UDC: 336.764/.768(437.3)
Keywords: currency options – emerging markets – risk neutral distributions – efficiency tests – OTC

An Interpretation of Czech FX Options

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Currency options are interesting for market and central bank economists, because they contain information, which is independent from that provided by spot and interest rate markets. Option prices reflect the market perception of uncertainty incidental to the future development of the exchange rate, and therefore, they could be used for monitoring the current market sentiment. It is then natural to ask how rational this sentiment is, i.e. how much about actual future development can be predicted from option prices.

These issues have been studied for main currency pairs, but our article is one of the first that addresses them in the Czech koruna context. Indeed, the OTC (over-the-counter) koruna option market has been developing and expanding now for several years, and thus data time series are becoming rich enough for analytical purposes.

In the first section of the article, we briefly describe the structure and history of the Czech FX option market. We characterise four main categories of contracts traded on the market and suggest how to interpret the prices of these structures. In addition, we show how probabilistic distributions implied by option prices may be used for monitoring market sentiment.

Next, we explore the behavior of option prices during three eventful periods of the history of the Czech koruna between January 1997 and January 2002. First, we observe that at-the-money-forward (ATMF) implied volatility-signalled market worries weeks before the crisis unfolded in May 1997. Moreover, other option contracts – risk reversals – demonstrated even a greater information lead than ATMF straddles. This finding is consistent with the results of Campa and Chang (1998), who formally showed that options warned against the looming crisis much earlier than other markets. Secondly, we briefly discuss the sharp drop in risk reversal prices that occurred during the first months of 1999. It coincided with the outflow of short--term capital, which had speculated on the interest rate differential between the Czech koruna, German mark and dollar instruments. And finally,

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We solely express our own views and not the views of the institutions. We would also like to thank Gordon Gemmill, Tony Gravelle, Josef Jílek, Richhild Moessner, Ladislav Mochář, Jan Strakoš, Martin Špaňár and David Vávra for their valuable suggestions and worthwhile discussions. All errors and omissions are ours.

TABLE 1 Approximate Daily Averages in Billions of USD

	Spot, outright forwards and forex swaps	Options
All currency pairs	1500	87
USD – DM (1998)	250	17
USD – JPY (1998)	260	32
CZK – EUR	0.75	0.09

Source: BIS (1999); CNB (2003); own estimates

we analyse the behavior of the option market in the context of forex interventions of the Czech National Bank. We also point out how shifts in market sentiment during this period are reflected in risk neutral distributions (RND) implied by option prices.

The behavior of option prices before the currency crisis in 1997 is an anecdote that supports a hypothesis of the rational market expectations. In the final part of our study, we investigate this question more formally and test whether the ATMF implied volatility of koruna options predicts actual future volatility of the exchange rate. We found that the koruna option market is quite efficient in this sense. This result is consistent with results for other currencies.

1. The Koruna FX Option Market

The Czech koruna option market is relatively young. Its origin dates back to approximately 1996. It is also comparatively small due to the size of the local economy. Nevertheless, it has already overcome the early stages of its development, and now it may serve as a source of valuable market information.

In the beginning, the market was dominated by a small number of local banks. Later, the market expanded, and foreign, namely London banks, took the lead. The market is structured as a typical OTC market where the bulk of the transactions take place on the interbank market. Banks sometimes trade directly with each other, but more often they make deals via brokers.[1]

In currency composition and average turnover, the koruna option market shadows the spot market. While in 1997 both mark and dollar options were traded in parallel. Since the year 2000, euro options have dominated the market and dollar options have become marginal. The average daily turnover may be roughly estimated to be about 80–120 mil. EUR[2] and the typical size of a deal being 10 mil. EUR; yet tickets as large as 100 mil. EUR are sometimes executed. In terms of notional amounts, which, as *Table 1*

[1] Approximately fifteen to twenty banks actively trade koruna options, but only about five of them form the market core. About five broker institutions serve the market as well.

[2] Unlike exchange markets the OTC markets are traditionally opaque, and one often has to rely on more or less precise estimates. The turnover number is a consensual estimate of several market participants, and it is also consistent with the indication from the Czech National Bank survey of foreign exchange market turnover realised through Czech banks.

shows, is very little in comparison with the trading volume of global FX options. Having turnover and liquidity lower than may be found for main currency pairs, the koruna option market shows bigger bid-ask spreads.[3] In addition, a smaller number of contract types and strategies are actively traded, and contrary to some more developed markets, continuous trading does not exist.

However, while the koruna option market is smaller than option markets for the main currencies, it is not small in comparison to the size of the koruna spot market. The ratio of turnovers in options and the cumulation of spot, forwards and swaps is not too different from other markets. It points to market satiation and its structural maturity.

1.1 OTC Quoting Conventions

In reality, the price of a European currency option is determined by market forces and is mainly affected by the current underlying spot rate, option's strike price and maturity, domestic and foreign interest rates, and, importantly, by the uncertainty of the realization of future spot rates. In the Black-Scholes model a volatility parameter is introduced to model the uncertainty. For given spot and strike prices, maturity and interest rates the Black-Scholes formula is a one to one mapping between the koruna price of the option and the volatility parameter. The implied volatility phrase is sometimes used to emphasize this relationship. The Black-Scholes volatility is thus an alternative way for quoting option prices.

The actual exchange rate does not follow the particular stochastic process required by the Black-Scholes model. Therefore, not only does the implied volatility change over time but also at a given moment the implied volatility depends on the strike price and maturity of the option. The dependence of the volatility on the strike (moneyness) is called a volatility smile and its dependence on maturity is termed the volatility run.

Furthermore, the OTC market developed a convention of measuring the moneyness of options by the option's Black-Scholes delta (*hedge ratio*) rather than by the difference between spot and strike price. Delta is a marginal change in the Black-Scholes price of an option with respect to a change in the spot rate, e.g. the more a call is in the money, the higher its delta, even though the relationship is non-linear.

To sum up, volatility and delta is used for option quotes instead of plain option premiums, spot and strike prices. To a great extent, this market convention enables separation of volatility, which measures underlying uncertainty, from other observable market variables that affect option prices most. Under this convention the volatility smile is described the by relationship between implied volatility and delta instead of using strike and option prices expressed in koruna terms.

Remember that the delta of the call option is always between 0 and $e^{-r \cdot T}$, where r is a foreign interest rate and T is the maturity of the option. Further,

[3] While a typical bid-ask spread on the Czech market is about 0.5–1 percentage point in terms of implied volatility, on the developed markets it might be as low as 0.2 %. Nevertheless, Czech spreads are lower than in other European emerging markets.

the delta of the put is always between $-e^{r \cdot T}$ and 0. The following jargon for delta quotes is used. A call option with delta δ_c is referred to as 100 δ_c, i.e. a 25-delta call is a call option with $\delta_c = 0.25$. Similarly, a put option with delta δ_p is referred to as –100 δ_p, i.e. a 25-delta put is a put option with $\delta_p = -0.25$. Moreover, since for short maturity options the term $e^{-r \cdot T}$, which facilitates transformation between the delta of a put and the delta of a call, is close to one, a call counterpart to the 25-delta put is often referred to as a 75-delta call instead of a 100 $(e^{-r \cdot T} - 0.25)$ delta-call.

Another abbreviation is used for an at-the-money-forward (ATMF) call. It is an option with a strike price equal to the forward rate. Denote the market quotes of ATMF volatility as $(\sigma_{atmf}, \delta_{atmf})$. Sometimes, people refer to it as a 50-delta call, i.e.$(\sigma_{atmf}, 0.5)$. In fact, it is easy to show that, given a market quote of volatility σ_{atmf}, the delta of a call option with $X = F$ is $e^{-r \cdot T} N\left(\frac{1}{2}\sigma_{atmf}\sqrt{T}\right)$, where $N(.)$ denotes the cumulative distribution function of the standard normal distribution. For example the delta for half a year ATMF call is about 0.52.

A more detailed technical description of the market quoting conventions and transformations between variables is provided in (Cincibuch, 2004).

1.2 Traded Contracts and Their Interpretation

Contracts traded on the koruna market might be classified into four main categories. The first one consists of the ATMF straddle, which is the main contract of the market and represents about 30 %–40 % of the option turnover. Its quoted volatility run (its term structure) ranges from one week to one year, but a one-month horizon seems to be most representative. A long ATMF straddle is a combination of long positions in the ATMF call and ATMF put options. ATMF implied volatility reflects the level of uncertainty perceived by the market and it relates closely to the variance of the distribution of expected returns. The terminal straddle payoff function as well as the payoff functions of contracts mentioned below are discussed and illustrated e.g. by Hull (1996).

Plain vanilla call and put options fall into the second most important group which has accounted for about 20 %–40 % of the option turnover. Singles are traded as OTM (out-of-the-money) options for various strikes between approximately 20 to 50 delta. Nevertheless, ATMF and 25-delta contracts are the most usual.

The third category of contracts is formed by risk reversals, which have accounted for about 20 % of the total option turnover. A long risk reversal is also a combination of two OTM (most often 25 delta) options: a long position in the OTM call and a short position in the OTM put. The risk reversal price is quoted as the difference between the volatilities of its two components.

Risk reversals are also quite interesting from an analytical point of view. A decrease in the risk reversal price means that the call option becomes less expensive than the put option. It might be interpreted in a way that the market attributes a smaller likelihood to the euro appreciating significantly (koruna depreciating) than the likelihood of the euro depreciating significantly (koruna appreciating).[4]

Therefore, risk reversals could be seen as an indicator of the asymmetry of market expectations. As such, risk reversals relate to the skewness[5] of the distribution of expected returns.

This phenomenon, however, might be seen from a different "dynamic" perspective, which is shared by many market practitioners (Gemmill, 1996). Assume that the koruna is expected to become more volatile in the wake of a remarkable depreciation than after appreciation of a similar magnitude. Then, an option which would become e.g. at-the-money after the depreciation scenario would have a higher time value than the option that would be at-the-money in the appreciation scenario. Consequently, the first option should have a higher price (implied volatility) than the latter one and the risk reversal would be positive.

Indeed, volatility asymmetry between the two scenarios would transform into the asymmetry of the terminal dis-tribution of returns, and in the risk neutral world the two interpretations are completely equivalent. Nevertheless, investors' attitudes toward risk might also be distinct under the two scenarios. In this case, higher time value of the options in the depreciation scenario would reflect increased risk aversion rather than actually expected volatility and the "dynamic" approach would seem more appropriate.

The remaining group representing 10 %–20 % of turnover encompasses strangles and various spreads (butterfly, calendar, currency). A long strangle contract is a combination of long positions in two options: an OTM call and OTM put. It is quoted as the average of the volatilities of its components above ATMF volatility. Strangle contracts reflect how concentrated expectations around the forward are. The higher the strangle value, the higher likelihood which market attributes to extreme values of returns. Thus, the value of strangles might be associated with kurtosis[6] of the distribution of returns.

ATMF implied volatilities are often quoted several times a day, but risk reversal and strangle prices change less frequently. For example, it seems sufficient to sample risk reversals only once every two days for the koruna market. However, this lower frequency does not necessarily mean low informational value of the data. Indeed, even for the dollar–yen, which is the most liquid and most heavily traded currency pair, a 25-delta risk reversal often stays constant for several days.

To see why this makes sense, consider the difference in meaning between ATMF-implied volatility and other prices. While the ATMF implied volati-

[4] It should be emphasised that a change in the risk reversal, holding other things equal, does not alter the mean of the distribution of expected returns. Thus, a somewhat lower likelihood of significant koruna depreciation might be offset, for example, by the higher likelihood of mild depreciation of koruna.

[5] Skewness is the third central moment of a probability distribution, normalised by the third power of its standard deviation.

[6] Kurtosis is the fourth central moment of a distribution, normalised by the fourth power of its standard deviation.

lity measures an overall level of uncertainty and makes the essence of option prices, risk reversals and strangles determine only the shape and curvature of the volatility smile[7].

They serve as first and second order adjustments of the Black and Scholes model, which would imply a flat volatility smile and run. In this sense, a change in the risk reversal or strangle amounts to the model change. A certain analogy might be found between volatility smiles and yield curves. Changes of the ATMF-implied volatility resemble parallel shifts of some yield curve and risk reversal, and strangle changes are similar to the changes of the yield curve spread and curvature. Indeed, spread and curvature of yield curves tend to change more slowly than the interest rate level.

1.3 Implied Risk Neutral Distributions: A Tool for Interpreting Option Prices

It is possible to interpret directly quoted option prices along the lines described above; or alternatively, one might want to construct some embracive characteristic. Risk neutral distributions (RNDs) turn out to be such a summarizing tool, encapsulating all available information contained in market prices. This comfortable feature of RNDs stems from the theoretical result that under the assumption of no arbitrage and frictionless markets, the price of a traded security can be expressed as an expected discounted security payoff, where the expectation is taken with respect to an appropriate RND (Cox – Ross, 1976), (Ross, 1976), (Breeden – Litzenberger, 1978).

More thorough treatment of the implied distributions and their estimation could be found e.g. in (Rubinstein, 1994) or (Bahra, 1997). The latter summarises issues relating to the usefulness of implied RNDs and their interpretation. And, Clews, Panigirtzoglou and Proudman (2000) describe methods used at the Bank of England for estimating RNDs, which enter as a regular input to its Monetary Policy Committee briefings. In Cincibuch (2004), a classification of estimating methods according their generality is provided as well as a more detailed literature survey.

In this paper, so called Malz (1997) method for RND estimation is utilised. The method uses the fact that under some restrictions an equivalence might be established between risk neutral distributions and volatility smiles.[8] Thus, by means of estimating a proper volatility smile one can reach risk neutral distribution and *vice versa*. The Malz method is based on the quadratic interpolation of the volatility smile. Specifically, implied volatilities for several different strike prices (measured by delta) are calculated from quotes of straddles, strangles and risk reversals. Further, it is assumed that volatility $\widetilde{\sigma}$ is approximately a quadratic function of the call delta δ_c, i.e. $\widetilde{\sigma} = a\delta_c^2 + b\delta_c + c + \varepsilon$, where parameters a,b and c are estimated from the observed prices and ε represents the random error. Finally, this volatility smile is transformed into the RND via a method devised by Breeden and Litzenberger (1978).

[7] volatility as a function of delta

[8] For discussion of this equivalence see e.g. (Cincibuch, 2004).

The use implied distributions for monitoring market sentiment changes is illustrated in the section 2.3, which deals with market reaction to forex interventions of the CNB.

2. The Czech Koruna in 1997–2002

In this section, we make several brief case studies of the development of the Czech koruna from the option price point of view. First, in 2.1, we observe that option price behavior before the currency crisis in 1997 indicated their rational forward-looking nature as they predicted the break of the currency peg. Also, in section 3 we investigate this rationality issue more formally, where we test whether option prices predict actual future volatility of the koruna exchange rate. Secondly, part 2.2 shows that a significant change in the level of prices of risk-reversals in the beginning of 1999 marks a break in the FX market structure and the composition of market participants. Options, as a quantitative indicator, may help to understand this change, which had been otherwise known only on the level of rumours. And third, we investigate how forex interventions have been perceived by option markets and show how probabilistic distributions implied by option prices might be used for monitoring market sentiment.

The data set we used consists of time series of mid-rate quotes[9] for Czech koruna–German mark and euro option contracts with one-month maturity. For ATMF straddles and 25-delta risk reversals, we use the time series from January 1997, and data for 25-delta strangles have been available from 1998. Whenever we needed spot exchange rates and interest rates, we used the close of business interbank quotes.

2.1 Options Look Forward: The Currency Crisis in May 1997

One of the most prominent events in the recent history of the Czech koruna was the currency crisis in May 1997. Šmídková et. al (1998) explicate its roots and gives a detailed description of its course and the reaction of the central bank.

The current account deficit and other problems of the Czech economy were highly publicised, and the issue of devaluation was discussed in the media a long time before the actual crisis occurred. However, as benign developments of the spot rate, implied volatility and risk reversals suggest (*Figure 1* and *2*) the market seemed to be unruffled until spring 1997. Indeed, in the middle of February, the koruna was close to the appreciation side margins of its ±7.5% band, and the CNB spokesman had to declare that the central bank was concerned about the strength of the currency.

Figure 1 demonstrates that ATMF implied volatility significantly increased already in April 1997, well before the crisis actually happened. However, risk reversals suggest that the market began to worry as early as February. The elevated likelihood of large depreciation as it was perceived

[9] proprietary CSOB trading desk database

FIGURE 1 Exchange Rate and Implied Volatility before Crisis in May 1997

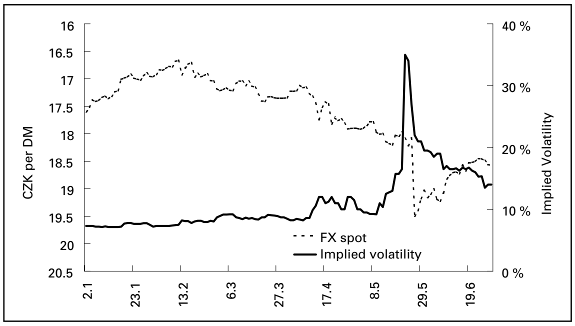
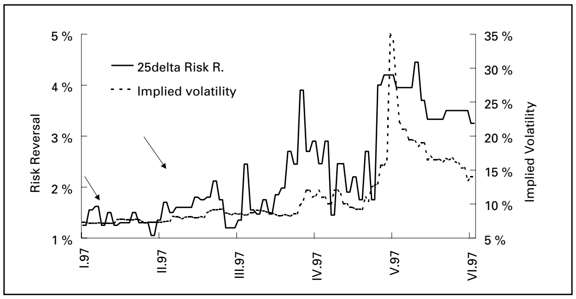


FIGURE 2 ATMF Implied Volatility and Risk Reversals before the Crisis in May 1997



by market participants was manifested in higher risk reversal prices. Figure 2 illustrates that risk reversals tended to react before ATMF implied volatility, and as such, they were an earlier and more sensitive indicator of potential future problems. One might even argue that since investors operating on the option market are quite sophisticated and since option contracts enable high leverage, high option prices might have revealed speculators' positioning before they started attacking the koruna exchange rate regime.

The forward-looking information contained in options before the crisis was also studied by Campa and Chang (1998). They constructed arbitrage-based tests[10] of credibility of the target zone based on the forward rates and on the option prices, and they showed that the koruna exchange rate band lost its credibility weeks before the actual devaluation.

In the final part of the article, we econometrically support the notion that

[10] Their tests consist of constructing bounds for option prices that should not be violated if the target zone is perfectly credible. Consequently, from violating such a bound one could infer non-perfect credibility of the arrangement. It may be proved that option-based tests are more powerful than simple forward rate tests.
In particular, they report that a convexity test based on options signalled a credibility loss already 29 days before the breakdown of the regime. In comparison, the simple Svensson test of credibility based on the forward rate level indicated a credibility loss only 11 days in advance, which just coincides with the beginning of the speculation wave against the currency.

not only do options mirror current market perception, but that this sentiment is highly rational and that option prices carry information about future volatility of the spot. Therefore, the behavior of option prices during the pre-crisis period may be viewed as an illustration of this options' forward-looking nature.

2.2 Options Help to Identify and Understand Structural Breaks: The Outflow of Hot Capital in 1999

Most observers of the koruna market agree that the relative importance of reasons for currency trades changed substantially in early 1999. The wide interest rate differential was an important impetus for capital flows throughout 1998, but afterwards, as Czech inflation and interest rates dropped, it was replaced by privatization and direct investment flows, and the structure of market participants changed accordingly. As some traders noted, this change was also reflected in a structural shift in market behavior: since the second quarter of 1999, they described the currency market as being relieved in comparison with the previous period. Nevertheless, beyond option prices there is a lack of directly observable indicators that might have shown this shift.[11]

For an interpretation of how this structural shift was manifested in the option market, it is useful first to recall the economic environment in 1998. The Czech koruna was quite strong at that time. According to market sources[12], it was the world's third-best-performing currency against the dollar and mark in 1998. Its strength stemmed from the interest rate differential, which was about twelve percentage points above the mark in terms of one-month deposits during the first months of the year. Domestic interest rates were kept relatively high by the Czech National Bank, which had adopted direct inflation targeting in January 1998 and set an interval of about six per cent for the net inflation target for the end of the year.[13] During 1998, the Czech economy experienced fast disinflation, which resulted from a combination of subdued domestic and foreign demands, declining world commodity prices and strengthening of the currency. The Czech National Bank reacted with a series of interest rate cuts in the second half of the year.[14]

In these circumstances, the koruna exchange rate was influenced by conflicting forces. From the point of view of the real economy, the strength of the currency was not justified by the competitiveness of domestic producers

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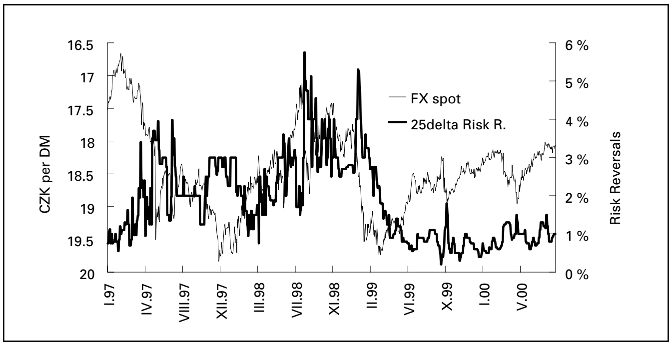
[11] Also, surveys of the Czech National Bank showed that the turnover of koruna spot, forward and FX swaps somewhat decreased from the high levels experienced in 1998.

[12] Bloomberg

[13] Although many considered the inflation target to be too ambitious, after several months it became increasingly clear that, not only could the target be hit, but that it would even be undershot.

[14] The Czech National Bank's policy was a source of controversy. Many blamed the conjunction of monetary and fiscal restriction for causing the recession or making it worse. Others claimed that the recession was a result of structural problems related to inefficient institutions in the market economy.

FIGURE 3 Koruna Risk Reversals 1997–2000



(e.g. (Cincibuch – Vávra, 2000)), and also interest rate cuts would have normally led to the currency weakening. However, the rate cuts actually provided support for the koruna as they led to soaring bond prices along the entire length of the yield curve, and investors were attracted by capital gains. Such an obviously unstable situation seemed to mirror the learning process of capital markets during the transition to a low inflation environment. The longer end of the yield curve had not reflected the expectations of such fast inflation and the ensuing interest rate decline tended to react only ex--post and to move together with the short end. Clearly, interest rate cuts and the consequential capital gains could not have gone on forever, and it was only a matter of time before the currency would lose its last supporting pillar. Actually, it happened in January and February 1999 when a depreciation of almost ten per cent was triggered by the Brazilian currency crisis, bad trade data and further interest rate cuts.[15]

The option market correctly reflected this uncertainty. *Figure 3* shows high levels of at-the-money-forward, implied volatility and, in particular, of risk reversals[16] in 1998, and their dramatic decline in early 1999 documents the structural shift and the end of the hot-capital period.

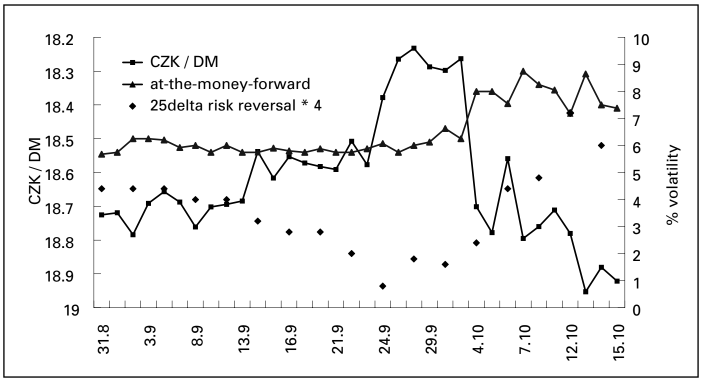
As it was discussed above in section 1.2, higher positive quotes of risk reversals may indicate market worries about the sustainability of a currency's strength. However, it seems that high risk reversals were also a by-product of hedging short term speculative positions. Indeed, the very presence of mercurial capital increases the vulnerability of the market. As short-term investors were being replaced by others with a medium- or long-term investment horizon, the value of risk reversals went down.

2.3 Options Help to Monitor Market Sentiment

September 1999

Forex interventions naturally provide a good opportunity for observing changes in market sentiment. Therefore, by way of the example of interventions pursued by the Czech National Bank, we illustrate how options might be used for sentiment monitoring.

FIGURE 4 Exchange Rate and Option Prices in September and October 1999. Risk Reversals Quotes Quadrupled



In August and September 1999, a series of reports caused market sentiment towards the koruna to be very optimistic. Reports showed that the economy was recovering from the recession earlier than had been expected and that annual inflation rose for the first time in 17 months. This led market participants to the belief that the central bank would forbear further interest rate cuts. Moreover, the external position of the economy improved: the current account was in surplus in the second quarter of the year and the August trade deficit was lower than expected. Most importantly, strong foreign capital inflow was expected for privatisation, real economy projects, as well as new issues of government eurobonds. All of these factors together with the low level of overall debt were cited in the market as a reason for further strengthening of the koruna with a minimal downside risk. *Figure 4* shows how the option market reflected these changes. The decreasing price of 25-delta risk reversal contracts during the first two decades of September indicated that appreciation of the koruna was not a random aberration within the usual market volatility, but might have developed in a strong trend.

The central bank was worried that some parts of the economy might have had problems with adjusting efficiently to the continued fast pace of appreciation. Moreover, expected substantial inward investment seemed to inspire secondary speculation. Therefore, at the end of the month, one of the members of the central bank's board tried to talk the koruna down. He stressed the readiness of the bank to stem undue nominal appreciation through sterilising[17] the inflow of privatisation capital. Moreover, he did not

[15] The eurobond market may serve as an illustration of this development. Investors tended to redeem koruna eurobonds issued by foreign institutions. In 1999, the outstanding amount of these instruments decreased by more than 26 %.

[16] Risk reversal quotes of approximately 3 %–5 % are quite high in comparison with developed markets where values less than 2 % are typically observed.

[17] The government established a special account with the central bank for privatisation proceeds in foreign currency. Later and according to the market situation, the central bank would either buy this foreign currency for its reserves or convert it to koruna on the market.

FIGURE 5 Implied Distributions of Monthly Returns in September 1999

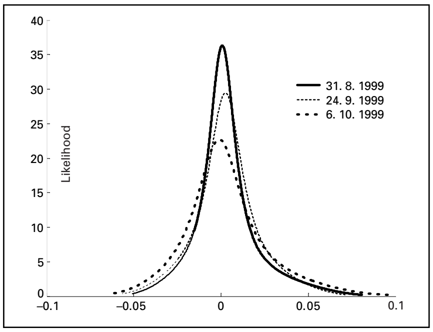


TABLE 2 Summary Statistics for Implied Distributions of Monthly Returns in September 1999 (in %)

	31-Aug-99	24-Sep-99	6-Oct-99
Downside risk (>3 %)	8.38	8.24	12.29
Upside risk (>3 %)	3.37	4.77	7.21
Mean	0.31	0.31	0.27
Mode	0.07	0.25	–0.10
Median	0.14	0.27	0.05
Standard deviation	1.84	1.89	2.40
Skewness	73.99	18.43	57.36
Pearson statistic	9.77	2.32	9.39
Kurtosis	188.37	87.35	98.80

exclude the possibility of further rate cuts. This verbal intervention resulted in some increase of risk reversals.

The situation changed further on September the 4th, when the central bank sold koruna on the market and also cut the official repo rate. In response, the koruna weakened, and the price of risk reversals increased. Also, the main contract of the option market, the ATMF straddle, began to rise already before the intervention as a result of CNB comments. In the wake of intervention, its implied volatility rose reflecting the uncertainty which the central bank introduced in the market to stem the view that koruna was a one-way bet. However, market fears waned, and the skewness soon fell again in late October. The currency also began to appreciate once again. Nevertheless, the intervention seemed to have effectively slowed appreciation, because the exchange rate reached the intervention level only in January of the following year.

This development is documented also in the behavior of risk neutral distributions estimated from market option prices graphed in *Figure 5* and characterised in *Table 2*. The distribution from September the 24th in comparison with the distribution from the end of August shows an elevated upside risk[18] and a reduced downside risk, which reflects the market's opti-

[18] Upside (downside) risk is defined here as a risk adjusted probability that the currency will appreciate (depreciate) 3 % or more.

mism and its shift towards a one-track view of the exchange rate. Also, lower distribution asymmetry measured by its skewness and Pearson statistics[19] supports this interpretation. On the contrary, higher variance and asymmetry observed for distributions estimated after intervention reflected higher market uncertainty.

Winter 2002

From 1999, yield differentials have played a smaller role, and the effects connected with longer-term investment flows have become the most important factor affecting the koruna exchange rate. Foreign direct investment flows accounted for about 10 % of GDP in 1999 and since then it has been high. In comparison, the current account deficit was much smaller, the capital account was negligible, and thus, as the balance of payments identity stipulates, this inflow had to be offset by induced outflows in other parts of the financial account or possibly by an increase in the Czech National Bank's international reserves. In this situation, the abundance of foreign exchange had an impact on the exchange rate and led to relatively quick appreciation.

In the last quarter of 2001 the rate of appreciation fastened and in December we observed market turbulences. In one week the exchange rate strengthened by more than 5 %; likely in reaction to government's announcement that the gas distribution industry buyer has been chosen. Market participants had not been convinced that the central bank and the government were determined enough to stem the appreciation and the market almost collapsed. Its shallowness is illustrated by the bid/ask spreads on the spot market of about 15 halers, while otherwise it is about only 2 halers. In this situation, the option market makers were not able to hedge in the spot market.

As *Figure 6* shows, until December, there was a long downward trend in volatility, but it was interrupted and volatility spiked from a low of 4.25 % to more than 8 %. The initial jump reflected mainly the short covering in the illiquid market, but the volatility did not fall. It kept rising and in July 2002 reached levels of about 12 %. It reflects high level of uncertainty regarding the future development of the spot rate in the short/medium term.

The comparison of risk neutral distributions estimated from data as of December the 11th and one month later, which is documented by *Figure 7* and *Table 3*, illustrates the sentiment change. In January the market attributed about 25% probability to the event that spot appreciates or depreciates more than 3 % in one month, while in December such probability was about only 5 %.

3. Predictive Power of Implied Volatility

It is believed that option prices carry rational forward-looking information. Here, we attempt to test the hypothesis of the rational market more

[19] Pearson statistics is the difference between the mean and median normalised by standard deviation.

FIGURE 6 Spot and Option Prices in 2001 and 2002

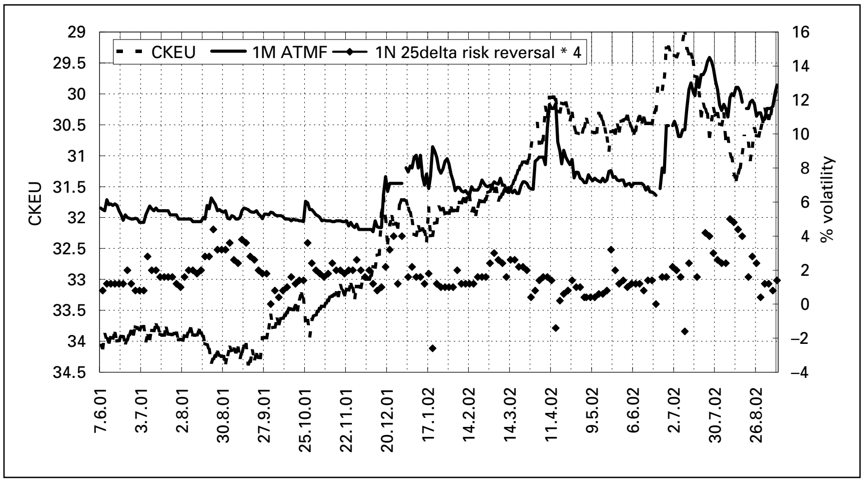


FIGURE 7 Jump in Uncertainty in December 2001

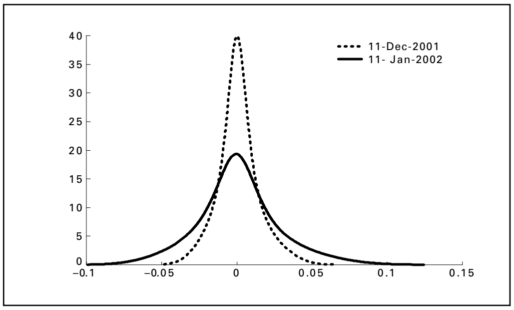


TABLE 3 Summary Statistics for Implied Distributions of Monthly Returns in Winter 2002 (in %)

	11-Dec-01	11-Jan-02
Downside risk (> 3 %)	3.6	13.1
Upside risk (> 3 %)	1.7	11.4
Mean	0.12	0.12
Mode	0.07	0.25
Median	0.02	–0.03
Standard deviation	1.4	2.8
Pearson statistic	4.4	3.5
Kurtosis	112	97

formally over a longer time span. We follow authors who estimated how well implied volatility can predict actual realised volatility for various option markets including those in main currency pairs.

Two regression specifications were investigated in the literature. The first specification is a conventional test of market efficiency:

$$\sigma^A_{t,k} = \alpha_0 + \alpha_i \sigma^I_{t,m} \tag{1}$$

and then the second is an extended "encompassing" one:

$$\sigma^A_{t,k} = \alpha_0 + \alpha_i \sigma^I_{t,m} + \alpha_h \sigma^A_{t,-l} \tag{2}$$

In the equations, the letter m denotes the maturity of the option, the symbol $\sigma^i_{t,m}$ denotes implied volatility observed at date t and referring to the option with the maturity date $t+m$. Actual volatility is defined as a standard deviation[20] of the daily exchange rate returns over a given period of time. Specifically, the symbol $\sigma^A_{t,\,k}$ denotes the volatility between dates t and $t + k$:

$$\sigma^A_{t,k} = \sqrt{\frac{1}{k-1}\sum_{i=t}^{t+k-1}(r_i - \bar{r}_{t,k})^2} \tag{3}$$

where $r_t = \log(S_{t+1}) - \log(S_t)$ represent daily exchange rate returns and $\bar{r}_{t,\,k} = \frac{1}{k}\sum_{i=t}^{t+k-1} r_i$ their appropriate average. To denote historical volatility, we use the shortcut $\sigma^A_{t,\,-k} \equiv \sigma^A_{t-k,\,k}$.

The rationale for regressions, which use Black-Scholes implied volatility as an explanatory variable even when it is not believed that assumptions of the Black-Scholes model hold, was given by Heynen, Kemna and Vorst (1994). They showed that Black-Scholes implied volatility is an accurate forecast of average expected volatility over the remaining life of the option for various GARCH, EGARCH or mean reverting stochastic processes governing the development of the underlying security.

Implied volatility was found to be a good predictor for actual future volatility for stock indices and main currencies. Although, Canina and Figlewski (1993) estimated equations 1 and 2 for S&P 100 index options[21] over the period 1983–1987 and claimed that implied volatility was a poor forecast of subsequent realised volatility and that implied volatility had less predictive power than the historical, other works qualified their results. For example, Christensen and Prabhala (1998), examining S&P 100 index options for the longer time span of 1983–1995, observed that implied volatility well predicted future realised volatility and that it outperformed past volatility. Moreover, they found a structural shift that happened around the market crash in 1987, after which implied volatility seemed to have more predicting power. This partially explains the inconsistency of their results with Canina and Figlewski's (1993) findings. As another source of difference, Christensen and Prabhala cite their different and safer sampling

[20] Sometimes volatility is measured as a sample standard deviation, e.g. (Christensen – Prabhala, 1998); other authors (Jorion, 1995) use the average of squared returns without adjustment for the mean. However, differences between these definitions should not lead to distinct qualitative results.

[21] Chicago Board Options Exchange OEX options

TABLE 4 Predictive Power of Implied and Historical Volatility for Main Currencies

	Information content coeficients for				Predictive power coeficients for			
	const.	implied vol.	historical vol.	R^2	const.	implied vol.	historical vol.	R^2
DM	–0.080	0.852[a]		0.052	0.323[a]	0.547[a,b]		0.156
	–0.095	0.785[a]	0.085	0.052	0.401[a]	0.622[a]	–0.173	0.160
JY	–0.006	0.783[a]		0.036	0.327[a]	0.496[a,b]		0.097
	–0.076	0.668[a]	0.210	0.037	0.042	0.421[a]	0.474	0.105
SF	–0.041	0.854[a]		0.041	0.392[a]	0.520[a,b]		0.145
	–0.040	0.858[a]	–0.005	0.041	0.526[a]	0.609[a]	–0.240	0.149

Source: (Jorion, 1995)

Notes: [a] significantly different from zero at the 5 percent level
[b] significantly diferent from unity at the 5 percent level

procedure as they use non-overlapping monthly sampling, while Canina and Figlewski used daily data, corrected for their serial correlation.

Jorion (1995) analyzed the forecasting ability of options on currency futures traded at the Chicago Mercantile Exchange for the German mark, Japanese yen and Swiss franc. He distinguished between the informational content and the predictive power of volatility implied by option prices. While predictive power measures the ability to forecast average volatility over the period before a contract's maturity, the informational content is less demanding and measures how good the implied volatility is in forecasting one-day actual volatility. In our notation, investigating the predictive power and informational content would mean estimating equations 1 and 2 for $k = m$ and $k = 1$, respectively. As Jorion's results presented in *Table 4* shows, in both cases and for all three currencies, options contain a significant amount of information about future volatility and that they have more forecasting power than time series models.

3.1 Sampling Procedure and Estimation Results

We investigated whether Jorion's results hold also for the exchange rate of the Czech koruna. Concerning the sampling methodology, we took into account Christensen and Prabhala's (1998) warning suggesting that an improper econometric approach towards the overlapping data might lead to biased estimates. To diminish the possible problems stemming from possibly correlated data in overlapping samples, we constructed non-overlapping samples and estimated Equations 1 and 2 on these restricted data sets. Specifically, for a given number of trading days (k) over which actual future volatility is calculated, we used only a subset of observations that would allow the calculation of the actual volatilities from disjoint sets of spot rates. Formally, if one data point for Equation 1 consists of $\sigma^A_{j,k}, \sigma^I_{j,m}$ then the next one in a subsample consists of $\sigma^A_{j+k,k}, \sigma^I_{j+k,m}$. Similarly for regression 2, if one data point consists of $\sigma^A_{j,k}, \sigma^I_{j,m}, \sigma^A_{j,-k}$ then the next one in our sample consists of $\sigma^A_{j+k,k}, \sigma^I_{j+k,m}, \sigma^A_{j+k,-k}$. It follows that for a given k, we may obtain k such non-overlapping subsamples.

TABLE 5 Typical Estimation Results for the Market Efficiency Equation

k	α_0	t-stat.	5% c.i.	α_i	t-stat.	5% c.i.	R^2
5	0.005	0.50	(–0.014; 0.024)	0.907	8.86	(0.71, 1.11)	0.26
10	0.017	1.29	(–0.009; 0.044)	0.862	6.25	(0.59, 1.14)	0.27
20	0.028	1.57	(–0.008; 0.065)	0.813	4.28	(0.43, 1.19)	0.26

TABLE 6 Typical Estimation Results for the Encompassing Equation

k:j	α_0	t-stat.	5% c.i.	α_i	t-stat.	5% c.i.	α_h	t-stat	5% c.i.	R^2
5	0.004	0.43	(–0.015; 0.024)	0.808	6.75	(0.57, 1.04)	0.110	1.62	(–0.02, 0.24)	0.27
10	0.023	1.80	(–0.002; 0.049)	0.737	4.08	(0.38, 1.09)	0.047	0.42	(–0.18, 1.27)	0.24
20	0.030	1.60	(–0.007; 0.066)	0.609	2.12	(0.04, 1.36)	0.088	0.42	(–0.33, 0.51)	0.26

We chose three values of $k \in \{5,10,20\}$, and using $l = k$, we ran ordinary least squares regressions for all $j \in \{1,2,..., k\}$. As we used one-month options $m \approx 1M$, estimating the equations for $k = 20$ was quite close to measuring the predictive power, while for $k = 5$, we moved closer to Jorion's informational content. For the sake of brevity, we present only typical estimation results in *Tables 5* and *6*.

In general, our results confirm Jorion's findings also for the Czech koruna, an example of an emerging market currency. The results in Table 5 show that Czech koruna options carry a significant amount of information and that they predict well the character of currency movements. In all cases, estimates of the coefficient α_i are significantly different from zero and in virtually all cases the estimates are not significantly different from unity. It is not surprising that estimated coefficients on implied volatility tend to be higher for a shorter forecasting horizon k, because option dealers are naturally less uncertain in short-term volatility predictions, while for longer term predictions extrapolations might sometimes be used.

More importantly, when implied volatility is pitted against historical volatility, estimates show that implied volatility is a better instrument for forecasting actual volatility than past volatility. The estimates of the coefficient α_i are only marginally lower than for the previous regression, which contrasts with estimates of the historical volatility coefficient which are not significantly different from zero.

4. Conclusions

The Czech koruna option market is structured as a typical OTC market. While in absolute terms it is much smaller than markets for currency options on major currency pairs, when measured relatively to the magnitude of the underlying spot market and the economy, its size is similar to other developed markets. Three brief case studies lead to the conclusion that the option market may be a source of a valuable information that helps to interpret market sentiment. Indeed, contrary to cheap market talk, this information is based on actual large currency bets and hedges. Finally, by quantitative means it is illustrated that, similarly to other currencies, koruna options are more useful in predicting future volatility of the exchange rate than backward looking time series estimates. It strengthens the view that markets are efficient and dominated by rational agents.

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SUMMARY

JEL classification: G13, G14, G15
Keywords: currency options – emerging markets – risk-neutral distributions – efficiency tests – OTC

An Interpretation of Czech FX Options

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This paper opens with a brief description of the Czech FX options market. Several case studies of the Czech koruna option market illustrate how options reflect market sentiment and structural breaks. Risk-neutral implied distributions are suggested as a monitoring tool. Moreover, clear indications of the rational, forward-looking behavior of option prices were identified before the Czech Republic's 1997 currency crisis, and the results of statistical tests support the "rational market" hypothesis.