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Gas-rich coal field development

Gas fields in East Siberia: production outlooks

Газовая промышленность

Gas fields in East Siberia: production outlooks

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In his book "The past… for the future" academician Dmitry Likhachov wrote: "Every scientist has to acknowledge his predecessors, be respectful to contemporaries, and assume responsibility to future scientists. Then his contribution will remain a guidance for many years."[1(p. 573)] This idea appears increasingly topical these days, in particular with regard to various projections where it is critical to be guided by the past and analyse the present day to gain explicit vision of the future. Guided in this research by the principles of this prominent scientist, the author presents his economic and mathematical models which are believed to be a useful tool for gas production outlooks in East Siberia.

The Eastern Gas Programme was approved on 3 September 2007 by the Ministry of Industry and Energy's order 340. It focuses on social and economic development of Russia's eastern regions and assumes it be driven by setting up an efficient gas sector framework.[2(p.14)] There are considerable natural gas resources in East Siberia, both non-associated gas and gas caps. In terms of feasible volumes, the East Siberian prospective and forecast resources, which are 25% of Russia's totals, are well comparable with those in Yamal-Nenets region's onshore fields (Table 1). In this connection, it is believed important to undertake an econometric analysis for gas production functions in East Siberia over 1968–2008 and to identify those, which would likely deliver the best production forecast accuracy.

RESEARCH METHODOLOGY AND HISTORY DATA PROCESSING

Over nearly half a century, the RAS Central Mathematics and Economic Institute (CEMI RAS) has been involved in development of economic and mathematical models for Russian economy including applications for the gas industry viewed as one of this country's core economic activities. Presently computable general equilibrium models and agent-based models created by academician Valery L. Makarov, CEMI RAS director,[12–13] and macroeconometric models including production potential models developed by professor Sergey A. Aivazyan[14, 15] have proved to be the key tools for economic-and-mathematical modelling and forecasting.

At CEMI RAS, the first econometric models for USSR gas industry production functions were introduced by Leonid Ye. Varshavsky in the mid-1970s,[16] and recently similar models for entire Gazprom gas production sector over 1989–2005 were estimated by Lev V. Shamis at NIIgazekonomika.[17(p.55–58)] This analisys em-

Table 1.

Booked in-situ reserves and resources of free gas including gas caps (as of 1 January 2009, Bcm)

Area	Gas reserves*			Gas resources*		
	$A+B+C_1$ [explored]	C_2 [preliminary estimated]	In total	C_3 [prospective]	D_1+D_2 [forecast]	In total
East Siberia totals	3,715.566	4,301.310	8,016.876	4,995.075	36,552.733	41,547.808
Krasnoyarsk Krai	819.317	1,000.516	1,819.833	3,491.385	20,483.357	23,974.742
Sakha Republic (Yakutia)	1,314.530	1,216.082	2,530.612	180.978	10,033.339	10,214.317
Irkutsk region	1,581.719	2,084.712	3,666.431	1,322.712	6,036.037	7,358.749
West Siberia totals**	32,712.504	9,301.044	42,013.548	17,220.372	29,974.980	47,195.352
Tyumen region (with okrug's)	32,471.408	9,263.273	41,734.681	17,217.017	29,325.345	46,542.362
- Yamal-Nenets	31,700.780	9,148.449	40,849.229	17,216.816	24,657.827	41,874.643
- Khanty-Mansi (Yugra)	766.621	97.538	864.159	0.201	4,667.518	4,667.719
- South Tyumen region	4.007	17.286	21.293	No data***	No data	No data
Tomsk region	239.953	37.771	277.724	3.355	649.635	652.990
Novosibirsk region	0.600	0	0.600	No data	No data	No data
Omsk region	0.543	0	0.543	No data	No data	No data
Russian totals	48,111.336	19,839.718	67,951.054	32,963.406	130,393.739	163,357.145

* According to the Russian classification system for reserves and resources.
** Onshore, excluding Yamal-Nenets region, in the Kara Sea. According to source 3, pp. 60–61, as of 1 January 2009, prospective resources (C_3) in West Siberian oil and gas basin were assessed at 24.2 Tcm, while the forecast resources (D_1+D_2) – at 48.8 Tcm.
*** As of 1 January 2009 – no data entries in the State mineral resources balance database.
Source references: 3, pp. 59, 62; 4, p. 8; 5, p. 8; 6, p. 20; 7, p. 8; 8, p. 3; 9, p. 9; 10, p. 3; 11, p. 3.

ploys the both abovementioned methodologies and is assumed to enhance previous results produced by the author and documented in his earlier publications.[18, 19]

Given the underlying considerations summarised in previous publications,[18, 19] and governed by the task involved in econometric research into gas production in East Siberia, the following gross natural gas production (Γ_t) factors were chosen: $\bar{\Phi}_{t(1990)}$ = annual average value of fixed industrial assets (FIA) in constant 1990 prices, and $G_{1968,t-1}$ = cumulative natural gas production from commercial start-up at East Siberia's pioneering Ust-Vilyuiskoye gas field (1968) through the year $t-1$.

Aiming to put in correspondence gas production volumes and FIA value history data, we decided to analyse production functions of medium-to-major gas producers in East Siberia (under OKONKH 11231 and OKVED 11.10.2, according to Russian classification of activities). These companies include Norilskgazprom, Taimyrgaz, Yakutgazprom, and ALROSA-Gaz – all headquartered in Krasnoyarsk Krai and Sakha Republic (Yakutia). We do not take into account statistical data for other enterprises involved in gas production in these regions together with Irkutsk region since, first, their key activity is crude oil (OKVED 11.10.11, "Crude oil and associated gas production") and, second, they report far smaller gas production volumes.

Table 2 summarises gas production statistics and key assets. As soon as annual averages for FIA value in Krasnoyarsk Krai over 2000–2008 were calculated based on actual capital construction price indices for Yamal-Nenets region, they were recalculated into 1990 prices using a known methodology,[19(p.4)] which is built around annual average price indices for actual capital construction (OKONKH 11230 for 2000–2004 and OKVED 11 for 2005–2008) in Krasnoyarsk Krai (Table 3).[19]

Table 2.

Statistics for econometric analysis of gas production functions in East Siberia over 1968–2008

Year	Gross natural gas output (MMcm)	Cumulative natural gas output from 1968 up to year (MMcm)	Annual average FIA value (in constant 1990 prices), thousand non-denominated roubles
t	Γ_t	$G_{1968,t-1}$	$\bar{\Phi}_{t(1990)}$
1968	47	0	918
1969	133	47	7,063
1970	628	180	27,704
1971	1,865	808	51,000
1972	2,310	2,673	75,599
1973	2,646	4,983	89,533
1974	2,913	7,629	129,959
1975	3,112	10,542	152,314
1976	3,362	13,654	170,424
1977	3,600	17,015	203,592
1978	3,817	20,615	260,911
1979	3,947	24,432	285,019
1980	4,457	28,379	310,762
1981	4,854	32,836	338,087
1982	5,442	37,690	339,737
1983	5,586	43,132	350,440
1984	5,791	48,718	392,386
1985	6,186	54,509	443,890
1986	6,422	60,695	546,468
1987	6,472	67,117	604,053
1988	6,458	73,590	663,640
1989	6,404	80,047	716,022
1990	6,495	86,451	744,567
1991	6,594	92,946	762,658
1992	6,576	99,541	778,237
1993	6,349	106,117	789,166
1994	6,416	112,466	798,730
1995	6,194	118,882	826,138
1996	6,225	125,076	858,193
1997	5,873	131,301	871,057
1998	5,588	137,174	900,985
1999	5,428	142,762	944,954
2000	5,328	148,190	972,667
2001	5,308	153,518	981,578
2002	5,337	158,826	1,006,816
2003	5,188	164,163	1 080 893
2004	5,291	169,351	1,127,698
2005	5,027	174,6430	1,139,252
2006	5,171	179,670	1,198,885
2007	4,910	184,841	1,314,394
2008	5,178	189,751	1,395,075

Source reference: 18, p. 37; 19, p. 5; and Table 3.

EAST SIBERIA: ECONOMETRIC ANALYSIS FOR INDEPENDENT GAS PRODUCERS

This econometric analysis was performed for various classes of production functions (linear, power, power-exponential, logarithmic power-exponential, and transcendental functions[20(p.22)]) with the use of least-squares method, Eviews 6.0 software package and Table 2 statistics as inputs. The power-exponential functions models appeared to be the best approximators of gas production performance in East Siberia between 1968 and 1979–2008, in terms of classical econometrics criteria and economic sense (Fig. 1 and Table 4)

$$\Gamma_t = e^{\alpha_0}(\bar{\Phi}_{t(1990)})^{\alpha_1+\alpha_2 G_{1968,t-1}} \quad (1)$$

in addition to transcendental functions over 1968 to 1979–2008 (Table 5)

$$\Gamma_t = e^{\alpha_0}(\bar{\Phi}_{t(1990)})^{\alpha_1} e^{\alpha_2 G_{1968,t-1}} \quad (2)$$

Where: t – time (years), α_i – production function coefficients (i = 0, 1, 2), e – natural logarithm base.

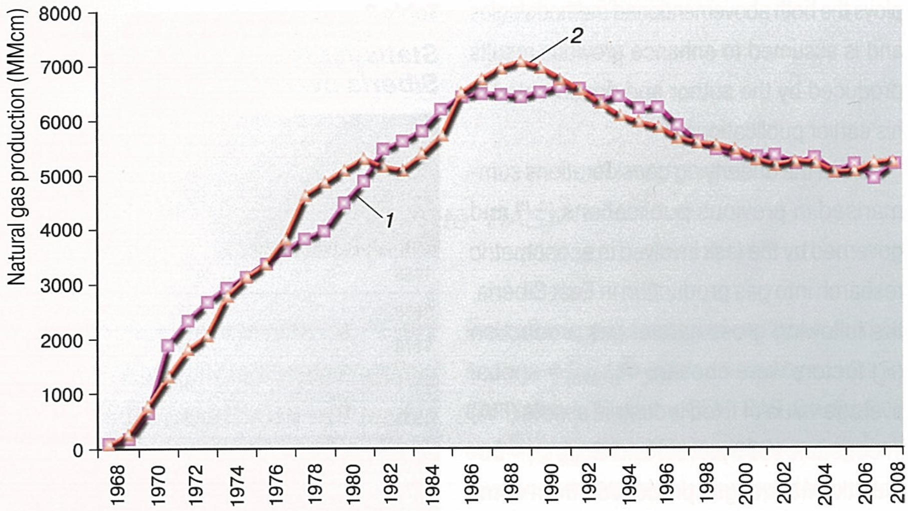

Fig. 1. Actual (1) and estimated (2, based on Eq. 1) natural gas production in East Siberia for 1968–2008

In fact, the coefficients of determination, R^2, are close to 1, and Durbin–Watson (DW) statistics indicate absence of residual autocorrelation at 1% significance level (for Eq. 1 in 2003–2008 and Eq. 2 in 2007–2008, they are located slightly left of uncertainty zone upper limit); t-statistics for α_i estimates are higher, in modulus 2 (except some years when they are slightly lower than 2); and correlation coefficients, r_1 and r_2, between explanatory variables are under 0.85 thereby evidencing the absence of multi-collinearity effect.[21 (p.75)] Therefore, the results with testing the main statistical hypotheses appear to well agree with the following conclusion: the econometric estimators of production function coefficients (Eqs. 1 and 2) over 1968 to 1979–2008 period, when using the least squares method, appear to be the best linear unbiased estimators among all linear unbiased estimators.

Table 3.

Average annual FIA value in Krasnoyarsk Krai gas sector recalculated for 1990 prices based on capital construction actual price indices – OKONKH 11230 (2000–2004) and OKVED 11 (2005–2008)

Year	New FIAs commissioned in actual prices (thousand roubles)	Capital construction actual price index, reporting year vs. previous year	FIA value in constant 1990 prices (thousand non-denominated roubles)				
			Avail. by beginning of reporting year	New FIAs commissioned	Phased out (write-offs)	Avail. by reporting yearend	Average annual value
t	$ФB_t$	$ИKC_t$	$ФH_{t(1990)}$	$ФB_{t(1990)}$	$ФЛ_{t(1990)}$	$ФK_{t(1990)}$	$\bar{Ф}_{t(1990)}$
2000	73,803	1.431	594,211	4,400	2,846	595,765	594,988
2001	146,484	1.219	595,765	7,164	6,263	596,666	596,215
2002	140,438	1.086	596,666	6,325	5,083	597,907	597,286
2003	2,068,140	0.990	597,907	94,080	5,942	686,046	641,976
2004	105,290	1.043	686,046	4,592	2,272	688,366	687,206
2005	60,431	1.114	688,366	2,366	3,037	687,695	688,031
2006	1,939,772	1.130	687,695	67,208	7,117	747,786	717,741
2007	686,588	1.145	747,786	20,776	5,342	763,221	755,503
2008	1,241,595	1.199	763,221	31,335	3,535	791,020	777,120

Data sources: Assets = Ref. 19 (p. 6), annual index averages = Rosstat.
Note: The value of phased-out FIA, in 2007 roubles, was Rb37,506,000, and in 2008 roubles was Rb24,821,000. As there was no re-assessment of all core assets in 2007 and 2008 by regional operator, actual asset re-assessment ratios were set equal 1 for these years.

Furthermore, positive coefficients of FIA, α_1, and negative coefficients of cumulative gas production, α_2, evidence that the gas production function models for East Siberia (Eqs. 1 and 2) are in accordance with economic sense.

It can be seen in Tables 4 and 5 that cumulative gas production, $G_{1968,t-1}$, as a measure of reserves depletion becomes statistically significant from 1979. The FIA coefficient, α_1, tends to decrease between 1979 and 1982 and remains nearly steady (the changes apply to the hundredths) in 1983–2008. Moreover, the Eqs. 1 and 2 coefficients, α_1, are nearly equal to each other from 1968 to 1979–2008. For each of these functions, α_0 and α_2 (dimensionality and accumulated production coefficients, respectively), remain nearly flat over 1994–2008. Therefore, these econometric results, first, confirm high verification level for chosen production function models (Eqs. 1 and 2) and, second, lead to the following economic outcome:

Over 1994–2008, the coefficients of East Siberian gas production functions, Eqs. 1 and 2, appear only marginally changing – within the hundredths of figures – which evidences stability of the institutional mechanism (rules of the game) available for East Siberian gas industry development.

THE BEST FIT MODEL FOR GAS PRODUCTION FORECATS: *EX-POST* EVALUATION METHOD

Aiming to identify the production functions (Eq. 1 or Eq. 2) that best fit the gas production performance and predict its volumes, it is believed necessary to use additional criteria of choice. The classical *ex-post* evaluation method would be likely the most reliable choice for the purpose.[21(pp.35–36, 315–316)] In accordance with this method, we need to choose a function featuring the lowest mean absolute percentage error (MAPE) of the *ex-post* forecasts for up to τ years ahead. The absolute percentage error (APE) of the *ex-post* forecasts for up to τ years ahead, designated $\varepsilon(\tau,i)_{OTH}$ can be produced using

$$\varepsilon(\tau,i)_{OTH} = \left| \frac{\widehat{\Gamma}_{t_{o6}+i-1+\tau}}{\Gamma_{t_{o6}+i-1+\tau}} - 1 \right|.$$

Where: $\widehat{\Gamma}_{t_{o6}+i-1+\tau}$ – *ex-post* gas production forecast over year $t_{o6}+i-1+\tau$; $\Gamma_{t_{o6}+i-1+\tau}$ – actual gas output over year $t_{o6}+i-1+\tau$; t_{o6} – the earliest end-year for a learning sample; i – number of learning samples; $(t_{o6}+i-1)$ – end-years for learning samples; τ – forecast horizon (years).

In our analysis, 1968 was chosen as the initial year for all learning samples, and 1985

Table 4.

Econometric results for power-exponential production function $\Gamma_t = e^{\alpha_0} (\bar{\Phi}_{t(1990)})^{\alpha_1+\alpha_2 G_{1968,t-1}}$ estimated from 1968 to 1979–2008

Years	Coefficients (t-statistics)			r_1*	R^2	DW
	α_0	α_1	α_2			
1968-1979	-2.87 (-4)	0.94 (14)	$-2.02\cdot10^{-7}$ (-1.93)	0.72	0.97	1.95
1968-1980	-2.82 (-5)	0.93 (15)	$-1.78\cdot10^{-7}$ (-2.15)	0.73	0.98	1.93
1968-1981	-2.74 (-5)	0.92 (16)	$-1.51\cdot10^{-7}$ (-2.23)	0.73	0.98	1.84
1968-1982	-2.60 (-4)	0.91 (16)	$-1.12\cdot10^{-7}$ (-1.97)	0.72	0.97	1.67
1968-1983	-2.48 (-4)	0.89 (17)	$-8.41\cdot10^{-7}$ (-1.76)	0.71	0.97	1.52
1968-1984	-2.41 (-5)	0.88 (17)	$-6.93\cdot10^{-7}$ (-1.73)	0.71	0.97	1.46
1968-1985	-2.37 (-5)	0.88 (18)	$-6.02\cdot10^{-7}$ (-1.79)	0.71	0.97	1.43
1968-1986	-2.37 (-5)	0.88 (19)	$-6.03\cdot10^{-7}$ (-2.11)	0.71	0.98	1.44
1968-1987	-2.38 (-5)	0.88 (20)	$-6.17\cdot10^{-7}$ (-3)	0.72	0.98	1.44
1968-1988	-2.39 (-5)	0.88 (21)	$-6.37\cdot10^{-7}$ (-3)	0.72	0.98	1.44
1968-1989	-2.40 (-6)	0.88 (22)	$-6.56\cdot10^{-7}$ (-4)	0.72	0.98	1.44
1968-1990	-2.40 (-6)	0.88 (23)	$-6.55\cdot10^{-7}$ (-4)	0.73	0.98	1.44
1968-1991	-2.39 (-6)	0.88 (24)	$-6.39\cdot10^{-7}$ (-4)	0.73	0.98	1.44
1968-1992	-2.36 (-6)	0.88 (25)	$-6.18\cdot10^{-7}$ (-5)	0.73	0.98	1.43
1968-1993	-2.34 (-6)	0.88 (26)	$-6.01\cdot10^{-7}$ (-5)	0.73	0.98	1.42
1968-1994	-2.32 (-6)	0.87 (26)	$-5.78\cdot10^{-7}$ (-6)	0.73	0.98	1.40
1968-1995	-2.30 (-6)	0.87 (27)	$-5.64\cdot10^{-7}$ (-6)	0.73	0.98	1.39
1968-1996	-2.28 (-7)	0.87 (28)	$-5.50\cdot10^{-7}$ (-6)	0.73	0.98	1.38
1968-1997	-2.27 (-7)	0.87 (29)	$-5.43\cdot10^{-7}$ (-7)	0.73	0.98	1.37
1968-1998	-2.27 (-7)	0.87 (30)	$-5.43\cdot10^{-7}$ (-7)	0.73	0.98	1.38
1968-1999	-2.27 (-7)	0.87 (30)	$-5.46\cdot10^{-7}$ (-8)	0.73	0.98	1.38
1968-2000	-2.28 (-7)	0.87 (31)	$-5.49\cdot10^{-7}$ (-9)	0.73	0.98	1.38
1968-2001	-2.27 (-7)	0.87 (32)	$-5.47\cdot10^{-7}$ (-9)	0.73	0.98	1.38
1968-2002	-2.27 (-8)	0.87 (33)	$-5.44\cdot10^{-7}$ (-10)	0.73	0.98	1.38
1968-2003	-2.27 (-8)	0.87 (34)	$-5.45\cdot10^{-7}$ (-11)	0.73	0.98	1.38
1968-2004	-2.27 (-8)	0.87 (34)	$-5.43\cdot10^{-7}$ (-11)	0.73	0.98	1.38
1968-2005	-2.27 (-8)	0.87 (35)	$-5.44\cdot10^{-7}$ (-12)	0.74	0.98	1.38
1968-2006	-2.26 (-8)	0.87 (36)	$-5.42\cdot10^{-7}$ (-13)	0.74	0.98	1.38
1968-2007	-2.27 (-8)	0.87 (37)	$-5.47\cdot10^{-7}$ (-13)	0.74	0.98	1.38
1968-2008	-2.27 (-8)	0.87 (37)	$-5.48\cdot10^{-7}$ (-14)	0.75	0.98	1.39

*$r_1 = r(\ln \bar{\Phi}_{t(1990)}, G_{1968,t-1} \ln \bar{\Phi}_{t(1990)})$ – correlation coefficient between explanatory variables $\ln \bar{\Phi}_{t(1990)}$ and $G_{1968,t-1} \ln \bar{\Phi}_{t(1990)}$.

Table 5.

Econometric results for transcendental production function $\Gamma_t = e^{\alpha_0}(\bar{\Phi}_{t(1990)})^{\alpha_1} e^{\alpha_2 G_{1968,t-1}}$ estimated from 1968 to 1979–2008

Years	Coefficients (*t*-statistics)			r_2*	R^2	*DW*
	α_0	α_1	α_2			
1968–1979	-2.89 (-4)	0.94 (14)	$-2.53\cdot10^{-6}$ (-1.89)	0.73	0.97	1.94
1968–1980	-2.83 (-4)	0.93 (15)	$-2.26\cdot10^{-6}$ (-2.12)	0.74	0.97	1.92
1968–1981	-2.76 (-5)	0.92 (16)	$-1.94\cdot10^{-6}$ (-2.22)	0.74	0.98	1.84
1968–1982	-2.62 (-4)	0.91 (16)	$-1.45\cdot10^{-6}$ (-1.97)	0.73	0.97	1.68
1968–1983	-2.50 (-4)	0.89 (16)	$-1.09\cdot10^{-6}$ (-1.76)	0.72	0.97	1.53
1968–1984	-2.43 (-5)	0.89 (17)	$-9.06\cdot10^{-6}$ (-1.74)	0.72	0.97	1.47
1968–1985	-2.38 (-5)	0.88 (18)	$-7.95\cdot10^{-6}$ (-1.80)	0.72	0.97	1.44
1968–1986	-2.39 (-5)	0.88 (19)	$-8.04\cdot10^{-6}$ (-2.13)	0.72	0.98	1.45
1968–1987	-2.40 (-5)	0.88 (20)	$-8.29\cdot10^{-6}$ (-3)	0.73	0.98	1.45
1968–1988	-2.42 (-5)	0.89 (21)	$-8.63\cdot10^{-6}$ (-3)	0.73	0.98	1.45
1968–1989	-2.43 (-6)	0.89 (22)	$-8.94\cdot10^{-6}$ (-4)	0.74	0.98	1.45
1968–1990	-2.44 (-6)	0.89 (23)	$-8.99\cdot10^{-6}$ (-4)	0.74	0.98	1.45
1968–1991	-2.42 (-6)	0.89 (24)	$-8.81\cdot10^{-6}$ (-4)	0.74	0.98	1.45
1968–1992	-2.40 (-6)	0.88 (24)	$-8.55\cdot10^{-6}$ (-5)	0.74	0.98	1.44
1968–1993	-2.38 (-6)	0.88 (25)	$-8.34\cdot10^{-6}$ (-5)	0.74	0.98	1.43
1968–1994	-2.35 (-6)	0.88 (26)	$-8.03\cdot10^{-6}$ (-6)	0.74	0.98	1.41
1968–1995	-2.34 (-6)	0.88 (27)	$-7.84\cdot10^{-6}$ (-6)	0.74	0.98	1.40
1968–1996	-2.32 (-7)	0.87 (28)	$-7.66\cdot10^{-6}$ (-6)	0.74	0.98	1.39
1968–1997	-2.31 (-7)	0.87 (29)	$-7.58\cdot10^{-6}$ (-7)	0.74	0.98	1.39
1968–1998	-2.31 (-7)	0.87 (29)	$-7.59\cdot10^{-6}$ (-7)	0.74	0.98	1.39
1968–1999	-2.31 (-7)	0.87 (30)	$-7.64\cdot10^{-6}$ (-8)	0.74	0.98	1.39
1968–2000	-2.32 (-7)	0.88 (31)	$-7.69\cdot10^{-6}$ (-9)	0.74	0.98	1.39
1968–2001	-2.32 (-7)	0.88 (32)	$-7.68\cdot10^{-6}$ (-9)	0.74	0.98	1.39
1968–2002	-2.31 (-8)	0.87 (33)	$-7.64\cdot10^{-6}$ (-10)	0.74	0.98	1.39
1968–2003	-2.32 (-8)	0.87 (33)	$-7.68\cdot10^{-6}$ (-11)	0.74	0.98	1.39
1968–2004	-2.32 (-8)	0.87 (34)	$-7.68\cdot10^{-6}$ (-11)	0.74	0.98	1.39
1968–2005	-2.32 (-8)	0.88 (35)	$-7.70\cdot10^{-6}$ (-12)	0.74	0.98	1.39
1968–2006	-2.32 (-8)	0.88 (36)	$-7.69\cdot10^{-6}$ (-13)	0.75	0.98	1.39
1968–2007	-2.33 (-8)	0.88 (36)	$-7.78\cdot10^{-6}$ (-13)	0.75	0.98	1.39
1968–2008	-2.34 (-9)	0.88 (37)	$-7.82\cdot10^{-6}$ (-14)	0.75	0.98	1.39

*$r_2 = r(\ln \bar{\Phi}_{t(1990)}, G_{1968,t-1})$ – correlation coefficient between explanatory variables $\ln \bar{\Phi}_{t(1990)}$ and $G_{1968,t-1}$.

standing for the earliest final year, t_{o6} = 1985, as the statistical significance of cumulative gas production over 1979–1984 appears essentially low. The maximal number of learning samples is 23 as their respective end-years range between 1985 and 2007. The maximum for forecast years is also at 23, since our forecasts are targeting the 1986–2008 period.

The MAPE of the *ex-post* forecasts for up to τ years ahead, $\bar{\varepsilon}(\tau, n)_{OTH}$, uses the following formula:[20(p.23)]

$$\bar{\varepsilon}(\tau, n)_{OTH} = \frac{1}{n(\tau)}\sum_{i=1}^{n(\tau)}\left|\frac{\hat{\Gamma}_{t_{o6}+i-1+\tau}}{\Gamma_{t_{o6}+i-1+\tau}} - 1\right|.$$

Where: $i = 1, \ldots, n(\tau)$, $n(\tau)$ – number of years for *ex-post* forecasts horizon τ, and $n(\tau) = 23 - \tau + 1$.

Tables 6–9 summarise APEs and MAPEs for Eq. 1 and Eq. 2 estimated with the use of the learning samples data (since 1968 up to 1994–2007).* It can be seen that the lowest MAPE (at or under 5%) for up to 14 years ahead applies to the power-exponential function in Eq. 1 (see Tables 7 and 9, and Fig. 2).

Therefore, Eq. 1 appears to deliver the best fit for gas production in East Siberia and, also, it will be likely most suitable for production forecasts in this region (for fields both under production and, possibly, planned for the short term), for up to 14 years ahead.

At the same time, we cannot rule out potentially changing Eqs. 1 and 2 production function coefficients, in line with progressive bringing new fields on exploitation. This can be associated with plans for gaining far greater production volumes over the Eastern Gas Programme implementation period as well as with individual aspects of new fields to be brought on stream. To provide necessary offsets, better forecast accuracy would likely call for including additional arguments into Eqs. 1 and 2 (such as initial well productivity, initial formation pressure, average bed depths, initial reserves volume and field geographic co-ordinates) or introducing new production functions, either for a group of new fields or for each field separately.[22(p.1026)]

Meanwhile, analysis of Eqs.1 and 2 coefficients for East Siberian gas production functions

*Essentially high MAPEs of ex-post forecasts were produced from Eqs. 1 and 2 estimated with the use of learning samples data over 1968 to 1979–1993. At the same time, the errors of forecasts for up to five-years-ahead commonly remain under 5.5%.

and experience to date with similar coefficients for the entire Tyumen region's gas sector and local Gazprom subsidiaries would fail to confirm necessary and significant changes in production function coefficients under the Eastern Gas Programme implementation. For example, bringing online Pelyatkinskoye gas-condensate field in Krasnoyarsk Krai in 2003 did not affect the econometric estimates for Eqs. 1 and 2 coefficients over next years (see Tables 4 and 5). Furthermore, entry of new fields, both major (such as Zapolyarnoye and Yuzhno-Russkoye) and small-to-medium fields, first, failed to seriously affect production function coefficients across Tyumen region from 1987 to 1993–2008 and for Gazprom's subsidiaries from 1984 to 1997–2008 and, secondly, did not diminish econometric forecasts accuracy (Tables 10–13).

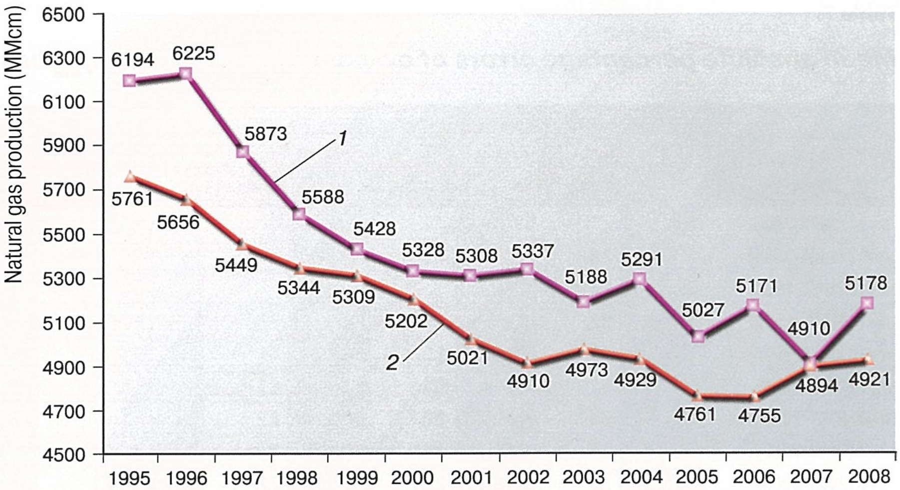

Fig. 2. Actual volumes (1) and ex-post forecast (2) for 14-years-ahead (1995–2008) of gas production in East Siberia made by Eq. 1 estimated for 1968–1994 (see Tables 4 and 6)

In fact, among all author's studies of gas production functions for Russian regions,[18–20, 23] the lowest MAPEs of *ex-post* forecasts appear to be associated with transcendental functions for Tyumen region which was reported to be the Russian leader in terms of explored and booked reserves of non-associated gas (as of 1 January 2009: 32.5 Tcm and 41.7 Tcm, respectively – see Table 1) and production volumes – 563.8 Bcm in 2008,[23(p.39)] along with the lowest gas production costs among regions (about 421 roubles/1,000 m^3 in 2008). These functions,

$$\Gamma_t = e^{\alpha_0} (\bar{\Phi}_{t-1(1990)})^{\alpha_1} e^{\alpha_2 G_{1963,t-2}}, \quad (3)$$

were estimated for a period from 1987 to 1993–2007 using around history data available from numerous publications.[19(p.10); 20(p.20); 23(p.39, 43)] The functions (Eq. 3) have steady econometric estimates of the coefficients (see Table 10) and offer to predict gas production for up to 10 years ahead, with APEs and MAPEs under 2%, and for up to 15 years ahead with MAPEs under 4% (Fig. 3).[18(p. 44–46)]

However, it appears impossible to forecast gas output for all Tyumen region fields in 2009 and 2010 as the author has no access to Form

Table 6.

Absolute percentage errors of ex-post forecasts $\varepsilon(\tau, i)_{отн}$ made by Eq. 1 estimated with the use of learning samples data from 1968 to 1994–2007 (%)

Ex-post forecast horizon, years (τ)	Learning samples for power-exponential function, Eq. 1, over years 1968 to 1985+*i*-1													
	i = 10 1994	*i* = 11 1995	*i* = 12 1996	*i* = 13 1997	*i* = 14 1998	*i* = 15 1999	*i* = 16 2000	*i* = 17 2001	*i* = 18 2002	*i* = 19 2003	*i* = 20 2004	*i* = 21 2005	*i* = 22 2006	*i* = 23 2007
τ = 11 - *i* (1995)	7.0													
τ = 12 - *i* (1996)	9.1	7.7												
τ = 13 - *i* (1997)	7.2	5.6	4.1											
τ = 14 - *i* (1998)	4.4	2.6	0.9	0.1										
τ = 15 - *i* (1999)	2.2	0.3	1.6	2.4	2.5									
τ = 16 - *i* (2000)	2.4	0.4	1.6	2.5	2.5	2.1								
τ = 17 - *i* (2001)	5.4	3.4	1.4	0.4	0.4	0.8	1.2							
τ = 18 - *i* (2002)	8.0	5.9	3.9	2.9	2.9	3.3	3.7	3.5						
τ = 19 - *i* (2003)	4.2	1.9	0.4	1.4	1.5	1.0	0.6	0.8	1.3					
τ = 20 - *i* (2004)	6.8	4.5	2.2	1.2	1.1	1.6	2.0	1.8	1.3	1.5				
τ = 21 - *i* (2005)	5.3	2.9	0.4	0.7	0.8	0.2	0.2	0.0	0.6	0.4	0.6			
τ = 22 - *i* (2006)	8.0	5.6	3.1	1.9	1.9	2.5	2.9	2.7	2.1	2.3	2.1	2.1		
τ = 23 - *i* (2007)	0.3	2.4	5.2	6.6	6.6	6.0	5.5	5.7	6.4	6.2	6.4	6.3	6.6	
τ = 24 - *i* (2008)	5.0	2.2	0.6	1.9	1.9	1.3	0.8	1.1	1.7	1.5	1.7	1.6	1.9	1.1

Table 7.

Mean absolute percentage errors of ex-post forecasts, $\bar{\varepsilon}(\tau, n)_{отн}$ based on Eq. 1 and Table 6 data (%)

Number of ex-post forecast periods, *n* and years (in brackets)	Years ahead, τ													
	τ = 15–*n*	τ = 14–*n*	τ = 13–*n*	τ = 12–*n*	τ = 11–*n*	τ = 10–*n*	τ = 9–*n*	τ = 8–*n*	τ = 7–*n*	τ = 6–*n*	τ = 5–*n*	τ = 4–*n*	τ = 3–*n*	τ = 2–*n*
n =14 (1995-2008)	3.0													
n =13 (1996-2008)	2.9	2.6												
n =12 (1997-2008)	2.6	2.4	2.2											
n =11 (1998-2008)	2.1	2.2	2.1	2.1										
n =10 (1999-2008)	2.1	1.8	2.1	2.2	2.3									
n =9 (2000-2008)	2.5	2.1	2.0	2.2	2.2	2.2								
n =8 (2001-2008)	2.8	2.5	2.3	2.0	2.1	2.2	2.2							
n =7 (2002-2008)	3.1	2.5	2.4	2.4	2.3	2.4	2.4	2.4						
n =6 (2003-2008)	3.2	2.3	1.9	2.2	2.3	2.2	2.2	2.1	2.2					
n =5 (2004-2008)	4.3	3.0	2.3	2.2	2.3	2.5	2.4	2.6	2.4	2.4				
n =4 (2005-2008)	4.5	3.6	2.6	2.4	2.4	2.6	2.7	2.5	2.7	2.7	2.6			
n =3 (2006-2008)	3.7	4.2	3.9	3.3	2.9	3.0	3.4	3.5	3.3	3.4	3.4	3.3		
n =2 (2007-2008)	1.3	1.5	3.6	4.2	3.9	3.4	3.3	3.7	4.0	4.0	4.0	4.1	3.9	
n =1 (2008)	5.0	2.2	0.6	1.9	1.9	1.3	0.8	1.1	1.7	1.5	1.7	1.6	1.9	1.1

11 data for independent gas producers. At the same time, when using Gazprom's history data,** it is believed possible to forecast gas production for both years by Gazprom's subsidiaries in Tyumen region based on power-exponential functions

$$\Gamma_t = e^{\alpha_0} (\bar{\Phi}_{t-1(1990)})^{\alpha_1+\alpha_2 G_{1963,t-2}}, \quad (4)$$

estimated from 1984 to 1997–2008. These functions feature essentially steady econometric estimates of the coefficients (see Table 11) and also relatively small MAPEs of the *ex-post* forecasts (under 3.3%) for up to 11 years ahead (see Table 13). Moreover, of all functions introduced by Eq. 4, the lowest APE of the *ex-post* forecast (under 2.3%) for 1998–2008 can be expected from production function

$$\Gamma_t = e^{4,01089470256} (\bar{\Phi}_{t-1(1990)})^{0,597843058826-5,5807142565\cdot 10^{-9}\cdot G_{1963,t-2}}, \quad (5)$$

estimated in 1984–1997 (see Tables 11–12 and Fig. 4).

For 2009, Eq. 5 produces natural gas production forecast totalling 491.5 Bcm with 10.3 Bcm standard RMS error and 15.8% forecast accuracy. Such essentially high error in this estimate stems from Eq. 5, along with Eqs. 1 through 4 which typically offer relatively good gas production forecast accuracy for cases when there is no *strong demand volatility*, whereas in 2009, Russian gas demand (including Gazprom's output) was reported to plummet due to global financial and economic crisis. In this connection, more arguments presumably need to be added (mainly to reflect crisis periods) to production function models for achieve better forecast accuracy, thereby making provisions for gas sector capacity utilisation, such as share of producing wells in total fleet or average diameter of wellhead chokes which control hole pressure. However, at the moment the author has no relevant data to access *annual averages* for 1984–2009.***

In 2010, gas demand and production volume growth trends have become more pronounced. For this year, Eq. 5 predicts Gazprom's gas output in Tyumen at 476.3 Bcm (see Fig. 4 and Table 10), with standard RMS error within 10 Bcm which essentially agrees with Gazprom's cumulative target of 519.3 Bcm.[35(p.4)] About the same, or slightly larger gas production forecast volumes come from other functions

** Actual gas production statistics for 1984–2009 and average FIA annual value in 1990 roubles for 1983–2006 are available in literature.20(p.20); 24(p.12, 16) and shown in Fig. 4. Over 2008–2009, the computation of FIA value in 1990 roubles followed a methodology from literature,20(p. 20–22) based on history data on new FIAs commissioned by Gazprom (including Severneftegazprom), with such data represented by reporting formats which also applied to 1999–2007.25(p.168); 26(p.164); 27(p.189); 28(p.219); 29(p.229–230); 30(p.251–252); 31(p.256–257); 32(p.224–225); 33(p.287); 34(p.301) FIA value averages for 2008–2009 did not account for Purgaz assets (as Form 11 [reporting format] remains nonavailable to the author), Purgazdobycha (merged into Gazprom Dobycha Noyabrsk in 2008), and Gazprom Dobycha Nadym (as most new FIAs commissioned remained idle in 2007–2009 at Bovanenkovskoye field still awaiting commercial production). According to Rosstat, capital construction price indices (OKVED 11) for Yamal-Nenets region (December of reporting year against December a year earlier) in 2008–2009 stood at 1.099 and 0.9825, respectively. Methodology aspects of gas sector statistics processing for computation of the annual average FIA value for 2007 are summarised in literature.20(p.38); 24(p.16); 33(p.287)

*** Many reporting items for capacity utilisation are included into Statistical Reporting Form 2-TEK (gas) and relate to the end of reporting year or the last month of reporting year.

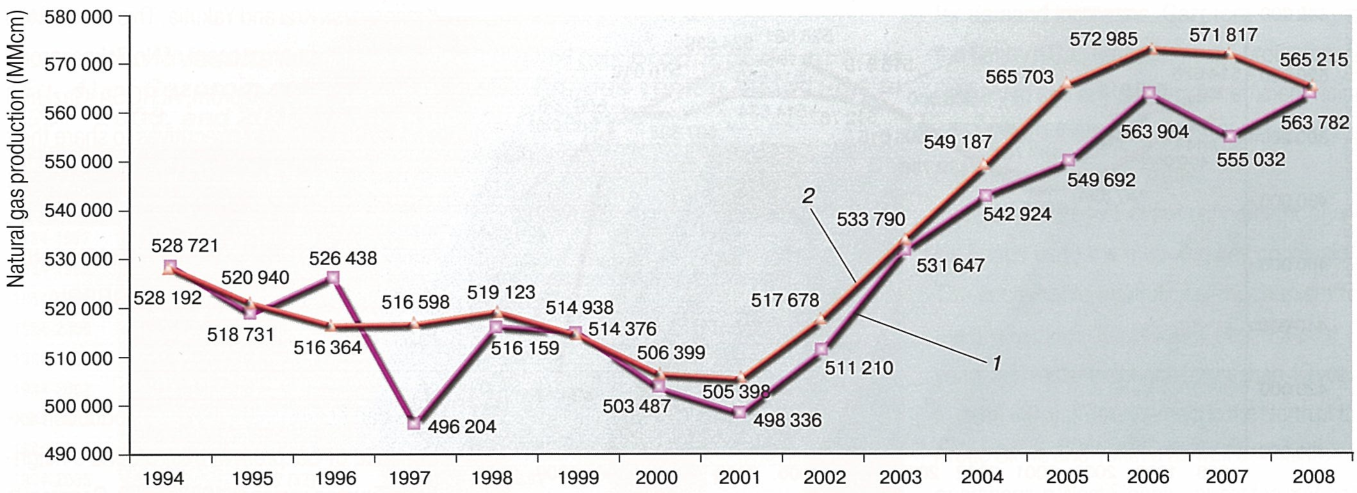

Fig. 3. Actual volumes (1) and ex-post forecast (2) for 15-years-ahead (1994–2008) of total gas production in Tyumen region made by Eq. 3 estimated for 1987–1993[18]

Table 8.

Absolute percentage errors of ex-post forecasts, $\varepsilon(\tau, i)_{OTH}$ made by Eq. 2 estimated with the use of learning samples data over 1968 to 1994–2007 (%)

Ex-post forecast horizon, years (τ)	Learning samples for transcendental function, Eq. 2, over years 1968 to 1985+*i*-1													
	i = 10 1994	*i* = 11 1995	*i* = 12 1996	*i* = 13 1997	*i* = 14 1998	*i* = 15 1999	*i* = 16 2000	*i* = 17 2001	*i* = 18 2002	*i* = 19 2003	*i* = 20 2004	*i* = 21 2005	*i* = 22 2006	*i* = 23 2007
τ = 11 - *i* (1995)	6.6													
τ = 12 - *i* (1996)	8.6	7.2												
τ = 13 - *i* (1997)	6.6	5.1	3.7											
τ = 14 - *i* (1998)	3.6	1.9	0.3	0.4										
τ = 15 - *i* (1999)	1.0	0.8	2.5	3.3	3.2									
τ = 16 - *i* (2000)	1.0	0.9	2.7	3.5	3.5	2.9								
τ = 17 - *i* (2001)	4.0	2.1	0.2	0.6	0.5	0.0	0.5							
τ = 18 - *i* (2002)	6.4	4.5	2.6	1.7	1.8	2.4	2.8	2.8						
τ = 19 - *i* (2003)	1.8	0.3	2.4	3.3	3.2	2.6	2.1	2.2	2.6					
τ = 20 - *i* (2004)	4.2	2.0	0.1	1.1	1.0	0.3	0.2	0.1	0.3	0.0				
τ = 21 - *i* (2005)	2.5	0.2	2.1	3.1	3.0	2.3	1.8	1.8	2.3	1.9	1.9			
τ = 22 - *i* (2006)	4.8	2.5	0.2	0.9	0.8	0.1	0.5	0.4	0.1	0.3	0.3	0.5		
τ = 23 - *i* (2007)	4.3	6.9	9.5	10.7	10.6	9.8	9.2	9.3	9.8	9.4	9.4	9.1	9.2	
τ = 24- *i* (2008)	0.2	2.8	5.4	6.6	6.5	5.7	5.0	5.1	5.6	5.2	5.2	4.9	5.0	4.0

Table 9.

Mean absolute percentage errors of ex-post forecasts, $\bar{\varepsilon}(\tau, n)_{OTH}$ based on Eq. 2 and Table 8 (%)

Number of ex-post forecast periods, *n*, and years (in brackets)	Years ahead , τ													
	τ = 15–*n*	τ = 14–*n*	τ = 13–*n*	τ = 12–*n*	τ = 11–*n*	τ = 10–*n*	τ = 9–*n*	τ = 8–*n*	τ = 7–*n*	τ = 6–*n*	τ = 5–*n*	τ = 4–*n*	τ = 3–*n*	τ = 2–*n*
n =14 (1995-2008)	3.3													
n =13 (1996-2008)	3.3	3.0												
n =12 (1997-2008)	3.1	2.8	2.6											
n =11 (1998-2008)	2.6	2.7	2.6	2.5										
n =10 (1999-2008)	2.5	2.5	2.8	2.8	2.8									
n =9 (2000-2008)	3.1	2.6	2.7	2.8	2.8	2.7								
n =8 (2001-2008)	3.7	3.3	2.8	2.7	2.8	2.7	2.7							
n =7 (2002-2008)	3.7	3.6	3.5	3.2	3.0	3.1	3.1	3.0						
n =6 (2003-2008)	3.9	3.2	3.5	3.7	3.5	3.2	3.2	3.1	3.0					
n =5 (2004-2008)	4.3	4.3	3.8	3.7	3.7	3.5	3.3	3.4	3.3	3.1				
n =4 (2005-2008)	5.3	4.4	4.8	4.7	4.4	4.4	4.3	4.1	4.2	4.1	3.9			
n =3 (2006-2008)	5.7	6.2	5.8	5.7	5.2	4.8	5.1	5.1	4.9	4.9	4.8	4.6		
n =2 (2007-2008)	3.6	6.2	8.1	8.6	8.1	7.4	7.1	7.5	7.5	7.3	7.2	7.1	6.6	
n =1 (2008)	0.2	2.8	5.4	6.6	6.5	5.7	5.0	5.1	5.6	5.2	5.2	4.9	5.0	4.0

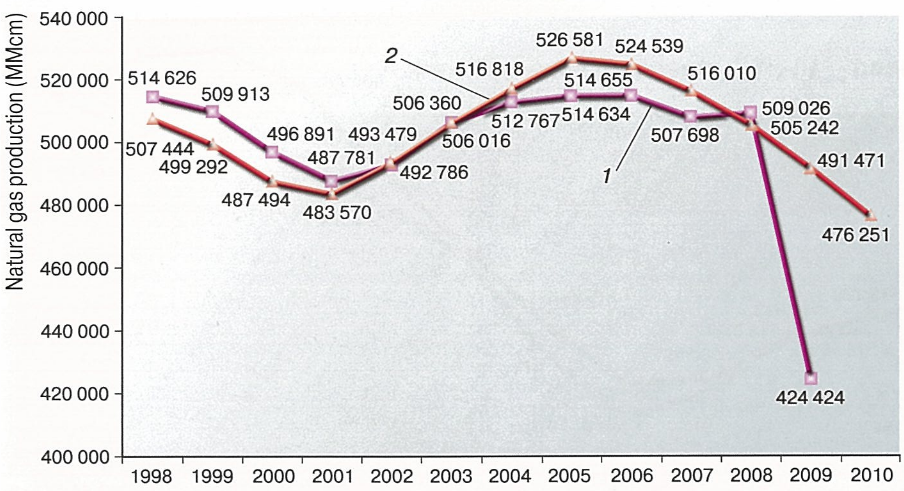

Fig. 4. Actual production (1) for 1998–2009 and ex-post forecast (2) for 1998–2010 of Gazprom's gas production in Tyumen region made by Eq. 5 power-exponential function estimated for 1984–1997

Table 10.

Econometric results for transcendental production functions (Eq. 3) of all gas industry in the Tyumen region over 1987 to 1993–2008 [18]

Years	Coefficients (*t*-statistics)			$r(\ln\overline{\Phi}_{t-1}, G_{1963, t-2})$	R^2	*DW*
	α_0	α_1	α_2			
1987-1993	5.61 (10)	0.49 (12)	$-7.19\cdot10^{-8}$ (-6)	0.96	0.99	1.63
1987-1994	5.63 (13)	0.49 (17)	$-7.13\cdot10^{-8}$ (-9)	0.95	0.99	1.93
1987-1995	5.55 (16)	0.50 (21)	$-7.33\cdot10^{-8}$ (-13)	0.94	0.99	1.97
1987-1996	5.83 (15)	0.48 (19)	$-6.71\cdot10^{-8}$ (-12)	0.94	0.99	1.92
1987-1997	5.35 (8)	0.51 (12)	$-7.76\cdot10^{-8}$ (-9)	0.94	0.96	2.28
1987-1998	5.39 (9)	0.51 (13)	$-7.67\cdot10^{-8}$ (-10)	0.95	0.96	2.85
1987-1999	5.48 (10)	0.50 (14)	$-7.48\cdot10^{-8}$ (-11)	0.95	0.96	2.73
1987-2000	5.50 (11)	0.50 (15)	$-7.44\cdot10^{-8}$ (-13)	0.95	0.96	2.74
1987-2001	5.47 (11)	0.50 (16)	$-7.51\cdot10^{-8}$ (-14)	0.96	0.96	2.74
1987-2002	5.46 (12)	0.50 (17)	$-7.52\cdot10^{-8}$ (-15)	0.96	0.96	2.74
1987-2003	5.45 (12)	0.50 (17)	$-7.51\cdot10^{-8}$ (-15)	0.97	0.96	2.72
1987-2004	5.46 (13)	0.50 (18)	$-7.50\cdot10^{-8}$ (-16)	0.98	0.96	2.74
1987-2005	5.58 (13)	0.50 (18)	$-7.43\cdot10^{-8}$ (-16)	0.98	0.96	2.57
1987-2006	5.58 (14)	0.50 (19)	$-7.43\cdot10^{-8}$ (-16)	0.98	0.96	2.64
1987-2007	5.63 (14)	0.49 (19)	$-7.41\cdot10^{-8}$ (-16)	0.98	0.96	2.57
1987-2008	5.61 (14)	0.49 (18)	$-7.39\cdot10^{-8}$ (-16)	0.99	0.96	2.60

(Eq. 4) estimated from 1984 to 1998–2008 (see Table 11).

Therefore, the production function models (Eqs. 1, 3–5), in addition to other models, methodologies and methods, can be recommended for Gazprom's core departments, its affiliates, independent gas producers, as well as for federal and regional ministries and agencies as a key tool for East and West Siberian short- and medium-term gas production outlooks.

In-depth analysis of gas sector operations in East Siberia, including Pareto-efficiency and innovative development implications, are believed to require annual history data for average upstream workforce and gas production cost structure of gas producers (production units) in Krasnoyarsk Krai and Yakutia. This is expected to largely hinge on consent of Norilskgazprom, Taimyrgaz, Yakutgazprom, ALROSA-Gaz, and Sakhatransneftegaz executives to share their production statistics with the author.

GAZPROM'S PARETO-EFFICIENCY AND INNOVATIONS: FROM WEST SIBERIA FURTHER TO RUSSIA'S EAST

As can be evidenced by gas production experience of Gazprom in East Siberia's neighbour, Tyumen region in 1993–2008, Gazprom's subsidiaries were reported to deliver gas at the lowest costs (under given technology and factors' prices) and to maintain Pareto-efficiency (see Table 14).[24] The author believes that placing Alexei B. Miller, the Gazprom's Chairman of the Management Committee, on the third position in a list of top international company CEOs for management performance by *Harvard Business Review* is to evidence the above.[36] Furthermore, the cost minimisation policy enabled Gazprom to top the best performers list for net revenue in 2009 (according to *Fortune*[37]), despite the global financial and economic crisis. Another important outcome of the mentioned research[24] concerns Gazprom's innovations-driven upstream performance in the market environment – this was illustrated in A. Miller's study[38] and in his 25 December 2009 keynote speech at the meeting of the Russian president's Commission on Russian Economy Modernisation and Technological Development.[39–40]

Marginal production costs are equal to average cost, in addition to their independence from gas production volumes over 1993–2008 (see Table 14 and paper[24(p.14)]), is believed to evidence that the Gazprom's upstream sector did not reach the output level for which all subsequent production expansions would be invariably associated with average cost increases. The high values for *t*-statistics of production functions' coefficients (see Table 14) confirm this conclusion. Hence, given the expectations for demand increases, Gazprom – acting as the Eastern Gas Programme co-ordinator – is unlikely to see any barriers for efficient rising of gas output not only in the Tyumen region but also in the Russia's East.

Finally, the results of this econometric analysis brings us to the following key conclusion: The sustainable institutional mechanism for the gas sector in East Siberia over the past 15 years and vast experience (more than 40 years to date) with gas development in the North of the Arctic Circle and Yakutia as well as Gazprom's operations in West Siberia – all set the stage for sustainable, innovations-driven, and efficient gas production development in Russia's Eastern regions and, hence, for successful implementation of the Eastern Gas Programme.

Table 11.

Econometric results for power-exponential gas production functions (Eq. 4) of Gazprom subsidiaries' in the Tyumen region over 1984 to 1997–2008, and 2010 gas production forecasts

Years	Coefficients (*t*-statistics)			r^*	R^2	*DW*	2010 forecast, Bcm
	α_0	α_1	α_2				
1984-1997	4.01 (10)	0.60 (22)	$-5.58 \cdot 10^{-9}$ (-12)	0.93	0.99	1.52	476.3
1984-1998	4.08 (11)	0.59 (24)	$-5.46 \cdot 10^{-9}$ (-14)	0.93	0.99	1.75	482.7
1984-1999	4.15 (12)	0.59 (26)	$-5.35 \cdot 10^{-9}$ (-15)	0.93	0.99	1.70	488.7
1984-2000	4.18 (13)	0.59 (28)	$-5.31 \cdot 10^{-9}$ (-17)	0.93	0.99	1.69	491.0
1984-2001	4.15 (14)	0.59 (30)	$-5.35 \cdot 10^{-9}$ (-20)	0.93	0.99	1.71	489.1
1984-2002	4.10 (14)	0.59 (31)	$-5.42 \cdot 10^{-9}$ (-21)	0.93	0.99	1.66	485.5
1984-2003	4.08 (15)	0.59 (32)	$-5.45 \cdot 10^{-9}$ (-23)	0.94	0.99	1.63	483.5
1984-2004	4.06 (15)	0.59 (33)	$-5.51 \cdot 10^{-9}$ (-24)	0.94	0.99	1.58	480.7
1984-2005	4.02 (14)	0.60 (32)	$-5.58 \cdot 10^{-9}$ (-24)	0.95	0.99	1.44	476.8
1984-2006	4.00 (14)	0.60 (32)	$-5.62 \cdot 10^{-9}$ (-25)	0.95	0.99	1.37	474.3
1984-2007	3.98 (15)	0.60 (33)	$-5.66 \cdot 10^{-9}$ (-26)	0.96	0.99	1.34	472.8
1984-2008	4.01 (15)	0.60 (34)	$-5.62 \cdot 10^{-9}$ (-27)	0.96	0.99	1.39	474.2

$^*r = r(\ln \Phi_{t-1(1990)}, G_{1963,t-2} \ln \Phi_{t-1(1990)})$ – correlation coefficient between explanatory variables $\ln \Phi_{t-1(1990)}$ and $G_{1963,t-2} \ln \Phi_{t-1(1990)}$.

Table 12.

Absolute percentage errors of ex-post forecasts, $\varepsilon(\tau, i)_{OTH}$ made by Eq. 4 estimated with the use of learning samples data over 1984 to 1997–2007 (%)

Ex-post forecast horizon, years (τ)	Learning samples for power-exponential function, Eq. 4, over years 1984 to 1997+*i*-1										
	i = 1 1997	*i* = 2 1998	*i* = 3 1999	*i* = 4 2000	*i* = 5 2001	*i* = 6 2002	*i* = 7 2003	*i* = 8 2004	*i* = 9 2005	*i* = 10 2006	*i* = 11 2007
τ = 2 - *i* (1998)	1.4										
τ = 3 - *i* (1999)	2.1	1.5									
τ = 4 - *i* (2000)	1.9	1.3	0.7								
τ = 5 - *i* (2001)	0.9	0.2	0.5	0.7							
τ = 6 - *i* (2002)	0.1	0.9	1.6	1.9	1.6						
τ = 7 - *i* (2003)	0.1	0.7	1.5	1.8	1.5	1.1					
τ = 8 - *i* (2004)	0.8	1.7	2.5	2.8	2.5	2.0	1.8				
τ = 9 - *i* (2005)	2.3	3.3	4.1	4.5	4.2	3.7	3.4	3.0			
τ = 10 - *i* (2006)	1.9	2.9	3.9	4.2	3.9	3.4	3.1	2.7	2.0		
τ = 11 - *i* (2007)	1.6	2.7	3.8	4.1	3.8	3.2	2.9	2.4	1.7	1.3	
τ = 12 - *i* (2008)	0.7	0.4	1.5	1.9	1.6	0.9	0.6	0.1	0.6	1.1	1.3

Table 13.

Mean absolute percentage errors of ex-post forecasts, $\bar{\varepsilon}(\tau, n)_{OTH}$ based on Eq. 4 and Table 12 (%)

Number of ex-post forecast periods, *n*, and years (in brackets)	Years ahead, τ										
	τ = 12–*n*	τ = 11–*n*	τ = 10–*n*	τ = 9–*n*	τ = 8–*n*	τ = 7–*n*	τ = 6–*n*	τ = 5–*n*	τ = 4–*n*	τ = 3–*n*	τ = 2–*n*
n = 11 (1998-2008)	1.5										
n = 10 (1999-2008)	1.8	1.5									
n = 9 (2000-2008)	2.0	1.8	1.5								
n = 8 (2001-2008)	2.1	2.0	1.8	1.6							
n = 7 (2002-2008)	2.2	2.2	2.2	2.0	1.7						
n = 6 (2003-2008)	2.5	2.6	2.5	2.3	2.1	1.8					
n = 5 (2004-2008)	2.7	3.0	2.9	2.7	2.5	2.2	1.9				
n = 4 (2005-2008)	2.7	3.2	3.3	3.0	2.6	2.5	2.2	1.9			
n = 3 (2006-2008)	2.1	2.9	3.2	3.0	2.6	2.1	2.0	1.8	1.6		
n = 2 (2007-2008)	1.0	2.1	2.8	2.8	2.4	1.9	1.5	1.5	1.4	1.3	
n = 1 (2008)	0.7	0.4	1.5	1.9	1.6	0.9	0.6	0.1	0.6	1.1	1.3

Table 14.

Econometric results for Gazprom gas production functions in Tyumen region over 1993–2008 based on history data (number of observations = 16)[24 (p. 12, 16)]

Production function	Coefficients(t-statistics)				R^2	F-test for 1st order residual autocorrelation	Shapiro–Wilk test (W) for normal distribution of residuals
	α_0	α_1	$1-\alpha_1$	α_2			
With time trend $\frac{\Gamma_t}{L_t} = e^{\alpha_0}\left(\frac{\bar{\Phi}_{t-1}}{L_t}\right)^{\alpha_1} e^{\alpha_2 t}$	166 (50)	0.91 (35)	0.09	-0.84 (-50)	0.996	F-ст. = 4.10 [p = 0.07]	W = 0.93 [p = 0.27]
With cumulative production up to year t - 1 $\frac{\Gamma_t}{L_t} = e^{\alpha_0}\left(\frac{\bar{\Phi}_{t-1}}{L_t}\right)^{\alpha_1} e^{\alpha_2 G_{1963,t-1}}$	-1.33 (-7)	0.91 (31)	0.09	$-1.66 \cdot 10^{-7}$ (-46)	0.995	F-ст. = 5.61 [p = 0.04]	W = 0.92 [p = 0.18]
With cumulative production up to year t - 2 $\frac{\Gamma_t}{L_t} = e^{\alpha_0}\left(\frac{\bar{\Phi}_{t-1}}{L_t}\right)^{\alpha_1} e^{\alpha_2 \cdot G_{1963,t-2}}$	-1.39 (-7)	0.90 (31)	0.10	$-1.65 \cdot 10^{-7}$ (-45)	0.994	F-ст. = 5.13 [p = 0.04]	W = 0.92 [p = 0.18]
1993-2008 average annual wages and social payments share in gas production costs for major Gazprom gas producers in Tyumen region*	0.10						

* Computations based on Gazprom statistics.
Source reference: 24, p. 13; 26, p. 93; 27, p. 100; 28, p. 118; 29, p. 123; 30, p. 271; 31, p. 277; 32, p. 245; 33, p. 308; 34, p. 315.

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