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CONSTRUCTION OF THE DYNAMIC INPUT-OUTPUT MODEL OF THE RUSSIAN ECONOMY WITH A HUMAN CAPITAL BLOCK

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Introduction

This paper provides a brief description of the extended dynamic input-output model with a human capital block, based on the input-output model from the KAMIN system (the System of Integrated Analyses of Interindustrial Information) developed at the Institute of Economics and Industrial Engineering of the Siberian Branch of the Academy of Sciences of the Russian Federation and at the Novosibirsk State University. The paper also presents some calculations and analysis of the derived results. The obtained results are the base for future calculations with the extended dynamic input-output model to forecast the Russian economy's economic development more efficiently.

1. The model used

The basic DIOM (the dynamic input-output model), which was extended by including a human capital block, was first described by Pavlov & Baranov (1994). Later it has been developed in several directions including a version of the model with fuzzy parameters (Baranov, Pavlov, & Pavlov, 2009). Full description of the extended model is presented in (Baranov, Pavlov, & Slepenkova, 2017).

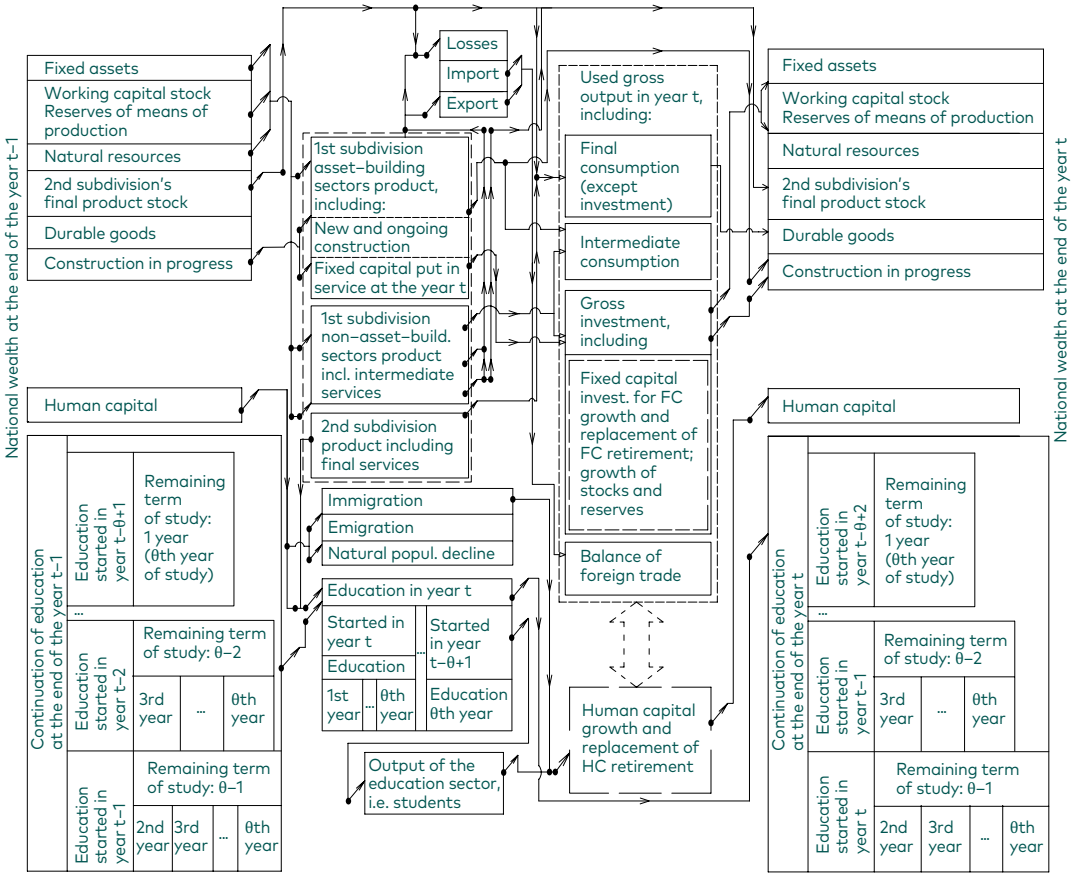

Fig. 1. National wealth reproduction.

The model is based on the theoretical scheme of the national wealth formation taking into account the reproduction of human capital. The scheme (Fig. 1) is developed by the authors in (Baranov, Pavlov, & Slepenkova, 2017).

The model includes n sectors. Among them $1 \le j \le k$ can be defined as asset-building sectors, $k < j \le (\tilde{\imath} + k)$ as sectors, which produce human capital, $(\tilde{\imath} + k) < j \le m$ as non-asset-building sectors in the first subdivision, and $m < j \le n$ as non-asset-building sectors in the second subdivision.

The extended model uses the following parameters:

m – the number of sectors in the first subdivision ($m < n$);

k – the number of asset-building sectors;

$\tilde{\imath}$ – the number of human capital investment types;

T – years of the forecast period.

Along with the parameters of the basic model, the extended DIOM requires the following parameters:
$h_{ij}(t)$ – human capital-output ratio, with human capital of type i (according to the investment type) and total output in sector j;
$\tilde{\theta}_{ij}$ – lag of type i human capital formation in sector j;
τ_{ij} – a year within the education or medical treatment process of human capital in sector j, so that $0 \le \tau \le \tilde{\theta}_{ij}$;
$\tilde{k}_{ij}(t)$ – replacement rate of human capital of type i in sector j at time t;
$BH_{ij}(t)$ – output of the education sector, i.e. students with i level of education who get a job at time t. They are included in new human capital of type i in sector j;
$H_{ij}(t,t+\tau)$ – human capital investment (of type i in sector j at time t) into the output of students for time $t+\tau$;
$H_{ij}(t)$ – human capital investment of type i in sector j at time t;
$HC_{ij}(t)$ – amount of human capital of type i in sector j by the end of time period t;
$NH_{ij}(t)$ – human capital (of type i in sector j) remaining in the education process (including "cultural education" and receiving medical services) by the end of time period t.

The basic model is extended with the additional equations that allow modeling human capital reproduction.

Output of students with i level of education is $BH_{ij}(t)$ determined by the human capital investment of type i in sector j:

$$BH_{ij}(t) = \sum_{\tau=0}^{\tilde{\theta}_{ij}-1} H_{ij}(t-\tau, \boldsymbol{t}) = \sum_{\tau=0}^{\tilde{\theta}_{ij}-1} \tilde{\eta}_{ij}(\tau) \cdot H_{ij}(t-\tau),$$

$$i = k+1, \dots, \tilde{l}; j = 1, \dots, n \qquad (1)$$

where $H_{ij}(t-\tau,t)$ is a total amount of human capital investment of type i deposited in $t-\tau$ time period and provided for type i human capital at time t in sector j; $\tilde{\eta}$ is the share of the previous years $(t-\tau)$ investment in operation of the human capital of the same type in sector j in t time period with the following conditions:

$\tilde{\eta}_{ij} \in [0,1]$ for any τ;

$$\sum_{\tau=0}^{\tilde{\theta}_{ij}-1} \tilde{\eta}_{ij}(\tau) = 1.$$

$H_{ij}(t-\tau)$ is human capital investment deposited in $t-\tau$ time period and $\tau \ge 0$, as it allows to take into account some short educational

programs (less than a year, e. g. qualification courses) and a shorter investment lag in case of medical treatment.

The necessary amount of human capital investment for human capital output in $t + \tau$ time period is defined as follows:

$$H_{ij}(t, \boldsymbol{t} + \boldsymbol{\tau}) = \sum_{\tau=0}^{\tilde{\theta}_{ij}-1} \tilde{\mu}_{ij}(\tau) \cdot BH_{ij}(t + \tau),$$
$$i = k + 1, \dots, \tilde{l}; \;\; j = 1, \dots, n \qquad (2)$$

where t is a year of investment and $(t + \tau)$ is a year of students output, as well as "output" of people who underwent a course of medical treatment and can return to work, i.e. $(t + \tau)$ is a year of human capital output.

$\tilde{\mu}_{ij}(\tau)$ stands for a ratio showing a share of human capital output in sector j in time period $(t + \tau)$ formed due to investment of type i in time period t so that

$\tilde{\mu}_{ij}(\tau) \in [0,1]$ for any τ;

$$\sum_{\tau=0}^{\tilde{\theta}_{ij}-1} \tilde{\mu}_{ij}(\tau) = 1.$$

Construction-in-progress human capital of type i in sector j (i. e. people remaining in the education process or medical treatment process) $NH_{ij}(t)$ can be calculated as follows:

$$NH_{ij}(t) = NH_{ij}(t-1) - \sum_{\tau=1}^{\tilde{\theta}_{ij}-1} H_{ij}(t - \tau, \boldsymbol{t}) + \sum_{\tau=1}^{\tilde{\theta}_{ij}-1} H_{ij}(t, \boldsymbol{t} + \boldsymbol{\tau})$$
$$= NH_{ij}(t-1) - \sum_{\tau=1}^{\tilde{\theta}_{ij}-1} \tilde{\eta}_{ij}(\tau) H_{ij}(t - \tau) +$$
$$+ \sum_{\tau=1}^{\tilde{\theta}_{ij}-1} \tilde{\mu}_{ij}(\tau) BH_{ij}(t + \tau), \quad i = k + 1, \dots, \tilde{l}; \; j = 1, \dots, n \qquad (3)$$

The total amount of human capital of type i in sector j by the end of time period t is determined as follows:

$$HC_{ij}(t) = BH_{ij}(t) + HC_i(t-1)\left(1 - \tilde{k}_{ij}(t)\right),$$
$$i = k + 1, \dots, \tilde{l}; \;\; j = 1, \dots, n \qquad (4)$$

Labor resources limits are defined by the system of inequalities:

$$\sum_{j=1}^{n} c_{kj}(t) x_j(t) \le L_k(t), \qquad k = 1, \dots, l; \;\; j = 1, \dots, n \qquad (5)$$

where $c_{kj}(t) = G(HC_{ij}(t))$ depends on the size of the human capital, $c_{kj}(t)$ is the labor intensiveness ratio of sector j for type k of labor resources in time period t.

Along with the basic constraints and equations described above, an additional constraint for human capital should be added:

$$\sum_{j=1}^{n} h_{ij}(t)x_j(t) \le HC_i(t)\,, \qquad i = k+1, \dots, \tilde{l};\ \ j = 1, \dots, n \tag{6}$$

where $x_j(t)$ is the domestic output in sector j at time t.

The same way as in the basic model, Ω defines a trajectory of the economic system development $x_j(t)$ under all basic constraints of the model as well as human capital restrictions in (1)–(5) described above. Defining the trajectory Ω with given parameters (e. g. amount of human capital, human capital-output ratio, etc.) for each moment from the [1; T] time period allows to get the system of economic development parameters (output, human capital investment, human capital output, etc.).

The optimization problem can be described as follows:

$$\sum_{t=1}^{T}\sum_{j=1}^{n} f_j(t)\, x_j(t) \Rightarrow max, \qquad x \in \Omega$$

with constraints described above and $f_j(t)$, which stands for weight coefficients of the production in sector j in the target function of the economic system.

2. Calculations and results

It is necessary to prepare and calculate some data including human capital investment, output of human capital in value terms, amount of human capital, and others for use in the extended model.

Human capital (HC) investment in value terms is treated as a sum of government and private expenditures on education, healthcare and culture.

Government and private expenses used for calculations were taken from the Federal State Statistics Service (www.gks.ru), Ministry of Finance of the Russian Federation (Brief information on execution of the consolidated budget of the Russian Federation), and The Federal Treasury (the information on execution of budgets of budgetary system of the Russian Federation) databases. The analyzed time period is from 1992 to 2015. As the data are given in current values, we used a price

Table 1

Human Capital Investment (Prices of 2015), bln. Rubles

Year	Education expenses		Healthcare expenses		Culture expenses		HC investment
	Government	Private	Government	Private	Government	Private	
1992	11 722.8	177.7	3 467.2	243.6	1306.3	121.6	17039.2
1993	4 950.4	106.3	1 514.4	104.1	452.9	42.8	7170.9
1994	2 945.9	92.6	1 398.1	145.9	366.5	42.2	4991.1
1995	1 983.1	97.0	1 130.9	191.9	420.7	54.8	3878.3
1996	1 954.6	140.5	1 128.6	218.8	383.7	71.2	3897.4
1997	2 143.6	221.0	1 280.5	270.1	432.6	93.8	4441.6
1998	1 604.6	275.8	875.9	280.5	243.5	70.8	3351.0
1999	1 772.5	339.9	998.2	318.2	288.2	82.3	3799.3
2000	1 928.4	373.0	1 201.5	341.4	356.5	88.0	4288.7
2001	1 822.6	367.4	1 159.8	362.8	311.9	101.6	4126.0
2002	1 972.5	351.1	1 241.1	375.8	336.5	111.4	4388.,5
2003	1 874.2	376.1	1 192.5	386.3	341.0	137.5	4307.5
2004	1 986.2	408.7	1 290.2	426.6	335.1	154.0	4600.8
2005	2 217.8	422.3	2 339.4	462.8	448.1	155.1	6045.5
2006	2 518.0	468.2	2 486.0	493.1	475.3	157.1	6597.7
2007	2 878.9	518.0	3 133.9	513.5	541.9	129.0	7715.1
2008	3 077.3	531.8	3 015.9	523.5	591.8	126.9	7867.4
2009	2 955.1	514.0	2 830.6	519.3	555.4	129.2	7503.6
2010	2 903.9	500.0	2 699.5	527.1	557.2	129.2	7316,9
2011	3 147.6	489.9	3 010.2	547.7	574.9	126.8	7897.1
2012	3 363.4	498.2	3 266.4	583.7	593.5	128.3	8433.5
2013	3 516.1	546.8	3 078.2	659.2	582.9	138.3	8521.5
2014	3 347.1	536.2	3 095.6	689.2	565.3	137.8	8371.3
2015	3 034.6	539.7	3 115.9	701.1	521.3	138.9	8051.5

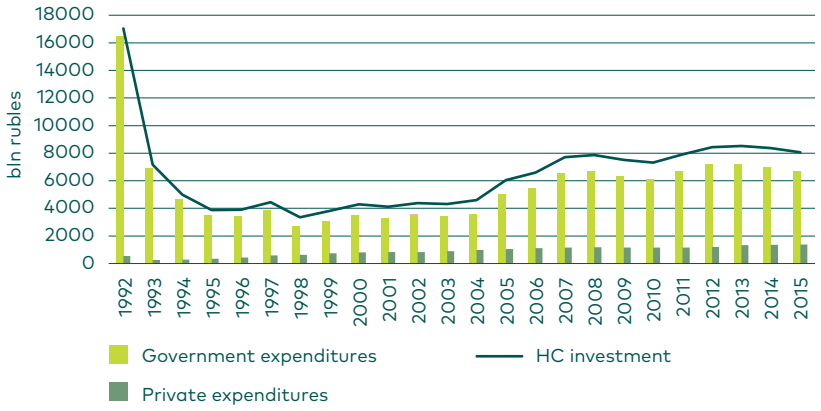

Fig. 2. Human capital investment (prices of 2015), bln rubles.

index for services, a price index for paid services of cultural institutions, and a price index for healthcare services to get the investment in constant prices.

Table 1 shows human capital investment by type in constant prices. The share of government expenditures on culture were stable enough and averaged 9 % of total government expenditure. Government expenditure on education and healthcare showed a similar trend up to 2005. From 1992 to 2005, the share of government healthcare expenses averaged 55 % of government education expenses, but in 2005 the amount of healthcare expenses became almost the same as the amount of government expenditures on education.

Figure 2 describes the dynamics of human capital investment, including the government and private components. The share of private expenses in the total amount of expenditures averaged 15 %. The maximum share runs up to 22 % in 2004. From 1992 to 1995 human capital investment fell dramatically, mostly because of the serious shrinkage in government expenditures on HC. Despite the upward trend after 1995 and significant economic and technological development, more than 20 years later the top level of investment, 17 trillion ruble in constant prices, has not been reached.

As Fig. 3 shows, there was a significant decrease of private expenses from 1992 to 1993 that is likely the result of the crisis in the 1990s in the Russian economy. However, afterwards, the steady positive trajectory in private investment in HC can be seen. The greatest increase takes place in healthcare investment: from 1993 to 2015 it increased 6.7 times. Education expenses increased 5 times and culture expenses increased more than 3 times.

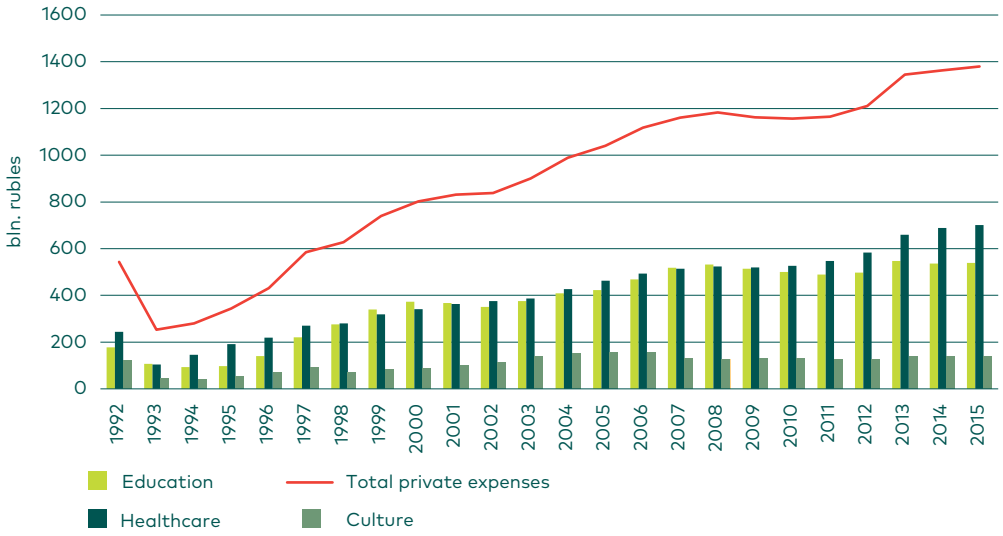

Fig. 3. Private human capital expenses (prices of 2015), bln rubles.

To calculate the output of human capital in value terms, we can either use the DIOM extended by the authors (using the equations described above), or calculate average costs of output per capita and multiply the result by the output of students.

It is not hard to calculate the output in the education sector, but it is difficult to define output for the healthcare sector, because even a minor ailment, which requires medical treatment, can seriously influence the labor productivity level. It significantly influences the medical treatment time as well, hence the HC investment lags in the healthcare sector can vary a lot.

The culture sector is also tricky, as one cannot measure the exact influence of cultural development on people, though it definitely influences their mentality and therefore labor productivity. In addition, lags in the culture sector can be enormous; the cultural development effects can be accumulated by decades. However, we can definitely consider that healthcare and culture expenditures do influence the output of the education sector, as it provides the socio-cultural environment for the education process.

To calculate the output of students in value terms, the 4-year lag was defined. It was chosen mostly because of the 4-year bachelor's degree programs, as the output mostly consists of the bachelors graduated. The average expenses for one student (h_t) are defined as follows:

$$h_t = \frac{\sum_{\tau=t-\tilde{\theta}+1}^{t} H(\tau)/_t}{\sum_{\tau=t-\tilde{\theta}+1}^{t} BB^H(\tau)/_t} = \frac{\sum_{\tau=t-\tilde{\theta}+1}^{t} H(\tau)}{\sum_{\tau=t-\tilde{\theta}+1}^{t} BB^H(\tau)} \quad (7)$$

where $H(\tau)$ is human capital investment in year t in billlion rubles, and $BB^H(\tau)$ is the output of students (number of persons, in thousands). HC investment includes education, healthcare and culture expenses; output of students includes graduates with vocational and higher education. The way we calculate the average expenses for one student allows us to take into account the previous years' investments, which influence the final students' output.

To calculate students' output in value terms it is necessary to multiply the average expenses by the number of graduates:

$$BH(t) = h_t \cdot BB^H(t) \quad (8)$$

where $BH(t)$ is the output of human capital in value terms, $BB^H(t)$ is the number of students, and h_t are the average expenses for one graduate.

The results are presented in Table 2.

To calculate the accumulated human capital amount, we are using the perpetual inventory method. Human capital by the end of the year t ($HC(t)$) is defined as follows:

$$HC(t) = BH(t) + HC(t-1)(1-\tilde{k}) \quad (9)$$

where $\tilde{k}$ is a replacement rate of human capital. The average time of work of a person is defined as 30 years, which gives a replacement rate of 3 %. The first year human capital amount is calculated as follows:

$$HC(1) = BH(1)\frac{1+g_{BH}}{g_{HC}+\tilde{k}} \quad (10)$$

where g_{HC} is the growth rate of the volume of human capital, and g_{BH} is the growth rate of human capital output. We assume the growth rate of human capital volume to be the same as the growth rate of human capital investment. We also use the average growth rate to make the calculations presented in Table 3 and Fig. 4.

It can be seen that from 1996 to 2015 HC investment doubled, HC output increased 1.7 times, but the total amount of accumulated human capital raised no more than 1.4 times. While the growth rate of HC output averaged 3 %, the growth rate of human capital amount is 1.7 %. The output does not cover HC retirement efficiently, that means we need more HC investment to increase the accumulation of human capital, as it is an important factor of economic growth and development.

To show the influence of HC on productivity level, the regression equation was estimated with an index of labor productivity growth (*Productiv*) as a dependent variable and an increase in investment in human capital (*Inv_HC*) and its first lag (*HC1*) as explanatory variables:

Table 2

Output of Human Capital in Value Terms (Prices of 2015)

Year	Output of students, number of persons, in thousands	Human capital investment (education, healthcare and culture), bln. rubles	Average expenses for one graduate (education, healthcare and culture), thousand rubles	Output of human capital, bln. rubles
1992	1 932.60	17 039.23		
1993	1 869.10	7 170.89		
1994	1 819.50	4 991.15		
1995	1 717.80	3 878.34	4 507.37	7 742.77
1996	1 745.90	3 897.42	2 787.61	4 866.88
1997	1 799.50	4 441.61	2 429.66	4 372.17
1998	1 834.60	3 350.96	2 193.40	4 024.02
1999	1 894.10	3 799.33	2 129.38	4 033.26
2000	1 977.20	4 288.73	2 115.89	4 183.55
2001	2 087.40	4 126.04	1 997.24	4 169.03
2002	2 255.40	4 388.46	2 021.23	4 558.67
2003	2 399.25	4 307.48	1 962.41	4 708.30
2004	2 487.30	4 600.79	1 887.76	4 695.42
2005	2 538.60	6 045.51	1 998.05	5 072.25
2006	2 634.20	6 597.65	2 142.43	5 643.58
2007	2 690.00	7 715.09	2 411.48	6 486.88
2008	2 634.30	7 867.37	2 688.90	7 083.36
2009	2 610.80	7 503.61	2 808.48	7 332.39
2010	2 620.50	7 316.88	2 880.27	7 547.74
2011	2 477.60	7 897.14	2 957.01	7 326.30
2012	2 367.00	8 433.50	3 091.65	7 317.93
2013	2 166.00	8 521.50	3 340.12	7 234.70
2014	2 080.20	8 371.26	3 654.62	7 602.33
2015	2 114.50	8 051.46	3 824.34	8 086.57

Table 3

Accumulated Human Capital Calculation

Year	Human capital investment, bln. rubles	Output of human capital, bln. rubles	Growth rate of human capital investment	Growth rate of human capital output	Human capital, bln. rubles	Growth rate of human capital
Average	5 980.96	5 817.27	0.015	0.03		0.017
1993	7 170.89		−0.58			
1994	4 991.15		−0.30			
1995	3 878.34		−0.22			
1996	3 897.42	4 866.88	0.00		103 108.92	
1997	4 441.61	4 372.17	0.14	−0.10	104 044.12	0.01
1998	3 350.96	4 024.02	−0.25	−0.08	104 600.00	0.01
1999	3 799.33	4 033.26	0.13	0.00	105 146.59	0.01
2000	4 288.73	4 183.55	0.13	0.04	105 825.25	0.01
2001	4 126.04	4 169.03	−0.04	−0.00	106 466.77	0.01
2002	4 388.46	4 558.67	0.06	0.09	107 476.56	0.01
2003	4 307.48	4 708.30	−0.02	0.03	108 602.31	0.01
2004	4 600.79	4 695.42	0.07	−0.00	109 677.65	0.01
2005	6 045.51	5 072.25	0.31	0.08	111 093.98	0.01
2006	6 597.65	5 643.58	0.09	0.11	113 034.43	0.02
2007	7 715.09	6 486.88	0.17	0.15	115 753.49	0.02
2008	7 867.37	7 083.36	0.02	0.09	118 978.40	0.03
2009	7 503.61	7 332.39	−0.05	0.04	122 344.85	0.03
2010	7 316.88	7 547.74	−0.02	0.03	125 814.43	0.03
2011	7 897.14	7 326.30	0.08	−0.03	128 946.91	0.02
2012	8 433.50	7 317.93	0.07	−0.00	131 966.61	0.02
2013	8 521.50	7 234.70	0.01	−0.01	134 802.42	0.02
2014	8 371.26	7 602.33	−0.02	0.05	137 911.34	0.02
2015	8 051.46	8 086.57	−0.04	0.06	141 400.87	0.03

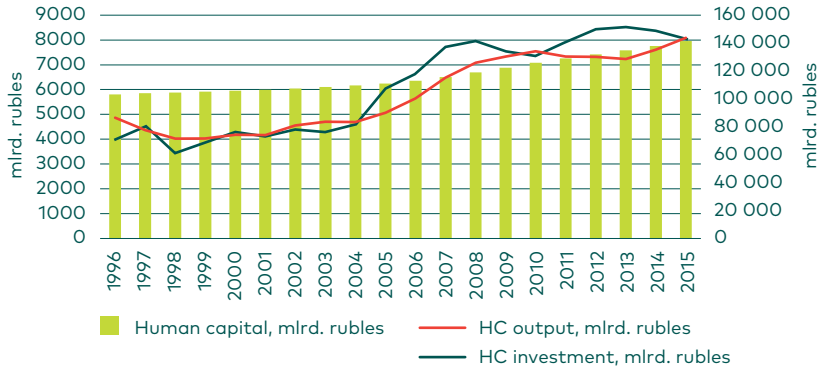

Fig. 4. Human capital, mlrd rubles.

Table 4

Labor Productivity and Human Capital Investment

Year	Index of labor productivity growth	Growth rate of human capital investment
1993	–7.2564	–57.9154
1994	–10.1449	–30.3971
1995	–13.8484	–22.2956
1996	–2.9369	0.4918
1997	3.3510	13.9630
1998	–3.8438	–24.5554
1999	5.6358	13.3803
2000	9.3587	12.8814
2001	4.3424	–3.7936
2002	3.7953	6.3603
2003	6.5248	–1.8453
2004	6.4855	6.8092
2005	5.7639	31.4016
2006	7.5377	9.1331
2007	7.1865	16.9370
2008	4.5495	1.9737
2009	–6.2736	–4.6237
2010	4.1352	–2.4885
2011	10.9756	7.9304
2012	3.1497	6.7918
2013	1.3512	1.0435
2014	4.0702	–1.7631
2015	–3.6904	–3.8202

$$Productiv = c0 + c1 \cdot Inv\_HC + c2 \cdot HC1. \quad (11)$$

Other lags were not significant at the 5 % level. The data used are presented in Table 4.

The results of estimation of the regression equation showed that all of the explanatory factors are significant. Some tests of the model had proved the significance of the model as well. The estimated equation is shown as follows:

$$Productiv = 2.1 + 0.22 \cdot Inv\_HC + 0.13 \cdot HC1. \quad (12)$$

It indicates the direct interdependence of labor productivity level and human capital investment.

Conclusions

Some of the calculations made show an important influence of human capital and human capital investment on economic growth and development. At the same time, the calculations are showing some problems we have, including lack of necessary investment and slow growth rates of important economic activities. Our future research and calculations with the extended dynamic input-output model will give more detailed information, including inter-industry information of human capital reproduction. Finally, all the information will be included in the model to forecast Russian economic development and to estimate necessary levels of investment and human capital to reach the target growth rate of the economy.

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