims in finance literature is based on the risk neutral valuation principle. The concept of risk neutral valuation dates back to early efforts of Samuelson (1965) on option pricing. Samuelson (1965) derives the random value of the option at exercise. His formulation included two parameters, the expected rate of return on the stock price and the discount rate of the options. Return parameter is the expected return from the stock price if investors hold it until the maturity of the option. Discounting parameter is the opportunity cost of investing in option. Since the option price is embedded with uncertainty, the discounting parameter should include the risk within options as well as alternative riskless investments. Both parameters of the models depend upon the unique risk characteristics of the underlying stock and the option. However, in an options contract, both the derivative and its underlying asset are subject to the same source of price changes or the same sources of risk. Thus, uncertainty surrounding the terminal stock price affects risk attitude of the investors towards both assets. Decisions on holding the stock or the option are both affected by the same risk. Accordingly, option price does not depend on the risk preference of the investors as long as the discounting and return parameters reflect the same degree of risk aversion. This framework, first advocated by Cox and Ross (1976), implies the irrelevance of risk preferences of investors to the option price and captures the essence of risk neutral pricing.

The mechanics of risk neutral valuation is as follows. One can calculate the option price by considering risk neutral investor’s behavior. In this setup, the expected return on underlying asset and discounting rate substituted with risk-free interest rate. A risk neutral investor can hedge the short/long position (whatever he prefers) by taking the opposite in the other asset. Short position in call option, for instance, can be hedged by long position in the underlying asset. By this approach, the option price can be calculated whatever the risk preference the investors have; because risk aversion is irrelevant to the option price.

It is important to note that the state prices of contingent claims in an Arrow-Debreu economy depend on the likelihood of the states, and on the attitude of the agents towards those states. In our approach, investors are assumed to be risk neutral. Thus the effects of risk-aversion are embedded in risk neutral probabilities. That is, likelihood of financial asset prices embedded in the options prices reflects the investors’ expectations as well as risk aversions about the unknown future. This perception serves as the main pillar of the literature on RNDs and the basis for our analysis.

The general conclusion of risk neutral valuation is that price of options can be deduced from the expectation of option payoff. Mathematically speaking, the expectation of asset payoff is an integral with respect to terminal asset price. Accordingly, the price of a European style call option C (K) at time t, with maturity τ and strike price K can be simplified as an integral under risk neutral probability measure,

$$\mathrm{C}(K) = e^{-r\tau}\int_{K}^{\infty}(S_T - K)\,p(S_T)\,dS_T \tag{1}$$

where S_T denotes the asset price at maturity. p (S_T) is the probability associated with price S_T at maturity based on the terminal asset price. Almost all option pricing models in mathematical finance literature deal with this integral representation. The models are based on various probability distribution assumptions for the terminal asset price.

The seminal work of Black and Scholes (1973) is founded upon the assumption that the distribution of the price S_T is lognormal i.e.; the asset price at maturity follows a geometric Brownian motion with constant volatility. This assumption yields a closed form formula for the option price. However, empirical facts show that financial asset prices do not admit geometric Brownian motions. Statistical properties of asset returns exhibit significant dispersion from Black-Scholes assumptions. The returns are not normally distributed; leptokurtic kernels have better fit performance than normal densities. Moreover, the volatility is not constant for the options with different strike prices. Volatilities across strikes show variations, presenting volatility smile patterns. Volatilities for options with different time-to-maturities are also different from each other, leading to a term structure of volatilities.

The variations of volatilities for different strike prices and maturities rendered the birth of the concept of implied volatility. Implied volatility is the volatility implied by the market price of the option. When plugged into the Black-Scholes formula, implied volatility yields a theoretical option price that is equal to the market price of the option. Implied volatility is used to remedy the shortcomings of constant volatility assumption of Black-Scholes model. It shows the characteristic features of options with different strikes. For this reason, it is used as the actual price of option. Market practitioners use implied volatility in Black-Scholes model as a tool of quotation. Especially in OTC markets, a trader presents his bid-ask prices for the options in terms of its volatility. However, this does not mean that Black-Scholes model is the proper model for option pricing or agreed upon model of the market. Rather, it is the model with which the practitioners use to determine the option price from volatility quotes.

Due to the limitations of Black-Scholes model, the literature on options pricing focused on flexible distributions for financial asset returns. A number of different stochastic processes are examined for the returns of the underlying asset. Results indicate that a number of stochastic processes can be matched for asset returns but the estimation of model parameters gets complicated as the number of parameters increases. Thus, assigning a stochastic process for the underlying asset is the general methodology of option pricing but its use in RND estimation is limited. Due to the large number of parameters involved in estimation, we opt to use a non-parametric method for RND estimation.

Most of the RND estimation techniques are based on the work of Breeden and Litzenberger (1978) who showed that RND could be derived from the second derivative of call prices with respect to strike prices.

$$\frac{\partial^2 C}{\partial K^2} = e^{-r\tau} p(K) \tag{2}$$

One can infer the RND by numerical differentiation of call options with respect to strikes when there are sufficient observations. However such direct estimation of RND is not generally possible due to the lack of available option prices. Also, these kinds of models lead to unstable density estimates[8]. Thus, direct numerical evaluation is regarded as an inaccurate way of density extraction and research focus shifted to indirect methods. A number of indirect density estimation methods are proposed to circumvent the shortcomings of direct density estimations. One of these attempts is documented in Malz (1997). The procedure is a non-parametric estimation of RND. It is based on the idea of fitting a curve for volatility smile on implied volatility and delta space.

Malz suggests estimating RND of exchange rates by using the information embedded in straddle, strangle and risk reversal options. Since volatilities for different strike levels vary, the model needs to build volatility as a function of strike price (delta). To this aim, Malz (1997) proposes a second order Taylor approximation to delta-implied volatility curve around the point δ_0=0.5 as follows,

$$\hat{\sigma}_t(\delta_0) = b_0 atm_t + b_1 rr_t(\delta - \delta_0) + b_2 str_t(\delta - \delta_0)^2 \tag{3}$$

where atm_t, rr_t and str_t are volatilities of at-the-money, risk reversal and strangle (or butterfly) options. The intuition behind this approach is such that the atm, rr and str show the level, skew and curvature of volatility smiles, respectively. This information is captured by Taylor approximation.

Plugging implied volatilities of options with deltas 0.50, 0.25 and 0.75, one can deduce the parameters as b_0=1, b_1=-2 and b_2=16. The curve fitting step needs caution since both sides of

[8] See Jondeau, Poon and Rockinger (2007).

the equation includes implied volatility. Right hand side is the implied volatility and left hand side includes the term delta, which is itself a function of volatility. This requires us to find a unique solution for implied volatility using numerical procedures. Once the implied volatility function is estimated, option prices are found by plugging implied volatility into Black-Scholes formula. Then, indirect estimation of the risk neutral density is carried out via Breeden and Litzenberger (1978) formula given in equation 2.

IV. Empirical Evidence

One of the important goals of the CBRT is to ensure financial stability in domestic markets. After the adopt of free-float exchange rate regime, the intervention of the Bank to FX market diminished considerably. The beginning of free float period coincided with the independence of CBRT and an agreement with IMF to intervene only in limited amounts in the foreign exchange market. The Bank was committed to intervene to smooth out extreme movements in exchange rates. Nevertheless, in certain periods when financial markets were hit by external shocks, the Bank actively intervened to stabilize the markets. Turkish economy experienced two financial large market turbulences during the second half of 2000's, one in May-June 2006 and the other in September-October 2008. The Bank took several precautionary measures to stabilize the financial market volatility.

During the May-June 2006 period, the first measure taken was to suspend the daily foreign exchange purchase auctions that the Bank had been carrying out starting from May 16, 2006. Afterwards, the Monetary Policy Committee (MPC) held an interim meeting on June 7, when policy rates were hiked by 175 basis points. Though the fluctuations in financial markets eased to some extent, the volatility intensified in the last week of June, putting pressure on exchange rates and medium and long-term interest rates. The MPC held another interim meeting on June 25 and not only increased policy rates by a further 225 basis points but also took a number of measures regarding TL and foreign exchange liquidity during the meeting. To increase the flexibility of monetary policy and gradually reduce the excess liquidity the Bank also initiated "Turkish Lira Deposit Buying Auctions" with standard maturities of one and two weeks as of June 26. In the meeting held in July 2006, the MPC raised interest rates by a further 25 basis points in order to alleviate the secondary effects of the exchange rate increases and improve inflation expectations. Consequently, the overnight borrowing rate was increased by 425 basis points in total from June 7 to July 20. The policy measures taken by the Bank provided stability in the financial markets in a short period of time.

Problems in global credit markets in autumn 2008 have raised concerns on the global financial system and adversely affected the global liquidity flows. Central banks acted promptly and took actions in a coordinated manner. The crisis had its adverse effects on Turkish foreign exchange markets in October. The turbulence intensifies on October 22.

In line with the efforts in the global economy, the Bank attempted to maintain healthy functioning of the domestic market through pre-cautionary measures. Ongoing foreign exchange buying auctions were suspended and selling auctions were introduced to inject foreign exchange liquidity into the market. The Foreign Exchange Deposit Market within the Bank was re-opened. This decision led to foreign exchange deposit transactions among banks in terms of both US dollar and Euro and prevented the decline in the flow of foreign exchange liquidity. The maturity of the FX deposit borrowed has been extended and the lending rate was reduced. Similar to the turmoil in 2006, the policy measures taken by the Bank were successful in achieving stability in the market by the end of October 2008.

It is worth noting the differences between the implied volatility and RND graphs before we depict the figures. While the figures of implied volatility provides information about the future dispersion of the asset price from one observed option price, the implied risk-neutral density, on the other hand, provides information about the entire distribution of the ultimate asset price from several option prices. Also, the RND could yield information about the higher moments of the terminal asset price as long as these moments are consistent across different estimation models.

Much of the information contained in RND functions can be captured through a range of summary statistics shown in Table 1. The mean is the average value of all possible future outcomes. The standard deviation is a measure of dispersion of the implied RND and commonly used to measure market uncertainty. Skewness characterizes the distribution of probability either side of the mean and provides a measure of asymmetry for the distribution. For example, a positively skewed distribution is one for which there is less probability attached to outcomes higher than the mean than to outcomes below the mean. Kurtosis is a measure of how peaked a distribution is or the likelihood of extreme outcomes. The greater this likelihood, the fatter the tails of the distribution.

Table 1: Descriptive Statistics of Risk Neutral Densities							
May-June 2006							
1 Month	**Mean**	**Variance**	**Skewness**	**Kurtosis**	**Standard Deviation**	**Lower Bound***	**Upper Bound***
8-May-06	1.31	0.02	1.60	5.23	0.12	1.27	1.38
15-May-06	1.48	0.03	1.48	5.36	0.16	1.36	1.66
13-Jun-06	1.58	0.04	1.32	5.35	0.20	1.39	1.87
21-Jul-06	1.53	0.03	1.80	6.70	0.17	1.42	1.72
September-October 2008							
1 Month	**Mean**	**Variance**	**Skewness**	**Kurtosis**	**Standard Deviation**	**Lower Bound***	**Upper Bound***
8-Sep-08	1.22	0.01	1.27	5.28	0.09	1.14	1.32
16-Sep-08	1.26	0.01	1.31	5.30	0.11	1.16	1.40
22-Oct-08	1.67	0.07	1.26	5.10	0.27	1.37	2.14
31-Oct-08	1.52	0.04	1.38	5.96	0.20	1.28	1.88

* Lower and upper bounds refer to 5 and 95 percent confidence levels.

Figures 1 and 2 present the implied volatilities across exercise prices during the two turmoil periods in Turkey. The implied volatility curve presents the volatility prices of the options for different exercise prices. The value in the y-axis is regarded as the price of the option in terms of volatility. The x-axis denotes the exercise prices. Accordingly, the price of the option is at the lowest level when the option is at-the-money (i.e. exercise price is close to spot price). As the exercise price goes up or down, the volatility price of the option increases. However, the increase in option volatility may be higher for high strikes than low strikes and vice versa. This effect is known as the volatility skew or smirk. This pattern appeared in stock options market after the 1987 crash.

Volatility skew may be seen in currency options, as well. This means that the market fears the depreciation of the local currency and willing to pay more for the possible depreciation than appreciation or vice versa. The volatility skew is more apparent when the market volatility gets higher and higher. Before May 2006 turbulence, the implied volatility difference between in-the money and out-of-the money options was low on May 8, 2006, whereas it widens during the turbulence on June 13, 2006 depicted in Figure 1. Similar pattern can be observed during the September-October 2008 turbulence shown in Figure 2.

The figures on RND indicate the probabilities attached to different price levels of the underlying asset. The x-axis denotes the future values of spot TL/USD exchange rates. The perceived risk neutral occurrence probabilities of these exchange rate levels are presented in the y-axis. A number of illustrations of RND functions are given in Figures 3-4, and changes in their shapes before and after the financial turmoil are presented in 2006 and 2008. Changes in the width of the confidence interval inform us about changes in market uncertainty about future asset price levels.

Figure 1. Implied Volatility Curve for May-June 2006

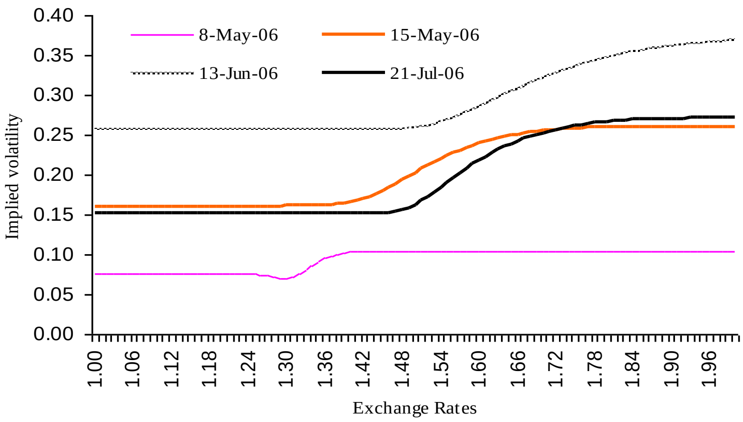


Figure 2. Implied Volatility Curve for September-October 2008

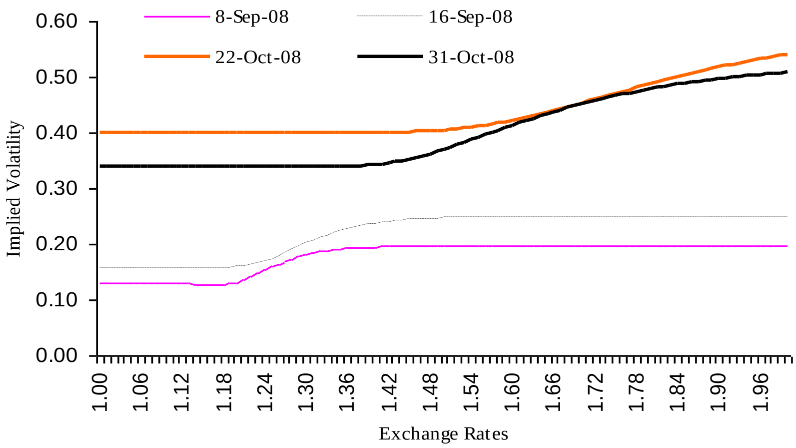
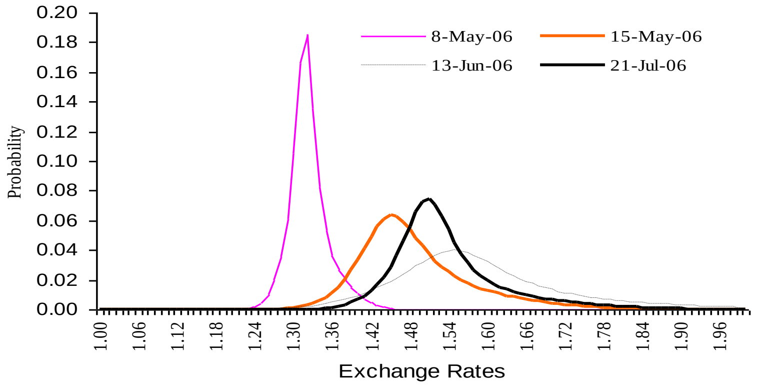


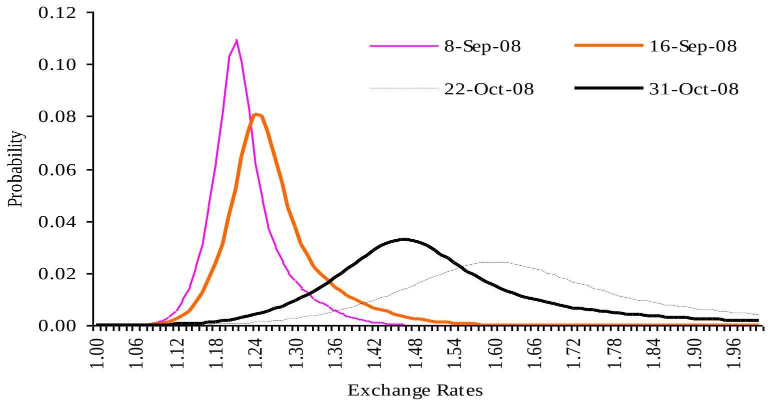
Figure 3 compares the one month implied RND for TL/USD option on dates before and after the financial turmoil in 2006. We see that as the turmoil intensifies by June 13, the confidence intervals get wider suggesting the fears of large movements of exchange rates. The right tail of RND function gets fatter indicating the rising uncertainty in the market sentiment or the perceived increase in the probability of a large depreciation. The RND graph on July 21, 2006 shows that the width of the confidence interval become narrower after the Bank intervened in the market. The good news is that the decrease of uncertainty about expected future exchange rate level can be visualized from RND figures and confidence bands.

Figure 3. Implied RND for the one-month TL/USD foreign exchange rate in May-June 2006.



A similar analysis on changes in implied RND function following the global crisis in September 2008 is given in Figure 4. We graph the RND functions before and after the bankruptcy of Lehman Brothers on September 15, 2008. When we compare the RND functions before and after the bankruptcy of Lehman Brothers, we see that the confidence intervals widens as the crisis intensifies and then diminished after the policy measures taken by the end of October. Case studies on RND functions show that policy measures including the foreign exchange intervention decreases prospective uncertainty in the foreign exchange markets.

Figure 4. Implied RND for the one-month TL/USD foreign exchange rate in September-October 2008.



It is important not to read too much information from graphs of risk-neutral distributions (BIS, 1999). The RNDs do not provide the actual probabilities of future asset prices. Rather, they give the values that option market participants attach to hedges of different possible outcomes. Thus the literature is much more interested in the intuitive notion captured by the change in the shape of RND. Also, risk neutrality of the RND stands for the assumption that individuals in the market are risk-neutral. Moreover OTC markets comprise of institutional investors who tend to be less risk averse.[9]

The time series representations of TL/USD and RND implied standard deviation provided in Figures 5 and 6 convey how the market uncertainty about the expected outcome changed over time and illustrate the rise in uncertainty in foreign exchange market during financial turbulence periods.

Figure 5: Nominal Exchange Rate (TL/USD)

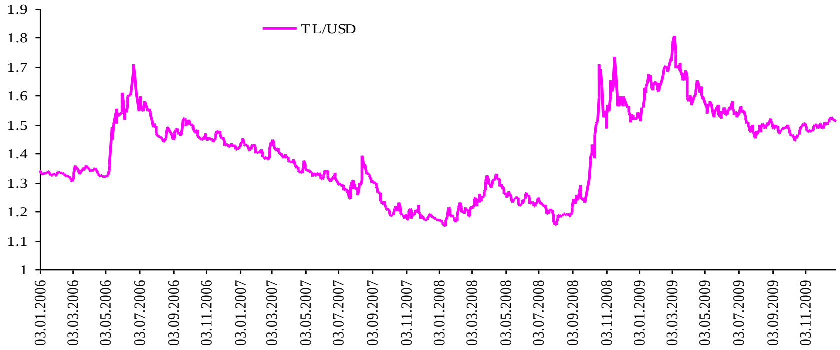
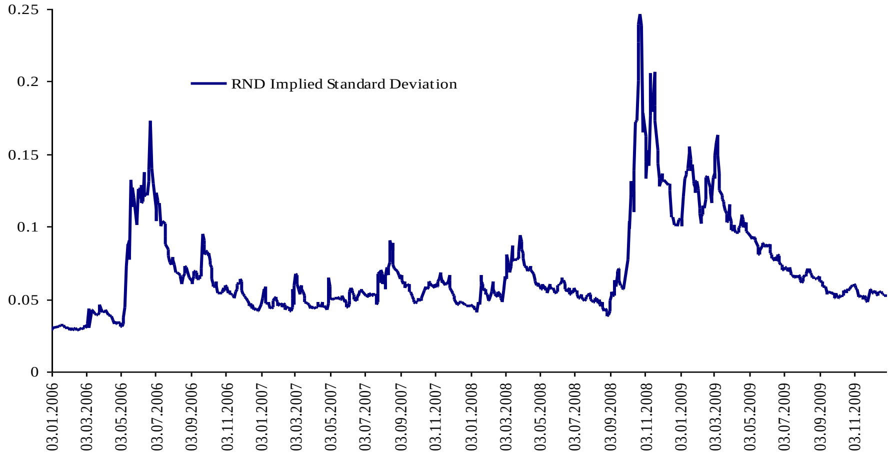


Figure 6: RND Implied Standard Deviation



Option implied risk neutral densities provide information about market expectations. In this paper we estimate the risk-neutral probability density (RND) functions for TL/USD currency options. We apply the method proposed by Malz (1996) due to its analytical tractability and simplicity. We investigated the information content of RNDs when financial markets were subject to a greater uncertainty during the period 2006 and 2008. We make inferences about

[9] Gürkaynak and Wolfers (2005) show that risk neutrality assumption can not be rejected in a market for institutional investors.

the effectiveness of monetary policy measures and see how the market perception changed throughout the crisis. For both periods we observed the widening of the confidence intervals as the financial turbulence hit the market, implying fears of large movements in exchange rates. We uncover the effectiveness of policy measures by observing shrinking densities and confidence bands. The overall result is such that the Bank was successful in stabilizing the markets during recent financial turbulences and the information content of RNDs facilitates to understand how market participants view the future and prices of risk associated with future outcome.

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Appendix

Strike Price(K): Strike price, or exercise price, is the price at which the owner of an option contract can exercise the option

Implied Volatility (σ): The volatility implied by the market price of the option based on an option pricing model, Black-Scholes (1973) model in this paper.

$$C(S_t,\tau,K,\sigma,r,r^*) = e^{-r^*\tau} S_t N\left[\frac{\ln\left(\frac{S_t}{K}\right)+\left(r-r^*+\frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}}\right] - e^{-r\tau} KN\left[\frac{\ln\left(\frac{S_t}{K}\right)+\left(r-r^*-\frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}}\right] \quad (1)$$

where S_t=spot exchange rate, τ =time to expiration, K=exercise price, σ =implied volatility, r=domestic interest rate, r^* =foreign interest rate, N=standard cumulative normal distribution function

Delta (δ): Delta is the rate of change of the option price (C) with respect to the underlying asset price (S). For instance, a delta of 0.80 means that for every $1 the underlying asset increases, the call option will increase by $0.80.

$$\delta(S_t,\tau,K,\sigma,r,r^*) = \frac{\partial C(S_t,\tau,K,\sigma,r,r^*)}{\partial S_t} = e^{-r^*\tau} N\left[\frac{\ln\left(\frac{S_t}{K}\right)+\left(r-r^*+\frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{\tau}}\right] \quad (2)$$

Kurtosis: Kurtosis measures the the peakedness of the probability distribution. It can be calculated as the fourth central moment of the probability distribution, normalised by the fourth power of its standard deviation.

$$Kurtosis = \frac{\mu^4}{\sigma^4} \quad (3)$$

Skewness: Skewness measures the the asymmetry of the probability distribution. It can be calculated as the third central moment of the probability distribution, normalised by the third power of its standard deviation.

$$Skewness = \frac{\mu^3}{\sigma^3} \quad (4)$$

At-the-moneyness: An option is at-the-money if the exercise price is equal to the current price of the underlying asset.

In-the-moneyness: A call option is in-the-money if the exercise price is below the current price of the underlying asset.

Out-of-the-moneyness: A call option is out-of-the-money if the exercise price is above the current price of the underlying asset.

Standard Option Combinations

At-the-money-straddle: A combination of at-the-money call and put options. Since straddle is an at-the-money option, its strike price is very close to prevailing exchange rate. The quotation in terms of call option implied volatilities is given as follows

$$atm = \sigma(0.50) \tag{5}$$

Risk reversal: An option strategy where the investor simultaneously purchases an out-of-the-money call option and sells an out-of-the-money put option. The quotation in terms of call option implied volatilities is given as follows

$$rr = \sigma(0.25) - \sigma(0.75) \tag{6}$$

Strangle: An option strategy consisting of a simultaneous purchases of an out-of-the-money put and an out-of-the-money call option. The quotation in terms of call option implied volatilities is given as follows

$$str = 0.5[\sigma(0.75) + \sigma(0.25)] - \sigma(0.50) \tag{7}$$

Payoff Diagrams of Standard Option Combination