Analysis of the EUR/HRK exchange rate and pricing options on the Croatian market: the NGARCH model as the alternative to the Black-Scholes model

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Outline

1. Croatian Market of Derivatives: a Challenge of forming one
   - An explosive increase in trading on the Croatian market
   - The goal of the study
2. Non-linear in mean asymmetric GARCH model
   - The NGARCH model for the EUR/HRK time series
   - Risk estimation
3. GARCH option pricing model
   - The European call option on the foreign currency
   - Analysis of foreign currency options

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Trading on the Croatian market

- The interest of professional investor for financial derivatives on the Croatian market has been increasing a lot recently
- The Croatian market of derivatives does not exist *yet*!
- Some law conventions...trading with derivatives is expected to follow

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- Croatia faces a possibility of changing the domestic currency
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- We analyze in details the empirical distribution of the EUR/HRK currency time series and the *consequences* of such analysis for pricing foreign currency

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The model of Black and Scholes

Connection to the Black-Scholes model

- Prices on option markets are commonly quoted in terms of Black-Scholes implied volatility
- This *does not* mean that market participants believe in the hypothesis of the Black-Scholes model
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The proposed model

The goal of this study is

- to estimate the parameters in the dynamics of the currency time series using the NGARCH model,
- to simulate the prices of fureign currency options by means of the GARCH options pricing model using the estimated parameters
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Modelling the EUR/HRK time series

- P_t ... the EUR/HRK exchange rate price at time t, defined as the number of Croatian kunas required to purchase 1 euro
- The dynamics of returns R_t is described with

a non linear in mean, asymmetric GARCH (1,1) model:

$$R_{t+1} = \ln\left(\frac{P_{t+1}}{P_t}\right) = r_d - r_f + \lambda\sigma_{t+1} - \frac{1}{2}\sigma_{t+1}^2 + \sigma_{t+1}Z_{t+1}, \quad (1)$$

$$\sigma_{t+1}^2 = \omega + \alpha(\sigma_t Z_t - \rho\sigma_t)^2 + \beta\sigma_t^2, \quad (2)$$

where Z_t are i.i.d. $N(0,1)$ and

$$\omega > 0, \quad \alpha \geq 0, \quad \beta \geq 0 \quad \text{and} \quad \alpha(1+\rho^2) + \beta < 1. \quad (3)$$

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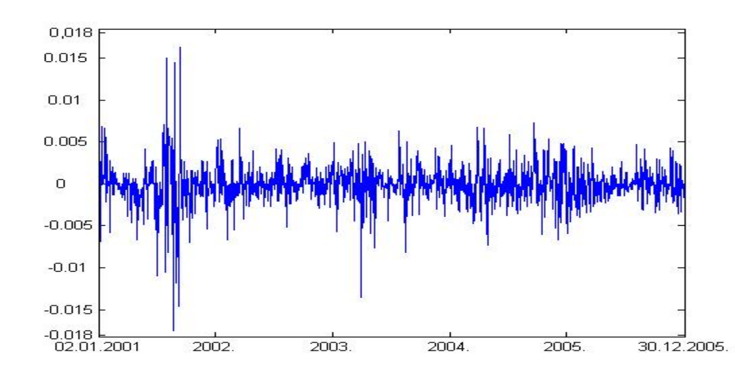
EUR/HRK 2001-2005



We use the MLE where the log-likelihood function is

$$L_T = \frac{1}{T}\sum_{t=1}^{T}\left[-\frac{1}{2}\ln(2\pi) - \frac{1}{2}\ln(\sigma_t^2) - \frac{1}{2}\frac{\left(P_t - (r_d - r_f + \lambda\sigma_t - \frac{1}{2}\sigma_t^2)\right)^2}{\sigma_t^2}\right], \quad (4)$$

where $T = 1297$.

Maximizing the L_T function we obtain

Parameter	Value	Sample standard error
$\hat{\omega}$	$1.7339 \cdot 10^{-7}$	$2.92 \cdot 10^{-8}$
$\hat{\lambda}$	-0.0301153	0.11311
$\hat{\alpha}$	0.095345	0.012028
$\hat{\beta}$	0.86840994	0.014289
$\hat{\rho}$	-0.1707379	0.074885
$\hat{\alpha}(1+\hat{\rho}^2)+\hat{\beta}$	0.96653484	-

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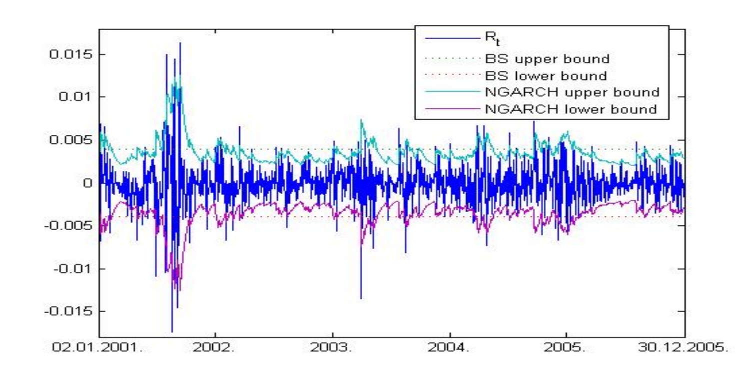
The NGARCH model gives a more accurate estimation of risk since it incorporates the *heteroscedasticity*.



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We use the GARCH option pricing model of Duan (1995).

Days to maturity are counted in calendar days (365) not in business days per year (256)

T . . . maturity
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Definition

The equilibrium price measure satisfies the local risk neutral valuation relationship (LRNVR) if every asset value X_t measured in domestic currency satisfies

1. X_{t+1}/X_t is conditionally log-normal distributed w.r.t the equilibrium measure *
2. $$E_t^*\left[X_{t+1}/X_t\right] = e^{r_d}, \quad (5)$$
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where $Z_{t+1}^* = Z_{t+1} + \lambda \sim N(0,1)$, i.e. Z_t^* are i.i.d. with respect to the measure *, satisfies properties 1, 2 and 3.

Relation (7) enables pricing foreign currency options!

We have even more: from relation (8) it follows that the risk premium λ has global influence on the conditional variance even the risk was locally neutralized with respect to *.

The option price given by the GARCH model will be a function of the risk premium.

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The *fair* price of the European call option, in the risk neutral world, in time t with strike K and maturity date $\tau + t$, $\tau > 0$ is given by

$$co_t = \exp(-r_d \tau) E_t^* \left[\max(P_{t+\tau} - K, 0) \right]. \tag{9}$$

$P_{t+\tau}$ is not known explicitly in analytical form!

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We use Monte Carlo simulations

$$c^{GH} \approx \exp(-r_d\tau)\frac{1}{MC}\sum_{i=1}^{MC}\max\left\{P_{i,t+\tau}-K,0\right\}, \tag{10}$$

where $MC = 50000$, and for the $i - th$ simulation we have

$$P_{i,t+\tau} = P_t \exp\left(\sum_{j=1}^{\tau} R_{i,t+j}\right), \qquad i = 1, 2, \ldots, MC. \tag{11}$$

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Illustration: a simulation study

Option prices are calculated for:

- different days to maturity: $\tau = 30, 60$ and 90 days
- different moneyness $m = 0.97, 0.985, 1, 1.015$ and 1.03 which corresponds respectively to strikes $K = 7.11495, 7.224975, 7.335, 7.445$ and 7.555 for **currency spot price** $P_t = 7.335$.
- the obtained prices are then compared to their Black-Scholes counterparts with the average annual volatility 0.036128
- in order to analyze the effect of the asymmetry parameter ρ, we repeat the simulation procedure for $\rho = -0.461$ and $\rho = 0$

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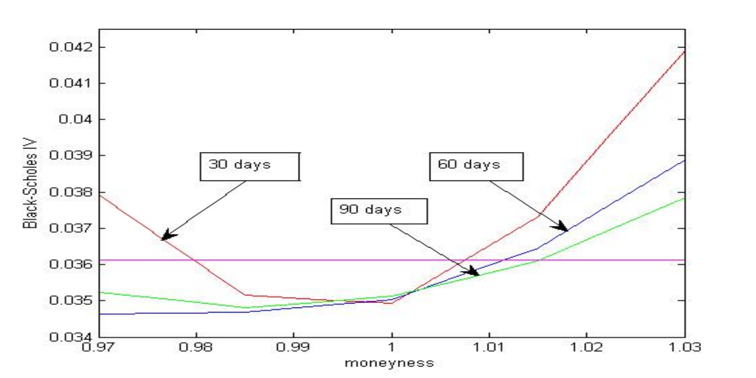
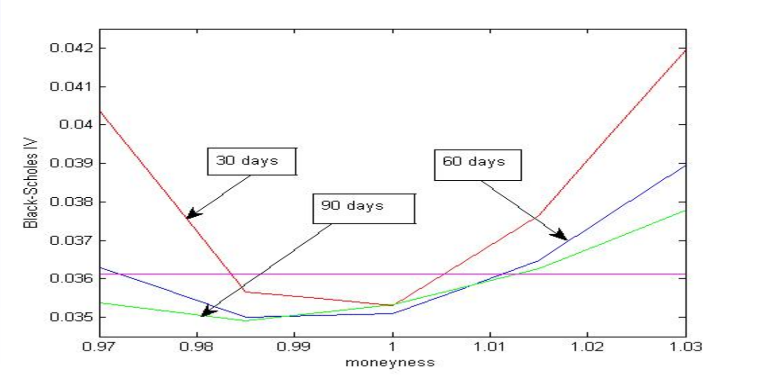
The comparison: $\rho = -0.17074$

Mild negative asymmetry $\Longrightarrow$ options out of the money ($K/P > 1$) are underpriced in the Black-Scholes model with constant volatility



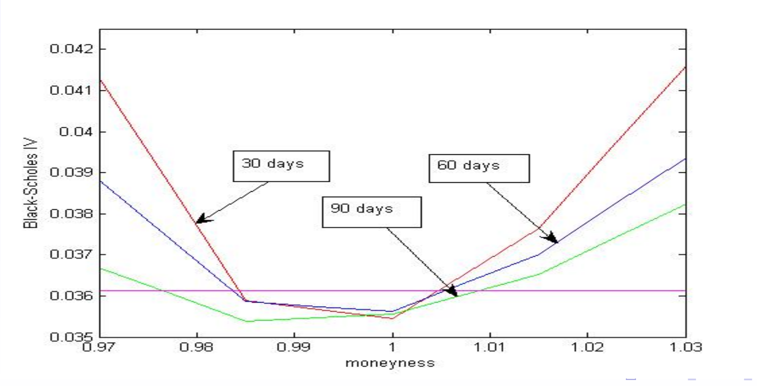
The comparison: $\rho = -0.461$

- Moderate asymmetry $\Longrightarrow$ options out of the money ($K/P > 1$) are underpriced in the Black-Scholes model with constant volatility and also some options ($\tau = 30$) in the money
- the underpricing effect in the constant volatility model is now more pronounced for options in the money



The comparison: $\rho = 0$

- the asymmetry is completely absent $\Longrightarrow$the graph of implied volatility becomes almost symmetric (centered in $K/P = 1$)
- options deeply in the money and deeply out of the money are underpriced in the constant volatility model



For all the graphs:

- for options out of the money, independently of ρ, the IV is a **decreasing** function of the maturity
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- introducing heteroscedasticity results in better fitting of the empirical distribution of foreign currency
- the locally risk-neutral measure for the domestic economy is identified
- the GARCH model for option pricing in its formulation incorporates the risk premium
- Still, it is not a priori obvious what should be the risk premium for the volatility–using the time series data from the underlying we find it not significant
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