

# A spatial analysis of the environmental correlates of COVID-19 incidence in the provinces in Spain

Antonio Paez<sup>\*,a</sup>, Fernando A. Lopez<sup>b</sup>, Tatiane Almeida de Menezes<sup>c</sup>, Renata Cavalcanti<sup>c</sup>, Maira Galdino da Rocha Pitta<sup>c</sup>

<sup>a</sup>*School of Geography and Earth Sciences, 1281 Main St W, Hamilton, ON, L8S 4K1, Canada*

<sup>b</sup>*Departamento de Metodos Cuantitativos, Ciencias Juridicas, y Lenguas Modernas, Calle Real Numero 3, 30201, Cartagena, Murcia, Spain*

<sup>c</sup>*Departamento de Economia da Universidade Federal de Pernambuco - UFPE*

## Abstract

Spreading with astonishing speed, the novel SARS-CoV2 has swept the globe, causing enormous stress to health systems and prompting social distance guidelines and mandates to arrest its progress. While there is encouraging evidence that early public health interventions have slowed the spread of the virus, this has come at a high cost as the global economy is brought to its knees. How and when to ease restrictions to movement hinges in part on the question whether SARS-CoV2 will display seasonality associated with variations in temperature and humidity. In this research, we address this question by means of a spatial analysis of the incidence of COVID-19 in the provinces in Spain. Use of a spatial SUR approach allows us to model the incidence of reported cases of the disease per 100,000 population, as a function of temperature and humidity, while controlling for GDP per capita, population density, percentage of older adults in the population, and presence of mass transit systems. Our results indicate that incidence of the disease is lower at higher temperatures. The evidence with respect to humidity is more mixed, with coefficients for this variable that are significant in only some equations. Our control variables also yield interesting insights, as population density and percentage of older adults display negative associations with incidence of COVID-19, whereas the presence of mass transit systems in the province is associated with a greater incidence of the disease.

## Introduction

From a small outbreak linked to a live animal market at the end of 2019 to a global pandemic in a matter of weeks, the SARS-CoV2 virus has threatened to overrun health systems the world over. In efforts to contain the spread, numerous governments in many nations and regions have either recommended or mandated

---

\*Corresponding Author

Email addresses: [paezha@mcmaster.ca](mailto:paezha@mcmaster.ca) (Antonio Paez), [fernando.lopez@upct.es](mailto:fernando.lopez@upct.es) (Fernando A. Lopez), [tatianedemenezes@gmail.com](mailto:tatianedemenezes@gmail.com) (Tatiane Almeida de Menezes), [email@ufp.br](mailto:email@ufp.br) (Renata Cavalcanti), [email@ufp.br](mailto:email@ufp.br) (Maira Galdino da Rocha Pitta)

social distancing measures, and as of this writing, millions of people in five continents shelter in place. There are encouraging signs that these measures have arrested the spread of the virus where they have been implemented, and have thus helped to keep a bad situation from becoming even worse (e.g., 2020). However, this has come at a high cost, and the consequences for all spheres of the economy, social, and cultural life have been dire (e.g., Fernandes, 2020; Luo and Tsang, 2020). As a result, there is a sense of urgency to anticipate the progression of the pandemic, in order to plan for progressive lifting of restrictions to movement and social contact (e.g., Kissler et al., 2020). Needless to say, this has become a delicate, and politically charged, balancing act between public health and the economy (Gong et al., 2020).

A salient question in the debate on how and when to ease social distancing measures is whether the virus will display seasonal variations. Earlier, diverse studies have shown the effect of temperature and humidity on the incidence of influenza (e.g., Mäkäinen et al., 2009; Jaakkola et al., 2014; Kudo et al., 2019). Jaakkola et al. (2014), for example, found that a decrease of temperature and absolute humidity precedes the onset of symptoms of influenza A and B viruses by 3 days in places where the temperature is low. After the 2002-2004 outbreak of SARS, researchers also began to investigate the relationship between these factors and SARS-CoV. In this way, Casanova et al. (2010) used two surrogates, namely the gastroenteritis (TGEV) and mouse hepatitis viruses (MHV), to find that virus inactivation was more rapid at temperatures of 20C than 4C, and at 40C than 20C; in terms of humidity, these researchers reported that survival of the virus was lower at moderate relative humidity levels. In a similar vein, but working directly with SARS-CoV, Chan et al. (2011) found that viability of the virus was lost at temperatures higher than 38C and relative humidity superior to 95%.

While existing research on similar pathogens suggests that SARS-CoV is more stable and potentially easier to transmit in conditions of low temperature and low humidity, it is far from certain that this will also be the case with the novel SARS-CoV2. If such is the case, there is the possibility of easing restrictions to social contact as the weather warms; however, weeks or possibly months of costly measures could become undone if not, and the restrictions are lifted prematurely. Not surprisingly, this issue has triggered a lively debate.

In this paper, we report results from a spatial analysis of incidence of COVID-19 in fifty provinces in Spain. Spain is one of the countries hardest hit by the virus, and enacted lockdown measures on March 16, 2020, in response to a rapidly growing outbreak of COVID-19. We combine data on reported cases of the disease with meteorological information, to create a spatio-temporal dataset covering a period of 30 days. We then join this dataset with provincial-level economic and demographic information to act as controls to our key environmental variables. These data are analyzed using a spatial SUR approach, which allows us to account for residual spatial autocorrelation.

The results provide persuasive evidence of the effect of temperature on the incidence of COVID-19, as **NOTE ABOUT THE MAGNITUDE OF THE EFFECT**. The evidence concerning humidity is more mixed: while the direction

Table 1: Descriptive statistics

Variable	Note	Min	Mean	Max	SD	Source
SARS-19 Incidence	Incidence in reported cases of SARS-19 per 100,000 people	0.38	153.61	1149.36	186.23	Source
GDPpc	GDP per capita in €1,000s	16.67	22.51	36.00	4.77	Source
Older	Percentage of people aged 65 and older in the province	15.16	21.03	31.36	3.95	Source
Population Density	Population density in the province in people per sq.km	8.60	140.04	829.76	181.25	Source

of the effect is negative, as anticipated, the coefficients for this variable are only significant in some of equations in the system. Our control variables also provide some intriguing insights. The results of this analysis provide support to the hypothesis of seasonality of the novel SARS-CoV2, and should be of interest to public health officials and policy makers wrestling with the question of the trajectory of the pandemic.

Please note that this paper is prepared as a reproducible research document. The source R Markdown document, as well as all data and code needed to reproduce/review/extend the analysis can be obtained from the following repository:

Include link to repository

## Context and Data

### *Covid-19 in Spain*

When was the first case reported? When did the country close international arrivals? When did initial measures of social distancing were implemented? The lockdown?

### *Selection of Variables*

Explain the rationale for selecting the variables.

### *Sources of Data and Data Preparation*

Explain the sources of data and data preprocessing.

Descriptive statistics of the incidence of COVID-19 and provincial economic and demographic variables are shown in Table 1.

## Methods: Spatial SUR

### The econometric model

The baseline model propouse in this paper is a classical SUR model without spatial effects (from here, SUR-SIM). Following the classical expresion for thios model in stacked form

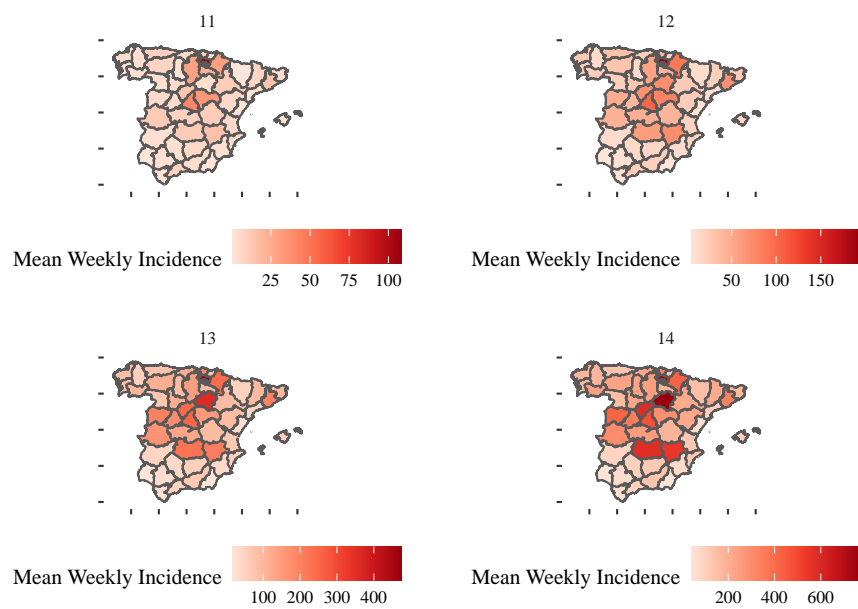


Figure 1: {fig:weekly-average-incidence-map}Mean weekly incidence of COVID-19 by province, in reported cases by 100,000 people

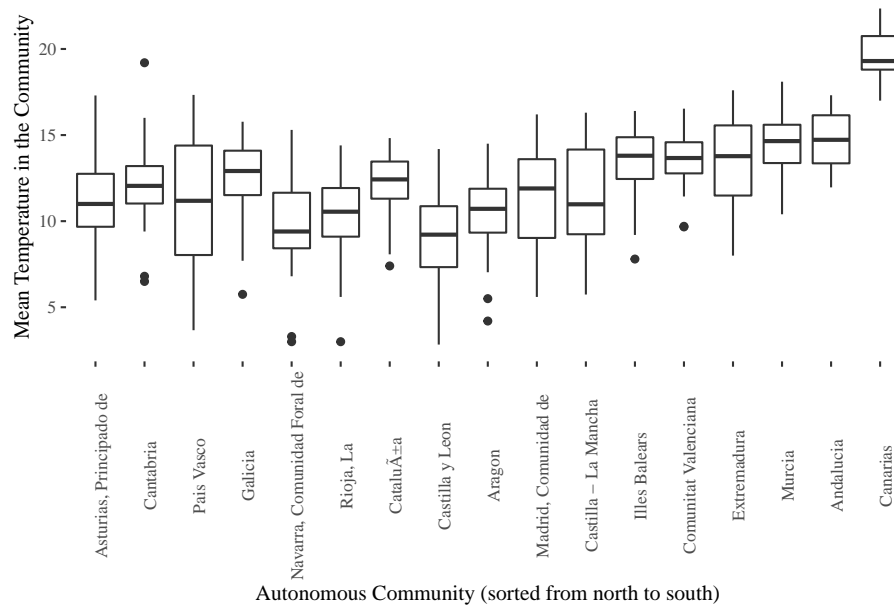


Figure 2: Distribution of temperatures in the Autonomous Communities in Spain between March 12, 2020 and April 11, 2020. The Autonomous Communities have been sorted by latitude, with communities to the left being the northernmost, and to the right the southernmost

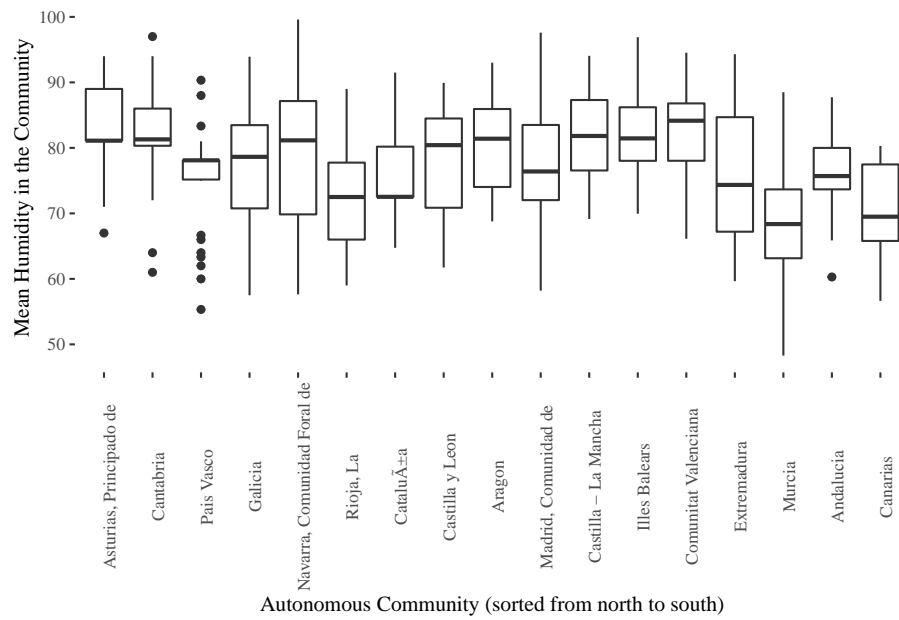


Figure 3: Distribution of humidity in the Autonomous Communities in Spain between March 12, 2020 and April 11, 2020. The Autonomous Communities have been sorted by latitude, with communities to the left being the northernmost, and to the right the southernmost

$$\begin{bmatrix} y_1 \\ y_2 \\ \dots \\ y_T \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \dots & 0 \\ 0 & X_2 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & X_T \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_1 \\ \dots \\ \beta_T \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \dots \\ \epsilon_T \end{bmatrix} \quad (1)$$

where  $y_t = (y_{1t}, \dots, y_{Nt})$  is the incidence ratio in the province  $s$  ( $s = 1, \dots, N$ ) the day  $t$  ( $t = 1, \dots, T$ );  $X_t$  is a  $N \times k_t$  matrix of the  $k_t$  independent variables;  $\beta_t = (\beta_{1t}, \dots, \beta_{Nt})$  is a vector of coefficients and  $\epsilon$  is the error vector. Like is characteristic in SUR model, we consider dependence among error vector  $E[\epsilon_t \epsilon_{t'}'] = \sigma_{tt'}$ . Note that this specification is flexible allowing changes in the coefficients  $\beta_{it}$  in order to modulate the effect of  $X_{it}$  on  $y_t$ . This flexibility is not always desirable and is possible impose restrictions and consider time constant some  $\beta$  coefficients. In this case we can reformulate the coefficients expression of  $\beta_t = (\beta_1, \dots, \beta_r, \beta_{r+1}, \dots, \beta_{Nt})$  if we want to consider the first  $r$  coefficients constant. The equation (???) can be write in compact form,

$$y = X\beta + \epsilon \quad (2)$$

where...

Like in case of cross-section, it is possible identify spatial autocorrelation in the residuals of (???) and several tests has been develop to test the null of spatial independence (López Mur Herrera). In case of reject the null alternative specifications has been propose to include spatial effects ((???), see also (??)). The taxonomy of spatial models that we present in this paper is well known (see Elhorst 2014) and we extend in the SUR framework.

The spatial lag SUR model (SUR-SLM) incorporates a spatial lag of the dependent variable as an explanatory factor.

In this paper we consider the spatial lag model

$$\mathbf{A}y = \mathbf{X}\beta + \epsilon \quad (3)$$

where  $\mathbf{A} = I_{TN} - \mathbf{\Lambda} \otimes \mathbf{W}$  with  $\mathbf{\Lambda} = \text{diag}(\lambda_1, \dots, \lambda_T)$ .

This model can be estimated by maximum likelihood (ref) or instrumental variables (ref). We considerer this methodology to estimate the model. This specification assumes that incidence in a province ( $y_{st}$ ) is partially determined by the weighted average ( $Wy_{st}$ ) of incidence in neighbouring provinces. Parameter  $\lambda_t$  identifies the intensity and the sign of the impacts. The strategies of selection and comparison between these models are present in López et al. (2014)

where  $y_t = (y_{1t}, \dots, y_{Nt})$  is the incidence ratio in the province  $s$  ( $s = 1, \dots, N$ ) in day  $t$  ( $t = 1, \dots, T$ ),  $X_{st} = (X_{st}^1, \dots, X_{st}^k)$  is a vector of  $k$  independent variables observed in  $(s, t)$ . The model consider  $\beta_t = (\beta_t^1, \dots, \beta_t^k)$  coefficients constant in  $s$ . The panel model enables correlation between residuals of explanatory models of each time period  $t$ , such that  $E[\epsilon_t \epsilon_{t'}'] = \sigma_{tt'}$

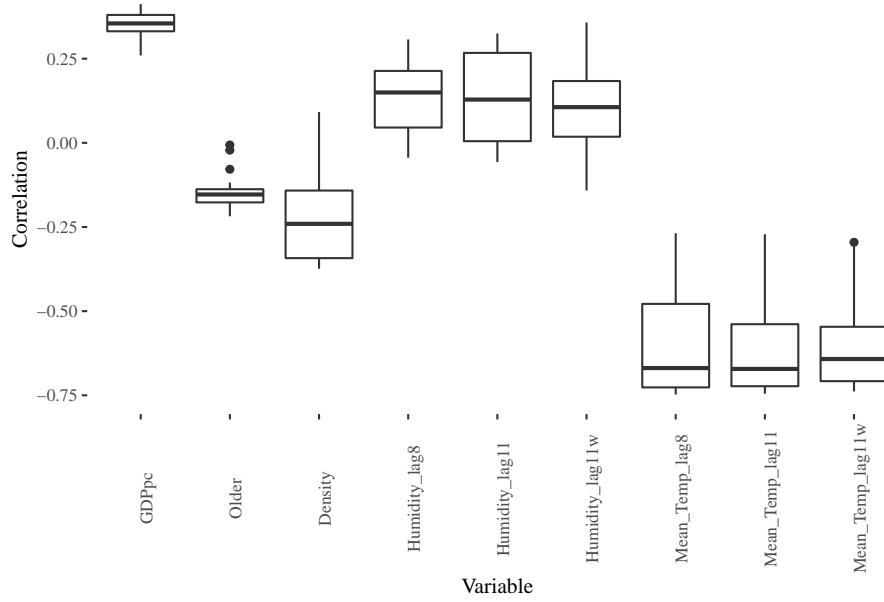


Figure 4: Distribution of daily correlations of the independent variables with daily incidence of COVID-19 (all variables have been log-transformed)

## Analysis and Results

### *Exploratory Data Analysis*

The literature about COVID-19 suggested that population density is the one of the most important proliferate cause of these viscous, however this ill spread with different intensity at big cities of the world. Controlling for socioeconomic characteristics the objective of this paper is observe the effect of clime on COVID-19 proliferation.

We begin with the exploratory analysis of the data. Figure 4 shows the distribution of daily correlations of the independent variables with incidence of COVID-19, after log-transforming all variables. It can be seen there that the correlation of GDPpc and temperature (in its three definitions) have the strongest positive and negative correlations with incidence, respectively. Percentage of older adults displays somewhat weaker negative correlations with incidence, as does density. It can be seen that the humidity variable, in its three forms, tends to be possitively correlated with incidence of COVID-19.

### *SUR Systems*

The goodness of fit of the three systems of equations is shown in Figure 5.



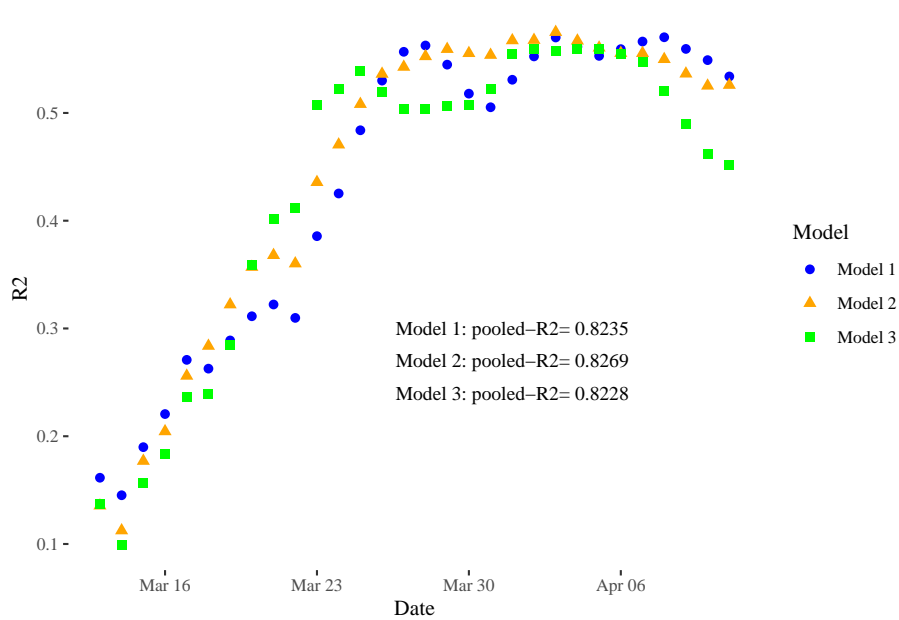


Figure 5: Goodness of fit of the SUR systems: by date and pooled

## Discussion

Possibly do some simulations with the model.

## Concluding Remarks

More words go here.

## Acknowledgments

Add acknowledgments as appropriate in final draft.

The following R packages were used in the course of this investigation and the authors wish to acknowledge their developers: `aemet` [], `ggthemes` (Arnold, 2019), `gridExtra` (Auguie, 2017), `kableExtra` (Zhu, 2019), `knitr` (Xie, 2015, 2014), `lubridate` (Grolemund and Wickham, 2011), `plm` (Millo, 2017), `rticles` (Allaire et al., 2020), `sf` (Pebesma, 2018), `spdep` (Bivand et al., 2013), `spsur` (Angulo et al., 2020), `tidyverse` (Wickham et al., 2019), `units` (Pebesma et al., 2016).

## References

- Allaire, J., Xie, Y., R Foundation, Wickham, H., Journal of Statistical Software, Vaidyanathan, R., Association for Computing Machinery, Boettiger, C., Elsevier, Broman, K., Mueller, K., Quast, B., Pruim, R., Marwick, B., Wickham, C., Keyes, O., Yu, M., Emaasit, D., Onkelinx, T., Gasparini, A., Desautels, M.-A., Leutnant, D., MDPI, Taylor and Francis, Ögreden, O., Hance, D., Nüst, D., Uvesten, P., Campitelli, E., Muschelli, J., Kamvar, Z.N., Ross, N., Cannoodt, R., Luguern, D., Kaplan, D.M., 2020. Rcticles: Article formats for r markdown.
- Angulo, A., Lopez, F.A., Minguez, R., Mur, J., 2020. Spsur: Spatial seemingly unrelated regression models.
- Arnold, J.B., 2019. Ggthemes: Extra themes, scales and geoms for 'ggplot2'.
- Auguie, B., 2017. GridExtra: Miscellaneous functions for "grid" graphics.
- Bivand, R.S., Pebesma, E., Gomez-Rubio, V., 2013. Applied spatial data analysis with R, second edition. Springer, NY.
- Casanova, L.M., Jeon, S., Rutala, W.A., Weber, D.J., Sobsey, M.D., 2010. Effects of air temperature and relative humidity on coronavirus survival on surfaces. *Appl. Environ. Microbiol.* 76, 2712–2717.
- Chan, K., Peiris, J., Lam, S., Poon, L., Yuen, K., Seto, W., 2011. The effects of temperature and relative humidity on the viability of the sars coronavirus. *Advances in virology* 2011.
- Fernandes, N., 2020. Economic effects of coronavirus outbreak (covid-19) on the world economy. Available at SSRN 3557504.
- Gong, B., Zhang, S., Yuan, L., Chen, K.Z., 2020. A balance act: Minimizing economic loss while controlling novel coronavirus pneumonia. *Journal of Chinese Governance* 1–20.
- Grolemund, G., Wickham, H., 2011. Dates and times made easy with lubridate. *Journal of Statistical Software* 40, 1–25.
- Jaakkola, K., Saukkoriipi, A., Jokelainen, J., Juvonen, R., Kauppila, J., Vainio, O., Ziegler, T., Rönkkö, E., Jaakkola, J.J., Ikäheimo, T.M., 2014. Decline in temperature and humidity increases the occurrence of influenza in cold climate. *Environmental Health* 13, 22.
- Kissler, S.M., Tedijanto, C., Goldstein, E., Grad, Y.H., Lipsitch, M., 2020. Projecting the transmission dynamics of sars-cov-2 through the postpandemic period. *Science* eabb5793. doi:10.1126/science.abb5793
- Kudo, E., Song, E., Yockey, L.J., Rakib, T., Wong, P.W., Homer, R.J., Iwasaki, A., 2019. Low ambient humidity impairs barrier function and innate resistance against influenza infection. *Proceedings of the National Academy of Sciences* 116, 10905–10910.
- Lancastle, N.M., 2020. Is the impact of social distancing on coronavirus growth rates effective across different settings? A non-parametric and local regression approach to test and compare the growth rate. medRxiv.
- Luo, S., Tsang, K.P., 2020. How much of china and world gdp has the coronavirus reduced? Available at SSRN 3543760.

- Mäkäinen, T.M., Juvonen, R., Jokelainen, J., Harju, T.H., Peitso, A., Bloigu, A., Silvennoinen-Kassinen, S., Leinonen, M., Hassi, J., 2009. Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections. *Respiratory medicine* 103, 456–462.
- Millo, G., 2017. Robust standard error estimators for panel models: A unifying approach. *Journal of Statistical Software* 82, 1–27. doi:10.18637/jss.v082.i03
- Pebesma, E., 2018. Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal* 10, 439–446. doi:10.32614/RJ-2018-009
- Pebesma, E., Mailund, T., Hiebert, J., 2016. Measurement units in R. *R Journal* 8, 486–494. doi:10.32614/RJ-2016-061
- Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D., François, R., Golemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T.L., Miller, E., Bache, S.M., Müller, K., Ooms, J., Robinson, D., Seidel, D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H., 2019. Welcome to the tidyverse. *Journal of Open Source Software* 4, 1686. doi:10.21105/joss.01686
- Xie, Y., 2014. Knitr: A comprehensive tool for reproducible research in R, in: Stodden, V., Leisch, F., Peng, R.D. (Eds.), *Implementing Reproducible Computational Research*. Chapman; Hall/CRC.
- Xie, Y., 2015. *Dynamic documents with R and knitr*, 2nd ed. Chapman; Hall/CRC, Boca Raton, Florida.
- Zhu, H., 2019. KableExtra: Construct complex table with 'kable' and pipe syntax.