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Regional economic impact of Covid-19: the role of sectoral structure and trade linkages

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Abstract

The paper provides an ex-post analysis of the determinants of within-country regional heterogeneity of the labour market impact of COVID-19. By focussing on the first wave of the pandemic in the four largest euro area economies, it finds that the propagation of the economic impact across regions cannot be explained by the spread of infections only. Instead, a region's economic structure is a significant driver of the observed heterogeneity. Moreover, our results suggest that a region's trade relations, both within and across countries, represent a relevant indirect channel through which COVID-19 related disruptions affect regional economic activity. In this regard, the analysis depicts vulnerabilities arising from potential disruptions of the highly integrated EU supply chains.

Keywords: COVID-19 pandemic, short-time work, input-output linkages, sectoral exposure, regional differences

JEL classification: R11, F14, J40, R15

Non-technical summary

This paper looks into the drivers of the significant regional heterogeneity of the economic impact of the COVID-19 observed in the four largest euro area economies during the earliest phase of the pandemic. We investigate how the interplay between the stringency of governments' containment measures, sectoral structure and trade linkages help explaining the within-country regional heterogeneity of the labour market impact of the pandemic, as measured by the number of employees in short-time work schemes.

In particular, we compute an indicator of regional economic exposure to COVID-19 which combines information about the susceptibility to the contagion of each economic activity and about the possibility to perform tasks remotely. In a first step, the latter is interacted with a country-wide indicator of stringency of containment measures, as a high sectoral exposure due to limited possibilities of social distancing at work and/or teleworking is likely to lead to larger economic shortfalls if combined with strict regulations, e.g. related to workplace closings. In a second step, we investigate whether a region's trade relations with other regions heavily exposed to the COVID-19 shock may imply an additional economic burden. To this end, we compute two measures of indirect exposure to the COVID-19 shock via regional exports and sourcing of intermediate goods. In both cases, we are able to account for regional trade linkages both across and within countries.

Overall, our results suggest that the propagation of the economic impact across regions cannot be explained by the regional spread of infections only. Instead, a region's economic structure is a significant driver of the observed heterogeneity. At the same time, regional trade linkages represent a relevant indirect channel of propagation of the crisis. On the one hand, this may be related to shortfalls in demand for the focal region's exports. The empirical results suggest that this channel is present only for intra-country trade. On the other hand, COVID-19 related shocks may have caused disruptions in inter-regional supply chains. Indeed, our results suggest that regions relying on intermediate goods sourced from foreign regions heavily exposed to the pandemic have experienced a significantly larger increase in the number of employees in short-time work. Further results indicate that this latter finding may be caused by disruptions in intra-EU supply chains.

1 Introduction

The COVID-19 pandemic was an unprecedented global health crisis which rapidly coupled with an equally unprecedented - both in scope and magnitude - global economic crisis. The latter was driven by lockdown measures which were adopted with varying intensity in several countries across the globe in order to deter the spread of the contagion. The need to rapidly "flatten the curve" led, in a very short time frame, to the partial or total shut-down of businesses, schools, cultural and sport activities, as well as to a sudden freeze in people's movement. The result was both an abrupt disruption of supply and a sharp contraction of demand, amplified by high and persistent uncertainty.

In the attempt to predict the path ahead and the possible shape of the recovery, a number of studies estimate the depth of the macroeconomic contraction based on the experience from previous crisis episodes, past epidemics and natural disasters (e.g., Jordà, Singh, and Taylor, 2020; Ludvigson, Ma, and Ng, 2020; Barro, Ursúa, and Weng, 2020; Boissay and Rungcharoenkitkul, 2020). A growing empirical literature points to the significant cross-country heterogeneity of the incidence of COVID-19, the related governments' containment measures and their economic implications. Such heterogeneity is shown to largely depend on countries' sectoral composition of production – with a number of "non-essential" activities in the services sector being relatively more severely hit - as well as on occupation-type exposure (e.g., Béland, Brodeur, and Wright, 2020; Dingel and Neiman, 2020; Mongey, Pilossoph, and Weinberg, 2020). Furthermore, small firms, more likely to become financially constrained, are shown to be relatively more exposed and vulnerable to the pandemic (Balduzzi, Brancati, Brianti, and Schiantarelli, 2020; Ding, Levine, Lin, and Xie, 2020; Fairlie, 2020). Finally, a number of contributions point to the role played by globalisation, via final and intermediate goods trade, in the propagation of the economic impact of the Covid-19 shock (Kohlscheen, Mojon, and Rees, 2020). By simulating a global lockdown as a contraction in labour supply, Bonadio, Huo, Levchenko, and Pandalai-Nayar (2020) find that about one third of the estimated contraction in GDP is due to disruptions in global supply chains, which amplified the negative impact of the shock in those countries imposing more severe lockdowns than in the respective average trading partner. Differently from previous pandemics, in a closely integrated world, supply chain trade is argued to have exacerbated the contagion

(Sforza and Steininger, 2020) and to represent a potential channel of "reinfection" (Baldwin and Freeman, 2020).

This paper contributes to the literature mentioned above by looking into the heterogeneous impact of the pandemic across regions, which has been relatively less explored so far also due to the limited availability of timely data with such level of granularity. In particular, we investigate how the interplay between the stringency of governments' containment measures, sectoral structure and trade linkages help explaining the within-country regional heterogeneity of the economic impact of the pandemic in the four largest euro area economies (France, Germany, Italy, and Spain) during the first quarter of 2020. The impact on activity is here captured by the number of employees in short-time work schemes (at the 2-digit region level of the NUTS classification), which at the early stage of the pandemic represented one of the main policy tools to contain mass layoffs.[1] In particular, by May 2020 around 11.3 million employees in France, 10.1 million employees in Germany, 8.3 millions employees in Italy, and 4 million employees in Spain were in short-time work schemes (Müller and Schulten, 2020).

We find that the propagation of the economic impact across regions cannot be explained by the regional spread of infections only. Instead, a region's economic structure is a significant driver of the observed heterogeneity. At the same time, regional supply chains represent a relevant indirect channel of propagation of the crisis, not only through trade with regions in other countries but also through interconnections within each economy. While available studies mainly focus on the role of trade linkages across countries, taking intra-country trade explicitly into account is in our view particularly relevant in the current context as regions with a limited incidence of the contagion (and/or a low degree of participation in global value chains) may have nevertheless taken a heavy toll on economic activity due to their dependence on other highly exposed (and/or highly integrated) regions in the same country.

The paper is structured as follows. Section 1 provides some descriptive evidence motivating our analysis. The data set and empirical strategy are presented in Section 2, followed by a description of the results in Section 3. Section 4 concludes.

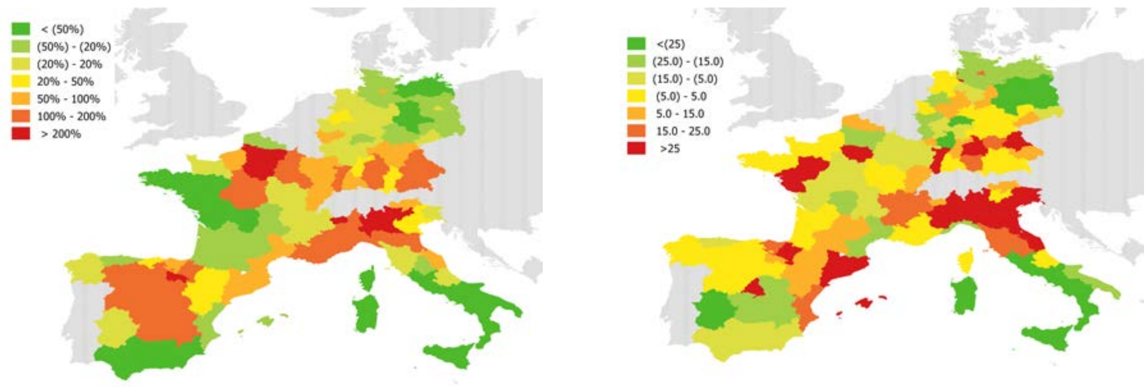
[1] As pointed out in Ludvigson et al. (2020) and in Coibion, Gorodnichenko, and Weber (2020), differently from previous natural disasters, the COVID-19 has not translated into a destruction of physical capital but rather severely impacted the labour force.

2 Regional heterogeneity of the COVID-19 and its labour market impact

COVID-19 made its first appearance in Europe in January 2020. The first severe outbreak was in Italy, followed by Spain and France and, lastly, by Germany. With a similar pattern, in each country the phenomenon started as a local shock, soon spreading within the territory. Yet, the incidence of the pandemic remained highly heterogeneous across regions (Figure 1).

Figure 1: Within country variation in COVID-19 infections and Employees in short-time work (STW)

COVID-19 infections | Employees in STW



NOTES: COVID-19 infections in March and April relative to regional population. Deviation from country-specific median. Data obtained from national sources. See Appendix A for details about the data.

NOTES: Employees in STW schemes in March and April relative to regional population. Deviation from country-specific median. Data obtained from national sources. See Appendix A for details about the data.

As a result of the governments' containment measures, already in the first phase of the pandemic, the economic toll of the crisis materialized in unprecedented labour market disruptions. Figure 1 shows the regional propagation of the economic impact, as measured by the number of employees in short-time work schemes (henceforth, STW), which were consistently implemented in Italy (the so-called *Cassa Integrazione Guadagni*), Spain (*Expediente de Regulación Temporal de Empleo*), France (*Activité Partielle*) and Germany (*Kurzarbeit*) and extended to a wider spectrum of beneficiaries in response to the outbreak.[2] Also in this case, quite a substantial

[2]For the main features of the STW schemes in each country, see Table A1 in Appendix. Such schemes aim at providing temporary support during economic downturns, in order to prevent lay-offs and preserve firms' production ability. More specifically, workers are temporary dismissed – fully or via working time reduction – to be re-employed on the same terms once original conditions no longer apply, or the maximum duration of the scheme has been reached. Under STW scheme, workers receive a variable share of their salary (in our countries

regional heterogeneity emerged; it's worth nothing, however, that the pattern does not fully mirror the within-country geographical distribution of the disease, suggesting that other factors are at play. With this paper we aim at explaining the drivers of such differences.

A first candidate to explain the heterogeneous labour market impact of COVID-19 relates to the interplay between country-wide containment measures and the regions' sectoral structure. Indeed, sectors have been differently exposed to governments' restrictions depending on the extent to which social distancing could be ensured and/or activities could be performed remotely. In order to capture this channel of regional exposure, we make use of two distinct sets of information. The first one is an indicator which informs about the susceptibility to the contagion of each economic activity at the 2-digit level of the Statistical Classification of Economic Activities (NACE), developed by the Italian National Institute for Insurance against Accidents at Work (INAIL, 2020). In particular, the latter assigns a sectoral risk score based on the extent to which workers are directly exposed to the virus (the highest score being for personnel working in hospitals); social distancing can be guaranteed while being at work; the workers' activities entail contacts with third parties. Since this indicator does not account for the possibility to still carry out some activities remotely via smart working, we consider an additional sectoral indicator of "teleworkability", which we obtain from Dingel and Neiman (2020).[3] Both the INAIL and the teleworkability indicators are converted into ordinal scale with three categories (low, medium, high) according to the variables' distributions, with sectors allocated as in Table 1. By averaging the two indicators and aggregating the sector-specific measure to the region level, by applying sectoral employment shares at the NUTS2 region level from the Eurostat's Labour Force Survey (LFS), we end up with the *Exposure* variable (at the country-region level) shown in Figure 2.

sample, ranging from 60 to 100 percent) which is covered by a public allowance. As outlined in Table A1, we usually have information about the number of employees in STW schemes, except for Italy, where the information is provided in hours worked, which we convert in number of persons assuming an average working time of 40 hours a week. Moreover, in the case of Germany and France, we use totals of STW cases in March and April, while in Italy and Spain we consider the cases reported in April. This choice is based on data availability and recommendations on the use of these data made by national sources. Also because of these country-specific features, in this study we focus on explaining within country variation in employees in short-time work and do not investigate potential drivers of cross-country heterogeneity.

[3]More specifically, Dingel and Neiman (2020) provide an indicator informing about the share of jobs that can be done remotely by sector; here we converted US NAICS codes into the European NACE classification codes, and aggregate industries in order to match the sectoral breakdown in Eurostat's Labour Force Survey, which provides us with region-specific sectoral employment shares. Note that both the risk score and the teleworkability score are based on country specific information (Italy in the first case, US in the second). The implicit assumption we are making here is that these indicators mainly relate to deep sectoral features, rather than country-specific aspects.

Table 1: Measure of sectoral exposure to the COVID-19 shock

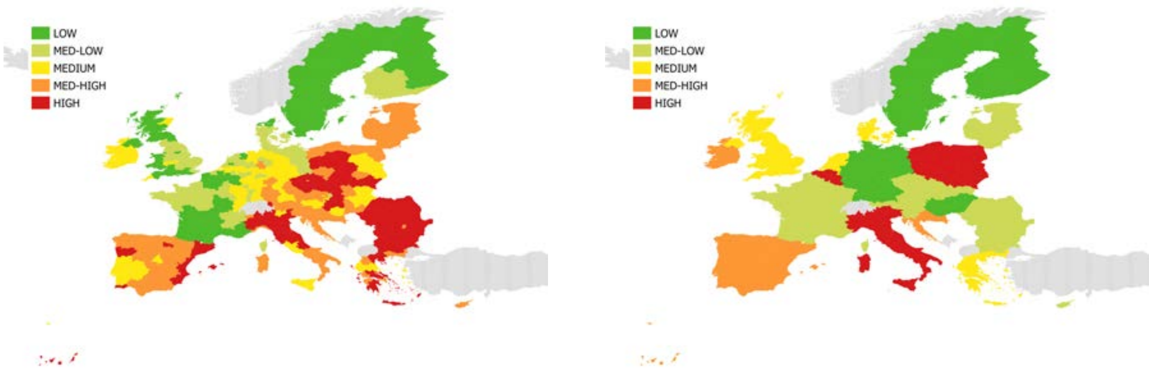
		Degree of Teleworkability		
		Low	*Medium*	*High*
INAIL sectoral risk	*Low*	Agriculture; Construction	-	Financial and insurance; Real estate
	Medium	Manufacturing	Professional services	Information and communication
	High	Retail and wholesale	Art, sport and entertainment	-

NOTES: see Table A2 for details

Figure 2: Sectoral exposure (across NUTS2 regions) and stringency of containment measures (across countries)

Sectoral exposure

Stringency of containment measures



NOTES: Measure based on information about sectoral exposure to COVID-19 (from INAIL and "teleworkability" from Dingel and Neiman (2020), aggregated to the regional level using a region's sectoral employment shares from Eurostat's labour force survey. Each category in the figure refers to a quantile of the variable's distribution. See Appendix A for details about the data.

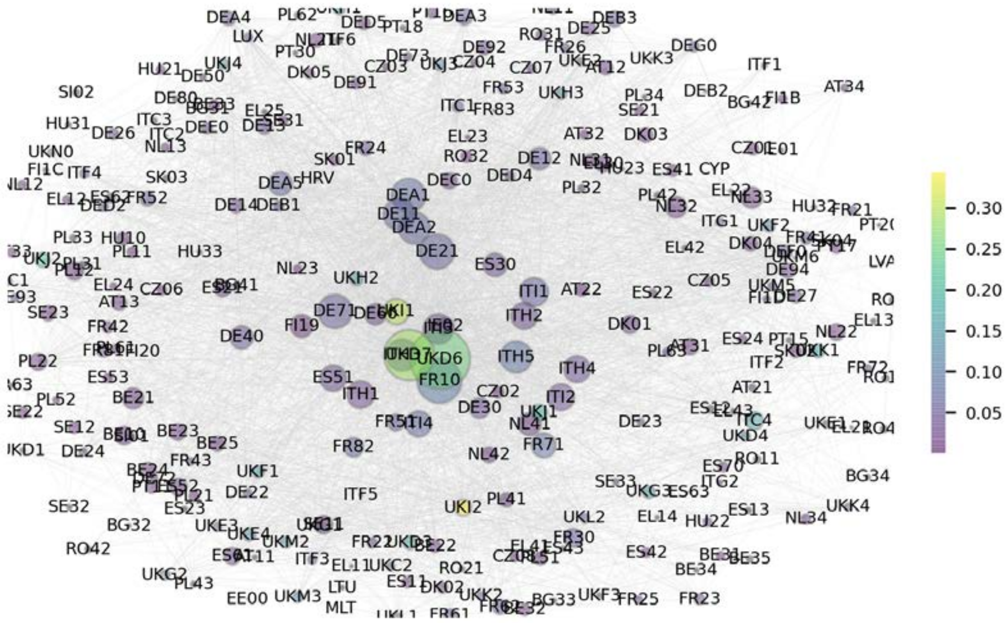
NOTES: Average of daily measures related to workplace closings, limits to private gatherings, "shelter-in-place" orders, and restrictions on internal movements until April 2020, obtained from Oxford COVID-19 Government Response Tracker. Each category in the figure refers to a quantile of the variable's distribution. See Appendix A for details about the data.

As for the containment measures adopted in different countries, we make use of four sub-indicators available at daily frequency from the Oxford COVID-19 Government Response Tracker (Hale, Angrist, Cameron-Blake, Hallas, Kira, Majumdar, Petherick, Phillips, Tatlow, and Webster, 2020), namely workplace closings, limits to private gatherings, shelter-in-place orders and restrictions on internal movements. We focus on countrywide measures over the period March to April 2020 of these four daily indicators which range from 0 to 3 (in part after rescaling).[4] Our

[4]As the aim is to focus the impact of lockdown measures in the early stage of the pandemic, we do not include

synthetic indicator of *Stringency* (of containment measures) - computed as a simple average of the four sub-indicators just mentioned – varies significantly across countries, as shown in Figure 2.

Figure 3: Regional trade network



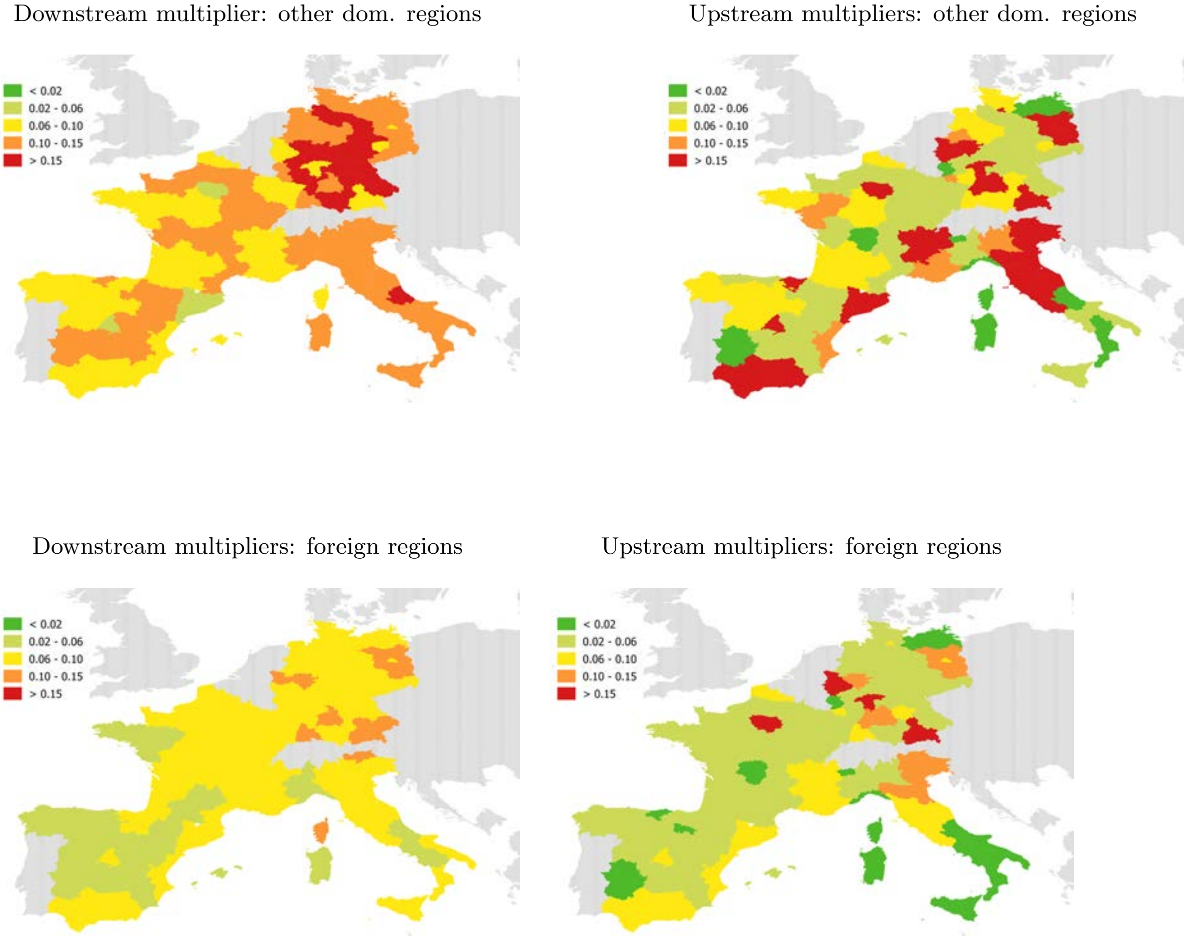
NOTES: Based on regional input-output tables from Thissen et al. (2019), using export flows that amount to at least 100,000 Euro. See main text and Appendix A for details about the construction of the figure and the data. The size of a region's node corresponds to total exports, while the colour refers to so-called eigenvector centrality and ranches from blue (low centrality) to yellow (high centrality). Eigenvector centrality is a measure of the influence of a node in a network, considering the degree to which a node is connected to many other nodes, which are themselves connected to many other nodes.

Beyond the direct impact related to the sectoral structure, regions may have been also indirectly affected by the pandemic via trade linkages. A visual inspection of trade flows among regions in all European Union countries - based on the regional input-output (RIO) tables from Thissen et al. (2019) [5] - indeed shows that selected regions are central in the trade network both in terms of size of trade flows and in terms of number of interconnections with other regions which are themselves central, suggesting that shocks to these areas may have potentially

in our analysis information on the fiscal, monetary and financial policy measures taken to mitigate the effect of the lockdown.

[5] Regional input-output tables refer to the year 2013 and inform to what extent a region is sourcing intermediate inputs from other regions as well as is exporting its products (both services and goods) to other regions.

Figure 4: Regional output multipliers



NOTES: Based on regional input-output tables from Thissen et al. (2019). See the main text for details about the computation of the multipliers.

significant spillover effects (Figure 3). Some of these regions were among the areas where the incidence of contagion was the highest.

Indeed, regional supply chains represent a powerful channel of propagation of the crisis, through international trade as well as interconnections within each country, as can be shown by means of so called output multipliers computed using again the RIO tables from Thissen et al. (2019). Output multipliers inform about the aggregate increase in gross output (measured in euros) per euro of additional output in a specific region (see, e.g., Izquierdo, Moral-Benito, and Prades, 2019). These multipliers can be distinguished into downstream propagation (i.e.

supply-driven shocks) and upstream propagation (i.e., demand-driven shocks), and decomposed into the effect related to the domestic economy and to foreign countries. Figure 4 shows quite significant regional heterogeneity in these multipliers, with some regions standing out as systemic in terms of their aggregate impact. This is the case, for instance, in the South of Germany and the North of Italy, which present relatively high downstream and upstream multipliers, for both the domestic economy and the other countries.[6] Such heterogeneity is another motivation for us to investigate the potential role of regional trade links in propagating the economic impact of the pandemic across regions.

3 Empirical approach

In this section, we lay out the empirical approach to investigate the regional economic impact of the COVID-19 shock and the role of trade linkages in transmitting this shock also to other regions.

Our empirical strategy has two purposes. First, we investigate the direct economic impact of a region's exposure to the COVID-19 shocks and applied containment measures. To be more precise, in the first step, we consider the measure of regional exposure introduced above (termed $Exposure$) and its interaction with the country-wide indicator of the stringency of containment measures (termed $Stringency$) in order to investigate the direct economic impact of COVID-19. The rationale for including this interaction term is that a high sectoral exposure (e.g., due to limited possibilities of social distancing at work and / or teleworking) is likely to lead to larger economic shortfalls if combined with strict containment measures (e.g., related to workplace closings and / or shelter-in-place orders). In particular, we are estimating the following model

$$\begin{aligned} y_{cr} = {} & \beta_1 Exposure_{cr} + \beta_2 Exposure_{cr} \times Stringency_c \\ & + \beta_3 IDE^{ex}_{cr} + \beta_4 IDE^{im}_{cr} + x'_{cr}\beta_5 + \gamma_c + \epsilon_{cr}, \end{aligned} \quad (1)$$

[6] Multipliers are computed using the Leontief matrix $B = (I-A)^{-1}$, where A is the matrix of input requirements (see Izquierdo et al., 2019). We treat the EU (plus the RoW component) as one large economy and generate B as a 268×268 matrix, where each element refers to a region in the EU and the RoW residual. The downstream output multipliers (from supplier regions to customer regions) are obtained by summing over rows of B, while upstream output multipliers (from customers to suppliers) are computed by summing over columns of B.

where y_{cr} is the outcome variable of interest introduced before; i.e., the (cumulated) number of persons in short-time work in region r located in country c by the end of April. x'_{cr} is vector of control variables, which includes regional average income (GDP per capita) and population (for the year 2018) as well as information about a region's exposure to COVID-19 based on the cumulative number of people infected with the virus by the end of April. Besides, we always control for country fixed effects (γ_c) in order to account for differences in the institutional framework of the short-time work schemes in the four countries under investigation.[7] We thus exploit within country variation in the regional sectoral exposure to COVID-19 in order to investigate the direct economic effects of the containment measures. Note that we estimate equation (1) using a Poisson model with robust standard errors to account for the fact that the dependent variable counts the number of persons in short-time work.

Second, we address the question of whether a region's trade relations with other regions heavily exposed to the COVID-19 shock may imply an additional economic burden. To this end, we exploit the regional input-output table introduced above to compute two measures of indirect exposure to the COVID-19 shock via regional exports (IDE^{ex}_{cr}) and sourcing of intermediate goods (IDE^{im}_{cr}). Regarding the former, we assess the role of the regional exposure and the stringency of containment measures in the focal region's export markets. More specifically, we compute a variable that capture this indirect effect as follows:

$$IDE^{ex}_{cr} = \sum_{jk \neq cr} b_{cr,jk} \times Exposure_{jk} \times Stringency_j,$$

where $b_{cr,jk}$ informs about the share of output (both goods and services) of focal region cr sold to partner region jk in cr's total output. Hence, this proxy allows us to investigate whether regions with a larger share of output sold to other regions with a high exposure to the COVID-19 shock are experiencing larger increases in the number of short-time workers, after controlling for the focal region's direct exposure to the COVID-19 shock. Importantly, a region's trade partners may be both belonging to the same country (i.e., $c = j$) and to other countries (i.e., $c \neq j$) and

[7] Cross-country differences in the number of persons in short-time work schemes likely reflect differences in implementation details which we do not try to measure in this study. Hence, the empirical model always includes country fixed effects. The appendix presents more details about the short-time work schemes in each country under investigation.

our data enables us to distinguish the effects accordingly.[8]

In order to also account for the role of disruptions in inter-regional supply chains, we generate a measure of other regions' exposure to the COVID-19 shock on the focal region through backward linkages in supply chains:

$$IDE_{cr}^{im} = \sum_{jk \neq cr} a_{jk,cr} \times Exposure_{jk} \times Stringency_j,$$

where $a_{jk,cr}$ informs about the amount of inputs supplied by region jk required to produce one unit of output in region cr. As before, we use this share $a_{jk,cr}$ as weight when summing up the regional exposure – as measured by the interaction between $Exposure_{jk}$ and $Stringency_j$ – across cr's trade partners. Moreover, we will again exploit the richness of the applied regional data in order to distinguish the effects of supply chain disruptions into national and international effects.

Table A4 in the appendix presents summary statistics for the variables used in the empirical analysis.

4 Results

We present the main results in Table 2. We first discuss the role of the control variables. In column 1, besides country fixed effects, we only control for the number of regional COVID-19 cases and obtain a large positive and significant coefficient. As expected, the coefficient magnitude shrinks when including regional population in the model (column 2), while it remains positive and statistically significant. However, once the average income in the region is taken into account (column 3) the coefficient of COVID-19 cases becomes insignificant. This may be explained by the fact that most regions heavily affected in terms of number of infections in the countries under investigation tend to be relatively rich regions (e.g., regions in Northern Italy, Southern Germany and regions including the Paris and Madrid areas).

In column 4, we add to the model the measure of exposure based on the regions' sectoral

[8] The regional input-output tables that we use in order the compute these indirect exposure variables inform about trade relations between all EU NUTS-2 regions and one rest-of-the-world (RoW) component. In order to measure the exposure and stringency in the rest of the world, we use data for the US, which is an important trade partner for EU countries.

Table 2: Main results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Exposure				0.294***	0.270***	0.260***	0.265***
				(0.048)	(0.044)	(0.049)	(0.047)
Exposure × Stringency					0.138***	0.118***	0.106***
					(0.038)	(0.036)	(0.034)
IDE^{ex} intra-national						0.094**	0.113**
						(0.046)	(0.057)
IDE^{ex} international						-0.062	
						(0.045)	
IDE^{im} intra-national						-0.012	-0.047
						(0.046)	(0.077)
IDE^{im} international						0.104***	
						(0.028)	
IDE^{ex} international EU							-0.049
							(0.056)
IDE^{ex} international RoW							-0.008
							(0.030)
IDE^{im} international EU							0.091***
							(0.029)
IDE^{im} international RoW							-0.018
							(0.040)
Log COVID cases	0.811***	0.147**	0.018	0.039*	0.031	0.027	0.032
	(0.123)	(0.064)	(0.039)	(0.022)	(0.019)	(0.022)	(0.022)
Log population		0.902***	0.869***	0.874***	0.868***	0.859***	0.872***
		(0.059)	(0.036)	(0.022)	(0.020)	(0.051)	(0.056)
Log GDP per capita			0.193***	0.148***	0.157***	0.152***	0.149***
			(0.029)	(0.024)	(0.021)	(0.024)	(0.030)
Observations	100	100	100	100	100	100	100
Pseudo R^2	0.686	0.938	0.957	0.977	0.980	0.984	0.984
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

NOTES: The Table presents Poisson regressions. The dependent variable is the (cumulated) number of persons in short-time work scheme in NUTS2 regions in France, Germany, Italy, and Spain by end of April. All variables are standardised to have a mean of zero and standard deviation of one. Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. McFadden's pseudo R-squared is computed as 1-ll(model)/ll(null) where ll refers to the log likelihood.

structure and obtain a highly significant and positive coefficient. Since all right-hand-side variables are standardised, the coefficient magnitude implies that a region with a one standard deviation higher exposure measure experiences 30% more persons in short-time work. Moreover, the impact of the regional exposure variable increase in the stringency of containment measures as indicated by the positive and significant interaction term in column 5. Overall, these results therefore suggest that a region's economic structure is an important determinant of the economic consequences of COVID-19 containment measures.

In the remaining two columns of Table 2, we investigate whether a region's trade links play a role in explaining the heterogenous economic impact of COVID-19, after controlling for the spread of infections and a region's direct exposure due to its sectoral structure. Indeed, the estimation results suggest that trade linkages are an additional indirect channel of propagation. Focussing first on the demand channel corresponding to a region's exports, we find a positive and significant coefficient for intra-country exports, while that of international exports turns out to be insignificant. This finding may be explained by the fact that regions tend to trade a lot with other close by regions which are located within the same national borders due to gravity forces (e.g., Anderson and van Wincoop, 2003). By contrast, when considering the role of supply linkages, a role for the international dimension emerges. In particular, regions heavily relying on intermediate inputs sourced from regions located abroad that are highly exposed to the COVID-19 shock experience a significantly larger increase in the number of people in short-time work. Quantitatively, this effect is non-negligible since a one standard deviation higher indirect exposure via international intermediate goods sourcing implies 10% more employees in short-time work. Column 7 further reveals that this effect is fully driven by international trade within EU borders. We rationalise this finding by two observations. First, in the early stages of the outbreak of the pandemic in Europe in March and April, several countries closed their intra-EU borders, which likely caused disruptions in intra-EU supply chains that are often based on just in time delivery (Pisch, 2020). Second, intermediate goods delivered in the context of global value chains are often associated with some sort of relationship specificity (Antràs, 2020), implying that it could be difficult to find substitutes in the short-run, especially, when constrained to the domestic market.

In order to assess the robustness of our results, in Table 3, we provide a number of sensitivity checks by adding further control variables to the model and changing the estimation framework. In particular, we control for the regional unemployment rate and the average number of hours worked in the region to account for structural aspects of the local labour market which the baseline specification may lack. Moreover, we include a measure of population density, since regions which are more densely populated may be more affected by the virus. Finally, we employ a linear estimation framework (OLS) where we use the log of the number of people in short-time work over total regional population as dependent variable and also scale the number of COVID-19 cases by the regional population on the right-hand side of the equation. Despite

Table 3: Robustness checks

	Poisson				OLS
	(1)	(2)	(3)	(4)	(5)
Exposure	0.248***	0.278***	0.262***	0.273***	0.149***
	(0.050)	(0.045)	(0.046)	(0.044)	(0.038)
Exposure × Stringency	0.095**	0.135***	0.117***	0.102***	0.135***
	(0.038)	(0.038)	(0.036)	(0.039)	(0.047)
IDE^{ex} intra-national	0.084*	0.101**	0.094**	0.088**	0.081*
	(0.046)	(0.047)	(0.046)	(0.044)	(0.048)
IDE^{ex} international	-0.064	-0.053	-0.060	-0.044	0.038
	(0.045)	(0.045)	(0.048)	(0.045)	(0.038)
IDE^{im} intra-national	-0.021	-0.007	-0.012	-0.017	-0.086
	(0.047)	(0.044)	(0.046)	(0.045)	(0.075)
IDE^{im} international	0.100***	0.095***	0.103***	0.081***	0.154***
	(0.029)	(0.028)	(0.028)	(0.027)	(0.036)
Log COVID cases	0.029	0.030	0.027	0.033	
	(0.022)	(0.021)	(0.022)	(0.022)	
Log population	0.869***	0.858***	0.858***	0.874***	
	(0.051)	(0.049)	(0.049)	(0.048)	
Log GDP per capita	0.128***	0.124***	0.149***	0.048	0.158***
	(0.027)	(0.033)	(0.027)	(0.046)	(0.039)
Unemployment rate	-0.068*			-0.129**	
	(0.041)			(0.054)	
Log mean hours worked		-0.035		-0.059**	
		(0.024)		(0.024)	
Log population density			0.008	0.020	
			(0.026)	(0.028)	
Log COVID cases per inhabitant					0.044
					(0.027)
Observations	100	100	100	100	100
Pseudo R^2	0.984	0.984	0.984	0.986	
Adjusted R^2					0.865
Country FE	Yes	Yes	Yes	Yes	Yes

NOTES: The Table presents Poisson regressions. The dependent variable is the (cumulated) number of persons in short-time work scheme in NUTS2 regions in France, Germany, Italy, and Spain by end of April in columns 1 to 4, and the log of this number scaled by regional population in column 5. All variables are standardised to have a mean of zero and standard deviation of one. Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1. McFadden's pseudo R-squared is computed as 1-ll(model)/ll(null) where ll refers to the log likelihood.

the relatively low number of observations, the main results are overall robust to these checks. The variable most sensitive to these checks relates to indirect exposure via intra-country exports. However, even this variable usually remains statistically significant at the 10% level.

5 Conclusion

The paper proposes an ex-post analysis of the determinants of within-country regional heterogeneity of the labour market impact of the COVID-19 pandemic, as measured by the number employees in short-time work. It finds that the propagation of the economic impact across regions cannot be explained by the regional spread of infections only. Instead, a region's economic structure is a significant driver of the observed heterogeneity. In particular, the estimation results suggest that the more the regional sectoral structure is characterised by activities which do not allow to easily engage in social distancing or remote working, the larger is the impact of containment measures. Moreover, the results suggest that a region's trade relations represent an important indirect channel through which COVID-19 related disruptions affect regional economic activity. On the one hand, this may be related to shortfalls in demand for the focal region's exports. The empirical results suggest that this channel is present only for intra-country trade. On the other hand, COVID-19 related shocks may have caused disruptions in inter-regional supply chains. Indeed, our results suggest that regions relying on intermediate goods sourced from foreign regions heavily exposed to the pandemic have experienced a significantly larger increase in the number of employees in short-time work. Further results indicate that this latter finding may be caused by disruptions in intra-EU supply chains.

Overall, the results thus suggest that domestic containment measures and regions' sectoral structure are key determinants of the regional economic impact caused by the pandemic, while international trade links also play a relevant role. On the latter, the analysis depicts vulnerabilities arising from potential disruptions of the highly integrated EU supply chains. This may suggest that joint efforts are needed to ensure a smooth functioning of the European production network during the second and potentially additional waves of the pandemic. Moreover, the results provide some ways of thinking about the consequences of more localised lockdowns. In particular, a region's sectoral structure and its position in inter-regional buyer-supplier networks are important determinants of the aggregate effects of such lock-down measure both on the domestic and on foreign economies.

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A Appendix

This appendix presents further information the about the data used in the paper. First, details about the short-time work schemes in place in the four countries under investigation, including information about data sources, are presented in Table A1. Note that data on employees in short-time work are collected from four national sources. Due to differences in the institutional frameworks, there are also differences in the reporting details across countries, which may e.g., imply that submitted requests rather than the employees actually covered by the scheme are reported. Importantly, this and other peculiarities in the request and authorisation processes are nationwide and not region specific. We thus account for such aspects by always including country fixed-effects in the model, relying only on within-country variation. Moreover, since delays in reporting due to agencies' overload likely happened in the first months of the pandemic, we consider the cumulative number of affected employees (if available) and included later revisions.

Table A1: Details about short-time work schemes in DE, ES, FR, and IT

	Germany	Spain	France	Italy
Scheme name	Kurzarbeit	Expediente de Regulación Temporal de Empleo (ERTE)	Activité partielle	Cassa Integrazione Guadagni (CIG)
Worker temp. status	Short-time work	Temporary dismissal	Partial unemployment	Temporary layoff
Gov. Agencies involved	Bundesagentur für Arbeit	Servicio Público de Empleo Estatal	Ministère du travail	Istituto Nazionale Previdenza Sociale
Eligibility (employees)	National social security affiliate.	National social security affiliate since min one year.	Employees under all contract types.	National social security affiliate since min 3 months.
Percentage of wage (general case)	60 – 90 % (raises over time)	10 – 70% (proportional to working hours reduction)	70% / 100% [min. wage ; 4,5*min.wage]	80% capped (ceiling per wage band)
Max duration	24 months	6 months	6 months (+ 6)	24 months
Reporting (data)	Nr. employees, Monthly	Nr. employees, Monthly	Nr. employees, Weekly (cum)	Nr. hours*, Monthly
Source (data)	Bundesagentur für Arbeit[a]	Ministerio de Trabajo y Economia Social[b]	Ministère du travail[c]	Istituto Nazionale Previdenza Sociale[d]

* Hours have been converted in head counts assuming a 40h week per employee.
a https://statistik.arbeitsagentur.de
b http://prensa.mitramiss.gob.es
c https://dares.travail-emploi.gouv.fr
d https://www.inps.it

Second, we include information about the sources for the regional heterogeneity in COVID-19 cases. In particular, for Germany, we obtain these data from https://www.arcgis.com, for France from https://www.data.gouv.fr , for Italy from https://github.com/, and for Spain from https://www.datoscoronavirus.es.

Next, in Table A2, we provide more information about the data that we use to generate the *Exposure* variable. As also outlined in the main text, we use for this purpose data from INAIL (2020), which informs about the virus exposure at work, and from Dingel and Neiman (2020), which informs about the possibilities to work remotely. In either case, the information is available at a broad sectoral level, which we transform into an ordinal scale in order to compute an overall measure based on both sets of information. Using sectoral employment shares at the regional level (from Eurostat) as weights, we then obtain a region-specific *Exposure* variables that aggregates the sectoral information provided in Table A2.[9]

Table A2: Measures of sectoral exposure to the pandemic

	INAIL		Teleworking		*Exposure*
	score	ordinal	score	ordinal	
Agriculture	1.0	1.0	0.0	3.0	2.0
Manufacturing	1.2	2.0	0.2	3.0	2.5
Construction	1.0	1.0	0.2	3.0	2.0
Retail and wholesale	2.1	3.0	0.2	3.0	3.0
Information and communication	1.2	2.0	0.7	1.0	1.5
Financial and insurance	1.0	1.0	0.8	1.0	1.0
Real estate	1.0	1.0	0.6	1.0	1.0
Professional services	1.3	2.0	0.5	2.0	2.0
Art, Sport, Entertainment	2.6	3.0	0.3	2.0	2.5

NOTES: In the case of teleworking, the score refers to the share of employees that can work remotely.

Moreover, in Table A3, we provide more details about the country-specific measure of the stringency of containment measures, which we obtain from Hale et al. (2020). As described in the main text, we obtain data on inter-regional-input-output tables from Thissen et al. (2019), which we use to generate measure of indirect exposure via trade links. Finally, Table A4 presents summary statistics for the main variables used in the empirical analysis.

[9] Note that wee assign a risk score of zero for employees in publicly dominated sectors (e.g., public administration, education, health care, defense), since STW schemes usually do not apply here.

Table A3: Stringency of containment measures (average of March and April)

	Workplace closings	Limits to private gatherings	Shelter-in-place orders	Restrictions on internal movements	Overall
AT	2.11	2.26	0.92	0.39	1.42
BE	2.31	2.16	1.44	2.36	2.07
BG	0.80	2.41	0.23	2.02	1.36
CY	1.02	1.92	1.25	1.87	1.51
CZ	2.21	2.25	1.38	0.00	1.46
DE	0.66	1.97	1.54	0.05	1.05
DK	1.53	2.39	0.79	2.36	1.77
EE	1.72	2.07	0.13	2.26	1.55
EL	1.64	2.16	1.28	1.92	1.75
ES	2.10	1.57	1.57	2.36	1.90
FI	1.57	0.82	0.75	1.38	1.13
FR	2.21	0.97	1.48	2.21	1.72
HR	2.00	2.07	1.28	1.92	1.82
HU	0.00	0.00	1.39	2.51	0.98
IE	1.97	2.36	1.15	1.77	1.81
IT	2.56	2.56	2.05	2.56	2.43
LT	1.72	2.07	0.13	2.26	1.55
LU	2.33	2.48	1.30	2.31	2.10
LV	1.72	2.07	0.13	2.26	1.55
NL	2.36	1.64	0.82	2.31	1.78
PL	1.57	3.00	1.30	2.45	2.08
PT	2.34	2.11	1.41	2.11	2.00
RO	1.64	2.13	1.43	0.44	1.41
SE	0.52	0.93	0.00	1.33	0.70
SI	1.89	2.31	0.79	1.57	1.64
SK	1.34	1.74	0.92	2.26	1.57
UK	2.05	1.92	1.28	1.97	1.80
ROW	0.64	0.00	0.00	0.25	0.22

Table A4: Summary statistics of main variables

	mean	sd	p1	p25	p50	p75	p99
Employees in STW (in Tsd.)	313847.70	368419.37	3078.00	128607.50	227581.50	377243.00	2195840.50
Exposure	1.78	0.15	1.29	1.69	1.79	1.87	2.07
Stringency	1.65	0.53	1.05	1.05	1.72	1.90	2.43
IDE^{ex} intra-national	0.55	0.28	0.27	0.38	0.43	0.61	1.47
IDE^{ex} international	0.20	0.07	0.08	0.15	0.20	0.25	0.45
IDE^{im} intra-national	0.25	0.11	0.07	0.19	0.22	0.28	0.56
IDE^{im} international	0.08	0.03	0.03	0.05	0.06	0.10	0.14
Log COVID cases	7.90	1.54	1.90	7.35	8.04	8.69	11.08
Log population	14.42	0.91	11.35	14.01	14.45	15.07	16.22
Log GDP per capita	-3.47	0.28	-4.05	-3.64	-3.46	-3.27	-2.77

NOTES: Number of observations amounts to 100.

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