

Table 3aParameter Estimates and Goodness-of-fit for the benchmark approach

Benchmark approach	Sample estimates	Without moving average				With moving average			
		Unconstrained par		Constrained par		Unconstrained par		Constrained par	
Panel 1. Constant forecast of the autonomous factors									
Param/stddev; α_c^μ	1.02	37755.00	1E-08	1.00	2E-04	2130.00	7E-05	1.02	9E-04
Param/stddev; α_c^μ	0.79	-0.90	2E-08	0.79	2E-04	-1.88	9E-04	0.79	1E-04
Param/stddev; α^π	0.37	89.07	9E-09	741.41	2E-04	2256.60	7E-06	3532.40	2E-07
Param/stddev; α_q^μ	1.61	-2.17	2E-08	1.55	7E-06	-0.59	0	1.61	9E-04
Param/stddev; c	1.74	0		2.82	2E-04				
Param/stddev; ma						0.91	4E-05	0.92	5E-05
Slope / Intercept; all observations		1.03		1.01		1.03		1.04	
Slope / Intercept; last day only		1.20	-9.08*	1.06		0.94		0.96	
Slope / Intercept; other than last days		0.91		1.00		1.16		1.12	
Slope / Intercept; only underbidding		0.57	56.6**	0.65	55.6***	0.13	67.5***	0.1	69.2***
Slope / Intercept; non-underbidding		0.55	-4.74*	0.50	-4.74**	1.07		1.18	
Adj RSQ all obs		0.36		0.32		0.60		0.57	
Adj RSQ only last day/ other days		0.51	0.27	0.41	0.26	0.59	0.63	0.52	0.62
Adj RSQ only underbidding/ other days		0.33	0.16	0.24	0.13	0	0.41	0	0.38
P-values for Wald test all obs.		0.97		0.99		0.90		0.88	
P-values only last day/ other days		0.14	0.35	0.33	0.42	0.40	0.15	0.68	0.27
P-values only underbidding/ other days		0.00	0.00	0.00	0.00	0.00	0.28	0.00	0.22
Panel 2. ECB forecast of the autonomous factors									
Param/stddev; α_c^μ	1.10	51.60	3E-06	1.10	5E-05	202.32	8E-05	2.77	5E-08
Param/stddev; α_c^μ	0.75	0.00	5E-06	0.75	2E-06	0.45	3E-04	2.34	1E-05
Param/stddev; α^π	0.37	79.58	5E-06	111.28	5E-05	5.71	4E-04	74.66	7E-09
Param/stddev; c	5.74	9E-06		5.86	1E-08				
Param/stddev; ma						0.79	2E-06	0.56	1E-05
Slope / Intercept; all observations		1.02		1.02		1.04		0.65	4.75**
Slope / Intercept; last day only		1.02		0.97		0.96		0.67	
Slope / Intercept; other than last days		1.02		1.08		1.13		0.63	7.03**
Slope / Intercept; only underbidding		0.48	51.6***	0.46	52.7***	0.34	53.6***	0.41	48.9***
Slope / Intercept; non-underbidding		0.72	-3.48*	0.72	-3.5*	1.22		0.35	
Adj RSQ all obs		0.57		0.57		0.70		0.48	
Adj RSQ only last day/ other days		0.61	0.52	0.61	0.52	0.67	0.73	0.44	0.52
Adj RSQ only underbidding/ other		0.49	0.30	0.46	0.32	0.30	0.51	0.53	0.16
P-values for Wald test all obs.		0.96		0.97		0.40		0.00	
P-values only last day/ other days		0.91	0.92	0.92	0.75	0.92	0.04	0.03	0.00
P-values only underbidding/ other days		0.00	0.01	0.00	0.01	0.00	0.14	0.00	0.00
Panel 3. Time-series forecast of the autonomous factors									
Param/stddev; α_c^μ	1.02	1.70E+05	0	0.99	2E-06	4020.40	4E-05	1.02	5E-04
Param/stddev; α_c^μ	0.80	-0.81	0	0.79	9E-06	-1.58	3E-06	0.80	9E-04
Param/stddev; α^π	0.37	294.66	0.115	1123.20	3E-05	1907.30	8E-06	5095.90	0.003
Param/stddev; α_q^μ	2.26	-3.13	0	2.10	9E-06	-0.34	9E-06	2.25	0
Param/stddev; c	9.60	0		8.93	1E-06				
Param/stddev; ma						0.95	4E-06	0.96	9E-04
Slope / Intercept; all observations		1.00		1.02		1.02		1.02	
Slope / Intercept; last day only		0.99		0.98		0.93		0.94	
Slope / Intercept; other than last days		1.06		1.15		1.13		1.15	
Slope / Intercept; only underbidding		0.55	61.6***	0.60	62.3***	0.13	67.7***	0.11	68.7***
Slope / Intercept; non-underbidding		0.58	-5.34**	0.56	-5.52**	1.05		1.10	
Adj RSQ all obs		0.29		0.24		0.59		0.58	
Adj RSQ only last day/ other days		0.36	0.23	0.29	0.21	0.58	0.63	0.56	0.62
Adj RSQ only underbidding/ other		0.11	0.18	0.09	0.14	0	0.41	0	0.40
P-values for Wald test all obs.		0.99		0.99		0.87		0.87	
P-values only last day/ other days		0.45	0.50	0.41	0.43	0.46	0.04	0.50	0.08
P-values only underbidding/ other days		0.00	0.00	0.00	0.00	0.00	0.64	0.00	0.51

Slope and intercept refer to the parameters obtained in the linear regression of the realized EONIA spread on the calibrated spread. The intercept is presented in basis points and is only shown if it was found to be significant. One star (*) corresponds to the 10% level of significance, two stars (**) to 5% and three stars (***) to 1%. The P-values express the significance level at which the joint hypothesis that slope=1 and intercept=0 can not be rejected by a Wald test.

Notation

α_c^μ	Forecast error, Overall level of variance
α_c^μ	Forecast error, Correlation of persistent part of the error
α^π	“residual” variance term

α_q^μ	Decreasing quality after announcement day
c	Natural spread
ma	Moving average coefficient

Table 3bParameter Estimates and Goodness-of-fit for the signal extraction approach

Signal extraction approach	Sample estimates	Without moving average				With moving average			
		Unconstrained par		Constrained par		Unconstrained par		Constrained par	
Panel 1. Signal extraction model. Constant forecast of the autonomous factors									
Param/stddev; γ	19.1	45529.00	5E-06	19.19	6E-06	769.57	0.99	19.14	2E-04
Param/stddev; $\alpha_{\epsilon}^{\epsilon}$	0.45	75.67	8E-07	0.20	2E-04	145.01	1.35	0.39	2E-04
Param/stddev; α_{ϵ}^{ξ}	0.79	-0.30	2E-05	0.59	1E-05	-0.40	0.13	0.63	2E-04
Param/stddev; α_{ρ}^{ϵ}	10.83	64.68	1E-08	10.82	5E-06	0.00	382.27	10.86	9E-04
Param/stddev; α_{ϵ}^{η}	1.10	0.00	2E-05	1.19	2E-04	39.22	9.80	1.10	2E-04
Param/stddev; α_{ϵ}^{η}	0.75	-413.29	2E-06	0.74	4E-05	-1.12	0.14	0.72	3E-04
Param/stddev; α^{π}	0.37	34.30	4E-06	435.22	4E-05	167.32	1.92	1053.50	1E-04
Param/stddev; c		13.92	2E-07	15.35	0				
Param/stddev; ma						1.13	0.15	1.08	0.001
Slope / Intercept; all observations		1.00		0.97		1.01		0.99	4.40**
Slope / Intercept; last day only		1.45		0.95		0.96		0.91	
Slope / Intercept; other than last days		0.92		1.19		1.08		1.08	3.82*
Slope / Intercept; only underbidding		0.30	65.3***	0.46	62.7***	0.32	55.4***	0.20	62.7***
Slope / Intercept; non-underbidding		0.56	-4.71**	0.43	-4.74***	0.98		1.05	3.27*
RSQ all obs		0.32		0.25		0.68		0.63	
RSQ only last day/ other than last days		0.29	0.36	0.19	0.32	0.61	0.73	0.56	0.69
RSQ only underbidding/ other days		0.11	0.12	0.14	0.07	0.16	0.42	0.05	0.39
P-values for Wald test all obs.		0.99		0.98		0.44		0.06	
P-values only last day/ other days		0.32	0.64	0.60	0.35	0.67	0.35	0.39	0.06
P-values only underbidding/ other days		0.00	0.00	0.00	0.00	0.00	0.89	0.00	0.23
Panel 2. Signal extraction model. Time-series forecast of the autonomous factors									
Param/stddev; γ	19.10	45529.00	9E-06	19.12	6E-09	345.08	487.17	19.08	3E-05
Param/stddev; $\alpha_{\epsilon}^{\epsilon}$	0.45	7.611	0	0.45	9E-09	16.22	86.77	0.46	1E-05
Param/stddev; α_{ϵ}^{ξ}	0.80	0.45	1E-07	0.54	9E-09	0.01	0.09	0.70	2E-05
Param/stddev; α_{ρ}^{ϵ}	34.82	35.20	2E-06	34.24	7E-09	52.13	376.7	34.85	1E-08
Param/stddev; α_{ϵ}^{η}	1.10	0.0002	2E-06	1.45	9E-09	14.59	154.98	1.08	7E-06
Param/stddev; α_{ϵ}^{η}	0.75	0.09	1E-04	1.14	9E-09	0.07	0.10	0.70	2E-05
Param/stddev; α^{π}	0.37	385.28	8E-06	342.26	1E-08	538.66	58.55	710.39	8E-06
Param/stddev; c		4.40	1E-06	4.70	4E-09				
Param/stddev; ma						0.95	0.02	0.93	4E-06
Slope / Intercept; all observations		0.98		0.94		1.02		1.02	
Slope / Intercept; last day only		1.13		1.09		0.97		0.96	
Slope / Intercept; other than last days		0.84		0.79		1.06		1.08	
Slope / Intercept; only underbidding		0.48	60.5***	0.46	61.3***	0.21	62.6***	0.20	63.2***
Slope / Intercept; non-underbidding		0.53	-4.7**	0.54	-4.88**	1.02		1.02	
RSQ all obs		0.33		0.32		0.63		0.59	
RSQ only last day/ other than last days		0.39	0.26	0.40	0.24	0.58	0.66	0.59	0.64
RSQ only underbidding/ other days		0.20	0.15	0.20	0.18	0.04	0.40	0.04	0.40
P-values for Wald test all obs.		0.98		0.87		0.78		0.77	
P-values only last day/ other days		0.84	0.63	0.91	0.44	0.95	0.59	0.96	0.50
P-values only underbidding/ other days		0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.88

Slope and intercept refer to the parameters obtained in the linear regression of the realized EONIA spread on the modeled spread. The intercept is presented in basis points and is only shown if it was found to be significant. One star (*) corresponds to the 10% level of significance, two stars (**) to 5% and three stars (***) to 1%. The P-values express the significance level at which the joint hypothesis that slope=1 and intercept=0 can not be rejected by a Wald test.

Notation

γ	Liquidity target, variance
$\alpha_{\epsilon}^{\epsilon}$	Difference between the market forecast on the announcement days and the ECB forecast on the allotment days (ϵ), Overall level of variance
α_{ϵ}^{ξ}	Difference between the market forecast on the announcement days and the ECB forecast on the allotment days (ϵ), correlation of persistent part of the error
α_{ρ}^{ϵ}	Difference between the market forecast on the announcement days and the ECB forecast on the allotment days (ϵ), variance of errors offset before the end of MP

α_{ϵ}^{η}	ECB forecast errors, overall level of variance
α_{ϵ}^{η}	ECB forecast errors, correlation of persistent part of the error
α^{π}	“residual” variance term
C	Natural spread
Ma	Moving average coefficient

Table 4**Residuals diagnostics**

(Residuals are presented in basis points)	Mean	Median	Std. Dev.	arque- Bera	Prob	MSE/ 100	Autocorrelation indicator
Panel A. Residuals of benchmark approaches							
Panel A.1. Constant forecast of the autonomous factors							
Without moving average, unconstrained parameters	-0.02	-0.50	26.89	0.70	0.70	7.17	0.34
Without moving average, constrained parameters	0.05	-1.00	27.88	0.56	0.76	7.71	0.35
With moving average, unconstrained parameters	-0.21	-1.00	21.49	28.23	0.00	4.58	-0.03
With moving average, constrained parameters	0.15	1.00	22.14	30.48	0.00	4.86	0.00
Panel A.2. ECB forecast of the autonomous factors							
Without moving average, unconstrained parameters	-0.02	1.00	22.08	5.43	0.07	4.83	0.42
Without moving average, constrained parameters	0.02	0.00	22.16	5.84	0.05	4.87	0.42
With moving average, unconstrained parameters	1.99	2.00	18.47	5.51	0.06	3.42	0.11
With moving average, constrained parameters	4.42	3.50	27.49	25.20	0.00	7.69	-0.06
Panel A.3. Time-series forecast of autonomous factors							
Without moving average, unconstrained parameters	-0.01	-3.00	28.45	5.58	0.06	8.03	0.43
Without moving average, constrained parameters	0.01	-1.00	29.44	6.74	0.03	8.60	0.41
With moving average, unconstrained parameters	0.92	1.00	21.56	27.80	0.00	4.62	-0.02
With moving average, constrained parameters	0.86	0.50	21.85	29.55	0.00	4.74	0.00
Panel B. Residuals of signal-extraction approaches							
Panel B.1. Constant forecast of autonomous factors							
Without moving average, unconstrained parameters	0.02	-2.00	27.81	14.02	0.00	7.67	0.48
Without moving average, constrained parameters	-0.01	-5.00	29.27	11.04	0.00	8.50	0.48
With moving average, unconstrained parameters	2.20	2.00	19.23	9.93	0.01	3.72	0.06
With moving average, constrained parameters	4.39	4.00	20.59	18.42	0.00	4.40	0.09
Panel B.2. Time-series forecast of autonomous factors							
Without moving average, unconstrained parameters	-0.02	-1.50	27.65	2.10	0.35	7.58	0.50
Without moving average, constrained parameters	0.02	-0.50	27.80	4.34	0.11	7.66	0.50
With moving average, unconstrained parameters	1.23	1.00	20.62	15.29	0.00	4.23	0.11
With moving average, constrained parameters	1.22	1.00	20.79	16.74	0.00	4.30	0.11

Table 5

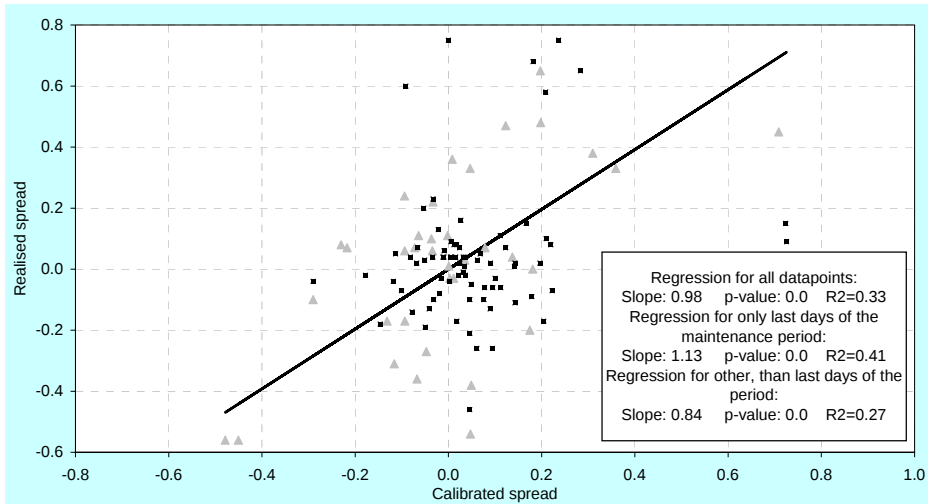
Analysis of the extent to which the models are complementing each other

Calibrated spreads that are regressed jointly on the observed spread. ¹	Coefficient in joint regression	p-value	Adj R ² of joint regression	Memo item: adj R ² of separate regression
A1: Benchmark approach with ECB forecast versus signal extraction approach with time-series forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, ECB forecast	0.90	0.00	0.62	0.57
Signal extraction approach, time-series forecast	0.22	0.08		0.33
<i>Constrained parameters</i>				
Benchmark approach, ECB forecast	0.91	0.00	0.61	0.57
Signal extraction approach, time-series forecast	0.19	0.11		0.32
A2: Benchmark approach with ECB forecast versus signal extraction approach with constant forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, ECB forecast	0.90	0.00	0.62	0.57
Signal extraction approach, constant forecast	0.23	0.06		0.32
<i>Constrained parameters</i>				
Benchmark approach, ECB forecast	1.01	0.00	0.60	0.57
Signal extraction approach, constant forecast	0.00	0.99		0.25
Panel A3: Benchmark approach with ECB forecast versus benchmark approach with time-series forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, ECB forecast	0.85	0.00	0.67	0.57
Benchmark approach, time-series forecast	0.49	0.00		0.29
<i>Constrained parameters</i>				
Benchmark approach, ECB forecast	0.88	0.00	0.66	0.57
Benchmark approach, time-series forecast	0.49	0.00		0.24
Panel A4: Benchmark approach with ECB forecast versus benchmark approach with constant forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, ECB forecast	0.83	0.00	0.65	0.57
Benchmark approach, constant forecast	0.40	0.00		0.36
<i>Constrained parameters</i>				
Benchmark approach, ECB forecast	0.85	0.00	0.64	0.57
Benchmark approach, constant forecast	0.40	0.00		0.32
Panel B.1 Benchmark approach versus signal extraction approach, both with time series forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, time series forecast	0.64	0.00	0.41	0.29
Signal extraction approach, time-series forecast	0.62	0.00		0.33
<i>Constrained parameters</i>				
Benchmark approach, time series forecast	0.65	0.00	0.39	0.24
Signal extraction approach, time-series forecast	0.65	0.00		0.32
Panel B.2 Benchmark approach with time-series forecast versus signal extraction approach with constant forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, time series forecast	0.70	0.00	0.46	0.29
Signal extraction approach, constant forecast	0.69	0.00		0.32
<i>Constrained parameters</i>				
Benchmark approach, time series forecast	0.82	0.00	0.40	0.24
Signal extraction approach, constant forecast	0.70	0.00		0.25
Panel B.3 Benchmark approach with time-series forecast versus benchmark approach with constant forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, time series forecast	0.51	0.00	0.41	0.29
Benchmark approach, constant forecast	0.69	0.00		0.36
<i>Constrained parameters</i>				
Benchmark approach, time series forecast	0.38	0.10	0.35	0.24
Benchmark approach, constant forecast	0.76	0.00		0.32
Panel C.1 Benchmark approach with constant forecast versus signal extraction approach with time series forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, constant forecast	0.70	0.00	0.44	0.36
Signal extraction approach, time-series forecast	0.55	0.00		0.33
<i>Constrained parameters</i>				
Benchmark approach, constant forecast	0.71	0.00	0.44	0.32
Signal extraction approach, time-series forecast	0.61	0.00		0.32
Panel C.2 Benchmark approach with constant forecast versus signal extraction approach with constant forecast				
<i>Unconstrained parameters</i>				
Benchmark approach, constant forecast	0.73	0.00	0.48	0.36
Signal extraction approach, constant forecast	0.64	0.00		0.32
<i>Constrained parameters</i>				
Benchmark approach, constant forecast	0.80	0.00	0.42	0.32
Signal extraction approach, constant forecast	0.61	0.00		0.25

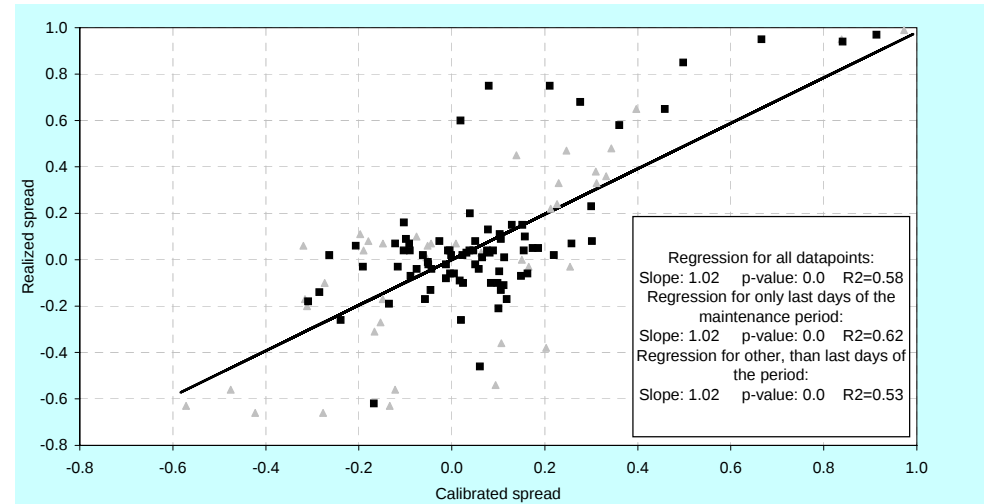
We estimate the following regression: $S^{\text{observed}} = \alpha + \beta_1 S^{\text{calibrated}}_{\text{model1}} + \beta_2 S^{\text{calibrated}}_{\text{model2}} + \varepsilon$, where α, β_1 and β_2 are parameters and ε is an error term. The parameters β_1 and β_2 are reported in the table together with the adjusted R². In order to allow for a comparison, the adjusted R² (from table 3) of the separate regressions are also shown.

Chart 1: realized and calibrated EONIA spreads for different models (observations for the last day of the maintenance period are shown with a gray triangle, others with a black cube).

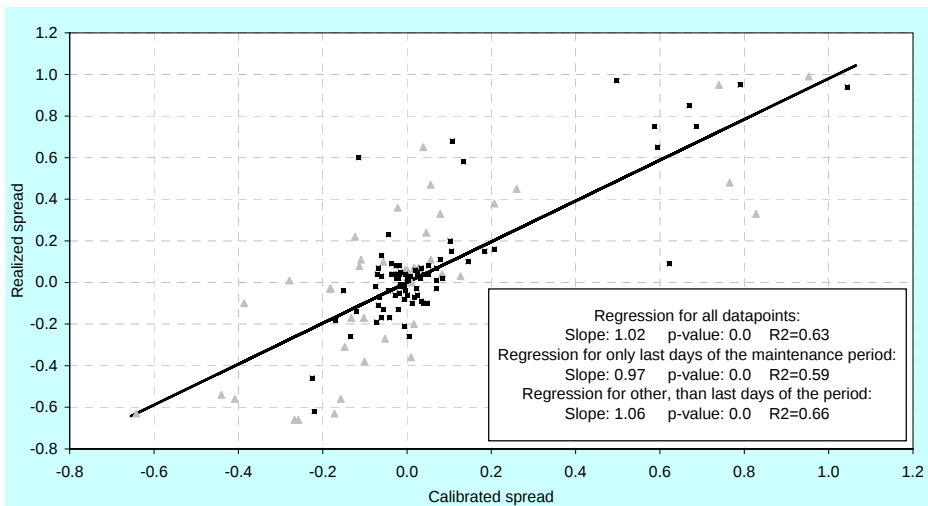
1a: Signal extraction approach. Time-series forecast of autonomous factors. Unconstrained parameters



1b: Benchmark approach. ECB forecast of autonomous factors. Unconstrained parameters.



1c: Signal extraction approach with moving average. Time series forecast. Unconstrained parameters.



1d: Benchmark approach with moving average. ECB forecast. Unconstrained parameters

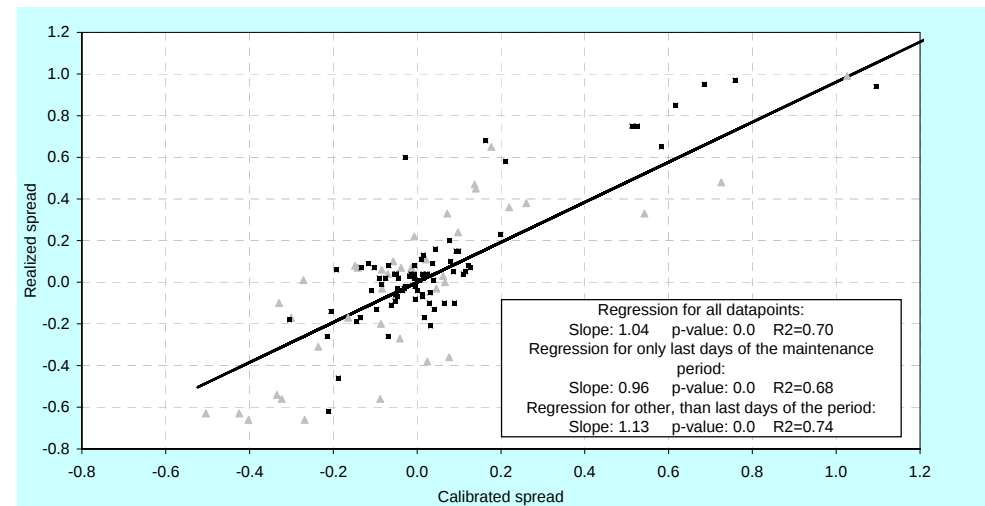
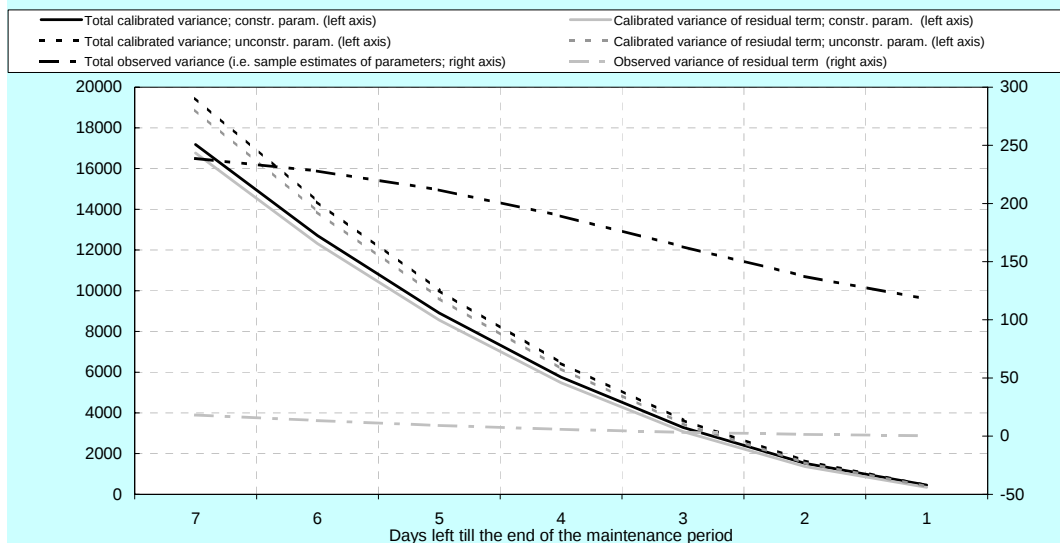
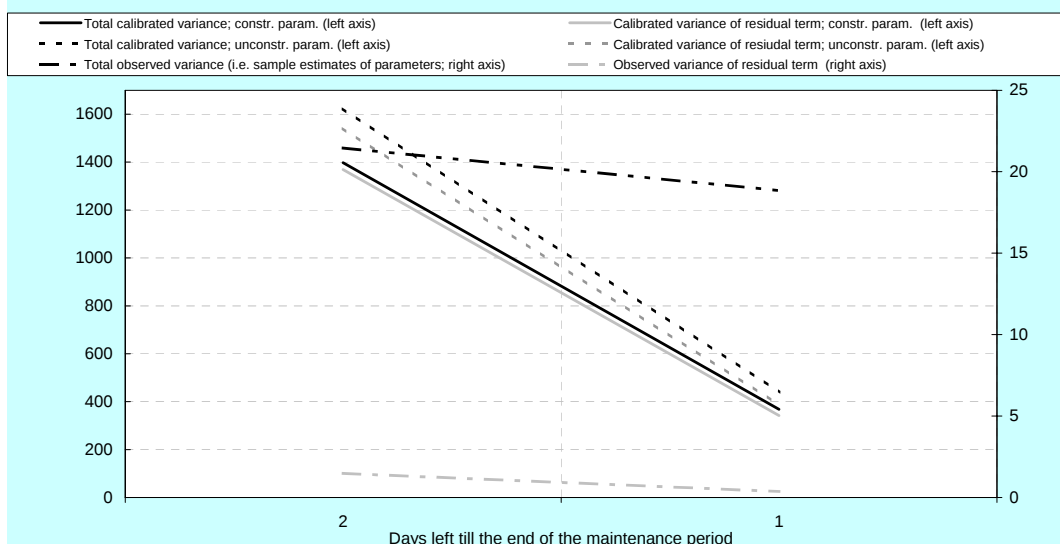


Chart 2: variance of the expected liquidity imbalance for different numbers of remaining days in the maintenance period.

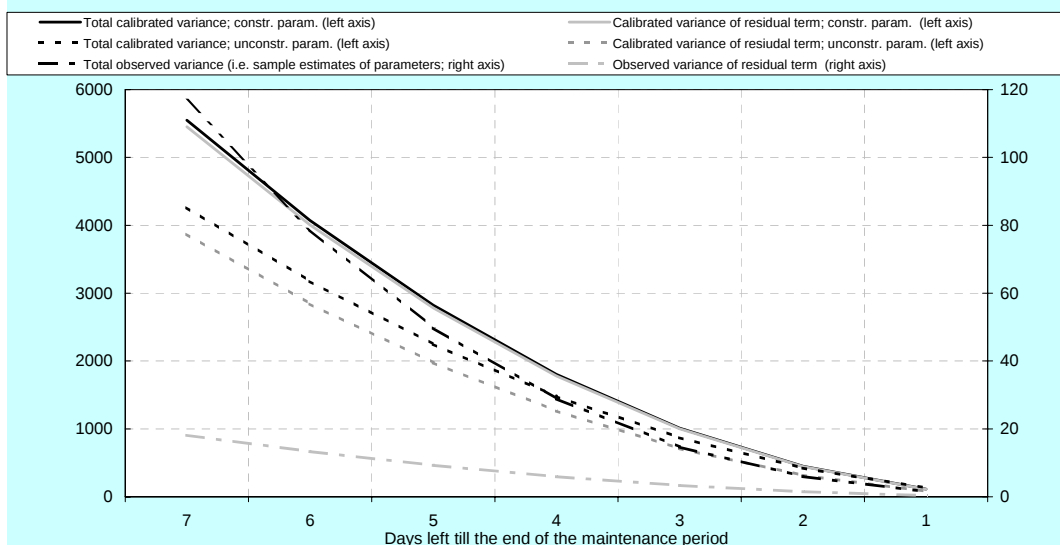
2a: signal extraction approach with time-series forecast of autonomous factors. 7 days from MRO settlement to the end of MP



2b: signal extraction approach with time-series forecast of autonomous factors. 2 days from MRO settlement to the end of the MP



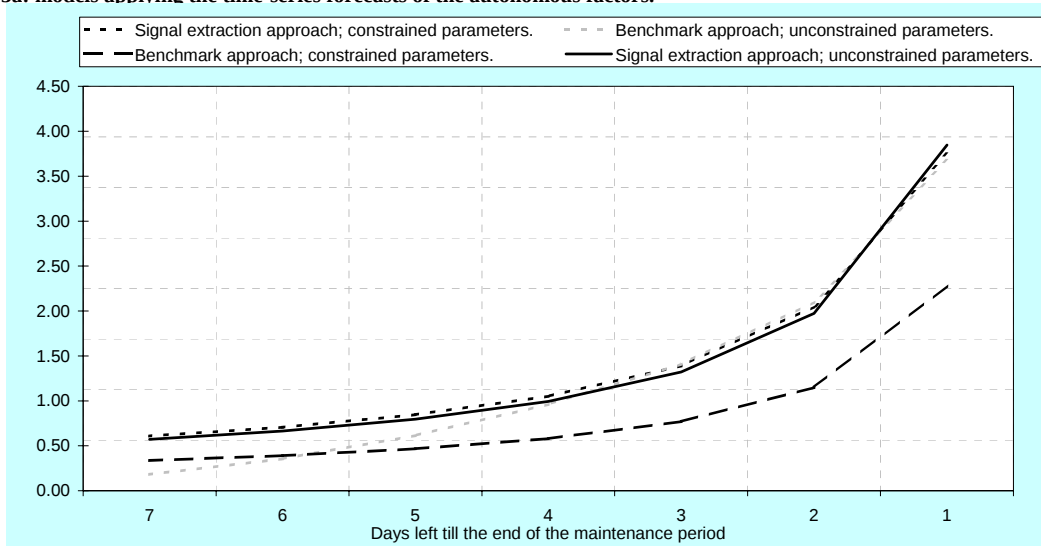
2c: benchmark approach with ECB forecast of the autonomous factors¹



1) Note that the pattern is in this case independent of the number of days between settlement and end of the maintenance period

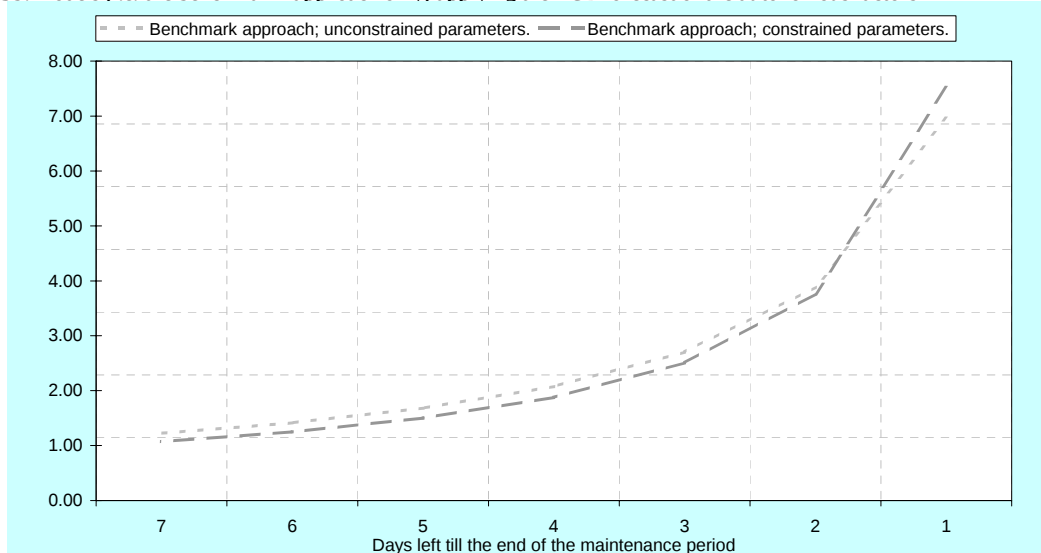
Chart 3: liquidity effect (i.e. sensitivity in basis points) for different numbers of remaining days in the maintenance period.

3a: models applying the time-series forecasts of the autonomous factors.¹

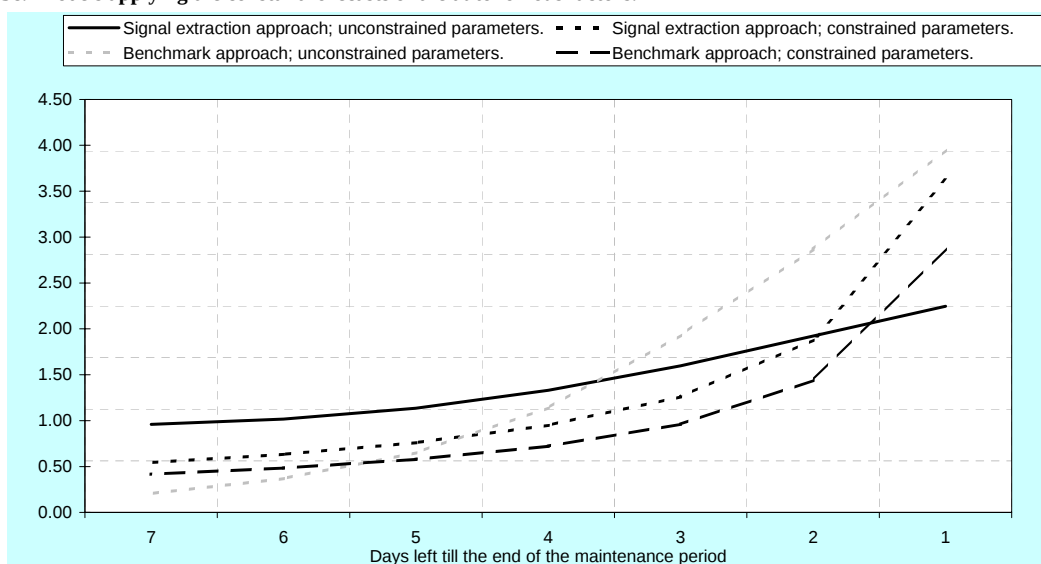


1) In the case of the signal extraction approach, we have assumed a 7 days period from the MRO settlement till the end of the maintenance period.

3b: models (i.e. the benchmark approach only) applying the ECB forecast of the autonomous factors



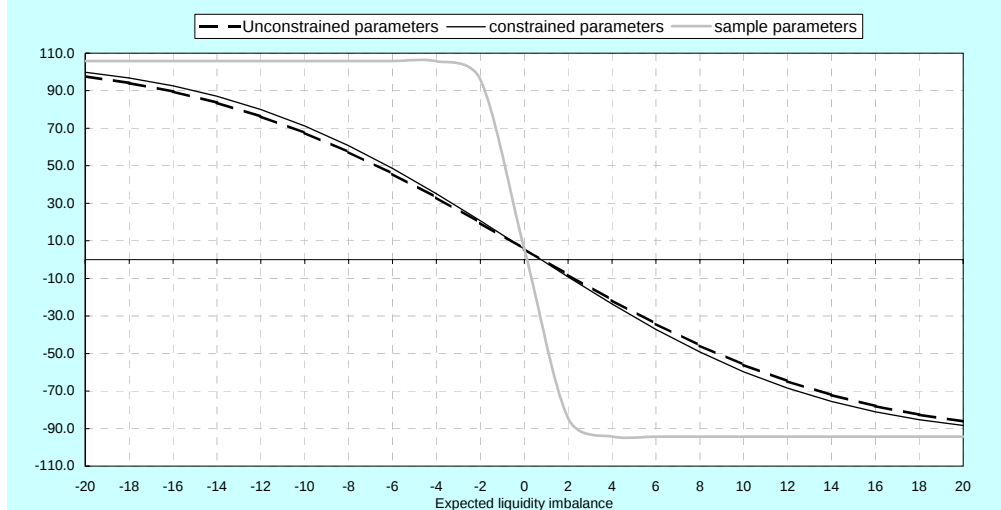
3c: models applying the constant forecasts of the autonomous factors.¹



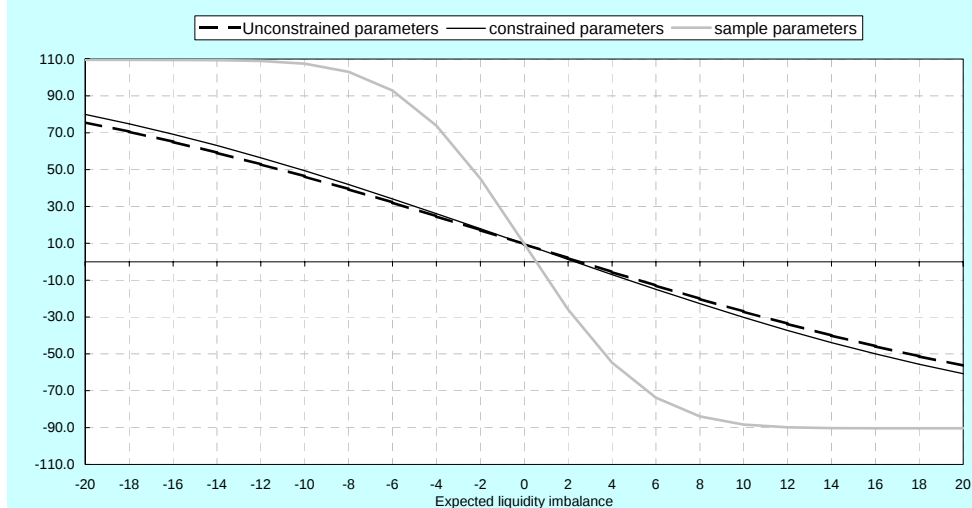
1) In the case of the signal extraction approach, we have assumed a 7 days period from the MRO settlement till the end of the maintenance period.

Chart 4: Examples of the identified relationship between the expected liquidity imbalance (EUR billions) and the overnight spread (basis points) on the last day of the maintenance period.¹

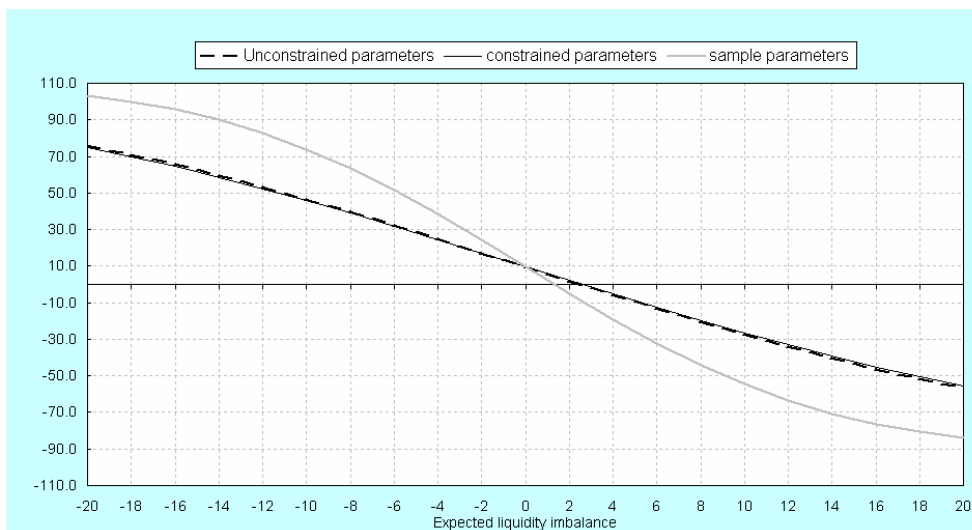
4a: benchmark approach I with ECB forecast



4b: signal extraction approach with time series forecast, assuming a 2 day period from the MRO settlement to the end of the MP



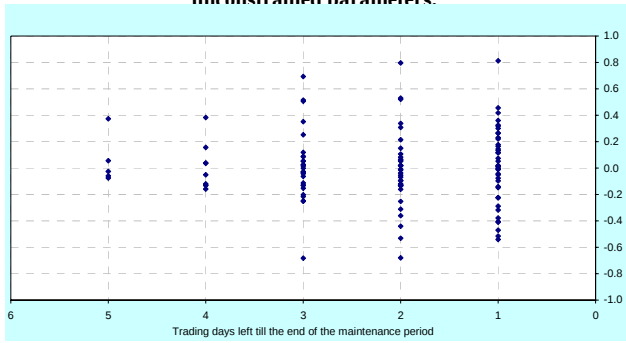
4c: signal extraction approach with time series forecast, assuming a 7 day period from the MRO settlement to the end of the MP



1) For the case of *sample* estimates of parameters, we assume the natural spread estimated via unconstrained parameters.

Chart 5: examples of residuals for different numbers of remaining trading days till the end of the maintenance period.

5a: benchmark approach; ECB forecast of the liquidity factors; unconstrained parameters.



5b: signal extraction approach; time-series forecast of the liquidity factors: constrained parameters.

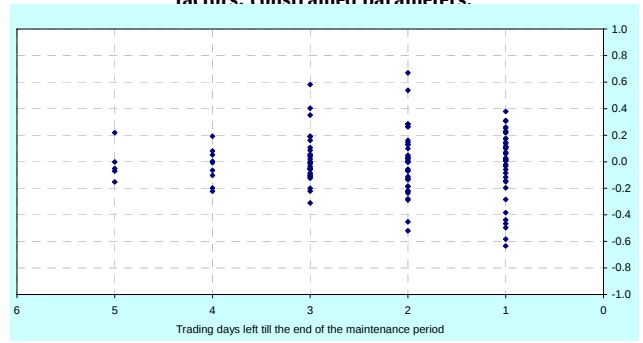
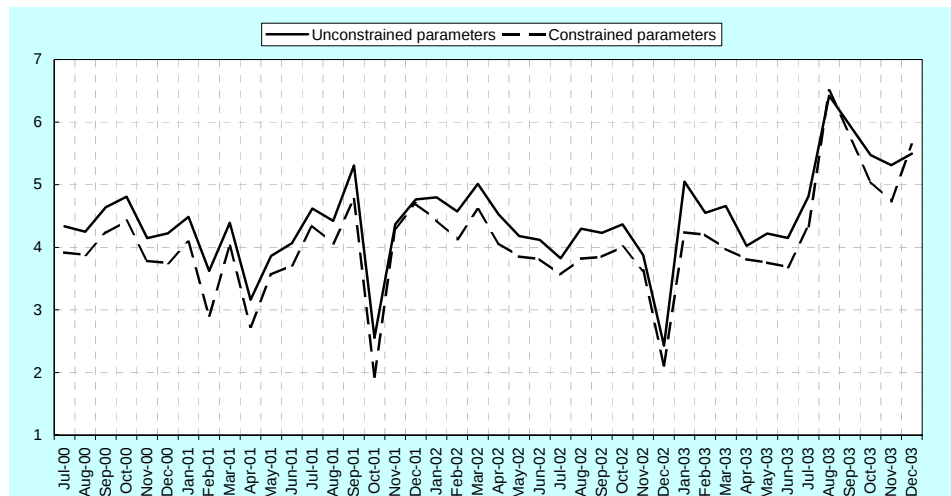
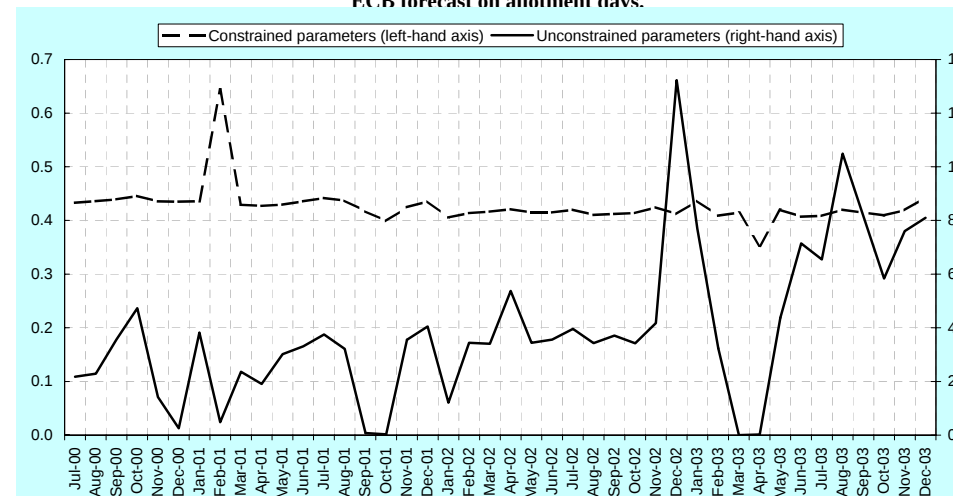


Chart 6: cross validation. Examples of changes of parameter estimates when sequentially leaving out the data points for one maintenance period at a time.

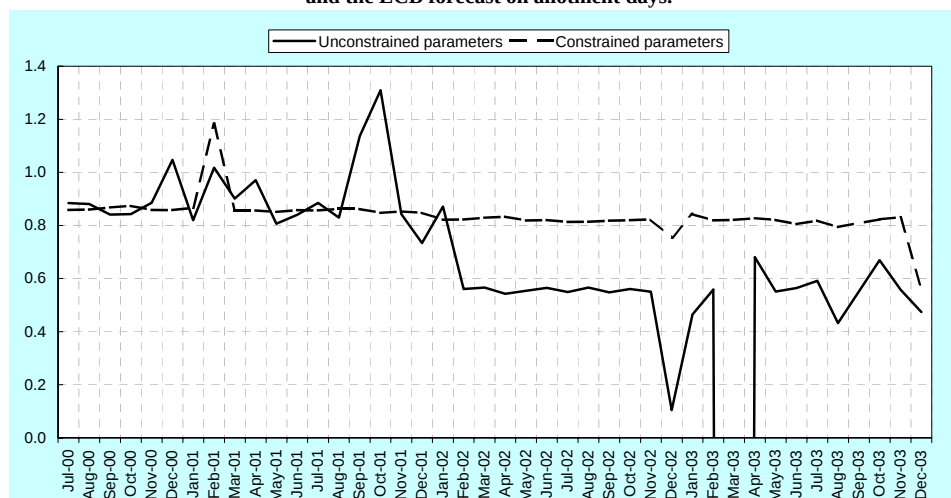
6a: signal extraction approach with time series forecast. Sequential estimates of natural spread (in basis points).



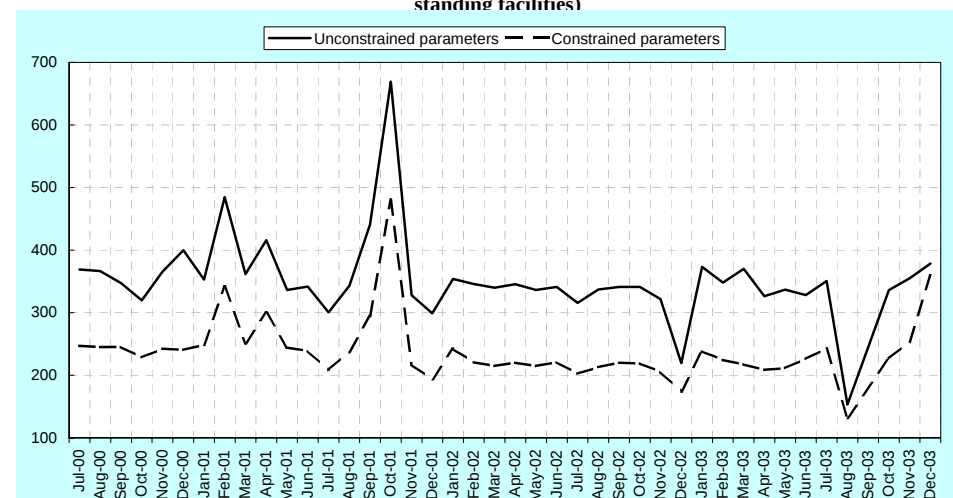
6b: Signal extraction approach with time-series forecast of autonomous factors. Sequential estimate of α_c^ε , the overall level of variance of the difference between the market forecast on announcement days and the ECB forecast on allotment days.



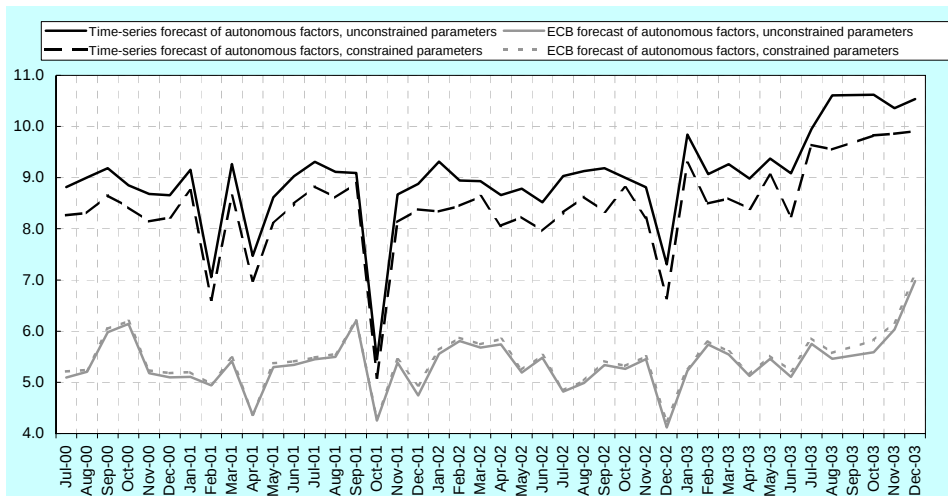
6c: signal extraction approach with time-series forecast of autonomous factors. Sequential estimate of α_c^ε , the correlation of the persistent part of the difference between the market forecast on announcement days and the ECB forecast on allotment days.



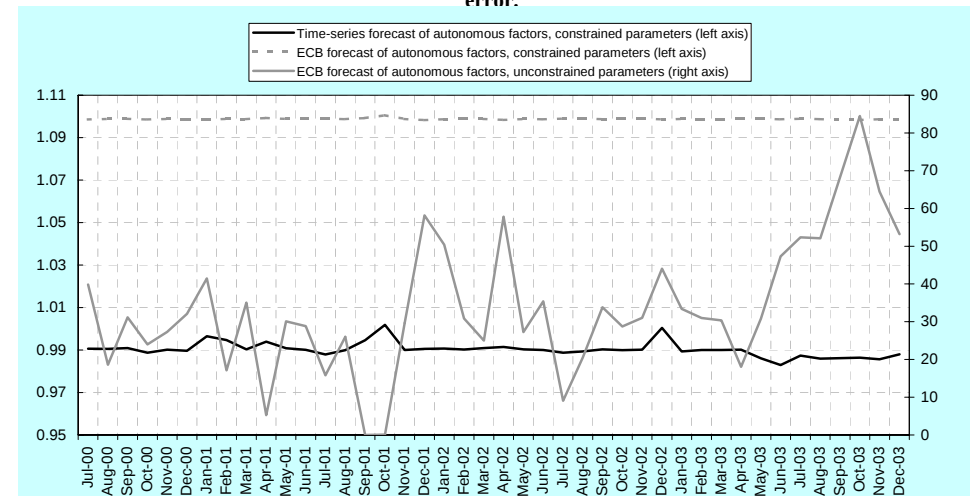
6d: signal extraction approach with time-series forecast of autonomous factors. Sequential estimates of α^π , the “residual” variance term (mainly covering uncertainty about excess reserves and individual recourse to standing facilities).



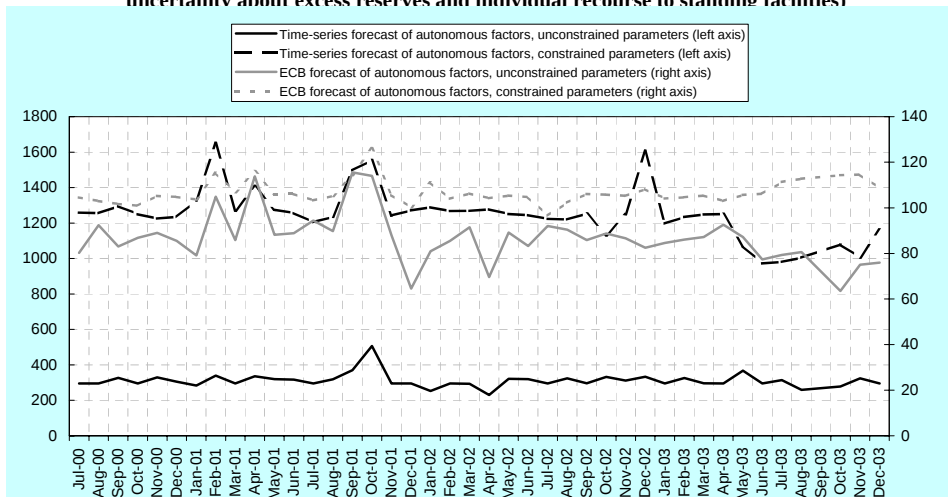
6e: benchmark approach. Sequential estimates of natural spread (in basis points).



6f: benchmark approach. Sequential estimates of α_c^H , the correlation of the persistent part of the forecast error.



6g: benchmark approach. Sequential estimates of α^π , the “residual” variance term (mainly covering uncertainty about excess reserves and individual recourse to standing facilities)



6f: benchmark approach. Sequential estimates of α_q^H , the decreasing quality of the autonomous factors forecast after the MRO announcement day.

