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How Do Economic Activities Spur the COVID-19 Pandemic in Russia? A Dynamic Panel Data Analysis*

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Abstract: Russia is one of the few countries in the world that has opted for almost no policy measures involving the strong suppression of economic activity in the face of the epidemic disaster brought about by the new coronavirus (COVID-19). This makes Russia a valuable subject of social experiments through which the association between economic activity and the spread of the virus can be explored. This paper presents a dynamic panel data analysis to examine the extent to which different types of economic activity contribute to the spread of COVID-19 infection using monthly and quarterly panel data of Russian regions between March 2020 and April 2021. The results strongly supported our expectation that economic activities have a greater impact on the levels of COVID-19 transmission when they involve a larger number of inhabitants or stimulate greater consumption or social activities among citizens. It was also revealed that Russian regions vary greatly in terms of the routes that link economic activity to the spread of COVID-19. These results have important policy implications for current and future epidemic control.

JEL classification codes: C33; E32; I15; I18; R11

Keywords: COVID-19 pandemic, economic activity, dynamic panel data analysis, Russia

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1 Introduction

The new coronavirus (COVID-19) that broke out in China quickly spread throughout the globe, causing a major shock to the world economy from which the international community has not recovered yet. Needless to say, Russia, which shares long borders with China, has also fallen victim to this unprecedented pandemic crisis. However, the actual damage of the COVID-19 pandemic to the Russian economy in 2020 has been less serious than expected by the International Monetary Fund (IMF) and the Ministry of Economic Development of the Russian Federation, which, in June 2020, projected Russia's real gross domestic product (GDP) growth rate for 2020 to be -6.6% and -5.0%, respectively (IMF, 2020; Nihon Keizai Newspaper, June 4, 2020). In fact, according to the Federal State Statistics Service (Rosstat), Russia's real GDP growth rate for 2020 was limited to -2.7%. This surprised many experts, who had expected Russia to suffer a much more severe economic recession as a result of the COVID-19 crisis, similar to the one the country went through when serious macroeconomic shocks stemming from the global financial crisis sent the country's 2009 GDP growth rate plummeting to -7.8% (Adachi and Iwasaki, 2021). In its preliminary estimate, Rosstat reported the real GDP growth rate for 2021 to be 4.7%. This points to a relatively stable economic situation in 2021.

These unexpectedly favorable economic conditions in Russia by no means imply that the damage caused by the COVID-19 pandemic has been relatively mild in the country. With a total of 3,085,107 confirmed COVID-19 cases (210.2 per 10,000 inhabitants) as of the end of 2020, Russia earned the dubious distinction of being the fourth worst-hit country in the world in terms of cumulative cases for the year 2020, following the USA, India, and Brazil. A total of 56,144 Russian citizens (3.8 per 10,000 inhabitants) were officially reported to have died from COVID-19 infection in 2020. However, even Russian government officials dismiss the total official death toll as a substantial underestimate, and, based on a comparison of monthly death tolls before and after the coronavirus pandemic, Russia's true death toll from COVID-19 is estimated to be at a level similar to those found in Brazil and India (Arai and Shida, 2021). The studies of excess mortality by Kobak (2021) and Timonin et al. (2022) also strongly back up this possibility. In fact, by estimating excess death rates based on the trend-adjusted average, Timonin et al. (2022) reported that, in 2020, Russia had the highest excess mortality of the 37 high-income countries investigated.

This makes Russia one of the hardest hit countries in the world in terms of the human damage caused by the COVID-19 pandemic, as indicated by both total infections and death toll.

Despite this grave situation, the Russian economy's performance is stronger than those of advanced economies because its state policies have consistently emphasized the need to sustain domestic economic activity. Although this study will not go into full details and reasons for the COVID-19 containment measures employed by the Putin administration, their earliest versions involved successively implementing emergency control measures, including the declaration of paid non-working days that virtually served as a lockdown, to tackle the earliest phase of the COVID-19 outbreak when confirmed cases first appeared in the country. However, during the period from early May in 2020 when the outbreak was brought under control to late October in 2021 when lockdown measures were implemented again in the entire territory of the Russian Federation following a sudden increase in COVID-19 cases and deaths, the government implemented virtually no policy measures that could potentially hamper business operations or production/distribution activity. During this approximately 16-month period, the federal government delegated to the local governments the authority to decide on restrictive measures to be implemented to curb the spread of infection. Nevertheless, a set of policy measures implemented by the overwhelming majority of the constituent entities of the Russian Federation (i.e., republics, autonomous oblasts, autonomous okrugs, krais, oblasts, and federal cities) reflected their neutral stance with respect to economic activity.

The government's reluctance to hit the brakes on economic activity was clearly reflected in the livelihood and mindset of Russian people. In fact, both residents of and business travelers to Russia have uniformly pointed out that, even during the second wave of the epidemic (September 2020 to February 2021), companies in Moscow were only asked to do their best to allow their employees to work from home, and this request is now treated as a mere call for work-at-home (Saito, 2021). Commercial and eating establishments in Moscow City mostly went about business as usual (Mimura, 2021), and industries, farming, construction, and transportation businesses in Vladivostok remained largely unaffected by the COVID-19 pandemic (Khuziyatov, 2021). Simply put, the Russian government refused to threaten the livelihood of the people by imposing stringent economic restrictions to curb the spread of COVID-19, and the citizens, who more or less seemed to agree with the state policy, tried to go about their daily business as they did before corona.

This unique circumstance in Russia, where no policy measures were implemented to suppress economic activity to prevent the spread of the virus, presents us with an opportunity to examine the extent to which different types of economic activities can contribute to the person-to-person transmission of COVID-19. This is an important topic that is extremely difficult to address elsewhere in the world, where economic activity has been strongly suppressed through lockdowns and other emergency control measures, such as mobility and work restrictions. Several publications have already investigated the relationship between the COVID-19 pandemic and the Russian economy (Afanasiev and Ponomareva, 2020; Åslund, 2020; Connolly et al., 2020; World Bank, 2020; Davis, 2021; Dokhov and Topnikov, 2021; Ma et al., 2021; Singh et al., 2021). To the best of our knowledge, however, no studies have empirically examined how economic activity spurs the COVID-19 pandemic.

In this paper, with Russia presenting us with a valuable opportunity for a kind of social experiment that cannot be conducted anywhere else in the world, we examine the role of economic activity in the spread of COVID-19 by performing a unique dynamic panel data analysis of the Russian regions. More concretely, through such an empirical analysis, we try to elucidate three research questions: First, what types of economic activities specifically increase the person-to-person transmission of new coronaviruses? Second, what is the time lag structure of the effect of economic activity on the spread of COVID-19 infection? Third, are the trends observed throughout the Russian federation common to each region? Or do marked differences exist among regions from this viewpoint?

The remainder of this paper is organized as follows: In the next section, annual data for 2020 is used to explore the association between the COVID-19 pandemic and economic performance in the Russian regions. Section 3 describes the methodology and data used to examine the role of economic activity in the spread of COVID-19. Section 4 reports estimation results, and Section 5 presents major findings and concludes the paper.

2 COVID-19 pandemic and economic performance in 2020

This section uses data on COVID-19 case and death counts and economic performance in 2020 to explore the association between these two factors. The Russian federal government has announced the numbers of COVID-19 cases and deaths on a daily basis, with data on each of the constituent entities also being made widely available. Based on the data disclosed by the Russian government, the left four columns in **Table 1** show the total number of cases and deaths in the entire population and per 10,000 inhabitants in 2020 for the Russian Federation as a whole and for each of its federal districts and constituent entities. As shown at the bottom of this table, the mean and median numbers of COVID-19 cases (deaths) per 10,000 inhabitants in all 82 constituent entities (excluding Nenets, Khanty-Mansi, and Yamalo-Nenets due to the limited availability of data) were 216.7 (3.2) and 180.0 (2.7), respectively, with the standard deviation being as large as 126.8 (2.2), indicating notable regional variation in COVID-19 transmission levels.

Data on the economic performance of the Russian Federation as a whole and of each of its federal districts and constituent entities for 2020 was published by Rosstat, which shows rates of growth of five different economic performance measures (i.e., industrial production, agricultural production, fixed investment, housing, and the number of registered job openings) compared to the previous year. The right five columns in **Table 1** show these five economic performance measures. As shown in this table, industrial production, fixed investment, and housing suffered negative growth amidst the harsh economic environment across the entire federation. Agricultural production and the number of registered job openings, on the other hand, recorded positive growth of 1.5% and 16.6%, respectively. Although this finding confirms the robustness of agricultural production against the epidemic disaster, a considerable increase in the number of job openings in the face of an economic downturn implies the grave impact the population crisis has on the Russian labor market.

What makes Russia peculiar is that, while COVID-19 transmission levels vary by region, even greater regional variation can be observed in economic performance. In fact, overall, industrial production, fixed investment, and housing recorded negative growth in 2020; however, looking at each of the 82 constituent entities of the Russian Federation reveals that these three economic performance measures have flat or positive growth in 33, 33, and 42 constituent entities, respectively. Conversely, although agricultural production and the number of registered job openings recorded positive growth in Russia as a whole, the same economic performance measures suffered negative growth as compared to 2019 in 23 and 14 constituent entities, respectively. Regional variability in COVID-19 transmission levels and economic performance measures can be easily compared by using the coefficient of variation. If the coefficients of variation of the numbers of COVID-19 cases and deaths per 10,000 inhabitants are 0.6 and 0.7, respectively, those of industrial production, agricultural production, fixed investment, housing, and the number of registered job openings are -15.4, 4.3, -7.3, -22.9, and 2.2, respectively, which are far greater than the former two coefficients. These facts signify the presence of remarkable regional variation in Russia's economic performance in 2020.

The primary question of interest in the present study is whether there is a positive correlation between COVID-19 transmission levels and economic performance in the Russian regions. To answer this question, we adopted the number of COVID-19 cases per 10,000 inhabitants and the growth rate of industrial production as representative measures of COVID-19 transmission levels and economic performance, respectively, and split the constituent entities into octiles in **Figure 1**. As shown in Panel (a) of the figure, while the regions in which COVID-19 transmission levels remained relatively high throughout 2020 were concentrated in the Northwestern Federal District, Siberian Federal District, and Far Eastern Federal District, COVID-19 transmission levels remained relatively low in the constituent entities in the Volga Federal District and Ural Federal District. On the other hand, Panel (b) in the same figure shows that regions that maintained relatively good economic performance in 2020 were concentrated in the western part of Russia, namely, the North Caucasus Federal District, Southern Federal District, and Central Federal District. Thus, the findings presented in **Figure 1** do not confirm the expected association between COVID-19 transmission levels and economic performance.

Next, correlations between each of the five economic performance measures listed in **Table 1** and the number of COVID-19 cases per 10,000 inhabitants were examined except for the regions that showed extremely good or poor economic performance (outliers). The results are presented in **Figure 2**. The distribution in each panel of the figure does not clearly show an explicit correlation between COVID-19 transmission levels and economic performance. In fact, in each panel except the one that shows the relationship between COVID-19 transmission levels and agricultural production, the slope of the approximate line appears to be very flat. Furthermore, in all panels, the coefficient of determinants (R^2) of the approximate line shows an extremely low value.

Considering the possibility that the results presented in **Figure 2** could be flawed due to the exclusion of outliers and the use of a parametric approach that assumes normal distribution, another estimation was made by including all data and by using a non-parametric approach that is independent of the shape of the population distribution. Specifically, we computed Spearman's and Kendall's correlation coefficients (ρ (τ)) that represent the association between the number of COVID-19 cases per 10,000 inhabitants and each of the five economic performance indicators, namely, industrial production, agricultural production, fixed investment, housing, and the number of registered job openings; all turned out to be extremely small, as follows: -0.0308(-0.0210), 0.0685(0.0466), -0.0379(-0.0241), -0.0823(-0.0636), and -0.0010(-0.0068), respectively. The p values that indicate their statistical significance also turned out to be very low, namely, 0.785(0.785), 0.559(0.541), 0.737(0.754), 0.465(0.403), and 0.993(0.932), respectively. In other words, non-parametric tests also failed to detect any statistically significant relationship between COVID-19 transmission levels and economic performance in the Russian regions.

In **Table 1**, the excess death rates per 100,000 inhabitants estimated by Timonin et al. (2022) are also reported. For a robustness check, we computed Spearman's and Kendall's correlation coefficients between their estimates of excess mortality and each of the five economic performance indicators. We found that, except for agricultural production, the coefficients are not statistically significant, which is the same finding as in tests using the official statistics of COVID-19 cases and deaths.

To sum up, the univariate analysis using 2020 data presented in **Table 1** failed to capture clear positive correlations between COVID-19 case and death counts and economic performance in the Russian regions. This finding is not consistent with the notion that sustained or intensified economic activity in Russia would lead to the spread of infections through sustained or increased flow of people. In the following sections, we carry out a further verification using a more rigorous approach to determine whether this finding is true.

3 The role of economic activity in the spread of COVID-19: methodology and data

Frankly, there are several shortcomings in using the annual data in **Table 1** to verify the correlations between economic activity and COVID-19 infection. First, COVID-19 transmission levels as expressed by the number of COVID-19 cases per 10,000 inhabitants can be influenced a great deal by not only daily economic activities but also several other factors, including population age structure, population density, public awareness of health care and public hygiene, local government's administrative capabilities, social infrastructure, and geographical conditions. In order to determine the impact of economic activities on COVID-19 transmission levels, these factors, which are called “fixed effects” because they remain essentially unchanged over time (that is, since community transmission of COVID-19 became evident in March 2020 until now), must be simultaneously controlled for at the regional level.

Second, economic activities may not only influence COVID-19 transmission levels but also be influenced by them. This possibility cannot be denied in Russia, where virtually no policy measures have been implemented to slow economic activity to suppress the spread of infection. In the field of economics, the presence of an endogenous relationship is suspected when two factors, i.e., economic activity and COVID-19 transmission levels, interact with one another. This endogenous relationship must be properly addressed to ensure the validity of the econometric analysis.

Another important consideration that cannot be addressed with the annual data presented in **Table 1** is the state dependency of virus infection. The presence of state dependency implies that COVID-19 case and death counts during one period strongly depend on those during the previous period. It actually explains some typical patterns of virus infection, such as the exponential growth of COVID-19 in a short time period or sudden improvement in the COVID-19 situation. Another important consideration that needs to be addressed is the time-lag effect, which refers to the delay between the time of certain economic activities and the subsequent changes in COVID-19 infection levels. The well-known fact that individuals infected with COVID-19 develop symptoms approximately two weeks after exposure to the virus strongly implies the importance of giving analytic consideration to the time-lag effect when determining the role of economic activity in the spread of COVID-19.

To address the four issues mentioned above, namely, (a) fixed effects at the regional level, (b) endogeneity between economic activities and COVID-19 transmission levels, (c) state dependency of COVID-19 transmission levels, and (d) the time-lag effect economic activities have on COVID-19 transmission levels, we estimate a state-dependent dynamic model by using panel data of the Russian regions. In a state-dependent dynamic model, the lag term of a dependent variable (explained variable) is introduced to the right-hand side of the regression equation along with an independent variable (explanatory variable). Specifically, the following equation—where y_{it} is the COVID-19 transmission level in the i-th region during period t, μ is a constant term (intercept), x_{it-1} is the level of economic activity in the i-th region during period $t-1$, φ_i is the fixed effect for the i-th region, ε_{it} is a disturbance term, and γ and β are the parameters to be estimated—is a typical state-dependent dynamic model:

$$y_{it} = \mu + \gamma y_{it-1} + \beta x_{it-1} + \varphi_i + \varepsilon_{it}. \qquad (1)$$

Hereafter, the above equation (1) is referred to as model type A. This model introduces the 1-period lagged term of the independent variable (y_{it-1}) and regional fixed effects (φ_i) to the right-hand side of the equation to address issues (a) and (c); it employs a 1-period lagged value of the economic activity level (x_{it-1}) to not only address issue (d) but also avert or mitigate issue (b). In this regard, we emphasize that controlling for the lagged endogenous variable y_{it-1} is extremely useful for alleviating the omitted variable bias as well (Iwasaki and Kumo, 2020).

Taking account of the possibility that the 1-period time-lag structure assumed by model type A may not accurately represent the effect of economic activity levels on COVID-19 transmission levels, we also estimate model type B, which incorporates the lagged 3-period moving average of economic activity levels, and model type C, which simultaneously estimates 1-period, 2-period, and 3-period lagged values. The following regression equations (2) and (3) represent model type B and model type C, respectively:

$$y_{it} = \mu + \gamma y_{it-1} + \beta \sum_{j=t-1}^{t-3} x_{ij} \Big/ 3 + \varphi_i + \varepsilon_{it} \qquad (2)$$

$$y_{it} = \mu + \gamma y_{it-1} + \beta_1 x_{it-1} + \beta_2 x_{it-2} + \beta_3 x_{it-3} + \varphi_i + \varepsilon_{it} \qquad (3)$$

One major issue that must be considered in the estimation of a state-dependent dynamic model as formulated above is the correlation between the lagged endogenous variable and the disturbance term, both of which are included in the right-hand side of the equation. Furthermore, this type of dynamic model is plagued with endogeneity problems arising from a correlation between a disturbance term and a lagged endogenous variable (Wooldridge, 2010). The Arellano–Bover/Blundell–Bond system generalized method-of-moments (GMM) estimator can solve these problems. The system GMM estimator not only corrects for fixed-effects bias by taking the first difference from the model but also addresses endogeneity bias by using the lagged value of an endogenous variable as a valid instrumental variable (Shibata, 2016). The dynamic models presented herein use the Arellano–Bond test to examine the autocorrelation of the disturbance term and the Sargon test, which evaluates the overidentifying restrictions of the model, to determine whether the instrumental variable is orthogonal to the disturbance term. Generally, the valid use of a system GMM estimator requires that no second-order serial correlation be detected in the disturbance term by the Arellano–Bond test and that the Sargon test accepts the null hypothesis that overidentifying restrictions are valid in the model.

Next, we explain the data used in the estimation of the three models mentioned above. A single type of variable is far from sufficient to serve as a proxy for the economic activity levels in the Russian regions. Rather it is reasonable to assume that different economic activities can have widely varying impact on COVID-19 transmission levels depending on the state and extent of the economic activities in question. We expect that economic activities can have a greater impact on COVID-19 transmission levels when they involve a larger number of inhabitants or stimulate greater consumption or social activities among citizens. One way to verify this hypothesis is to regress COVID-19 transmission levels on a variety of economic activity variables. To this end, we adopted a total of 12 types of independent variables, which include (a) industrial production output, (b) construction output, (c) retail sales, (d) service sales, (e) wages, (f) employment, (g) market entry rates, and (h) market exit rates, all of which are monthly data from the observation period of March 2020 to April 2021, as well as (i) agricultural output, (j) money income, and (k) the number of job openings, all of which are quarterly data from the first quarter of 2020 to the first quarter of 2021, and (l) monthly self-isolation index developed and disclosed by Yandex, a leading IT company in Russia. We predict the impact on COVID-19 transmission levels to be positive for variables (a) through (k) and negative for variable (l). For variables (a) through (k), their growth rates as compared to those of the previous year are used for the purpose of seasonal adjustment.

For a dependent variable, monthly or quarterly data of the number of COVID-19 cases per 10,000 inhabitants is used as a proxy for COVID-19 transmission levels. One of these data types is introduced to the models depending on the type of independent variable used. Note that, for regression estimation, a logarithm of the variable is used. The name, definition, and descriptive statistics of the above-mentioned dependent and independent variables are listed in **Table 2**.

4 Estimation results

The estimation results for all constituent entities of the Russian Federation combined, obtained by using the methodology and data described in the previous section, are provided in **Table 3**. This table reports for each independent variable (economic activity variable) the estimation results obtained from model types A, B, and C. Note that, due to data limitations, only estimation results from model type A are available for those independent variables for which quarterly data is employed.

As shown in this table, all of the 30 estimation results for the lagged endogenous variable y_{it-1} are positive at the 1% significance level, which strongly suggests the state dependency of COVID-19 infection. When monthly data is used, the lagged endogenous variable y_{it-1} produces a coefficient close to 0.40 in almost all models, whereas when quarterly data is used, the coefficients take on a value ranging from 0.10 to 0.20. Considering that both the dependent variable and the lagged endogenous variable have been converted to logarithms, these estimation results imply that a 1% increase in the

COVID-19 transmission level during the previous month (or quarter) can by itself contribute to raising the COVID-19 transmission level for the current month (or quarter) by 0.4% (or 0.1% to 0.2%). These elasticities may seem small at first glance, but when the number of COVID-19 cases doubles or triples, they are enough to trigger abrupt fluctuations in the COVID-19 transmission rates.

Now, let us look at the estimation results for economic activity variables, which represent the centerpiece of our empirical analysis. In Models [1], [2], and [3] in **Table 3**, which use the growth rate of industrial production output as a proxy for the economic activity level, economic activity variable x produces a positive coefficient with statistical significance at the 1% level. This implies that the Russian regions achieving greater industrial production output in the immediate past relative to the same period the year before end up with greater COVID-19 transmission levels during the current term. Looking at Model [1] and taking into consideration that the dependent variable has been converted to a logarithm while the economic activity variable has not, we find that when the industrial production output in the previous month is 1% higher than that in the same period the year before, the COVID-19 transmission level for the current period increases by approximately 0.28%. In other words, industrial production activities not only have statistically significant impact on COVID-19 transmission levels but also actually cause a substantial spread of the virus.

Furthermore, estimation results from Models [2] and [3] tell us that not only industrial production activities that took place a month before the current month but also those that took place at least three months before can exert a positive impact on the current COVID-19 transmission levels in a wavelike manner. Specifically, Model [2] shows that when the average industrial production output during the past three months is 1% higher than that during the same period the year before, the COVID-19 transmission level for the current month increases by approximately 1.8%. Model [3] shows that production performance two months or three months before the current month can exert a greater impact on the current COVID-19 transmission levels than does production performance a month before. These findings suggest that industrial production activities are highly likely to have contributed greatly to the spread of COVID-19 in Russia with a few months of time lag between the activities and the spread of the virus.

Let us now take a look at other estimation results. In Models [4], [5], and [6], which use construction output as an independent variable, none of the coefficients is statistically significantly different from zero. This implies that, in the Russian regions, construction plays no role in the spread of the virus. On the other hand, in Models [7] to [12], which use the variable of retail and service sales to capture economic activity levels, the independent variables are estimated to be positive and significant at the 1% level regardless of the lag structure, with all coefficients being several times greater than those estimated for industrial production output. This result indicates that activities in the field of retail and service play far greater roles in the spread of COVID-19 in Russia than do activities in the field of industry. In Models [19] to [21], which examine the role of market entry rates in the spread of the virus, the coefficients are positive and statistically significant regardless of the lag structure, showing a trend similar to that seen in industrial production and the retail and service sector. The elasticity of these coefficients is almost equivalent to that of the coefficients estimated for industrial production output, indicating that the foundation of new companies, which involves diverse stakeholders, plays a role in transmitting the virus from person to person.

Results obtained from models that use wages, employment, and market exit rates as independent variables indicate the possibility of longer time lags in the impact on COVID-19 transmission levels as compared to other economic activities. In fact, in these models, the only variables that produce a positive and significant coefficient are the lagged 3-period moving average and the 3-period lag. In Models [28], [29], and [30], which employ quarterly data, the coefficient produced by the 1-period lag for money income is estimated to be positive and statistically significant. This finding is consistent with the results of Models [14] and [15] that introduce wages in the right-hand side of the equation.

In Models [25], [26], and [27], which use the self-isolation index as an independent variable, the lagged 3-period moving average, the 2-period lag, and the 3-period lag produce negative and statistically significant coefficients in agreement with our expectation. This means that staying at home helps prevent the spread of COVID-19 in Russia, just as it does in any other country. On the other hand, the coefficient of the 1-period lag for the self-isolation index is different from what we expected, as are the coefficients of the 1-period lag for wages and market exit rates, and is quite difficult to interpret.

To find out whether the aforementioned trends observed in the entire federation as a whole can be reproduced in an analysis that focuses on a specific region, following the example of Iwasaki and Kumo (2020), we classified the eight federal districts into four regional groups according to their socioeconomic similarities and then estimated the same models presented in **Table 3** for each of these regional groups. In **Table 4**, Panel (a) summarizes the estimation results presented in **Table 3**, and Panels (b), (c), (d), and (e) summarize the estimation results for specific regional groups, namely, Central and Northwestern Federal Districts, North Caucasus and Southern Federal Districts, Volga and Ural Federal Districts, and Siberian and Far Eastern Federal Districts, respectively. The sign and statistical significance of the coefficients of economic activity variables are presented for each model type (A, B, and C) in a simplified form by using plus signs, minus signs, and parentheses.

The panels in **Table 4** tell us that none of the estimation results derived from the regional groups resembles those derived from the Russian Federation as a whole. Within the vast territory of Russia, characterized by marked geographical variations in economic and social maturity, substantial heterogeneity is present even at the federal district level; this may be revealing itself as the regional differences that seem to exist in the routes that link economic activities to COVID-19 infection. On the other hand, estimation results produced by models that use retail sales, service sales, self-isolation index, or money income as an independent variable are very similar across all panels, indicating the presence of COVID-19 transmission routes that are commonly found in all parts of Russia.

In all other models, however, especially those that use industrial production output, wages, employment, market exit rates, or agricultural output as a proxy for the economic activity level, the estimation results vary substantially across different regional groups. In fact, the results produced by some of these models strongly contradict our assumption about how economic activities influence COVID-19 transmission levels. The substantial regional differences demonstrated in the estimation results allow us to uncover important clues about the distinct regional circumstances that determine the routes of COVID-19 transmission, which, along with some findings that are commonly noted across all regions of the Russian Federation, can provide insightful policy implications for economic activities and COVID-19 epidemic control in Russia.

As reported in **Table 3**, both the Arellano–Bond test and the Sargan test reject the null hypothesis in all cases, suggesting that the dynamic models estimated in this section have some room for improvement in model specification. As a robustness check, therefore, we performed the estimation using a series of alternative estimators including the pooling OLS, between effects, population averaged, random effects, fixed effects, random effects with AR(1) disturbances, and fixed effects with AR(1) disturbances and found no remarkable differences from the estimation results reported in **Tables 3** and **4**.

5 Conclusions

Until the time when the second lockdown measures were implemented in late October 2021, the COVID-19 containment measures adopted and maintained by the Russian government had consistently been free of any strict economic restrictions, which stood in sharp contrast to the pandemic control measures adopted elsewhere in the world. As a result, Russia earned the dubious distinction of being the fourth worst-hit country in the world in terms of the cumulative number of COVID-19 cases in 2020 (as of the beginning of December 2021, Russia was ranked fifth worst in the world, following the USA, India, Brazil, and England). However, the economic downturn caused by the pandemic was actually relatively mild in Russia. Although questions are likely to be raised about whether the path the Russian government took to fight the epidemic disaster was the appropriate one, it is quite understandable that the government was unwilling to put their people through even greater hardship after suffering from long years of economic sanctions imposed on the country following its annexation of Crimea. For now, a series of decisions made by the Russian government with regard to the COVID-19 crisis awaits the judgment of history. The predicament faced by Russia makes it one of the few countries in the world providing the valuable opportunity to examine the role of economic activities in the spread of COVID-19. The issue addressed in the present study concerns matters that are both lamentable to human beings and of great significance academically.

According to 2020 annual data from each constituent entity of the Russian Federation regarding COVID-19 case and death counts and economic performance, no apparent correlation seems to exist between these two factors. However, dynamic panel data analysis covering the period from March 2020 to April 2021 that considers the various factors that can affect this correlation, including fixed effects at the regional level, endogeneity between economic activities and COVID-19 transmission levels, state dependency of COVID-19 transmission levels, and the time-lag effect economic activities have on COVID-19 transmission levels, clearly showed that economic activities do contribute to the spread of the infection in the Russian regions.

From the empirical analysis, the answers to the three research questions raised in the Introduction are as follows: First, the dynamic panel data analysis in this paper strongly supported our expectation that economic activities can have a greater impact on the levels of COVID-19 transmission when they involve a larger number of inhabitants or stimulate greater consumption or social activities among citizens. Second, the widely varying time lags between economic activities and the resulting changes in COVID-19 transmission levels can be explained by the different types and modes of economic activities. Third, Russian regions can vary greatly from each other in terms of the routes that link economic activities to the spread of COVID-19 and the extent to which the former can affect the latter. These findings provide useful insight for current and future epidemic control.

As mentioned earlier, in its attempt to address a dramatic increase in the number of COVID-19 cases and deaths, Russia implemented a de facto lockdown measure across its entire territory that covered a period of nine "non-working days" from October 30 to November 7 in 2021. During this period, corporate employees were banned from commuting to work; all commercial establishments and entertainment facilities except those selling food, medical supplies, and essential goods were temporarily closed; restaurants and cafes were permitted to remain open for delivery only; and large-scale cultural and sports events were banned. According to the empirical results presented in this paper, this kind of COVID-19 surge in Russia was inevitable considering that economic activities were continued even when the vaccination rate had only reached 30% as of October 2021. The Putin Administration is now under intense pressure to reconsider its vaccination strategy and review its political attitude toward domestic economic activities.

The ongoing Russian military invasion of Ukraine will not only cause tremendous human and material damage to Ukraine but will also force Russia into a significant economic recession. The economic damage to Ukrainian and Russian businesses and citizens will be immeasurable. At the same time, according to the empirical results reported in this paper, a dramatic slowdown in economic activity would likely reduce the spread of COVID-19 infection in Russian regions. From this perspective, the future of the Russian economy will also attract worldwide attention.

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Table 1. COVID-19 cases and deaths and economic performance in the Russian Federation, federal districts, and constituent entities, 2020

	COVID-19 cases and deaths in 2020 (persons)					Economic performance in 2020 (growth rate, %)				
	Total number of cases	Total number of deaths	Number of cases per 10,000 inhabitants	Number of deaths per 10,000 inhabitants	Excess death rates per 100,000 inhabitants, as estimated by Timonin et al. (2022)	Industrial production	Agricultural production	Fixed investment	Housing	Number of registered job openings
Russian Federation	3,085,107	56,144	210.2	3.8	244	-2.6	1.5	-1.4	-1.8	16.6
Central Federal District	1,310,592	20,047	332.4	5.1	264	5.2	3.7	-3.4	-2.3	2.5
Belgorod Region	21,817	258	140.8	1.7	225	1.4	0.0	-4.5	-8.8	-20.0
Bryansk Region	23,139	216	194.0	1.8	241	0.3	2.3	8.2	4.8	6.2
Vladimir Region	18,563	501	136.7	3.7	278	19.3	1.7	1.6	-2.6	20.9
Voronezh Region	46,205	1,145	198.8	4.9	253	3.8	-0.7	-15.7	-8.3	-6.5
Ivanovo Region	21,257	514	213.2	5.2	181	3.5	5.6	14.5	-0.1	26.8
Kaluga Region	21,049	172	209.9	1.7	264	-0.8	3.6	-4.2	3.2	3.8
Kostroma Region	15,001	234	236.8	3.7	234	-11.1	4.9	-4.8	22.0	5.0
Kursk Region	20,798	303	188.4	2.7	258	1.7	5.6	-9.5	-7.5	31.6
Lipetsk Region	16,029	258	140.7	2.3	371	2.2	6.6	0.7	-4.0	12.0
Moscow Region	155,330	2,899	202.0	3.8	289	9.2	1.1	-9.2	1.2	16.5
Orel Region	21,369	268	291.3	3.7	289	5.3	10.9	-8.6	46.1	21.4
Ryazan Region	18,158	159	163.8	1.4	297	6.3	14.5	-15.3	-19.0	19.5
Smolensk Region	17,052	333	182.4	3.6	226	5.0	-3.6	-14.2	3.3	62.5
Tambov Region	17,651	185	175.3	1.8	292	4.1	9.9	0.1	-24.1	8.7
Tver Region	22,269	453	176.7	3.6	243	-3.5	-1.8	-17.3	2.6	28.2
Tula Region	22,845	750	155.8	5.1	309	12.4	8.9	-32.2	4.4	11.5
Yaroslavl Region	22,291	190	177.8	1.5	267	-3.3	-1.0	-6.6	-6.6	-0.5
Moscow Federal City	809,769	11,209	638.7	8.8	231	5.1	-39.2	1.7	-3.8	-9.7
Northwestern Federal District	486,118	10,571	347.7	7.6	212	-3.0	3.0	-0.3	-5.9	20.8
Republic of Karelia	27,545	160	448.6	2.6	233	2.2	0.4	9.0	4.7	25.7
Komi Republic	30,353	575	369.9	7.0	169	-7.0	14.8	11.5	-14.7	7.7
Arkhangelsk Region	43,327	439	381.2	3.9	179	-7.8	1.3	-4.8	12.5	19.5
Vologda Region	23,435	425	201.9	3.7	154	2.3	0.2	-5.7	-14.6	4.4
Kaliningrad Region	17,792	174	175.7	1.7	154	-6.5	9.4	-8.2	20.6	-3.6
Leningrad Region	23,832	254	127.0	1.4	279	-1.4	0.1	5.2	-18.9	13.2
Murmansk Region	36,106	651	487.0	8.8	225	-1.8	4.0	4.8	-27.8	39.9
Novgorod Region	18,309	99	306.9	1.7	202	-1.6	-5.2	-18.2	-1.5	150.0
Pskov Region	23,295	100	372.1	1.6	241	-1.1	8.9	7.9	-5.9	21.8
St. Petersburg Federal City	242,124	7,694	448.5	14.3	279	-1.8	na	-2.6	-2.9	21.1
Southern Federal District	191,570	4,874	116.3	3.0	211	-1.0	-4.7	-1.5	1.2	27.6
Republic of Adygeya	11,025	92	238.1	2.0	106	5.1	14.1	-16.9	0.4	290.0
Republic of Kalmykia	14,782	200	545.2	7.4	161	-7.9	-8.5	120.0	-13.5	60.5
Republic of Crimea	25,187	509	131.7	2.7	na	-0.2	-15.0	-11.8	-3.0	-2.3
Krasnodar Territory	27,729	930	48.9	1.6	242	-3.0	-8.7	-0.3	-0.2	3.1
Astrakhan Region	19,010	385	189.0	3.8	252	-2.8	2.3	2.2	14.5	88.7
Volgograd Region	35,423	458	142.2	1.8	280	-0.7	1.7	-3.7	5.8	14.9
Rostov Region	51,651	2,061	123.0	4.9	222	1.7	-2.9	6.2	0.1	48.2
Sevastopol City	6,763	239	150.6	5.3	na	-4.7	-13.7	-40.9	12.5	25.5
North Caucasus Federal District	122,303	2,489	123.2	2.5	173	6.5	-5.4	6.8	-2.9	35.5
Republic of Daghestan	23,461	1,119	75.4	3.6	180	4.5	1.4	13.6	-6.0	480.0
Republic of Ingushetia	12,136	140	239.3	2.8	87	-1.7	0.1	-13.2	-37.4	90.4
Kabardino-Balkarian Republic	15,825	263	182.2	3.0	193	11.0	10.0	3.6	5.4	14.7
Karachayevo-Chircassian Republic	15,126	41	324.9	0.9	186	-11.6	-7.6	-22.6	-39.9	1.7
Republic of North Ossetia—Alania	12,010	101	172.4	1.4	185	24.7	14.1	-17.6	4.6	11.4
Chechen Republic	8,668	92	58.6	0.6	203	11.4	-0.4	0.0	10.1	-2.0
Stavropol Territory	35,077	733	125.1	2.6	177	1.0	-18.1	12.7	2.7	32.7

(Continued)

(Table 1 continued)

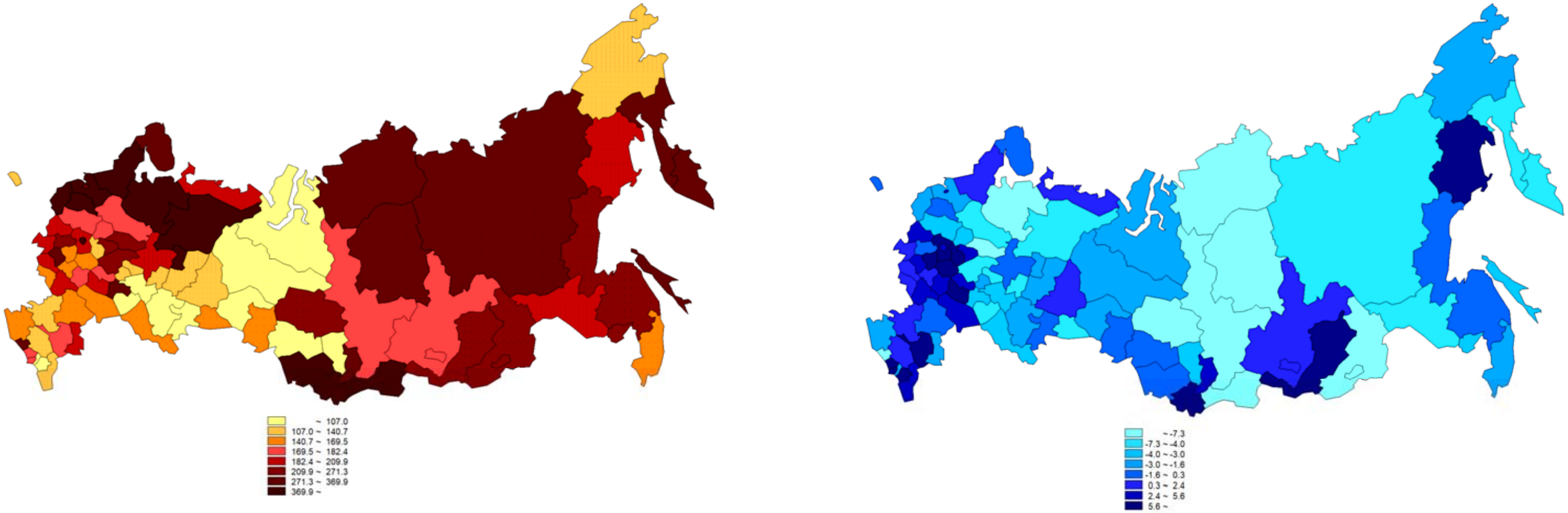
	COVID-19 cases and deaths in 2020 (persons)					Economic performance in 2020 (growth rate, %)				
	Total number of cases	Total number of deaths	Number of cases per 10,000 inhabitants	Number of deaths per 10,000 inhabitants	Excess death rates per 100,000 inhabitants, as estimated by Timonin et al. (2022)	Industrial production	Agricultural production	Fixed investment	Housing	Number of registered job openings
Volga Federal District	374,939	6,617	128.0	2.3	305	-3.4	6.6	-4.1	-2.3	21.1
Republic of Bashkortostan	19,064	142	47.2	0.4	301	-2.0	3.1	0.9	3.5	30.3
Republic of Mari El	9,185	120	135.2	1.8	268	-6.4	4.1	23.5	-7.1	17.7
Republic of Mordovia	13,489	95	170.7	1.2	345	2.4	6.2	-18.4	-6.8	19.1
Republic of Tatarstan	13,284	182	34.0	0.5	318	-3.6	4.0	-8.9	0.2	15.6
Udmurtian Republic	19,634	385	130.8	2.6	258	-7.3	4.3	-2.9	5.6	36.7
Chuvash Republic	16,381	528	134.5	4.3	316	-2.4	5.0	-24.0	-12.0	-25.1
Perm Territory	30,629	1,133	117.8	4.4	255	-3.0	5.0	-8.3	1.9	-7.4
Kirov Region	25,626	229	203.0	1.8	248	0.1	6.4	-13.4	-9.2	32.2
Nizhny Novgorod Region	69,815	1,646	218.0	5.1	286	-6.6	4.7	20.6	4.7	38.6
Orenburg Region	28,742	343	146.9	1.8	341	-4.0	7.4	-8.9	-2.6	21.6
Penza Region	26,048	318	199.5	2.4	355	7.3	15.7	0.2	1.8	81.8
Samara Region	31,401	606	98.8	1.9	362	-4.5	7.3	-11.8	-23.9	11.5
Saratov Region	35,328	416	145.9	1.7	281	2.8	9.3	-3.6	-3.6	13.5
Ulyanovsk Region	36,313	474	295.3	3.9	329	-3.1	15.4	-5.3	1.5	27.8
Ural Federal District	128,644	2,415	104.1	2.0	247	-2.3	-7.0	3.3	1.7	34.3
Kurgan Region	11,992	170	145.0	2.1	232	-4.8	-14.1	-9.6	-1.1	48.5
Sverdlovsk Region	58,582	1,509	135.9	3.5	261	2.3	-2.8	-9.9	-1.7	41.8
Tyumen Region	23,365	198	62.2	0.5	188	-3.0	-2.3	6.4	5.3	26.0
Chelyabinsk Region	34,705	538	100.1	1.6	305	-0.9	-10.7	0.1	1.5	36.6
Siberian Federal District	274,239	6,839	160.2	4.0	210	-4.4	1.7	0.9	4.0	21.5
Republic of Altay	13,822	98	627.8	4.5	157	21.4	-4.1	-39.0	-10.5	320.0
Republic of Tuva	14,758	157	450.8	4.8	146	-36.9	-1.1	-12.5	9.6	-21.1
Republic of Khakassia	17,552	258	328.5	4.8	194	3.1	1.1	-1.9	16.0	30.3
Altay Territory	32,912	877	142.0	3.8	223	-0.1	-3.7	2.9	9.1	27.9
Krasnoyarsk Territory	46,513	1,705	162.3	5.9	194	-9.4	8.7	4.8	-8.4	30.6
Irkutsk Region	40,519	1,220	169.5	5.1	204	2.2	3.1	3.7	5.0	23.8
Kemerovo Region	25,749	468	96.9	1.8	192	-4.0	6.6	-11.5	7.7	-0.9
Novosibirsk Region	27,885	967	99.7	3.5	254	-0.5	2.5	1.4	10.3	30.9
Omsk Region	30,111	871	156.3	4.5	306	-0.7	-0.2	13.6	-2.4	20.0
Tomsk Region	24,418	218	226.2	2.0	228	-9.3	2.9	-4.4	3.0	-14.0
Far Eastern Federal District	196,702	2,292	240.8	2.8	167	-4.1	2.4	-12.6	-0.5	7.5
Republic of Buryatia	25,724	591	260.9	6.0	109	7.4	0.0	-3.6	2.8	5.1
Republic of Sakha (Yakutia)	26,369	392	271.3	4.0	161	-5.1	0.6	-49.1	-10.9	-16.2
Trans-Baikal Territory	27,239	386	257.0	3.6	150	-2.4	-1.0	20.5	-21.3	8.7
Kamchatka Territory	10,102	82	322.7	2.6	176	-5.7	3.2	21.2	52.3	59.2
Primorye Territory	29,287	375	154.5	2.0	179	-20.6	4.3	-9.5	15.4	11.6
Khabarovsk Territory	35,081	203	266.6	1.5	237	-0.9	4.6	24.7	-24.3	14.3
Amur Region	15,866	105	200.8	1.3	244	-4.6	1.4	-6.1	-24.0	6.0
Magadan Region	7,006	65	499.9	4.6	124	5.6	3.5	-0.4	21.1	9.5
Sakhalin Region	15,740	17	322.4	0.3	163	-3.4	5.8	-15.2	31.4	-24.5
Jewish Autonomous Region	3,750	72	236.9	4.5	253	-3.3	17.9	-6.7	-39.5	3.7
Chukotka Autonomous Area	538	4	107.0	0.8	45	-1.9	1.4	9.1	32.3	26.7
Descriptive statistics for constituent entities										
Mean	37623.3	684.7	216.7	3.2	231.6	-0.5	1.9	-2.6	-0.7	33.1
Median	22992.0	310.5	180.0	2.7	235.5	-1.0	2.5	-4.0	0.1	19.3
S.D.	91502.9	1504.3	126.8	2.2	65.6	8.0	8.4	19.2	15.9	71.9
Max	809769.0	11209.0	638.7	14.3	371.0	24.7	17.9	120.0	52.3	480.0
Min	538.0	4.0	34.0	0.3	45.0	-36.9	-39.2	-49.1	-39.9	-25.1

Note: Excess death rates for federal districts are the simple averages of constituent entities in the district.
Source: Websites of the Russian Federal Government and Federal State Statistics Service (Rosstat) (https://стопкоронавирус.рф; https://rosstat.gov.ru/) except for excess death rates per 100,000 inhabitants, which were obtained from Timonin et al. (2022, Appendix Table A1, Method B, pp. 9–12).

Figure 1. COVID-19 transmission levels and industrial production performance in the Russian Regions, 2020

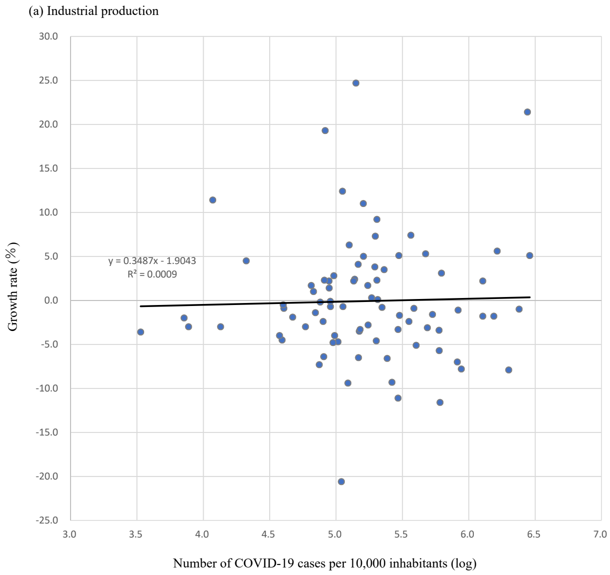
(a) Number of COVID-19 cases per 10,000 inhabitants (persons)

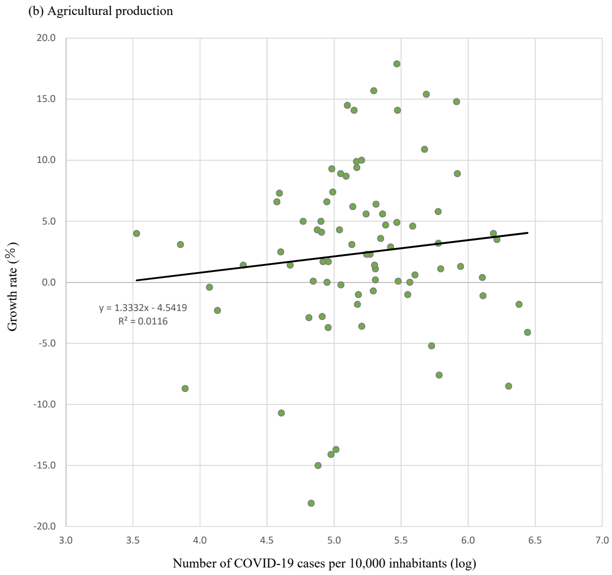
(b) Industrial production growth rate (%)

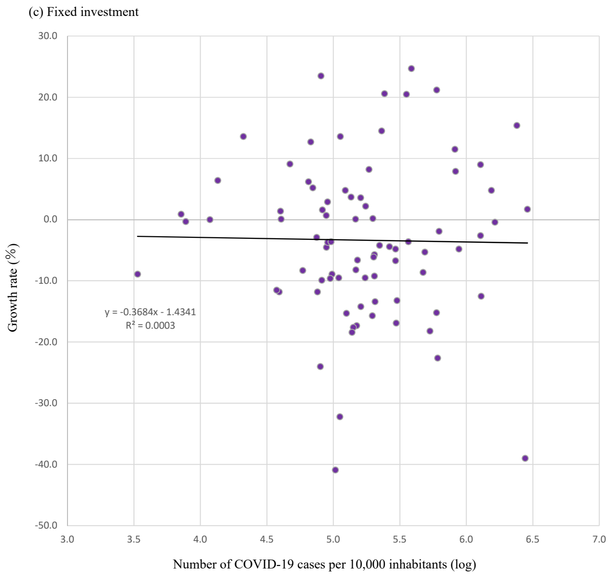


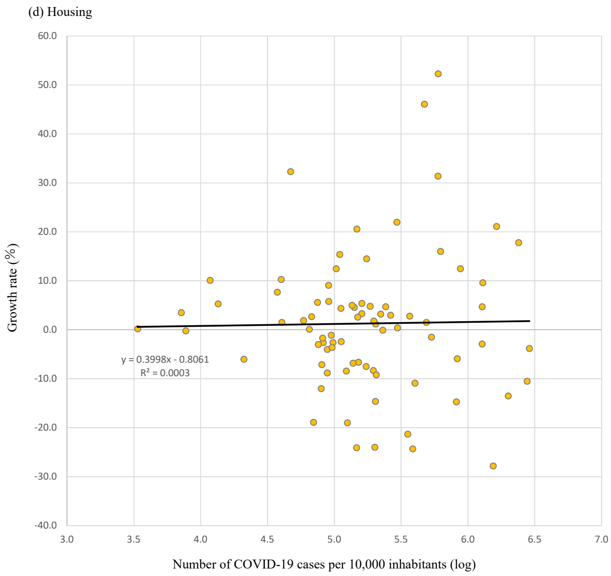
Source: Author's illustration based on Table 1

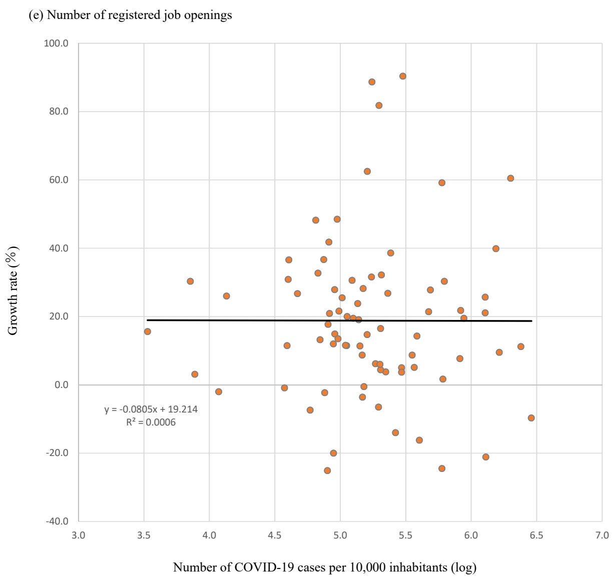
Figure 2. Scatter plots of COVID-19 transmission levels and economic performance indicators in the Russian Regions, 2020











Note: Outliers are excluded.

Source: Author's illustration based on Table 1

Table 2. Definition and descriptive statistics of variables used in empirical analysis

Variable name	Definition	Descriptive statistics[a]														
		Russian Federation			Central and Northwestern Federal Districts			North Caucasus and Southern Federal Districts			Volga and Ural Federal Districts			Siberian and Far Eastern Federal Districts		
		Mean	Median	S.D.	Mean	Median	S.D.	Mean	Median	S.D.	Mean	Median	S.D.	Mean	Median	S.D.
COVID-19 transmission level I[b]	Number of COVID-19 cases per 10,000 inhabitants (monthly)	23.30	15.06	25.74	28.72	20.17	30.94	18.98	12.56	19.80	17.59	12.79	17.28	24.32	15.12	26.75
COVID-19 transmission level II[b]	Number of COVID-19 cases per 10,000 inhabitants (quarterly)	63.28	42.91	69.96	77.41	48.56	81.99	51.95	35.21	56.15	47.44	37.33	49.17	66.88	42.46	73.92
Industrial production output	Growth rate of industrial production (%) (monthly)	0.24	-0.30	13.81	1.86	1.35	12.47	3.27	0.20	19.06	-1.27	-1.45	9.19	-2.73	-2.50	13.85
Construction output	Growth rate of construction volume (%) (monthly)	8.92	-2.34	70.16	17.29	0.47	87.45	17.41	-0.97	88.89	1.62	-4.20	31.53	-1.71	-8.94	49.54
Retail sales	Retail sales growth rate (%) (monthly)	-3.52	-1.75	8.28	-3.01	-1.80	7.36	-3.82	-0.65	11.47	-4.05	-2.75	7.67	-3.50	-1.60	7.18
Service sales	Service sales growth rate (%) (monthly)	-11.52	-8.20	12.51	-11.73	-8.30	11.74	-10.03	-5.55	14.74	-12.49	-9.80	12.24	-11.41	-8.95	11.99
Wages	Growth rate of total wages (%) (monthly)	1.38	0.60	12.27	1.31	0.70	11.65	1.42	0.80	13.12	1.37	0.50	11.47	1.45	0.55	13.19
Employment	Growth rate of total employment (%) (monthly)	42.78	-19.09	407.40	25.60	-24.87	187.41	24.84	-15.61	188.86	126.97	-2.24	776.89	-0.38	-23.25	122.18
Market entry rates	Growth rate of newly established companies per 1,000 organizations (%) (monthly)	-8.82	-11.27	35.01	-8.13	-10.05	28.19	-5.96	-10.10	50.54	-13.34	-12.60	22.13	-7.70	-12.00	38.79
Market exit rates	Growth rate of closed companies per 1,000 organizations (%) (monthly)	29.66	-12.87	241.63	16.24	-10.21	84.53	116.93	-10.40	529.83	3.23	-17.33	79.11	8.78	-14.61	91.08
Self-isolation index[c]	Restricted mobility of citizens (monthly)	1.92	1.87	0.44	1.96	1.89	0.45	1.91	1.84	0.49	1.96	1.89	0.39	1.81	1.80	0.44
Agricultural output	Agricultural production growth rate (%) (quarterly)	2.20	1.88	10.89	3.04	1.88	10.36	-0.09	1.20	11.45	3.78	3.70	9.77	1.31	0.71	11.88
Monetary income	Monetary income growth rate (%) (quarterly)	2.49	3.10	4.59	2.30	2.45	4.32	2.10	3.30	6.30	2.20	3.00	4.25	3.30	3.40	3.65
Number of job openings	Growth rate of the number of job openings (%) (quarterly)	13.47	12.40	10.56	14.14	12.62	9.72	13.32	11.97	10.69	12.84	12.73	12.25	13.24	12.30	9.97

Notes:

[a] Descriptive statistics for economic activity variables are calculated using one-period lagged values.

[b] In regression estimation, log-transformed values are used.

[c] It takes a value between 0 and 5, meaning that the higher the value, the more restrictive the flow of people on the street is.

Source: Websites of the Federal State Statistics Service (Rosstat) and Yandex (https://rosstat.gov.ru/; https://yandex.com/)

Table 3. System GMM estimation of the effect of economic activities on the spread of COVID-19 in the Russian regions

Dependent variable	COVID-19 transmission level I (monthly)														
Independent variable (economic activity variable)	Industrial production output			Construction output			Retail sales			Service sales			Wages		
Model type	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Model No.	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]
Lagged endogeneous variable	0.36999***	0.38387***	0.38217***	0.36858***	0.36824***	0.36782***	0.38441***	0.45602***	0.45539***	0.38086***	0.45294***	0.45911***	0.35828***	0.35497***	0.35036***
	(0.0165)	(0.0171)	(0.0172)	(0.0164)	(0.0168)	(0.0168)	(0.0161)	(0.0166)	(0.0166)	(0.0167)	(0.0167)	(0.0167)	(0.0168)	(0.0169)	(0.0171)
Economic activity variable 1-period lagged	0.00278*		0.00482***	0.00006		-0.00004	0.01521***		0.02141***	0.01156***		0.00919***	-0.00896***		-0.00469
	(0.0015)		(0.0016)	(0.0002)		(0.0003)	(0.0019)		(0.0025)	(0.0014)		(0.0017)	(0.0013)		(0.0034)
Economic activity variable 2-period lagged			0.00578***			-0.00007			0.01483***			0.01193***			0.00352
			(0.0022)			(0.0003)			(0.0020)			(0.0015)			(0.0022)
Economic activity variable 3-period lagged			0.00521***			-0.00015			0.02851***			0.01911***			0.00281**
			(0.0018)			(0.0003)			(0.0025)			(0.0016)			(0.0013)
Economic activity variable lagged 3-period moving average		0.01819***			-0.00017			0.06296***			0.04053***			0.01268***	
		(0.0047)			(0.0007)			(0.0049)			(0.0026)			(0.0033)	
Const.	1.85573***	1.82858***	1.83171***	1.85737***	1.86038***	1.86245***	1.88790***	1.89943***	1.90603***	1.97783***	2.18637***	2.16807***	1.87096***	1.89116***	1.89137***
	(0.0504)	(0.0506)	(0.0504)	(0.0505)	(0.0529)	(0.0528)	(0.0498)	(0.0512)	(0.0518)	(0.0520)	(0.0599)	(0.0606)	(0.0510)	(0.0514)	(0.0516)
N	819	819	819	819	819	819	819	819	819	819	819	819	819	819	819
Arellano–Bond test (z)[a]	-2.469**	-2.719***	-2.735***	-2.399**	-2.455**	-2.496**	-3.291***	-4.262***	-3.763***	-3.205***	-4.037***	-4.434***	-2.888***	-2.278**	-2.747***
Sargan test (χ^2)[b]	1096.188***	1051.447***	1059.259***	1104.024***	1104.219***	1102.232***	1016.233***	599.950***	574.100***	973.239***	567.358***	522.227***	1056.601***	1140.634***	1085.396***
Wald test (χ^2)[c]	509.62***	507.22***	550.98***	524.35***	548.54***	548.42***	588.38***	767.31***	777.71***	547.25***	918.93***	1007.44***	802.01***	527.42***	902.82***

Dependent variable	COVID-19 transmission level I (monthly)												COVID-19 transmission level II (quarterly)		
Independent variable (economic activity variable)	Employment			Market entry rates			Market exit rates			Self-isolation index			Agricultural output	Monetary income	Number of job openings
Model type	A	B	C	A	B	C	A	B	C	A	B	C	A	A	A
Model No.	[16]	[17]	[18]	[19]	[20]	[21]	[22]	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]
Lagged endogeneous variable	0.35521***	0.35611***	0.35766***	0.37103***	0.39741***	0.39781***	0.36786***	0.36720***	0.36740***	0.36947***	0.59037***	0.62091***	0.11616***	0.20074***	0.11547***
	(0.0183)	(0.0185)	(0.0184)	(0.0163)	(0.0172)	(0.0177)	(0.0164)	(0.0164)	(0.0164)	(0.0162)	(0.0208)	(0.0195)	(0.0106)	(0.0167)	(0.0107)
Economic activity variable 1-period lagged	-0.00015		-0.00014	0.00161**		0.00337***	-0.00008**		-0.00003	0.18638***		0.31994***	0.00412	0.09559***	0.00262
	(0.0001)		(0.0001)	(0.0008)		(0.0007)	(0.0000)		(0.0000)	(0.0289)		(0.0300)	(0.0083)	(0.0157)	(0.0088)
Economic activity variable 2-period lagged			0.00001			0.00430***			0.00001			-0.20368***			
			(0.0000)			(0.0006)			(0.0001)			(0.0326)			
Economic activity variable 3-period lagged			0.00005***			0.00451***			0.00016*			-0.49730***			
			(0.0000)			(0.0013)			(0.0001)			(0.0368)			
Economic activity variable lagged 3-period moving average		0.00010**			0.01257***			0.00013			-0.40896***				
		(0.0000)			(0.0024)			(0.0002)			(0.0431)				
Const.	1.97281***	1.96330***	1.96430***	1.86619***	1.90594***	1.90183***	1.86593***	1.86257***	1.86208***	1.50707***	2.02344***	1.89916***	3.71729***	3.50030***	3.70535***
	(0.0552)	(0.0571)	(0.0568)	(0.0504)	(0.0548)	(0.0531)	(0.0502)	(0.0501)	(0.0500)	(0.0767)	(0.1085)	(0.1220)	(0.0632)	(0.0575)	(0.1212)
N	556	556	556	819	819	819	810	810	810	729	729	729	155	155	155
Arellano–Bond test (z)[a]	-1.936*	-1.882*	-1.908*	-2.457**	-3.763***	-4.106***	-2.302**	-2.405**	-2.323**	-2.750***	-3.855***	-5.854***	-	-	-
Sargan test (χ^2)[b]	714.536***	709.043***	706.021***	1075.168***	842.375***	835.533***	1089.040***	1095.400***	1083.044***	1060.844***	783.465***	373.430***	86.956***	75.242***	88.331***
Wald test (χ^2)[c]	379.15***	400.47***	468.73***	516.49***	531.79***	577.89***	515.73***	502.37***	521.27***	587.36***	1008.05***	2260.25***	120.37***	159.52***	119.16***

Notes: Figures in parentheses beneath regression coefficients are robust standard errors. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

[a] Autocorrelation test for AR(2). Null hypothesis: no autocorrelation

[b] Test results that use estimates with normal standard errors. Null hypothesis: overidentifying restrictions are valid.

[c] Null hypothesis: all coefficients are zero.

Source: Authors' estimation. See Table 2 for definitions and descriptive statistics of the variables used in the estimation.

Table 4. Summary of estimation results

(a) Russian Federation

Economic activity variable	Industrial production output	Construction output	Retail sales	Service sales	Wages	Employment	Market entry rates	Market exit rates	Self-isolation index	Agricultural output	Monetary income	Number of job openings
Model type A 1-period lagged	+	(+)	+++	+++	---	(-)	++	--	+++	(+)	+++	(+)
Model type B lagged 3-period moving average	+++	(-)	+++	+++	+++	++	+++	(+)	---	na	na	na
Model type C 1-period lagged	+++	(-)	+++	+++	(-)	(-)	+++	(-)	+++	na	na	na
2-period lagged	+++	(-)	+++	+++	(+)	(+)	+++	(+)	---	na	na	na
3-period lagged	+++	(-)	+++	+++	++	+++	+++	+	---	na	na	na
N	819	819	819	819	819	556	819	810	729	153	155	155

(b) Central and Northwestern Federal Districts

Economic activity variable	Industrial production output	Construction output	Retail sales	Service sales	Wages	Employment	Market entry rates	Market exit rates	Self-isolation index	Agricultural output	Monetary income	Number of job openings
Model type A 1-period lagged	(+)	(+)	+++	+++	---	--	+++	(+)	+++	-	+++	(+)
Model type B lagged 3-period moving average	++	(-)	+++	+++	(+)	---	+++	+++	---	na	na	na
Model type C 1-period lagged	(+)	(-)	+++	+++	---	(-)	+++	++	+++	na	na	na
2-period lagged	(+)	(-)	+++	+++	-	---	+++	++	---	na	na	na
3-period lagged	++	(-)	+++	+++	-	---	+++	+++	---	na	na	na
N	278	278	278	278	278	194	278	278	252	52	54	54

(c) Southern and North Caucasus Federal Districts

Economic activity variable	Industrial production output	Construction output	Retail sales	Service sales	Wages	Employment	Market entry rates	Market exit rates	Self-isolation index	Agricultural output	Monetary income	Number of job openings
Model type A 1-period lagged	(-)	(-)	+++	+++	---	(+)	(+)	--	(+)	(-)	+++	(-)
Model type B lagged 3-period moving average	(-)	(-)	+++	+++	--	(-)	(+)	(-)	---	na	na	na
Model type C 1-period lagged	(-)	(-)	+++	+++	---	+	(+)	---	+++	na	na	na
2-period lagged	(+)	---	+++	+++	---	-	++	(-)	---	na	na	na
3-period lagged	(+)	(-)	+++	+++	---	-	(+)	(+)	---	na	na	na
N	147	147	147	147	147	91	147	147	126	27	27	27

(d) Volga and Ural Federal Districts

Economic activity variable	Industrial production output	Construction output	Retail sales	Service sales	Wages	Employment	Market entry rates	Market exit rates	Self-isolation index	Agricultural output	Monetary income	Number of job openings
Model type A 1-period lagged	+++	---	+++	+++	---	(-)	(+)	+++	+++	+++	+++	+++
Model type B lagged 3-period moving average	+++	(-)	+++	+++	+++	+++	+++	+++	-	na	na	na
Model type C 1-period lagged	+++	--	+++	+	(-)	(-)	(+)	+++	+++	na	na	na
2-period lagged	+++	(+)	+++	+++	(+)	(+)	+++	+++	---	na	na	na
3-period lagged	+++	(-)	+++	+++	--	+++	+++	+++	---	na	na	na
N	189	189	189	189	189	128	189	189	171	37	37	37

(e) Siberian and Far East Federal Districts

Economic activity variable	Industrial production output	Construction output	Retail sales	Service sales	Wages	Employment	Market entry rates	Market exit rates	Self-isolation index	Agricultural output	Monetary income	Number of job openings
Model type A 1-period lagged	++	+	(+)	(+)	(-)	(-)	(+)	(+)	+++	+++	++	(+)
Model type B lagged 3-period moving average	(+)	++	+++	+++	+++	(-)	++	(+)	--	na	na	na
Model type C 1-period lagged	++	++	+++	(+)	++	(-)	(+)	+	+++	na	na	na
2-period lagged	(-)	++	+++	(+)	+++	(+)	++	(+)	(-)	na	na	na
3-period lagged	(-)	+	+++	+++	+++	-	(+)	(+)	---	na	na	na
N	205	205	205	205	205	143	205	196	180	37	37	37

Notes: Each symbol denotes the following: +++: significantly positive at the 1% level; ++: significantly positive at the 5% level; +: significantly positive at the 10% level; (+): the coefficient is positive but statistically insignificant; ---: significantly nagative at the 1% level; --: significantly negative at the 5% level; -: significantly negative at the 10% level; (-): the coefficient is negative but statistically insignificant; na: not available due to data constraints.

Source: Authors' estimation. See Table 2 for definitions and descriptive statistics of the variables used in the estimation.