Combined Digital Economic-Epidemic Model for the Evaluation of Economic Results of Several Scenarios of Quarantine Measures

Ivan D. Grachev1(✉), Dmitry I. Grachev2, Sergey N. Larin1, Natalija V. Noack1, and Nina M. Baranova3

1 Central Economics and Mathematics Institute RAS, Moscow, Russia
idgl9@mail.ru, n.noack@mail.ru, sergey77707@rambler.ru
2 Department of Physics, Department of Biophysics, Moscow State University, Moscow, Russia
dimitril995@yandex.ru
3 Peoples’ Friendship University of Russia (RUDN University), Moscow, Russia
baranova_nm@pfur.ru

Abstract. Purpose: Substantiation of the selection of the potential option of the implementation of quarantine measures and of the obtaining of evaluations of its potential economic consequences for Moscow on the basis of the use of instruments of the combined digital economic-epidemic model, developed by authors.

Methods: In order to carry out the research the modified SIR-model was used as the basic epidemic one. As the economic growth model was used the model of probability of mixed economic systems, developed by authors. The consolidation of such models to its lowest terms allowed to form the combined digital economic-epidemic model. As basic ones were considered three potentially possible options for the implementation of quarantine measures. On the basis of the model, developed by authors, were developed feasibility studies for each of three options of quarantine measures. While carrying out calculations as initial terms was adopted the dynamics of the daily accrual of people, infected with COVID-19 for the week between 01.04 and 08.04.2020.

Result: On the basis of the combined digital economic-epidemic model were determined possible economic consequences at the implementation of basic options of quarantine measures, feasibility studies were provided, its scientific analysis has been performed with the substantiation of the development of one of considered options. As most optimal option of the implementation of quarantine measures B option was selected.

Conclusion: The offered model and settlements, performed on its basis, can be applied in all regions of Russia in order to select the potential option of the implementation of quarantine measures and of the evaluation of possible economic consequences for each region. This is a universal model. With it can be studied events of all epidemiologic periods and world regions.

Keywords: Coronavirus pandemic · Combined digital economic-epidemic model · Quarantine measures · Implementation options · Evaluation of economic consequences
1 Introduction

Since the end of February 2020 and till the present time Russian economics are heavily influenced by two negative factors at once–drastic spreading of the COVID-19 pandemic and its impact on both Russian and world economics and of slumping oil prices. According to evaluations of some economists the cost of quarantine measures, implemented in Russia for the fighting against COVID-19 makes 2–3% of the GDP of the country. For other countries Economic Stimulus Index gives following evaluations of economic consequences of the implementation of quarantine measures by 01.04.2020: USA– 10.5% of the GDP, Australia– 9.7%, Canada– 6%, Japan– 4.9%, Great Britain– 2.5% (Rosbalt, 2020).

The modern dynamics of the growth of the number of registered people, infected with coronavirus, corresponds to projected values, obtained on the basis of the digital model, offered by authors in the work (Grachev et al., 2020). At the initial stage of the development of the epidemic by analogy with the overwhelming number of other countries the situation, on the practical level, is, has been brought to the average daily growth of infected people at the 20% level by such measures as “self-isolation” and “social distancing” (Chowdhury et al., 2020). This does not lift the potential opportunity for the development of the explosive path of the epidemic with the exponential speedup of the number of infected persons (Riou and Althaus, 2020).

As a result of the epidemic explosion, when the number of daily registered coronavirus infected persons in Moscow achieved more than 10 thousand, authorities hardened quarantine measures. In this juncture it seems necessary to substantiate the selection of the potential option of the implementation of quarantine measures and to evaluate its possible economic consequences for Moscow, in a more detailed way than in the research (Grachev et al., 2011, 2020).

2 Materials and Method

Provided that the basic research of authors (Grachev I.D. and Grachev D.I., 2011; Grachev et al., 2020) have been used earlier in staffs for countermeasures against the coronavirus infection in some RF regions, and, provided the correspondence of model dynamics for $\beta = 0.2$ with real facts, it is necessary to analyze economic consequences of different options of the hardening of quarantine measures with use of the combined digital economic-epidemic model (Grachev et al., 2020; Edelstein-Keshet, 2005).

Provided the variety of options for the implementation of quarantine measures by regions (Pajouheshnia et al., 2017, 2020; Chowdhury et al., 2020; Verity et al., 2020; Zhao et al., 2020), as well as the determining character of the dynamics of the registration of coronavirus infected persons both by the phase and by the amplitude in the city of Moscow, the article will consider results, obtained on the basis of the application of the digital economic-epidemic model, developed by authors. It has been formed in order to carry out the research by means of the consolidation of the basic epidemic
model, when the modified SIR-model was used as such, as well as the model of probability of mixed economic systems, which has been used by authors as model, characterizing the economic growth. The article represents lowest terms of the combined digital economic-epidemic model in the form of the unified system of discrete equations (Hernán et al., 2020).

The use of this model never revokes the generality of evaluations. The work (Grachev et al., 2020) shows the model stability against changing initial terms, namely, against the initial numberedness of potentially infected persons, which varies considerably for each region (Asheim et al., 2020).

3 Results

The article considers Moscow as basic region – the largest world metropolis. At early stages of the development of the pandemic for the period of 25.03.2020–10.04.2020 the level of people, infected with the coronavirus in Moscow, was almost 2/3 of the daily growth from the total number of revealed infected people all over the country. Anyway, at this time period – by 13.05.2020–16.05.2020 it became practically twice less and approaches to 1/3 of the daily growth from the total number of revealed infected people all over the country (Fig. 1) (Rambler news, 2020).

![Fig. 1. Dynamics of COVID-19 for Moscow, the Moscow region and Russia Source: Rambler news, 2020.](image-url)

The general view of the combined digital economic-economic model with detailing of initial terms for the city of Moscow is as follows (Grachev et al., 2020):

$$\frac{dS(t)}{dt} = -\beta \times \frac{S(t) \times I(t)}{N}$$ (1)
\[
\frac{dI(t)}{dt} = + \beta \times \frac{S(t) \times I(t)}{N} - \gamma \times I(t) \tag{2}
\]

\[
\frac{dR(t)}{dt} = + \gamma \times I(t) \tag{3}
\]

\(S(t)\) – individuals, prone to the disease; \(S(0) = N \approx 3 \times 10^6\);
\(I(t)\) – individuals infected and able to spread infection;
\(R(t)\) – individuals, «withdrawn» because of the convalescence or death;

\[
\bar{A}_{i+1} = \bar{A}_i + \text{diag}(\bar{\xi}_i) \times \bar{A}_i - \langle \bar{\xi}_i, P \rangle \times \bar{A}_i \tag{4}
\]

\(\bar{A}_i\) – vector of gross productions (capitalizations) of economic system agents.

All other symbols and ultimate simplifications (1)–(4) have been made with the assumption of fully identic agents and endless resources, as well as assuming in a first approximation the uniform suppression of all agents by the quarantine (Grachev et al., 2020).

For Moscow, provided stable and uncooperative residents we take \(N_0\) as 3 mln people, \(\beta_0 = 0.2\), what approximately corresponds to current rates of the epidemic.

\(I(0) = 1000, R(0) = 0\), the cost of the treatment of one patient, provided that not less than a half of patients have undergone the treatment at home, monitored by physicians. We adopt this value to perform following calculations in the amount of 30 thousand rub a day.

In itself the combined digital economic-epidemic model, developed by authors, can be used for the evaluation of possible economic consequences in the context of three antipodal options of the implementation of quarantine measures (Zambrano, 2017; Magnusson et al., 2020):

A. Suppression of the current intensiveness of contacts to «almost Wuhan» level for 1 month (28 days). The raw estimation of Wuhan data is \(\beta_k \approx 0.05\);

B. Full division of \(N_0\) into cells by \(m\) people, each of which can contain or not contained diseased persons with full exclusion of contacts between cells for one month;

C. Integral reduction of the intensiveness of contacts twice from the current level from 3 months, as recommended by authors in the article (Grachev et al., 2020).

In fact one of three basic options of quarantine measures -A, B, C can be implemented, but the need for the modeling of combinations of such options depends on principal difference of results of the digital modeling by «clear» options (Makarov et al., 2007).

The Fig. 2 shows the dynamics of the growth of the numberedness of infected persons by days at the implementation of quarantine measures with the A option. Typical results of digital experiments by (1)–(4), represented for the implementation of A type quarantine measures (Fig. 2), to the initial peak and the phase difference of 60–70 days corresponds to the off-quarantine course of the epidemic with permanent \(\beta = 0.2\), i.e. with the daily growth of the number of infected persons approximately by 20% at the initial stage (about 1000 infected persons).
So, modeling results show that the implementation of the such kind of quarantine measures can be justified from the medical point of view for regions, which are dramatically late with preparatory antiepidemic measures (Chowdhury et al., 2020; Riou et al., 2020; Verity et al., 2020; Kucharski et al., 2020; Geloven et al., 2020).

The Fig. 3 shows the fragment of the Fig. 2 from the 1st to the 70th day. It illustrates the feasibility of the expectation of the second wave, namely, in China (Riou et al., 2020; Xu et al., 2020) and, consequently, the impossibility to return to the pre-quarantine level of the intensiveness of contacts during 3–12 months.

The Fig. 4 shows economic consequences of the severe 1 month option of the implementation of A type quarantine measures. The annual fall level, represented by the vertical axis, shows that with the any level of the starting intensiveness of contacts ($\beta = 0 \div 0.02$) the intermediate quarantine does not provide for any economic
advantages in comparison with the off-quarantine course of the epidemic. General integral evaluation of the annual economic recession for the implementation of this option of quarantine measures is about 6%.

The Fig. 5 shows the dynamics of the growth of the number of infected persons by days for the purpose of the implementation of the option of monthly quarantine measures of the B type.

Fig. 4. Dependence of the economic recession (vertical axis) from the time (days at the left horizontal axis) and of the initial intensiveness of contacts, where $\beta$ (right horizontal axis with $\beta (360) = 0.2$). Source: developed by authors

The Fig. 5 shows the dynamics of the growth of the number of infected persons by days for the purpose of the implementation of the option of monthly quarantine measures of the B type.

Fig. 5. Dynamics of the growth of the number of infected persons by days for the purpose of the implementation of the option of monthly quarantine measures of the B type. Source: developed by authors
With that it was assumed to divide the whole population into N/m cells with absolutely impermeable borders. In I(t) cells there is at least one patient at the moment of the fixation of quarantine measures (the B type).

In other cells (N/m–I(t)) there are no patients. In 28 days cells are opened with the restoration of the pre-quarantine intensiveness of contacts. In a detailed experiment m = 10, what is not critical.

As it fell out, this option of the implementation of quarantine measures of the B type is much worse than the option of the implementation of quarantine measures of the A type. Namely, with the preservation of the epidemic peak amplitude the phase difference is much less, approximately 20 days and is represented by the fragment of the Fig. 5 (Fig. 6). The Fig. 6 represent the fragment of the model 5 from the first to the 70th day. Practically, that means the integral inefficiency of the «confinement in barracks» at enterprises for 1 month.

The Fig. 7 represents economic consequences of the implementation of the severe 1 month option of quarantine measures of the B type. The Fig. 7 also illustrates the economic futility of quarantine measures of the B type. The integral decrease at yearend for the implementation of such option of quarantine measures will be approximately 8%, therefore, from both medical and economic positions this option is worse than the option of A type quarantine measures.
The Fig. 8 represents results of the modeling of the long term (1 year) decrease of the intensiveness of contacts twice from the achieved level $\beta_k = \frac{0.2}{2} = 0.1$.

From the medical point of view results (about 25 thousand patients maximum per amplitude) look more than good. It makes intuitive sense that this is referred to the selection in the model $t = 11$ days, as with that the average convalescence rate is about 9% patients a day. Anyway, the analysis of the real data for the RF, starting from 1000 patients (the statistics become authentic – Fig. 1), on drawing near the hinge point we are really moving to $t = 11$–12 days.

The Fig. 8 economic consequences of the implementation of the long term option of quarantine measures of the C type.
Its illustration shows the economic optimality of this option of quarantine measures ($\beta = 0.1$) during 3–12 months. With that it is expected that the annual integral downfall of economics will be about 2%. From the organizational point of view this strategy is easily implemented. It is enough to provide for the average daily growth of the number of infected persons less than 10%, what, provided about 9% of convalescents, guarantees the situation from the epidemic explosion. In its turn it allows to optimize the structure of the decrease of the average intensiveness of contacts, leaving the whole real sector in the working condition without any multiple days off.

Provided above results of the modeling for the (1)–(4) model for Moscow show the low efficiency of options of monthly quarantine measures of any achievable severity of A and B types, and, consequently, of any of its real combinations. With minimal epidemic results (phase shift of 30–50 days with the preservation of the epidemic amplitude) it causes catastrophic economic consequences.

Figures 8, 9 demonstrate acceptable results (economic-epidemic), when $\beta = 0.1$, what corresponds to the decrease of the intensiveness of contacts twice from the current level of the 20% of the average daily growth.

4 Conclusion

In conformity with the given target on the digital combined economic-epidemic model was analyzed the implementation of three basic options of quarantine measures on the basis of the real current data for the city of Moscow.

Was substantiated the inexpedience of the implementation of superhard options of one month quarantine measures of A and B types, which epidemically do not cause the achievement of significant indices, and, before everything, the effective resistance to the epidemic of the coronavirus.
It has been substantiated that the only option of the implementation of quarantine measures, acceptable by its economic-epidemic consequences, is the long term suppression of intensive contacts to the level, twice less than the current one, corresponding to 20% of the daily growth of infected persons of the C type.

The model, offered in the article, has been initially considered for dates of the beginning of the infection of regions of Russia WITH COVID-19, anyway, such model can be used also for any other time spans in conformity with initial terms of the model. Besides that, the model, built and time-tested at the example of Moscow, as of the world level metropolis, can be implemented both within frames of other large scale cities of Russia, as well as within frames of metropolises of other countries.

References

Rosbalt. Business. News (2020). https://www.rosbalt.ru/business/2020/04/08/1837079.html Accessed 08 Apr 2020
Grachev, I.D., Grachev, D.I., Larin, S.N., Noack, N.V.: Digital model of economically optimal antiepidemic restrictions. J. Econ. Entrepreneurship 14(2,115), 869–872 (2020)
Chowdhury, R., Heng, K., Shawon, M.S.R. et al.: Dynamic interventions to control COVID-19 pandemic: a multivariate prediction modelling study comparing 16 worldwide countries. Eur. J. Epidemiol. (2020) https://doi.org/10.1007/s10654-020-00649-w
Riou, J., Althaus, C.L.: Pattern of early human-to-human transmission of Wuhan 2019 novel coronavirus (2019-nCoV), december 2019 to January 2020. Eurosurveillance 25(4), 2000058 (2020)
Grachev, I.D., Grachev, D.I.: Stochastic market model. methods and econophysical instruments for the modeling of the economic progress. Germany, Saarbrucken: «Lambert», 340 p. (2011)
Edelstein-Keshet, L.: Mathematical Models in Biology. Society for Industrial and Applied Mathematics, pp. 242–254 (2005)
Pajouhesnia, R., Peelen, L.M., Moons, K.G.M., Reitsma, J.B., Groenwold, R.H.H.: Accounting for treatment use when validating a prognostic model: a simulation study. BMC Med. Res. Methodol 17(1), 103 (2017)
Pajouhesnia, R., Schuster, N.A., Groenwold, R.H.H., Rutten, F.H., Moons, K.G.M., Peelen, L. M.: Accounting for time-dependent treatment use when developing a prognostic model from observational data: a review of methods. Stat. Neerlandica 74(1), 38–51 (2020). https://doi.org/10.1111/stan.12193
Verity, R., Okell, L.C., Dorigatti, I., et al.: Estimates of the severity of coronavirus disease 2019: a model-based analysis. Lancet Infect Dis (2020). https://doi.org/10.1016/S1473-3099(20)30243-7
Zhao, X., et al. Incidence, clinical characteristics and prognostic factor of patients with COVID-19: a systematic review and meta-analysis. medRxiv, p. 2020.03.17.20037572 (2020)
Hernán, M.A., Hsu, J., Healy, B.: A second chance to get causal inference right: a classification of data science tasks. Chance. 32, 42–49 (2019). https://doi.org/10.1080/09332480.2019.1579578
Asheim, G.B., Mitra, T.: Characterizing sustainability in discrete time. Econ. Theory (2020). https://doi.org/10.1007/s00199-020-01250-8
Rambler news: Moscow authorities delineated liberalization terms (2020). https://news.rambler.ru/moscow_city/44184537-vlasti-moskvy-oboznachili-sroki-smyagcheniya-mer-ogrаниcheniya/?utm_source=head&utm_campaign=self_promo&utm_medium=news&utm_content=news Accessed 16 May 2020

Zambrano, A.: Motivating informed decisions. Econ. Theory. 67, 645–664 (2019) https://doi.org/10.1007/s00199-017-1087-3

Magnusson, M., Jonsson, L., Villani, M.: DOLDA: a regularized supervised topic model for high-dimensional multi-class regression. Comput. Stat. 35, 175–201 (2020). https://doi.org/10.1007/s00180-019-00891-1

Grachev, I.D., Larin, S.N., Sokolov, N.A.: Application of modern digital instruments for the selection of the strategy of the development of economical entities. J. Econ. Entrepreneurship 14(1,114), 1132–1136 (2020)

Makarov, V.L., Bakhtizin, A.R., Sulakshin, S.S.: Application of Numerical Models in the Public Administration. Center of the Problem Analysis and of the State Administrative Design. Scientificexpert, Moscow vol. 2007, p. 302 (2007)

Kucharski, A.J. et al.: Early dynamics of transmission and control of COVID-19: a mathematical modelling study. Lancet Infect Dis 2020 (2020)

van Geloven, N., Swanson, S.A., Ramspek, C.L. et al.: Prediction meets causal inference: the role of treatment in clinical prediction models. Eur. J. Epidemiol. (2020)https://doi.org/10.1007/s10654-020-00636-1

Xu, S., Li, Y.: Beware of the second wave of COVID-19. Lancet 395(10233), 1321–1322 (2020)

Baranova N.M. Some estimates of human capital and its role in the economic development of Russia. RUDN J. Econ. 26(4), 559–569 (2018). https://doi.org/10.22363/2313-2329-2018-26-4-559-569