Approved by the Academic council
of the Education program
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Protocol No. ___, __. __. 20

Time series analysis (Semester II)

Instructor's name Grigoriy Kantorovich, Professor, Cand.Sc.

Class Times and Locations

Email

Phone

Office Location

Office Hours

Section 1. General information about the course

This course provides tools for quantitative analysis of economic time series, for example, macroeconomic and financial series. The course is an introduction to univariate statistical methods of analysis and forecasting of economic and financial time-series. ARIMA(p,d,q,) model, stationarity concept, Box-Jenkins approach and different forecasting issues are discussed in this course. Models and concepts from this course can be used in stochastic processes, mathematical models in economics, optimal control problems, statistical forecasting, financial mathematics, decision making under uncertainty.

The stress in the course is made on the sense of facts and methods of time series analysis. Conclusions and proofs are given for some basic formulas and models; this enables the students to understand the principles of economic theory. The main stress is made on the economic interpretation and applications of considered economic models.

Section 2. Course goals, learning objectives, expected learning outcomes

The students should get acquainted with the main concepts of time series theory and methods of analysis. They should know how to use them in examining economic and financial processes and should understand methods, ideas, results and conclusions that can be met in the majority of books and articles on economics and finance. In this course, students should master traditional methods of time series analysis, intended mainly for working with time series data. Students should understand the differences between cross-sections and time series, and those specific economic problems, which occur while working with data of these types. During this course students will get knowledge about how to analyze economic time series, what potential problems and pitfalls can exist in such cases, and how to compare different statistical models using in-sample and out-of-sample statistical measures of accuracy.

Time series analysis is built on concept of a mathematical description of statistical processes, therefore, students for successful and easy accomplishment should have good knowledge in calculus, difference equations, linear algebra, optimization, mathematical statistics and probability theory, economics statistics and econometrics. Necessary prerequisites are statistics, econometrics, the knowledge of economic theory and computer-based information systems. The course is taught in English.

Section 3. Course Outline

№	Topic/Focus/Activity	Week	Course format: lectures, seminars, consultations, workshops, etc. (in hours)				Readings and assignments
1	Time series as a discrete stochastic process. Stationarity of stochastic processes.		Lectures (4 hours)	Seminars (4 hours)	Self-study (14 hours)		
2	Autoregression-moving average model ARMA(p,q). Autocorrelation and partial autocorrelation functions.		Lectures (4 hours)	Seminars (4 hours)	Self-study (15 hours)		
3	Estimation of coefficients in ARMA(p,q) processes. Information criteria.		Lectures (4 hours)	Seminars (4 hours)	Self-study (15 hours)		
4	Forecasting using Box-Jenkins approach.		Lectures (4 hours)	Seminars (4 hours)	Self-study (15 hours)		
5	Nonstationary time series. Box-Jenkins approach for determination of a degree of integration of time series.		Lectures (4 hours)	Seminars (4 hours)	Self-study (15 hours)		

Section 4. Texts, readings and other informational resources

1. Required readings:
   1. Enders, W., 2003, Applied Econometric Time Series, Wiley Publ., 2nd ed.
   2. Канторович Г.Г. Лекции по курсу «Анализ временных рядов». Экономический журнал ВШЭ, 2002, 2003
2. Additional readings:
   1. Mills, T.C. and R.N. Markellos, 2008, The Econometric Modelling of Financial Time Series, Cambridge University Press, 3rd ed.
   2. Mills, T.C., 2008, 1999, The Econometric Modelling of Financial Time Series, Cambridge University Press, 2nd ed.
   3. Hamilton J.D., 1994, Time Series Analysis, Princeton University Press.
3. Websites and other informational resources (databases, software, etc.)____________________

Section 5. Examination/Evaluation

One home assignment should be handed in. Final test will be held in the form of a written exam. Home assignment weights 20% and exam weights 80%. Final exam is graded according to 10-grade scale. Course grade is a weighted average of home assignment grade and final exam grade.

Make-ups are provided in the form of the final exam and according to general NRU HSE rules. No late submissions of the home assignment are allowed.

Example problems for assignment and exam:

Problem 1.

A) Give definitions of weak and strong stationary processes.

B) Is the process $y_t = 1 + y_{t-1} - 0,5y_{t-2} + \varepsilon_t, \quad \varepsilon_t \sim WN\left(0, \sigma^2\right)$ stationary in a broad sense? Why?

C) Is the process $y_t = \varepsilon_t + 2\varepsilon_{t-1} + \varepsilon_{t-2}, \quad \varepsilon_t \sim WN\left(0, \sigma^2\right)$ stationary of the second order? Why?

Problem 2.

A) Derive an autocorrelation function and calculate first five autocorrelation and partial autocorrelation values for the following process

$$y_t = 0,6y_{t-1} - 0,2y_{t-2} + \varepsilon_t, \quad \varepsilon_t \approx WN\left(0, \sigma^2\right), \quad E\left(\varepsilon_{t-i} y_{t-s}\right) = 0 \ \left(\forall s \geq 1, \forall i < s\right).$$

B) Describe main properties of autocorrelation and partial autocorrelation functions of AR(p) and MA(q) processes.

C) First two values of a sample autocorrelation function for a process with 226 observations are 0.5 and 0.7. Estimate first two values of partial autocorrelation function of the process.

Problem 3.

For processes

A) MA(1): $y_t = 1 + \varepsilon_t + 0,5\varepsilon_{t-1}, \quad \varepsilon_t \sim WN\left(0,\sigma^2\right), \quad y_T = 2,6,\ \varepsilon_t = 1,2$;

B) ARMA(1, 1): $y_t = 1 + 0,6 y_{t-1} + \varepsilon_t + 0,6\varepsilon_{t-1}, \quad \varepsilon_t \sim WN\left(0,\sigma^2\right), \quad y_T = 2,\ \varepsilon_t = 0,5$

make forecasts h steps (h=1, 2, 3, …) ahead. Calculate a variance of a forecasts error.

Problem 4.

In Table 1 values for sample autocorrelation and partial autocorrelation functions of a growth rate of the Russian Index of Consumer Prices since September 1992 to December 2000 are presented.

A) Using this data what you judge about a process ARIMA(p,d,q), which describes a growth rate of the Russian ICP. Explain the answer.

B) Explain in detail what can you say about the process using values of Q-statistics.

Table 2 contains values of Akaike and Schwartz information criteria for ARMA(p, q) models ($p \leq 2$, $q \leq 2$).

C) Using information criteria select the best model which describes the data. Explain your answer.

Table 1

	AC	PAC	Q-Stat	Prob
1	-0.299	-0.299	9.2340	0.002
2	-0.099	-0.208	10.261	0.006
3	0.120	0.025	11.776	0.008
4	-0.010	0.024	11.787	0.019
5	-0.082	-0.059	12.508	0.028
6	-0.044	-0.110	12.721	0.048
7	-0.011	-0.097	12.735	0.079
8	0.000	-0.048	12.735	0.121
9	0.014	0.003	12.757	0.174
10	0.023	0.031	12.816	0.234
11	-0.033	-0.029	12.941	0.297
12	0.008	-0.031	12.949	0.373
13	-0.044	-0.087	13.181	0.434
14	0.006	-0.042	13.185	0.512
15	0.023	0.008	13.251	0.583
16	0.010	0.035	13.264	0.653
17	-0.026	-0.014	13.349	0.713
18	-0.014	-0.055	13.372	0.769
19	-0.044	-0.111	13.613	0.806
20	0.006	-0.063	13.617	0.849
21	0.006	-0.015	13.621	0.885

22	0.017	0.032	13.658	0.913
23	0.017	0.033	13.697	0.935
24	0.041	0.038	13.927	0.948
25	0.012	0.013	13.945	0.963

Table 2

Criteria	p\q	0	1	2
AIC	**0**		-3,4040	-3,4164
	1	-3,2774	-3,4312	-3,3848
	2	-3,4083	-3,3884	-3,3939
BIC	**0**		-3,3519	-3,3904
	1	-3,3513	-3,3791	-3,3066
	2	-3,3562	-3,3103	-3,2897

Problem 5.

Tables 3 and 6 present results of estimation of ARMA(p,q) models for a growth rate of the Russian Index of Consumer prices for a period September 1992 – December 2000.

A) Using estimation results write down explicitly an equation for each model.

In Tables 4,5,7,8 and on Graphs 1,2 results of different tests for residuals in corresponding models are shown.

B) What hypotheses are tested in these tests?

C) What can you say about residuals in these models? Are the residuals white noise processes?

D) Using results from C), what can be judged about statistical adequacy of the models?

Table 3: Model 1

Dependent Variable: CPIGR				
Method: Least Squares				
Included observations: 100				
Convergence achieved after 7 iterations				
Backcast: 1992:08				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
AR(1)	0.425843	0.157574	2.702501	0.0081
MA(1)	-0.787388	0.106920	-7.364257	0.0000
R-squared	0.155539	Mean dependent var		0.000332
Adjusted R-squared	0.146922	S.D. dependent var		0.046654
S.E. of regression	0.043091	Akaike info criterion		-3.431218
Sum squared resid	0.181968	Schwarz criterion		-3.379115
Log likelihood	173.5609	Durbin-Watson stat		2.097771
Inverted AR Roots	.43			
Inverted MA Roots	.79			

Table 4: ACF, PACF and Q-statistics for residuals from model 1

	AC	PAC	Q-Stat	Prob

1	-0.050	-0.050	0.2564	
2	0.031	0.028	0.3545	
3	0.170	0.174	3.3970	0.065
4	0.031	0.049	3.4998	0.174
5	-0.061	-0.070	3.8974	0.273
6	-0.048	-0.092	4.1502	0.386
7	-0.029	-0.049	4.2454	0.515
8	-0.018	0.005	4.2826	0.638
9	-0.008	0.027	4.2890	0.746
10	-0.002	0.017	4.2893	0.830
11	-0.046	-0.052	4.5305	0.873
12	-0.007	-0.028	4.5361	0.920
13	-0.043	-0.052	4.7500	0.943
14	0.003	0.016	4.7513	0.966
15	0.019	0.040	4.7958	0.979
16	0.002	0.020	4.7962	0.988
17	-0.020	-0.032	4.8468	0.993
18	-0.020	-0.053	4.8985	0.996
19	-0.045	-0.066	5.1584	0.997
20	0.006	0.015	5.1636	0.999
21	0.020	0.055	5.2141	0.999
22	0.038	0.072	5.3993	0.999
23	0.041	0.039	5.6167	1.000
24	0.053	0.018	5.9980	1.000
25	0.021	-0.016	6.0607	1.000

Table 5: Breusch-Godfrey test for residuals from model 1

F-statistic	0.503982	Probability		0.916389
Obs*R-squared	7.104042	Probability		0.896710
Test Equation:				
Variable	**Coefficient**	***Std. Error***	**t-Statistic**	**Prob.**
AR(1)	0.356824	0.671489	0.531392	0.5965
MA(1)	-0.309720	0.281625	-1.099761	0.2745
RESID(-1)	-0.132986	0.669012	-0.198780	0.8429
RESID(-2)	0.127342	0.331528	0.384107	0.7019
RESID(-3)	0.320325	0.211240	1.516402	0.1331
RESID(-4)	0.180434	0.170596	1.057671	0.2932
RESID(-5)	0.024304	0.150351	0.161648	0.8720
RESID(-6)	-0.025914	0.136706	-0.189563	0.8501
RESID(-7)	0.009773	0.127160	0.076856	0.9389
RESID(-8)	0.066268	0.120190	0.551363	0.5828
RESID(-9)	0.080387	0.116076	0.692533	0.4905
RESID(-10)	0.058295	0.114098	0.510917	0.6107
RESID(-11)	-0.022076	0.111056	-0.198787	0.8429
RESID(-12)	-0.008309	0.109898	-0.075605	0.9399
RESID(-13)	-0.034726	0.108771	-0.319258	0.7503
R-squared	0.071040	Mean dependent var		-0.001012
Adjusted R-squared	-0.081965	S.D. dependent var		0.042861

S.E. of regression	0.044582	Akaike info criterion	-3.245472
Sum squared resid	0.168946	Schwarz criterion	-2.854696
Log likelihood	177.2736	Durbin-Watson stat	1.985118

Graph 1: Jarque-Bera test for residuals from model 1

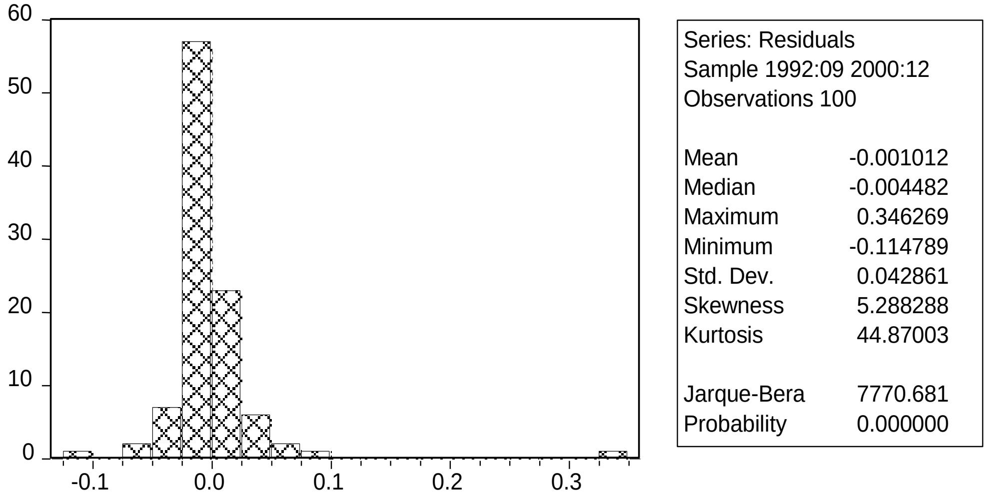


Table 6: Model 2

Dependent Variable: CPIGR				
Method: Least Squares				
Included observations: 100				
Convergence achieved after 7 iterations				
Backcast: 1992:08				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
MA(1)	-0.421104	0.089630	-4.698255	0.0000
R-squared	0.125637	Mean dependent var		0.000332
Adjusted R-squared	0.125637	S.D. dependent var		0.046654
S.E. of regression	0.043625	Akaike info criterion		-3.416420
Sum squared resid	0.188411	Schwarz criterion		-3.390369
Log likelihood	171.8210	Durbin-Watson stat		1.912277
Inverted MA Roots	.42			

Table 7: ACF, PACF and Q-statistics for residuals from model 2

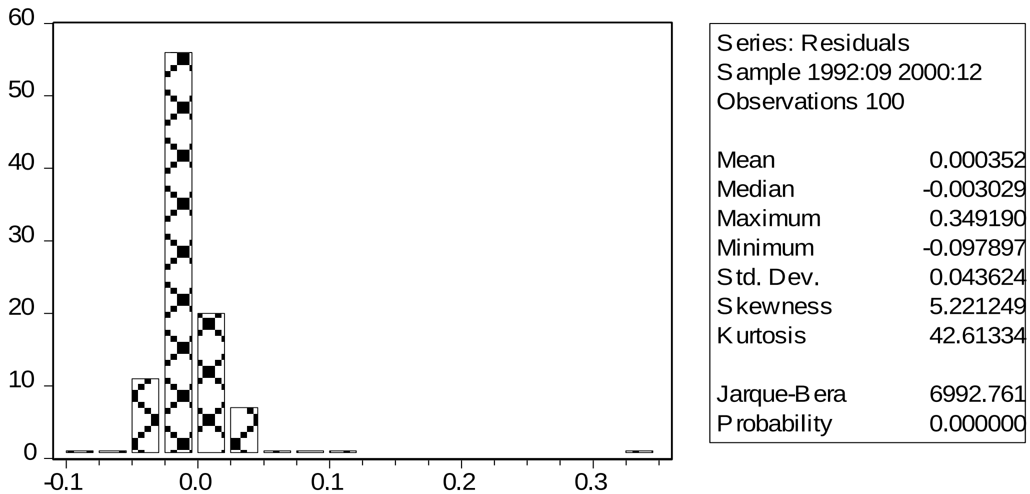
	AC	PAC	Q-Stat	Prob
1	0.043	0.043	0.1928	
2	-0.050	-0.052	0.4514	0.502
3	0.091	0.096	1.3294	0.514
4	-0.022	-0.034	1.3801	0.710
5	-0.124	-0.113	3.0386	0.551
6	-0.104	-0.107	4.2153	0.519
7	-0.053	-0.053	4.5218	0.606
8	-0.014	0.000	4.5446	0.715
9	0.012	0.021	4.5596	0.803

10	0.012	0.001	4.5753	0.870
11	-0.038	-0.065	4.7402	0.908
12	-0.022	-0.047	4.7983	0.941
13	-0.050	-0.070	5.0960	0.955
14	-0.002	0.009	5.0962	0.973
15	0.025	0.028	5.1686	0.983
16	0.002	0.003	5.1694	0.991
17	-0.038	-0.061	5.3496	0.994
18	-0.047	-0.083	5.6295	0.995
19	-0.063	-0.089	6.1348	0.996
20	-0.010	-0.003	6.1466	0.998
21	0.019	0.032	6.1913	0.999
22	0.045	0.052	6.4568	0.999
23	0.060	0.032	6.9295	0.999
24	0.075	0.025	7.6897	0.999
25	0.043	0.002	7.9406	0.999

Table 8: Breush-Godfrey test for residuals from model 2

Breusch-Godfrey Serial Correlation LM Test:				
F-statistic	0.542026	Probability		0.891722
Obs*R-squared	7.566852	Probability		0.870630
Test Equation:				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
MA(1)	-0.737316	0.506569	-1.455510	0.1492
RESID(-1)	0.752896	0.510854	1.473799	0.1442
RESID(-2)	0.248064	0.235433	1.053648	0.2950
RESID(-3)	0.230338	0.137823	1.671267	0.0983
RESID(-4)	0.027926	0.113141	0.246824	0.8056
RESID(-5)	-0.096674	0.107877	-0.896143	0.3727
RESID(-6)	-0.115786	0.107652	-1.075559	0.2851
RESID(-7)	-0.065404	0.108137	-0.604829	0.5469
RESID(-8)	-0.003121	0.107583	-0.029013	0.9769
RESID(-9)	0.020794	0.106805	0.194688	0.8461
RESID(-10)	0.008007	0.106808	0.074964	0.9404
RESID(-11)	-0.067815	0.106266	-0.638164	0.5251
RESID(-12)	-0.046712	0.106379	-0.439106	0.6617
RESID(-13)	-0.071467	0.106460	-0.671299	0.5038
R-squared	0.075669	Mean dependent var		0.000352
Adjusted R-squared	-0.064056	S.D. dependent var		0.043624
S.E. of regression	0.044999	Akaike info criterion		-3.235171
Sum squared resid	0.174143	Schwarz criterion		-2.870447
Log likelihood	175.7585	Durbin-Watson stat		2.060491

Graph 2: Jarque-Bera test for residuals from model 2



Section 6. Requirements for computer software

In the course R and/or Econometric Views programs are used. These programs are installed in computer classes, also, R program is free software and can be downloaded from the official site.

Section 7. The methods

The following methods and forms of study are used in the course:
- Lectures;
- practices in computer class;
- self-study in computer class (doing home assignments using R and Econometric views, work with data, appliances in Internet);
- self-study with literature.

In total the course includes 20 hours of lectures and 20 hours of practices and classes. It is assumed that lectures and seminars are attended.

Section 8. Academic Integrity

The Higher School of Economics strictly adheres to the principle of academic integrity and honesty. Accordingly, in this course there will be a zero-tolerance policy toward academic dishonesty. This includes, but is not limited to, cheating, plagiarism (including failure to properly cite sources), fabricating citations or information, tampering with other students' work, and presenting a part of or the entirety of another person's work as your own. HSE uses an automated plagiarism-detection system to ensure the originality of students' work. Students who violate university rules on academic honesty will face disciplinary consequences, which, depending on the severity of the offense, may include having points deducted on a specific assignment, receiving a failing grade for the course, being expelled from the university, or other measures specified in HSE's Internal Regulations.