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ORIGINAL PAPER

The role of pre-pandemic teleworking and E-commerce culture in the COVID-19 dispersion in Europe

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Abstract
The threats of the coronavirus have shifted the workplace of many people from office to home and also made e-commerce the primary medium for purchases. While these changes were made in an effort to mitigate contagion, there are no studies, to the best of our knowledge, that address if teleworking and e-commerce culture prior to the pandemic influenced the dispersion of the virus. In our study we examine whether pre-existing teleworking practices and e-commerce activity have played an important role in the *COVID-19* dispersion in Europe. Based on a set of data from all European countries, the present study employs the Philips & Sul methodology to explore corona convergence patterns. Our findings suggest that pre-existing e-commerce activity and teleworking practices had little to no effect in reducing the initial opportunities of individuals to contract the virus leading to the conclusion that other social interactions must have played a more important role.

Keywords COVID-19 · Convergence analysis · E-commerce · Phillips & Sul · Teleworking

Mathematics Subject Classification J81 · I18 · L81

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1 Introduction

The corona pandemic (*COVID-19*) has worldwide prompted intense debates on the physical and environmental conditions shaping human health and determining the contamination of infectious diseases like SARS-CoV-2. Important issues at stake are inter alia: density of population, degree of social interaction, environmental quality conditions, indoor ventilation capacity, and disease exposure of elderly people. Some authors even regard nowadays the city as a source of threat to human health (Mishra et al. 2020) and advocate a 'post-corona city' in which ICT (Information and Communication Technology)-determined modes of working and living would allow to create a 'new rurality' (see for a critical review Couclelis 2020). Teleworking, tele-shopping and tele-recreating might then herald a new era with a different type of spatial mobility, and with less physical transport movements and interactions. Subsequently, public transportation will have to adapt to the decreased passenger demand and enforced hygiene measures (for a detailed discussion see Gkiotsalitis and Cats 2020). An interesting overview of various issues involved with "cities in a post-*COVID* world" can be found in Florida et al. (2020).

It is evident that *COVID-19* exerts a far-reaching influence on the socioeconomic and social geography of our planet. Changes in the frequency of home-to-work trips, shopping trips and social visit trips will affect local labour markets, the retail, entertainment and cultural sectors, and social interactions. Clearly, not everyone is equally hit by the pandemic. Labour markets in particular, are nowadays affected in an asymmetrical way, with blue-collar (often low-wage) workers being more exposed to the pandemic and with white-collar workers being more able to work at home from their newly created home offices (Fana et al. 2020). Thus, the 'new normality' of homework is unequally distributed among different income and professional classes, and has great implications for inequality and employment conditions at local, regional or national scales (Palomino et al. 2020). Especially interesting is the case of personal support workers who now face except for racial and gender discrimination increased health hazard as well (Rossiter and Godderis 2020).

It should be noted that teleworking is not at all a new phenomenon; it exists already for several decades, e.g. in the US, and has been advocated time and again as a vehicle to cope with the externalities of traffic jams and environmental pollution. But even though the technological means were available, the social and economic barriers against a full-scale teleworking policy prevented often a large-scale introduction. Nevertheless, various countries have over the past years gradually realised various systems of teleworking (e.g., one or a few days per week working from home). The lockdown measures during the corona crisis have meant an enormous boost to a home office practice, not in the first place for environmental or traffic reasons, but mainly for health policy reasons (Beck et al. 2020). This massive turn to teleworking in conjunction with a pandemic situation though raises numerous questions regarding the environment. For example, the reduction in traffic is at the same time accompanied by increased car use, due to social distancing, and freight distribution, due to home deliveries leaving no clear answer as to the level of carbon emissions (Beck and Hensher 2020).

After various lockdown measures in the course of 2020 in most countries in Europe, more and more people were encouraged to work at home (or were dismissed from their regular duties) in a dedicated effort to impede the spatial dispersion of the corona virus. In fact, this form of new labour practice, often referred to as teleworking[1] or telecommuting, had already grown slowly in size in the past years in the European Union (see Eurofound 2020). Prior to the pandemic, there were significant differences between countries and sectors in teleworking practice, with Northern European countries and ICT sectors being the leaders (see European Commission 2020). Over the past months, additional measures against the *COVID-19* pandemic included the closure of the physical location of many stores (excluding those which supply food and medical products), thus forcing many shops to embrace e-commerce as a new part of their business practice.

In the past years, there have been numerous studies that have explored the potential of teleworking (Raghuram et al. 2010), and how it relates to the health of employees, sometimes with both positive and negative results (Charalampous et al. 2019). Among other factors, a variance in definitions may be the main reason behind conflicting findings (Madsen 2003). While most studies show that teleworking has a positive effect on physical health, the results are mixed when mental health is examined (Tavares 2017). Possible increase in physical exercise seems to be the main driver behind health claims (Chakrabarti 2018; Henke et al. 2016), while negative feelings such as loneliness and guilt are the main cause of criticism (Mann and Holdsworth 2003) along with the existing ICT over-involvement at the workplace (Tarafdar et al. 2015). Moreover, the frequent complexity of the environmental impact teleworking may have, (through changes in employees' lifestyles as well as in terms of reduced transportation load) needs to be further studied, as Moos et al. (2006) very correctly point out, since such impact has the potential to affect the health of the whole population.

Regarding infectious diseases, workplaces and marketplaces present obviously a hazard. The probability of inhaling infectious aerosols (i.e. air particles which carry pathogens) from an ill coworker or a customer increases, as these places become more and more crowded (Jones and Brosseau 2015). Fomites, objects or surfaces that are potentially contaminated with viral loads present also a significant opportunity for indirect infection (Boone and Gerba 2007). Another source of infection in the workplace is through hand transmission of viruses (Beamer et al. 2015). Ahmed et al. (2018) who performed a systematic literature review on the effect of social distancing rules at the workplace on the reduction of influenza transmission, concluded that if early action is taken and compliance is high, then these measures can be effective. Regarding the SARS-CoV-2 pandemic, a US study of 350 affected participants of which 64% were employed, reported that 34% had close contact with an infected colleague in the previous two weeks, but only 17% of them had the ability to telework (Tenforde et al. 2020).

[1] Teleworking refers in particular to periodic work that takes place at home (or a satellite office) in an effort to reduce commuting (Ellison 1999).

On the other hand, it is noteworthy that e-commerce was studied in the literature mainly from an economic welfare perspective (Brynjolfsson et al. 2003; Nakayama 2009), since it is harder to trace infected individuals in marketplaces and hence to quantify the health effects of e-commerce. Nevertheless, a shopping mall in Wenzhou, China is known to be responsible for a cluster of *COVID-19* cases through some of the social and spatial transmission mechanisms described above (Cai et al. 2020). But, clearly, the effects of teleworking and e-commerce on the spread of corona are large unknown.

Since the degree of teleworking and e-commerce shows great differences in acceptance and implementation in various countries or regions in Europe, the question is pertinent whether the existing different adoption rates of teleworking and e-commerce are also reflected in corresponding differences in corona infection patterns. Therefore, the research question to be addressed in the present paper is: are geographical differences in pre-corona teleworking and e-commerce practices reflected in distinct dispersion patterns of *COVID-19* in Europe?

In this paper, we will examine whether the pre-corona teleworking population and e-commerce practice of people in Europe had an effect in containing *COVID-19* due to the limited possibilities of this population in contracting and spreading the virus. To do so, we employ the Phillips and Sul (2007, 2009) convergence approach in order to identify situations of convergent patterns between 35 European countries and compare the percentage of teleworkers and individuals who made purchases online among them. We find the existence of two convergence clubs for which neither teleworking nor e-commerce pre-corona activity appear to show significant differences. Our analysis contributes to the effort of better identifying the factors that can contain the spread of such infectious diseases in the present and future situations and also urges researchers to further study the relation between infectious diseases and information systems.

The remaining part of the study is structured as follows: In Sect. 2 we describe the database employed in our empirical analysis, while in Sect. 3 we discuss our methodological framework. Next, Sect. 4 presents and interprets our results, while Sect. 5 concludes this study.

2 Data

In the present section we describe the *COVID-19* as well as the teleworking and e-commerce data used in our research. The descriptive statistics are given in Table 1.

2.1 COVID-19 data

COVID-19 data used in our study were distilled from the ECDC (European Centre for Disease Prevention and Control) (ECDC 2020). Our analysis is limited to the period between March 18, 2020 and April 20, 2020 due to missing values in the previous days. Moreover, the fact that we examine the impact of pre-existing teleworking practices and e-commerce activity on *COVID-19* dispersion makes

Table 1 Descriptive statistics

Variables	N	Mean	SD	Min.	Max.
COVID-19 cases	1190	4.176	5.002	0	38.504
COVID-19 deaths	1190	2.635	4.751	0	43.425
$Teleworking_{2019}$	35	15.369	11.356	1.1	37.8
$E-commerce_{2019}$	35	46.086	19.000	12	80

N = Number of observations (Number of countries for $Teleworking_{2019}$ and $E-commerce_{2019}$ variables and number of countries x number of days for *COVID-19* cases and *COVID-19* deaths variables); *COVID-19* cases = Number of cases per 100,000 inhabitants; *COVID-19* deaths = Number of deaths per 1,000,000 inhabitants; $Teleworking_{2019}$ = Employed persons between 15 and 74 years old working from home as a % of the total employment in 2019; $E-commerce_{2019}$ = % of individuals who made their last online purchase in the last three months of 2019

the analysis of the first wave of the pandemic in Europe more appropriate. The cases and deaths were divided by the population in order to create a per capita value which was then multiplied by 100,000 and 1,000,000 respectively to obtain a rate. In the next two subsequent sections, we present several issues and limitations concerning the data extracted which we feel should be mentioned, though beyond our control. Our analysis proceeds in the absence of better and more reliable data.

2.1.1 COVID-19 cases

The cases reported by each country are subject to underreporting due to selection bias (e.g., testing only patients of older age with severe symptoms in hospitals). In turn, this selection bias decreases the cases when extrapolating the results for the total population. Then comes the second issue viz., testing of *COVID-19*. Assuming proper testing without contamination, most diagnoses were initially performed using Reverse Transcription-Polymerase Chain Reaction ($RT-PCR$) due to the lack/or low sensitivity and/or specificity of antibody based assays. In medical diagnosis, test sensitivity is usually conceived of its ability to identify true positives correctly, whereas test specificity is the ability of a medical test to identify the presence of true negatives correctly (Altman and Bland 1994). We should note that a *PCR* product is not in itself an infectious virus particle, but it is assumed due to the fact that this is an outbreak situation where many people are infected with SARS-CoV-2. Therefore, *PCR* positivity is generally considered a diagnostic tool. In any case, even with $RT-PCR$, false negative or false positive tests were not uncommon (Xiao et al. 2020). Despite the selection bias, the limitations in detection techniques (especially in serology) and the possibility of a false diagnosis, these are the only available data on a global scale.

2.1.2 COVID-19 deaths

The sampling bias mentioned above affects the death rate as well. Deaths on the other hand are more likely to suffer from overestimation. A positive test does not signify that this is the single cause of death, since underlying conditions have probably led critical patients to develop acute respiratory distress syndrome (*ARDS*), acute respiratory failure or related medical complications which resulted to their death (Huang et al. 2020). Moreover, co-infection with more that one virus or bacteria was not uncommon (Kim et al. 2020), and as the *CDC* (Centers for Disease Control and Prevention) correctly decrees: "...positive test results are indicative of active infection with *COVID-19* but do not rule out bacterial infection or infection with other viruses. The agent detected might not be the definite cause of death." (CDC 2020).

2.2 Teleworking & E-commerce data

The latest available data for e-commerce and teleworking were extracted from the Eurostat (2019a, 2019b) database. The teleworking data measure the employed persons between the age of 15 and 74 years who work from home (usually or sometimes) as a percentage share of the total employment in 2019, while e-commerce data measure the percentage of individuals who made their last online purchase in the last three months of 2019. The use of sector-specific data for teleworking would make our analysis much more sensitive, but unfortunately such data are not available.

3 Methodology

The convergence pattern of *COVID-19* is examined here through the methodology developed and advocated by Phillips and Sul (2007, 2009) (hereafter *PS*). The *PS* approach is based on its superiority over the traditional and common β and σ-convergence statistical analysis (for more information, we refer to Apergis et al. 2013). Below follows a brief outline of the methodology (the description of the methodology follows the one in Christopoulos and Eleftheriou 2020).

The panel data in our analysis capture the different *COVID-19* case and death rates which are here represented by X_{it} where i and t denote the country cross-section (i.e., the 35 European countries) and the time dimension, respectively. X_{it} consists of two components and is defined as follows:

$$X_{it} = \delta_{it}\mu_t, \tag{1}$$

where δ_{it} is the idiosyncratic component accounting for the deviation of each country (i) as compared to the common trend μ_t. This idiosyncratic component is equal to:

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-a}, \tag{2}$$

where δ_i is a fixed time-invariant value, σ_i represents an idiosyncratic scale parameter, ξ_{it} represents an iid (independent identically distributed) random variable over all countries i (with a zero mean and a unit variance), which is weakly dependent over t, while $L(t)$ represents a slowly varying function characterized by $L(t)\rightarrow \infty$, if $t\rightarrow \infty$ and is a decay rate parameter. From Eq. (2) it is easily shown that for all $a \geqslant 0$, δ_{it} converges to δ_i.

We use the above described *PS* approach in order to test whether all countries in our sample converge towards a joint steady-state, or toward multiple steady-states. Then, the null hypothesis in our research, $\mathcal{H}_0 : \delta_i = \delta$ and $a \geqslant 0$ of convergence of all countries i in contrast to the alternative hypothesis, $\mathcal{H}_A : \delta_i \neq \delta$ or $a < 0$ of non-convergence for some countries i, is examined here by means of an estimate of the long-run variance of the regression residuals[2]:

$$\log\left(\frac{H_1}{H_t}\right) - 2\log L(t) = \hat{c} + \hat{b}\log t + \hat{u}_t, t = [rT], [rT]+1, \dots, T, \tag{3}$$

where $L(t) = \log(t)$, $\hat{b} = 2\hat{a}$, in which $\hat{a}$ represents the least squares estimate of a, given the null hypothesis, $r = 0.3$ [this value of r provides satisfactory outcomes regarding the size as well as the power properties of our test (see Phillips and Sul , 2007)][3], and H_t equals

$$H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2, \tag{4}$$

where the relative transition component h_{it} is defined as

$$h_{it} = \frac{X_{it}}{N^{-1}\sum_{i=1}^{N} X_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N}\delta_{it}}. \tag{5}$$

The convergence hypothesis is tested by an autocorrelation and heteroskedasticity robust one-sided t-test (i.e., the test is performed using Heteroskedasticity and Autocorrelation Consistent (HAC) standard errors); it is rejected at a 5% level, if $t_{\hat{b}} < -1.65$. If there is no sample convergence, we follow the four-step procedure proposed by Phillips and Sul (2009) (2007, pp. 1800–1801) is adopted to identify convergence clubs. However, since the above procedure may imply an overestimation of the number of clubs, we also carry out club-merging tests, as suggested by Phillips and Sul (2009). The corresponding transition paths are also estimated. The application results will be presented in Sect. 4.

[2] For more details on the derivation of the log$t$ regression Eq. (3) from Eq. (2), see Appendix B in the Phillips and Sul (2007) paper.

[3] The parameter r determines the fraction of the time series data not included in the convergence test and $[rT]$ is defined as the integer part of rT [see Phillips and Sul (2007, p. 1789)].

Table 2 Main results

COVID-19 cases	Panel A: Phillips and Sul (2007)		Panel B: Phillips and Sul (2009)		
	log *t*	*t*-stat	Final club	log *t*	*t*-stat
Panel A: Club convergence results of COVID-19 cases					
Full sample	−0.394 (0.163)	−2.420**			
Club 1 [BEL, ESP, FIN, GBR, IRL, LUX, MKD, NLD, ROU, SRB, SVK, SWE, TUR]	0.477 (0.233)	2.045	*Club* 1 [BEL, ESP, FIN, GBR, IRL, LUX, MKD, NLD, ROU, SRB, SVK, SWE, TUR]	0.477 (0.233)	2.045
Club 2 [AUT, BGR, CHE, CYP, CZE, DEU, DNK, EST, FRA, GRC, HRV, HUN, ISL, ITA, LTU, LVA, MLT, MNE, NOR, POL, PRT, SVN]	-0.143 (0.193)	-0.739	*Club* 2 [AUT, BGR, CHE, CYP, CZE, DEU, DNK, EST, FRA, GRC, HRV, HUN, ISL, ITA, LTU, LVA, MLT, MNE, NOR, POL, PRT, SVN]	−0.143 (0.193)	-0.739
Panel B: Teleworking and e-commerce as COVID-19 containment factors					
	Club	$Teleworking_{2019}$		$E - commerce_{2019}$	
COVID-19 cases	1	18.9		48.692	
	2	13.282		44.545	

(i) Panel A: The numbers in square brackets denote the countries included in each club (countries' abbreviations are provided in the Appendix). The term log *t* denotes the convergence coefficient whereas *t*-stat is the convergence test statistic. The latter is distributed as a simple one-sided *t*-test with a critical value of −1.65. ** denotes rejection of the null hypothesis (convergence) at 5% level of statistical significance. Standard errors are reported in parentheses. The higher the number of the club, the lower the *COVID-19* cases on average. The results were estimated using the Stata codes of Du (2017). (ii) Panel B: The numbers reported in Panel B are the average values of the corresponding containment factor for each club. There is no statistically significant difference between the means of containment factors across clubs in all cases. The test for the equality of means is conducted allowing for both homogeneous and heterogeneous covariance matrices across groups (the test produces similar results under both options)

4 Results and interpretation

In the present section we present and discuss our findings (given the data restrictions mentioned in Sect. 2). The convergence tests for the *COVID-19* cases resulted in the formation of two convergent clubs (see Panel A in Table 2), while for the *COVID-19* deaths all countries converged into a singe club, with the exception of Belgium which diverted (the corresponding results for *COVID-19* deaths are available upon request and are not reported here for the sake of brevity).

Club 1 represents the club with the most cases per 100,000 inhabitants, and some spatial patterns around the United Kingdom, Scandinavia and the Balkans can be observed (Fig. 1). These patterns might be the product of similar policies in the management of the outbreak or of increased transmission patterns due to contiguity or even of similar testing practices. The same can be said for Club 2, though spatial clustering appears mainly in central Europe and the Baltic countries.

Regarding our main goal, namely the examination of the effect of teleworking and e-commerce on the dispersion of *COVID-19*, no statistical significant difference appears to exist in the mean $Teleworking_{2019}$ and the mean $E - commerce_{2019}$ between the two convergent clubs. However, Club 2 has a lower mean on both variables, meaning less teleworking and e-commerce activity than Club 1 (see Panel B in Table 2). Our analysis leads to the conclusion that the intensity of teleworking and e-commerce did not offer a significant explanation for the initial dispersion pattern of SARS-CoV-2. Possibly, other social interactions were the main drivers behind the escalation of the *COVID-19* pandemic, most likely at a micro scale of home, family and friends contacts.

The transition paths shown in Fig. 2 confirm the convergence results. The two clubs begin to diverge from late March with the gap becoming wider from the 8th of April. This gap might as well be the result of several government interventions that increased in intensity as the pandemic progressed.

The underlying mechanism behind our hypothesis is that teleworking and e-commerce affect human mobility, and therefore the chances of contracting and spreading the virus. The travel behaviour of teleworkers though tells a different story. A recent study on pre-*COVID-19* US data (Su et al. 2021) demonstrates that while telecommuters were more likely to stay at home during a workday, they exhibit more diversity in their trip destinations and time, as well as increased trips and vehicle miles traveled compared to regular commuters. Even though the population and circumstance of our analysis are different, another study also points to teleworking as the culprit for the increased number of trips during the pandemic (Riggs 2020). Therefore, the impact of teleworking on human mobility seems to be quite ambiguous corroborating in this way our findings. Unfortunately, in the case of e-commerce, there is very little empirical evidence connecting human mobility and e-commerce other than the increased e-commerce mobile app activity of individuals, when they are at their residence (Qiao et al. 2016).

Fig. 1 Estimated clubs for *COVID-19* cases. *Note*: Figure 1 was generated with the use of https://mapchart.net .

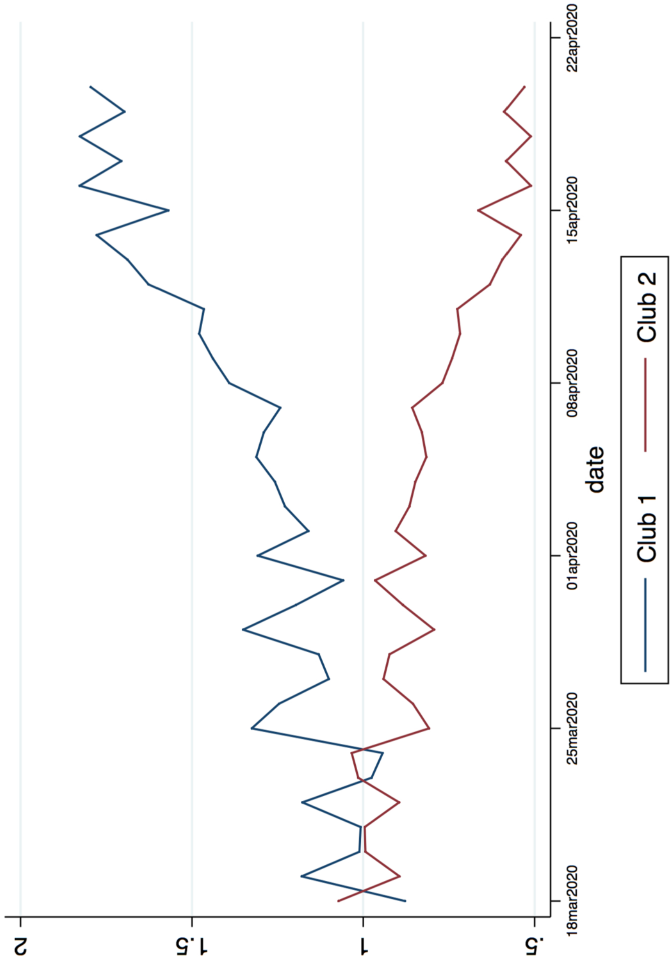

Fig. 2 Transition paths (*COVID-19* cases)

Table 3 Correlation with mobility indices

	RR	GP	P	TS	W	R
$Teleworking_{2019}$	−0.21	−0.56*	−0.29	−0.39*	−0.52*	0.45*
$E-commerce_{2019}$	−0.22	−0.58*	−0.29	−0.38*	−0.51*	0.46*

$Teleworking_{2019}$= Employed persons between 15 and 74 years old working from home as a % of the total employment in 2019; $E-commerce_{2019}$ = % of individuals who made their last online purchase in the last three months of 2019; *RR* = Retail & Recreation; *GP* = Grocery & Pharmacy; *P* = Parks; *TS* = Transit stations; *W* = Workplaces; *R* = Residential; * Indicate significance at 5% level

To further test the connection between teleworking/e-commerce and human mobility we use six mobility indices from Google (2020) to conduct a correlation analysis. These indices measure mobility trends as a percentage change from a pre-*COVID-19* baseline level in various locations. Since these data are available from the 15th of February and onwards, we take the mean change of 25 days (from the 15th of February to 11th of March) for each country.[4] This time period ends one week before the period used in our convergence analysis and on the date *COVID-19* was declared as a pandemic by the World Heath Organisation (Cucinotta and Vanelli 2020). A limitation of this analysis is that the data on teleworking and e-commerce precede mobility data temporally due to the lack of 2019 mobility data. However, it can be assumed that teleworking practices and e-commerce activity remained more or less unaltered in the early stages of the pandemic.

As it can be seen on Table 3, teleworking and e-commerce have a significant negative correlation with mobility trends in grocery and pharmacy, transit stations, and workplace locations, while they were positively correlated with residential locations. On the other hand, correlations with retail and recreation, and park locations, were negative but not statistically significant at the 5% level. These findings are evidence of a negative relation between teleworking/e-commerce and human mobility.

Despite the fact that teleworking and e-commerce appear to be negatively correlated with mobility, the pandemic circumstances (i.e., mobility restrictions) and the need of individuals to socialize may have led to increased contacts with family members and friends, which are far more intimate in nature than interactions with co-workers and shop employees. This fact may explain our main finding of non statistically significant differences in teleworking and e-commerce groups.

[4] Three countries, Cyprus, Iceland, and Montenegro, were excluded from the analysis due to absence of data.

5 Conclusions

Online work and shopping practices are often advocated as important vehicles in the battle against the corona crisis. The present study aimed to investigate whether pre-existing teleworking practices and e-commerce activity played actually a role in the dispersion of *COVID-19* in Europe. Our results suggest that neither teleworking nor e-commerce had a significant part in the dispersion of the virus. This implies that they alone are not sufficient as containment measures, and hence policy makers should look into additional social distancing measures to limit human mobility. However, the fact that the intensity of teleworking and e-commerce activity has changed since the beginning of the pandemic raises the question whether the increased teleworking and e-commerce will now have a different effect than their pre-existing values. Moreover, the period of our analysis happens to coincide with the beginning of lockdown measures in Europe, therefore conclusions must be drawn with caution, since our methodological approach does not allow us to control for such measures. Clearly, the supply of more detailed and reliable data regarding *COVID-19* cases and deaths is of imperative importance in order for future research to better explore which containment measures are the most effective. At the same time, more attention is needed for policy interventions that are less disruptive to the economy and do not widen the socioeconomic inequality gap between and within countries any further.

Appendix

See Table 4.

Table 4 Country abbreviations

Country	Abv.	Country	Abv.	Country	Abv.	Country	Abv.	Country	Abv.
Austria	AUT	Estonia	EST	Ireland	IRL	Netherlands	NLD	Slovakia	SVK
Belgium	BEL	Finland	FIN	Italy	ITA	North Macedonia	MKD	Slovenia	SVN
Bulgaria	BGR	France	FRA	Latvia	LVA	Norway	NOR	Spain	ESP
Croatia	HVR	Germany	DEU	Lithuania	LTU	Poland	POL	Sweden	SWE
Cyprus	CYP	Greece	GRC	Luxembourg	LUX	Portugal	PRT	Switzerland	CHE
Czechia	CZE	Hungary	HUN	Malta	MLT	Romania	ROU	Turkey	TUR
Denmark	DNK	Iceland	ISL	Montenegro	MNE	Serbia	SRB	United Kingdom	GBR

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Declarations

Conflict of interest No conflict of interest has been declared by the authors.

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