



COVID-19, lockdowns and international trade: evidence from firm-level data

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Abstract

The COVID-19 pandemics and the lockdowns imposed to mitigate the rise of infections beyond manageable levels strongly affected international trade. Although the health crisis and the mobility restrictions associated with lockdowns are closely related, their impacts on international trade have a different nature. This paper uses monthly firm-level trade data for Portuguese firms to measure the impact of partner countries' lockdowns on nominal export and import flows during 2020 and the first half of 2021, while also assessing the impact of the health crisis. The high time frequency and granularity of the data contribute to the identification of the impact of these obstacles on trade. We conclude that the detrimental impact of lockdowns is sizeable and broadly similar in exports and imports, and the impact of the health conditions is slightly stronger in exports. There is evidence that the detrimental impact of lockdowns was stronger for larger firms, for those with higher geographical concentration of trade, more integrated in global value chains and in the upper quartiles of the trade unit value distribution. The negative impact is also estimated to be larger for industries with high import content and for trade partners that are more important as sources of value added to be embodied in Portuguese exports. Results also suggest that exports adapted to the prevailing circumstances as of June 2020, but such an effect is not clear in imports.

Keywords International trade · COVID-19 · Portugal · Firm-level data

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1 Introduction

The COVID-19 pandemic was the strongest shock faced by the world economy in many decades. The initial impact on international trade flows was very large and comparable to the one recorded in the 2008-2009 great trade collapse. The deterioration in overall health conditions across the world and the containment measures taken by the authorities to limit the number of infections strongly affected the activity of firms, households' consumption decisions and the ability to move goods across borders. Quantifying the heterogeneous impact of these constraints on Portuguese international trade is our primary research question. The relevance of measuring the impact of lockdowns goes beyond the COVID-19 pandemic crisis. Public authorities may consider imposing lockdowns with characteristics similar to those of 2020 and 2021 under different circumstances. Climatic prolonged extreme events may justify such action and violent social unrest, and military conflicts have historically also led to this type of decisions. Conversely, health crisis that does not require lockdowns may also occur, for example, those due to natural disasters.

The evolution of overall health conditions, proxied by the number of deaths attributed to COVID-19 per thousand inhabitants, and the adoption of measures restricting the mobility of individuals and the operation of specific sectors, referred as lockdowns, have an impact on both demand and supply of foreign goods and thus on international trade flows. Since health conditions and lockdowns are not univocally associated with shocks on demand and supply, we take these two dimensions as separate, but put a stronger emphasis on lockdowns.

The correct identification of the impact of health conditions and lockdowns on export and import flows is a challenging task because several confounding effects are at play. One important feature is the global nature of the pandemic crisis, which caused a contraction in economic activity across the world, thus affecting foreign demand for domestic goods and imports. This effect is heterogeneous across countries and it is likely to be related with the intensity of the pandemics in each period of time. Another very important aspect concerns the existence of firm-specific characteristics that may impact on their export and import decisions over and above the effect of lockdowns and prevailing health conditions. Impacts accruing to the different type of goods produced and traded by the firm is an obvious example.

Our very rich firm-level monthly database provides strong cross-sectional variation and allows for the utilization of high dimensional fixed effects that control for several confounding features. This rich set of fixed effects and the monthly frequency of the data make it possible to separately identify the impact of stringency measures and health conditions on trade flows. Indeed, the utilization of high frequency firm-level data to measure the impact of lockdowns and health conditions on international trade is a distinctive feature of our paper. Moreover, we use data that extends up to the end of the first semester of 2021, thus taking aboard the three initial waves of the pandemics.

The two panels of Fig. 1 plot the aggregate monthly path of nominal exports and imports by Portuguese firms and the average of comparable country-level stringency indices, as reported by, and weighted according to the share of the partner country on each type of trade flow. The similarity between the sets of trade partners in exports and imports drives the resemblance of the stringency indices in the two panels. This figure

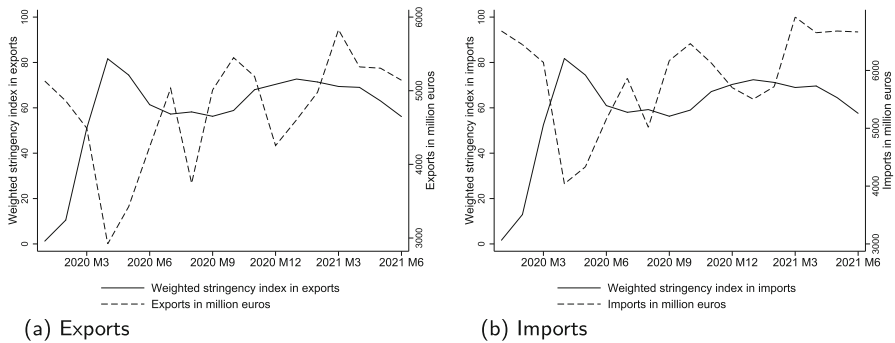


Fig. 1 Total value of trade flows and weighted stringency index. *Note:* The weighted stringency index in exports (imports) corresponds to the stringency index of each destination (origin) country weighted by its weight in total Portuguese exports (imports) in the reference period (2017 to 2019). Sources: Authors' calculations using International Trade Data (Statistics Portugal) and <https://covidtracker.bsg.ox.ac.uk/> for the lockdown stringency index

signals a decoupling between the stringency of lockdowns and trade flows during the period considered, which is very important for identification purposes. For example, there was a sharp contraction of exports and imports at the end of the first quarter of 2020 in parallel with a sharp increase in the weighted stringency index but this link broke in the second and third quarters of 2020.

The richness of the database at hand and the paths of monthly trade flows and the stringency indicator make it possible to address several research questions. Firstly, the strong heterogeneity in terms of the size of firms operating in foreign markets is likely to interact with their response under lockdown conditions. As for the comparison between traders and non-traders, Borino et al. (2021) refers that the former are more affected but also more resilient. The sign of this relationship amongst traders of different sizes is not obvious *a priori* and it is a matter to be settled empirically. On the one hand, larger traders may have a wider portfolio of clients and suppliers that allows to sustain the operation under lockdowns in specific geographies. On the other hand, smaller traders, dealing with more limited shipments, may be more agile in overcoming transport restrictions associated with lockdowns (for example by switching to alternative modes of transport). Bricongne et al. (2021) find that the largest exporters are affected relatively more by the foreign lockdowns, in opposition to the largest importers.

A related research question concerns heterogeneity in terms of firms' engagement in global value chains (GVCs), which also impacts their ability to cope with the shocks imposed by the lockdowns. The organization of production is based on GVCs (e.g. Yeats 1998; Hummels et al. 2001 and Baldwin 2006). Firms specialize in the production of specific parts and components or become assemblers and heavily rely on foreign supplies that are incorporated in the production process. Firms also tend to maintain low inventories of intermediate goods and strongly rely on just-in-time deliveries. Therefore, if lockdowns trigger disruptions in transportation systems or in the operation of key suppliers, the impact is large and propagates through a complex network of production linkages (e.g. Altomonte et al. 2012 and Foti et al. 2013).

Nevertheless, as the network of participants in international trade became denser, the likelihood of switching to alternative suppliers in order to make up for a broken link increases. Even so, Jiménez et al. (2022) uses concentration indices in an input–output set up and finds an increase of geographical and sectoral concentration of GVCs from 1995 to 2011.

The empirical testing of these hypothesis is possible by estimating the differential impact of lockdowns for firms more engaged in GVCs, proxied by those where there are foreign capital participations. Another proxy for engagement in GVCs is the operation in sectors where there is a higher import content in exports or even the fact that the unit value of trade flows is relatively larger. A similar reasoning can be used to analyse the impacts of lockdowns for specific trade partners. A different impact of lockdowns on international trade flows along the countries dimension, after controlling for the impact of the pandemics on country-specific demand, suggests that geography and GVCs play a role, as discussed in Antràs (2020).

Finally, it is important to assess if international traders adapted their activity and procedures in order to operate under lockdowns in destination and origin countries. It is fair to argue that the stronger the adaptation by firms the higher their resilience to shocks (Iftikhar et al. 2021). Our monthly-level data make it possible to estimate the differential impact of lockdowns along quarters, thus providing an empirical answer to this question. Using monthly bilateral trade data, Berthou and Stumpner (2022) and Hayakawa and Mukunoki (2021) found significantly negative effects of COVID-19 on international trade, which were stronger during the first wave and decreased afterwards.

Our paper contributes to answer the questions above. Firstly, we compute the overall impact of health conditions and lockdowns on nominal export and import flows, controlling for firm, trade partner and time specific effects. Secondly, we examine the differential impact of lockdowns along firms' size classes and quartiles of trade geographical concentration distribution. Thirdly, we detail the results according to firms' status in terms of foreign capital, along the quartiles of the trade flow unit value distribution, as well as along manufacturing industries and trade partners. Fourthly, in order to assess the ability of international traders to adapt along the different waves of the COVID-19 pandemics, we take our preferred econometric specification and estimate the differential impact of health conditions and lockdowns for the four quarters of 2020 and the two initial quarters of 2021.

The paper concludes that the impact of public health crisis and lockdowns on international trade is sizeable. Considering the period from January 2020 to June 2021, under our main econometric specification, an increase of 100 COVID-related deaths per million inhabitants led to, on average, a decrease of 2.5 percentage points in the growth rate of nominal exports and a decrease of about 2.2 percentage points in the growth rate of nominal imports. As for the stringency of containment measures, proxied by the composite indicator used, which ranges between 0 and 100, a one percentage point increase leads to, on average, a reduction of about 0.15 percentage points in the growth rate of nominal exports and a reduction of approximately 0.13 percentage points in the growth rate of nominal imports. However, when the effects are estimated at the quarterly level, differences emerge. As for exports, the strongest negative impacts of tighter stringency measures are observed in the first two quarters of

2020 and become not statistically different from zero in the last two quarters of 2020. With the third wave of the pandemics, the detrimental impact of lockdowns on export flows partly emerges in the first quarter of 2021, but it is not statistically significant at 1 percent and remains non-significant in the following quarter, suggesting an adaptation of exports to the underlying restrictive conditions. As for imports, the detrimental impact of lockdowns is significant in the first quarter of 2021 at 1 percent significance level, thus contradicting the adaptation narrative.

As for the relationship between the size of firms and the stringency of containment measures in partner countries, the negative impact is higher for the largest firms, both in export and import flows. The same applies for firms whose trade flows are more geographical concentrated, which are more affected by stringency measures. In addition, firms with foreign capital, proxying their participation in GVCs, are more severely affected by the stringency of containment measures. Moreover, the detrimental impact of lockdowns on exporters increases across the quartiles of the trade unit value distribution, and for imports the most negative effect is visible in the third quartile.

In what concerns the different impacts of tighter stringency measures on manufacturing exports, “transport equipment”, typically taken as an example of an industry strongly integrated in GVCs, posts the most negative coefficient, while “food and beverages” and “agriculture” do not seem to be affected. The industry labelled as “chemicals”, which includes pharmaceutical products, also posts a coefficient that is not significantly different from zero. As for sectoral imports the same pattern is present, with the exception that “food and beverages” posts a negative coefficient. Finally, as for the effects of stronger stringency measures emerging from specific trade partners, Spain is clearly the country with the strongest impact on exports and also with a negative impact on nominal import flows, close to Germany and France.

The paper is organized as follows. The next section briefly reviews the related literature. Section 3 describes the database of Portuguese international traders of goods and the details of the stringency index that is used as a proxy for the intensity of lockdowns. In addition, section 3 presents the econometric specifications that allow for the identification of the impact of health conditions and lockdowns on nominal export and import flows. Section 4 presents the results and is organized along five blocks. The initial subsection refers to the overall impact of health conditions and lockdowns on exports and imports. The second subsection analyses the impact of lockdowns by firms’ size and also by quartiles of trade geographical concentration. In the next two subsections we turn to the existence of foreign capital at the firm and its position in the trade unit value distribution, with a view to link with the operation of GVCs, and explore the sectoral and the partner country dimensions. The fifth subsection examines the time-varying dimension of impacts on both trade flows. Section 5 presents some concluding remarks.

2 Related literature

The literature about the impacts of the COVID-19 pandemics on the different dimensions of economic activity has been expanding. The early response of the profession to

the challenges emerging from the pandemics was presented in Baldwin (2019). Next, as the crisis unfolded the literature split along different strands. The contributions that are closest to the research questions addressed in our paper relate to the impacts of containment measures targeted at limiting the spread of the virus on overall economic activity, international trade flows and trade policy.

As for the impact of the pandemics on economic activity, Chen et al. (2020) uses high-frequency indicators such as electricity consumed, unemployment insurance claims and measures of mobility based on location data for the first months of 2020, together with the number of COVID-19 cases or deaths as a proxy for the severity of the outbreaks. The paper concludes that European countries and US states that experienced larger outbreaks also suffered larger economic losses. In addition, it refers that heterogeneity in impacts is mostly captured by changes in agents' mobility and not the timing of non-pharmaceutical interventions, as measured by the stringency index presented in. In the same vein, Deb et al. (2020) quantifies the effects of containment measures on activity using daily global data on real-time emissions, flights, energy consumption, maritime trade and mobility indices. Authors refer that the decision to implement containment measures is associated with the spread virus, which is itself linked to mobility and activity. The paper addresses causality issues by controlling for the change in the number of infections and deaths the day before implementation of containment measures and using lagged changes in daily economic indicators and country-specific time trends. Results signal a loss of about 15 percent in industrial production over a 30-day period following the implementation of measures. Overall, the research question in these two papers is similar to ours and the underlying explanatory variables and econometric issues are not distant either.

The specific impacts of the pandemics on international trade flows have also been discussed. Espitia et al. (2022) studies the effects of the COVID-19 pandemics using monthly trade data for 28 countries and multiple trading partners, at a detailed sector level, between February and June 2020. The aim of the paper is to assess the role of COVID-19 related shocks and sector characteristics on international trade flows. The paper bases on difference-in-differences specifications to explain monthly trade flows by interacting measures of the COVID-19 pandemics with time-invariant sectors' measures of vulnerability to the shock, such as possibility of remote work and GVC participation. Regression results show that the negative trade effects induced by COVID-19 vary widely across sectors. In particular, sectors with a higher share of occupations that can be performed remotely were less impacted by the pandemic and participation in GVCs increased vulnerability to shocks suffered by trade partners.

Cerdeiro and Komaromi (2022) quantifies the causal effect of supply spillovers from lockdown exposure on international trade using a novel dataset of daily bilateral seaborne trade. The trade volume data are associated with the satellite tracking of ships and weight carried, as explained in Cerdeiro et al. (2020). Beyond the lockdown exposure variable, which is computed as the weighted average of lockdown measures at the country-day level, as referred in, the preferred specification includes domestic lockdown stringency, domestic cases and deaths in ratio to population, and country and time fixed effects. These controls and the strong sources of variation in the data allow for the correct identification of the impact of lockdowns on trade flows. The paper finds strong but short-lived supply spillovers, notably in terms of the downstream propa-

gation of lockdowns through GVCs. Although with substantial differences regarding the type of data that is used, our paper is not distant from Cerdeiro and Komaromi (2022) in terms of empirical strategy. Finally, another close contribution is Bricongne et al. (2021), which uses French monthly firm-level trade data similar to ours and discusses the effects of the COVID-19 pandemics, with an emphasis on the margins of adjustment of exports and the granular impact of very large traders.

In a somewhat different strand, Liu et al. (2021) use a gravity-like approach to study how COVID-19 deaths and lockdowns affected countries' imports from China. Authors find that a country's own deaths and lockdowns significantly reduce imports from China. Conversely, COVID-19 deaths in the main trading partners induce more imports from China. The net effect is, on average, a reduction of nearly 10 percent in imports from China relatively to the pre-pandemic situation. Interestingly, the paper also finds that deaths and lockdowns in previous months tend to increase current imports, suggesting that trade is partially postponed.

Finally, the literature has also been discussing the impact of the COVID-19 pandemics on the future of international trade. Antràs (2020) discusses the observed slowdown in globalisation prior to the pandemics, arguing that there was little systematic evidence of a reversal in the process. However, the paper acknowledges that the pandemics may aggravate policy tensions across countries, thus further darkening globalisation prospects. Bonadio et al. (2020) analytically solve and calibrate a model with information of the OECD inter-country input–output (ICIO) tables to examine the role of GVCs in the relation between the pandemics and GDP developments in 64 countries. The paper simulates a global lockdown as a contraction in labour supply that interacts both with the fraction of work in each sector that can be done remotely and the stringency of lockdown measures. The paper concludes that the average real GDP downturn due to the shock was near 30 percent, with one quarter of it attributed to transmission through GVCs. Importantly, the paper refers that “renationalization” of GVCs do not in general make countries more resilient to contractions associated with pandemic shocks. The counterpart of a lower dependence on foreign inputs is a higher reliance on domestic inputs, which are also potentially disrupted due to domestic lockdowns. In a scenario of shrinking GVCs countries do not benefit from the diversification of risks that come from having alternative foreign suppliers. In the early reflection about the effects of the pandemics on international trade, Baldwin and Tomiura (2020) makes a similar point. Although not directly discussing trade policy, our paper also analyses the impact of lockdowns on GVCs' operation and their resilience.

3 Data and empirical strategy

Statistics Portugal collects, on a monthly basis, detailed information on export and import transactions of goods by firms located in Portugal, which is used to compute the official international trade statistics. For extra-EU trade, the data originally come from customs returns forms and for intra-EU trade it comes from the Intrastat reports. The dataset includes all transactions with non-EU countries but the intra-EU transactions are subject to the assimilation threshold, i.e. the annual trading value below which

Intrastat declaration is not mandatory. The assimilation thresholds in Portugal are 350 thousand euros for EU imports and 250 thousand euros for EU exports.

The database used in this paper includes all transactions reported by firms from January 2020 to June 2021.¹ A transaction record includes the firm tax identification, the eight-digit product code of Combined Nomenclature, the value and the quantity of the transaction (expressed in current euros and kilograms, respectively) and the destination or origin country. The firm-level data used in this paper cover more than 96 percent of total exports and more than 92 percent of total imports in this period, with 35,731 exporting firms and 130,760 importing firms operating in 2020 and in the first half of 2021.

Beyond international trade information, the database includes the five-digit firm code of Nomenclature of Economic Activities, the firm's total turnover, employment and the share of foreign capital. These variables are originally collected from the *Quadros de Pessoal* dataset for the most recent year available (2019) and externally added to the trade database. Table 6 presents some descriptive statistics at the firm-level for the period under analysis.

Firm-level international trade data were complemented with information related to the pandemics. The data on the stringency of containment measures in place in each trade partner, on a daily basis, were collected from the Oxford COVID-19 Government Response Tracker. This information is publicly available and put together by a cross-disciplinary Oxford University team of academics and students, led by the Blavatnik School of Government. The database traces a large set of measures, such as school closures, workplace closing, stay-at-home requirements and travel bans and a composite overall Stringency Index is also computed. A full description of the data and the composite index are presented in. The daily data start on January 2020 and covers about 180 countries. This index has been widely used in the most recent COVID-19 related literature (e.g. Bonadio et al. 2020; Chen et al. 2020; Deb et al. 2020; Naudé and Cameron 2020; Liu et al. 2021 and Bricongne et al. 2021).

The monthly average of the overall COVID-19 Stringency Index is our proxy for variation in governments' responses, and it is computed as a simple additive score of nine individual indicators measured on an ordinal scale and rescaled to vary from 0 (no restrictions) to 100 (full lockdown). The index takes into account the intensity of each type of restriction, as well as its geographic extent in the country. For example, the impact of a full blown closure of schools is 11 percentage points, the same as maximum constraints in international travel. However, the index cannot capture the degree of enforcement of the containment measures and some indicators may be more related to production and trade (e.g. workspace closing and movement restrictions) than others (e.g. cancel public events and public information campaigns). Although there is co-movement amongst the different types of restrictions, with a view to assess the robustness of the empirical analysis, we also construct different sub-indices and replicate our exercise.

In the same vein, we tested direct mobility indicators, such as those publicly available from Google Mobility Reports. These indicators directly track individu-

¹ The observations for 2020 correspond to final data, which assures high quality in terms of coverage and accurateness.

als' movements in different contexts but are narrower in terms of their assessment of specific barriers, notably those with impact on cross-border movements. Nonetheless, these indicators could be seen as close substitutes. Table 15 presents the correlations between specific mobility indices and the Stringency Index, which are generally very high.

The second type of data related to the pandemics is the number of infections and COVID-related deaths per thousand inhabitants. This information was collected from the COVID-19 Dashboard by the Coronavirus Resource Center of Johns Hopkins University (available at: <https://coronavirus.jhu.edu/map.html>).

The monthly export and import flows for each partner country were visibly affected by the implementation of containment measures, as proxied by increases in the lockdown stringency index. The panels of Fig. 2 plot the level of exports and imports and the stringency index from January 2020 to June 2021 for a set of main Portuguese trade partners. There is significant variation but it is clear that the increase in stringency in the first quarter of 2020 was accompanied by a drop in export and import flows in all cases. In the second quarter of 2020, the stringency measures were slightly reduced but trade flows broadly recovered to the pre-pandemics levels. In the final months of 2020, there was a mild increase in stringency in connection with the second wave of the pandemics and trade flows contracted once more. Lastly, in the first half of 2021, contingency measures were relaxed, in line with the progress in COVID-19 vaccination, specially in the second quarter. Both international trade flows increased in the first quarter of 2021 but declined in the following months.

In order to establish the relationship between the changes in export and import levels and the intensity of containment measures, while taking into account firm-specific characteristics, time effects and partner country characteristics we estimate a high-dimensional fixed effects model (HDFE, henceforth) separately for exports and imports:²

$$\left[\ln(TradeFlow_{ijt_n}) - \ln\left(\frac{\sum_{k=2017}^{2019} TradeFlow_{ijt_k}}{3}\right) \right] \times 100 \quad (1)$$

$$= \alpha + \beta X_{jt_n} + \gamma_i + \delta_j + \lambda_{t_n} + \epsilon_{ijt_n}$$

where the dependent variable for each trade flow corresponds to the rate of change (in log differences) of the value of exports or imports of each firm i either for or from each partner country j in a given month t of year n (2020 and 2021) in relation to the average value of the same month in the three years, k , before the pandemics (2017, 2018 and 2019). Establishing the reference period in this way deals with potential shifts in trade patterns that may have occurred specifically in 2019. The vector X_{jt_n} includes the relevant variables in each specification, usually the number of monthly deaths attributed to COVID-19 per thousand inhabitants and the lockdown stringency index, which is our main variable of interest. These variables vary both across partner country and time, which allows us to identify the parameters of interest. Our specifications

² We use the algorithm of Guimaraes and Portugal (2010) through the Stata command *reghdfe* (Correia 2016) to estimate the model with three high-dimensional fixed effects and dropping the singletons (Correia 2015).

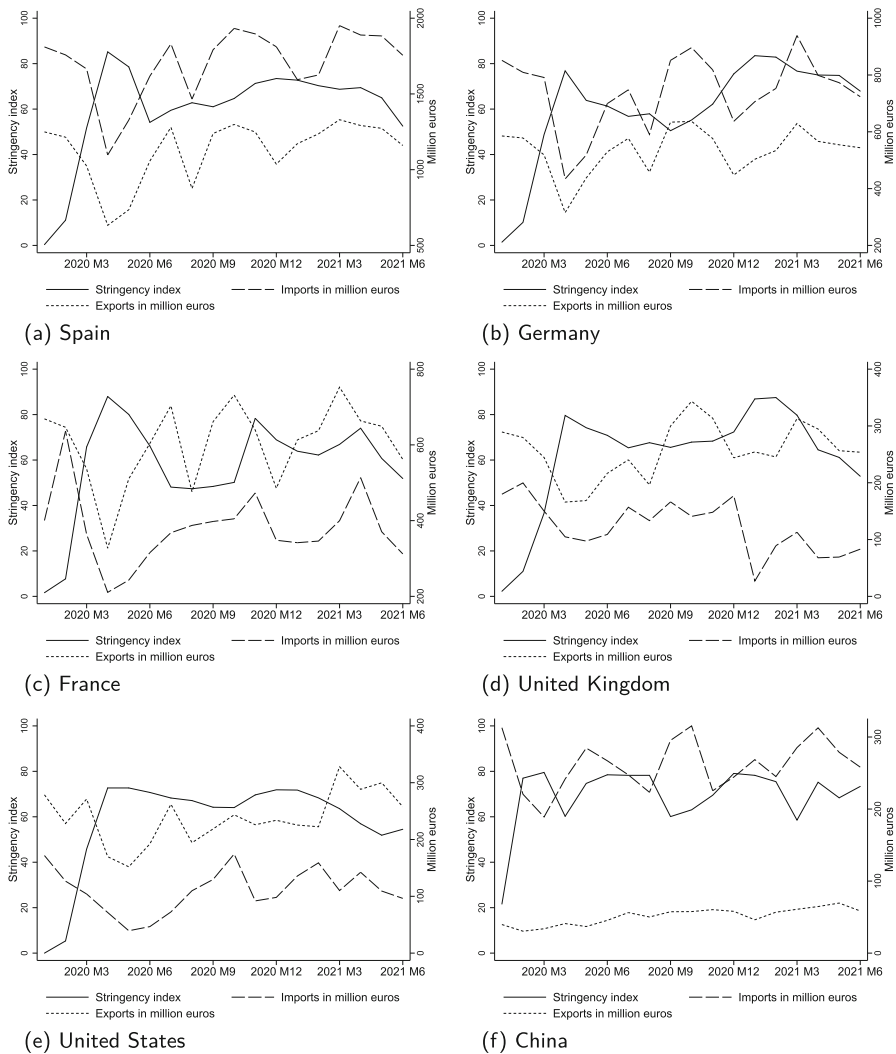


Fig. 2 Total trade flows and stringency index by partner country. Sources: Authors' calculations using International Trade Data (Statistics Portugal) and <https://covidtracker.bsg.ox.ac.uk/> for the lockdown stringency index

includes firm, γ_i , and country, δ_j , fixed effects to control for time-invariant factors that are specific to the firm (e.g. firm's location in Portugal) and to the partner country (e.g. distance to Portugal), respectively, and can impact trade flows. We also consider time fixed effects, λ_{t_n} , to account for the macroeconomic conditions. As our dataset only refers to transactions by Portuguese firms, the Portugal's stringency index is also captured by the time dummies. ϵ_{ijt_n} is the error term.

In order to discard endogeneity concerns linked with the existence of an omitted variable simultaneously determining the path of the stringency index, deaths and trade

Table 1 Stringency of lockdowns and firms' exports

Variables	(1) HDFE	(2) HDFE	(3) HDFE
Deaths per thousand	−31.197*** (3.806)		−25.250*** (3.994)
Stringency index		−0.213*** (0.031)	−0.149*** (0.032)
Constant	16.755*** (0.367)	26.449*** (1.745)	24.712*** (1.764)
Observations	447,535	447,535	447,535
Adjusted R-squared	0.117	0.117	0.117
Firm FE	YES	YES	YES
Country FE	YES	YES	YES
Time FE	YES	YES	YES

Estimates obtained in the sample of our main econometric specification presented in the third column. The dependent variable corresponds to the rate of change of the value of exports by each firm to a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average value of firm's exports for that country in the corresponding months of 2017, 2018 and 2019). Table 7 presents some statistics for the deaths and stringency variables

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

flows, we perform several robustness checks. The panels of Fig. 3 plot the number of deaths per thousand inhabitants due to COVID-19 and the stringency index for the main Portuguese trade partners. The visual inspection of the graphs shows an absence of co-movement between the two series, which could be associated with an omitted variable. In addition, we run regression (1) using the lagged stringency index as the independent variable. This basic procedure would potentially break the endogeneity link since changes in containment measures in previous months are less likely to affect negatively current trade flows. It turns out that results obtained do not change significantly, thus giving us comfort in terms of the interpretation of baseline results presented in the next section.

4 Results

This section presents the results from our empirical exercise organized along five blocks: (i) the overall impact of stringency measures on nominal export and import flows; (ii) the differential impact of lockdowns in relation to firm's size and its trade geographical concentration; (iii) the differential impact related to the presence of foreign capital, as a proxy for GVCs participation, and along the firm's trade unit value distribution; (iv) the impacts at industry and partner country level dimensions and, finally; (v) the time-varying dimension of the effect during the six quarters from the beginning of 2020 to mid-2021.

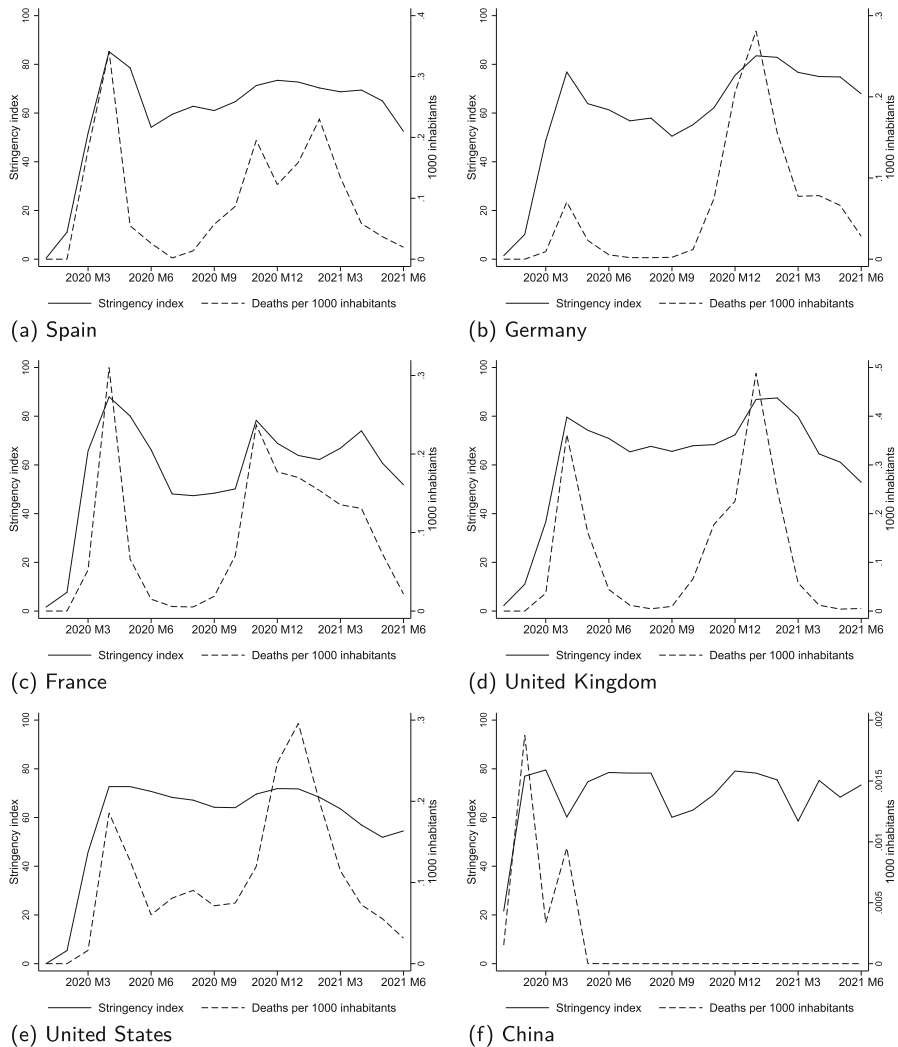


Fig. 3 Stringency index and deaths per thousand inhabitants due to COVID-19 by partner country. Sources: Authors' calculations using <https://covidtracker.bsg.ox.ac.uk/> for the lockdown stringency index and <https://coronavirus.jhu.edu> for deaths per thousand inhabitants due to COVID-19

4.1 Exports and imports

The estimates obtained for the specification presented in regression (1) taking monthly growth rates of nominal exports of Portuguese firms from January 2020 up to June 2021 are presented in Table 1. The first and second columns consider the number of deaths per thousand inhabitants and the stringency index separately, while the third column takes them jointly. In all cases, the coefficients are negative and highly significant. The inclusion of firm, destination country and time fixed effects allows for robust

conclusions regarding the impact of stringency measures on international trade flows. The comparison of the coefficients estimated for the impact of the number of deaths and for the stringency index in the three specifications offers further evidence on the independence of the two effects estimated. When variables are taken together in the regression, coefficients for deaths and for the stringency index do not strongly change their magnitude relatively to the specification where they are taken separately and both remain highly significant with the expected signal. It is worth noticing that the estimates for the three cases are obtained from a common sample, thus enabling the comparison of results.

Taking the last column of Table 1 as our main specification, we conclude that one percentage point increase in the stringency index leads to, on average, a negative change in the growth rate of nominal exports of approximately 0.15 percentage points. Another reading would be that full stringency (index equal to 100) would approximately reduce exports by about 15 percentage points in comparison with the reference period. However, this figure is plagued by the poor approximation of the difference in logarithms to the growth rate of a variable when changes are large. As for the coefficient of the number of deaths, it signals that one additional death per million inhabitants reduces the rate of change of nominal exports by approximately 0.025 percentage points.

The estimates obtained for imports are presented in Table 2 and are organized in the same way described above for exports. Coefficients for the number of deaths and the lockdown stringency index are negative and significant in all specifications. The consistency along the three specifications is also maintained. On average, under the most completed one, with both deaths and the stringency index included, an increase of one percentage point in the stringency index leads to a negative change in the growth rate of nominal imports of about 0.13 percentage points, a number slightly smaller than the one obtained for exports. The coefficients for the number of deaths is also smaller than the one obtained for exports, suggesting that deaths abroad have a lower impact for imports than for exports. Although supply effects also play a role, this corresponds to the expected result as health conditions abroad are likely to affect foreign rather than domestic demand decisions.

If firms switch to new suppliers or clients as a result of existing restrictions, a trade diversion effect would emerge. In this case we would expect the estimated coefficients to be amplified and results overstated. Firms would be trading above normal with partners imposing softer containment measures, which would be taken in the regression as a stronger impact from the stringency index.

The coefficients of specifications where the lockdown stringency index is taken with lags are presented in columns 1 and 2 of Tables 13 and 14 in Appendix F. Results of the one lag specification remain significant and qualitatively unchanged. Comparatively to our baseline result, the coefficient for the lockdown stringency index is less negative for exports and more negative for imports. The coefficients obtained under the two lag specification are not significant at a 5 percent significance level. As for the use of alternative variables to assess mobility constraints, as those publicly available from Google Mobility Reports, coefficients are presented in columns 3 and 4 of Tables 13 and 14 and our main results remain qualitatively unchanged. These coefficients are positive as higher mobility is equivalent to lower restrictions (Table 15).

Table 2 Stringency of lockdowns and firms' imports

Variables	(1) HDFE	(2) HDFE	(3) HDFE
Deaths per thousand	−28.265*** (3.667)		−22.013*** (3.901)
Stringency index		−0.196*** (0.029)	−0.133*** (0.031)
Constant	5.749*** (0.357)	14.999*** (1.699)	13.088*** (1.727)
Observations	522,687	522,687	522,687
Adjusted R-squared	0.120	0.120	0.120
Firm FE	YES	YES	YES
Country FE	YES	YES	YES
Time FE	YES	YES	YES

Estimates obtained in the sample of our main econometric specification presented in the third column. The dependent variable corresponds to the rate of change of the value of imports by each firm from a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average value of firm's imports from that country in the corresponding months of 2017, 2018 and 2019). Table 7 presents some statistics for the deaths and stringency variables

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The stringency index is a key ingredient in many COVID-related empirical exercises. In order to ascertain the robustness of results we run regressions with two variants of the index: one excluding dimensions that are not expected to interfere with traders' activity and one keeping only dimensions closely related to mobility. We construct the sub-indices with the same methodology of the overall stringency index, and results are presented in Table 16 in Appendix F. The coefficients in the regressions are qualitatively similar to those obtained in the baseline specification, thus sustaining our conclusions. Comparing with the benchmark specification, coefficients associated with the sub-index that excludes only some dimensions, in columns 1 and 3 of Table 16, are slightly lower for exports and slightly higher for imports. In turn, the coefficients associated with the more strict sub-index are both smaller but significant and with the expected sign. In addition, we ran regressions for each individual dimension separately and the indicator of international travel controls came out significant and with a magnitude higher than the baseline specification for the case of imports.

Another possible concern could be the use of COVID-19 reported cases instead of deaths per thousand inhabitants as a proxy for health conditions. We tested this alternative and the coefficient associated with the stringency index remains negative and significant. In any case, the number of reported cases is strongly associated with the intensity of testing and thus the deaths per thousand inhabitants are a much more reliable monthly source of information.

An additional robustness dimension relates to the use of nominal trade flows. This could raise the question of results being driven by price effects rather than quantities. Therefore, we also tested the growth rate of the quantities exported and imported

as dependent variable instead of their value. The results of this test are presented in Tables 17 and 18 and show that our parameters and conclusions are not driven by price effects.

A final important point is the existence of zeros in several firm-country-time observations. Since our dependent variable corresponds to log differences, if a firm does not trade with a given country in a given month in the pandemics or in the reference period, that observation is not taken into account in our regressions. We used this specification since these zeros in the data can occur due to actual absence of trade or due to, for instance, the assimilation thresholds. Moreover, contrary to papers focusing on margins, the partial disregard of the extensive margin of trade is not a relevant feature in our analysis. Even so, in order to address such concerns, we also considered the mid-point growth rate relatively to the reference period as the dependent variable and the estimates remain qualitatively unchanged. Furthermore, we considered the $\log(1 + y)$ transformation, which is also used in empirical studies where the dependent variable may take the value zero, and the coefficients of interest stay qualitatively unchanged.

Overall, results show that the pandemics had a sizeable impact on trade both due to restrictions to movement, as proxied by the lockdown stringency index, and due to confidence or demand effects, which are proxied by the number of deaths per thousand inhabitants. Nevertheless, this impact was heterogeneous along firms and was not uniform along the successive waves of the pandemics.

4.2 Size and geographical concentration of trade flows

The size of traders is an important heterogeneity dimension that may have affected the response of their trade flows to the pandemics and related lockdowns. In this subsection, we turn to this issue and run high-dimensional fixed effect regressions that control for the size of firms as measured by a combination of total turnover and employment in 2019. The econometric procedure uses size dummies that interact with the stringency index. Firms are labelled along four categories: micro, small, medium and large. The classification criterion corresponds to the definition used by the European Commission.³

The results for exports are plotted in Fig. 4 and show that the negative impact of the stringency of containment measures adopted in the destination countries increases with the firm size. This result is also obtained by Bricongne et al. (2021). Similarly, larger importers are also more affected by the lockdowns in the origin countries (Fig. 5). Modelling this differential impact and finding explanations for this result is beyond the scope of this paper. Nevertheless, it is reasonable to argue that larger firms deal with larger shipments, thus being less agile in finding ways of countervailing restrictions and adopting alternatives for transportation, when compared with smaller ones. This is

³ According to the Recommendation of the European Commission 2003/361/EC, the category of micro-sized comprises firms that employ fewer than 10 workers and an annual turnover or total annual balance sheet not in excess of 2 million euros. In turn, small firms employ fewer than 50 people and have an annual turnover or total annual balance sheet not in excess of 10 million euros. The medium-sized firms employ fewer than 250 people and have an annual turnover not in excess of 50 million euros or a total annual balance sheet not in excess of 43 million euros. Therefore, the large firms are those that do not belong to any of the aforementioned categories.

Fig. 4 Impact of lockdowns on exports by firm size. *Note:* Estimation results in Table 9

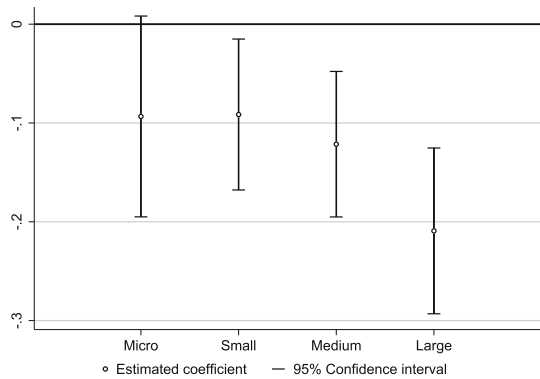
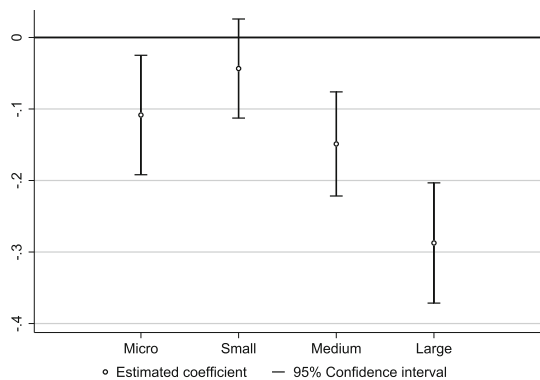


Fig. 5 Impact of lockdowns on imports by firm size. *Note:* Estimation results in Table 9



in accordance with the literature that identifies larger exporters as more dependent of foreign GDP, as in di Giovanni et al. (2020). However, Parr et al. (2002) and Grabher (1993) draw attention to the existence of agglomeration economies and lock-in effects, which can work in favour of larger firms.

Another relevant dimension of the firm's heterogeneous responses to lockdowns concerns the concentration of its trade flows in terms of partner countries. Opposing arguments could be raised. If a firm is forced to stop activity because a dominant destination country has imposed a severe lockdown, this may translate into a halt in exports to other smaller partners. Finding alternative export markets is also known to be costly and lengthy. Alternatively, concentration in specific export markets could give an edge in term of understanding the local reality and adapt to the new circumstances, thus minimizing. The literature is sparse in this domain but it generally takes diversification of activity and partners as a positive feature because overall risk is reduced. However, multi-regional input–output studies have also found that geographical concentration of trade positively impacts GDP per capita (Jiménez et al. 2022). Using our trade data, the lockdown indices and a categorical variable based on the quartiles of the distribution of the Herfindahl's concentration indices for firm's trade flows, we can assess whether the geographical concentration amplifies or mitigates the negative impact of lockdowns on trade flows.

Table 3 Impact of stringency of lockdowns on export and import flows by quartile of the geographical concentration distribution

Variables	(1) Exports	(2) Imports
<i>Deaths per thousand</i>		
Q1	−21.532*** (4.542)	−10.613** (4.629)
Q2	−34.353*** (7.146)	−36.068*** (6.324)
Q3	−38.356*** (9.121)	−30.309*** (7.290)
Q4	−24.537** (11.214)	−46.551*** (8.222)
<i>Stringency</i>		
Q1	−0.124*** (0.034)	−0.124*** (0.033)
Q2	−0.127*** (0.041)	−0.125*** (0.037)
Q3	−0.191*** (0.045)	−0.137*** (0.040)
Q4	−0.370*** (0.051)	−0.231*** (0.041)
Constant	24.794*** (1.764)	13.391*** (1.725)
Observations	447,535	522,687
R-squared	0.139	0.145
Firm FE	YES	YES
Country FE	YES	YES
Time FE	YES	YES

The quartiles of the concentration distribution are defined by trade flow in terms of the Herfindahl–Hirschman market concentration index by country in the reference period (2017, 2018 and 2019). The dependent variable corresponds to the rate of change of the value of exports and imports, respectively, by each firm for and from a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average value of firm's exports and imports, respectively, for and from that country in the corresponding months of 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3 shows that the negative impact of lockdowns on trade flows is stronger as their geographic concentration increases, both for exports and imports. On average, firms with more geographically diversified trade relationships are thus less affected. We also interacted the variables size and geographical concentration, but no clear evidence emerged.

4.3 GVC participation

The differential impact of lockdowns emerging from the participation of firms in GVCs is another important empirical question. The main obstacle in this analysis is finding a variable that accurately describes the firms' engagement in GVCs. The absence of firm-level input–output matrices makes it necessary to find proxy variables. One possibility is to simply use the share of imports on firm's total trade. However, many firms are not two-way traders simply because they are part of larger groups where GVC operations take place. Conversely, many firms import and export as part of their wholesale trade activity, which does not reflect GVC engagement. Another alternative is to associate GVC participation to *upstreamness* as defined in Antràs et al. (2012). Nevertheless, the latter concept places firms in the production chain and is not a direct measure of their involvement in complex GVCs. In this paper we take the existence of foreign capital at the firm-level as a proxy for their participation in GVCs. The association between foreign capital and GVCs has been established in several papers (e.g. Adarov and Stehrer 2021; Cadestin et al. 2018; Qiang et al. 2021 and Wang et al. 2021). It is relevant to note that, in our database, industries with the highest percentage of firms with foreign capital are also those with the highest import content. In practical terms, we define a binary variable for firms with and without foreign capital. Establishing a more restrictive threshold does not significantly change the results because the distribution of foreign capital shares has high density on lower and upper tails. This information was externally included in our database and is originally available at the *Quadros de Pessoal* dataset for 2019. The percentage of foreign capital is not reported for 13 percent of observations in exports and 26 percent in imports.

Table 4 shows that the detrimental impact of lockdowns is higher for firms with foreign capital, i.e. those more integrated in GVCs, for both export and import flows. Although the sample is not directly comparable, the magnitude of the impact of lockdowns is larger than in the baseline specification. This result is not surprising as the bottlenecks originated by limitations to mobility arising from containment measures affect primarily firms which are mostly dependent on international supply chains.

Information on value and quantity of each transaction allows us to obtain the unit value, which is the usual proxy for unobserved prices. Assessing the differential impact of lockdowns along the unit value distribution of the trade flows is another heterogeneity dimension and it is interesting *per se*. However, it also relates with firm's involvement in GVCs. The increase in unit values is associated with the improvement of the product at the firm level, namely through the development and commercialization of a product with improved performance characteristics (Hernández et al. 2014). The literature also suggests that firms placed in upstream or downstream segments of the production chain post higher unit value in their exports while those in the intermediate stages sell relatively cheaper products (Baldwin and Ito 2021).

Table 5 presents the differential impact of lockdowns by quartiles of unit value distribution in the reference period. In case of exports, the negative impact of lockdowns increases along the quartiles of the unit value distribution. This result suggests that, on average, the restrictions imposed in the destination countries affected more negatively Portuguese firms that are relatively more upstream or downstream and thus export

Table 4 Impact of lockdowns on export and import flows for firms with and without foreign capital

Variables	(1) Exports	(2) Imports
<i>Deaths per thousand</i>		
No foreign capital	−32.471*** (4.516)	−26.955*** (4.493)
With foreign capital	−7.397 (6.815)	−7.859 (5.999)
<i>Stringency</i>		
No foreign capital	−0.100*** (0.034)	−0.125*** (0.033)
With foreign capital	−0.241*** (0.042)	−0.163*** (0.039)
Constant	22.649*** (1.846)	11.285*** (1.827)
Observations	413,110	477,112
R-squared	0.134	0.136
Firm FE	YES	YES
Country FE	YES	YES
Time FE	YES	YES

“Foreign capital” is a binary variable for firms with and without foreign capital. The dependent variable corresponds to the rate of change of the value of exports and imports, respectively, by each firm for and from a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average value of firm’s exports and imports, respectively, for and from that country in the corresponding months of 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

more expensive goods. On the import side, the detrimental impact is not monotonically increasing across the quartiles of the unit value distribution. Portuguese firms that import cheaper products, such as raw materials, do not seem to be affected by the restrictions imposed in the origin countries, while firms in the third quartile are the most affected.

4.4 Industries and trade partners

Our database contains detailed information relatively to the goods traded by the firms and the partner countries involved. This makes it possible to assess the impact of lockdowns across different manufacturing industries and further discuss the impact of such containment measures on international supply chains. Firstly, we perform this sectoral analysis by organizing firms along their main economic activity, defined by the NACE Rev. 2 classification and creating a set of categorical variables that identify each manufacturing industry. The set of high dimensional fixed effects is also included. Secondly, we follow the same strategy for the trade partner dimension.

Table 5 Impact of stringency of lockdowns on export and import flows by quartile of the unit value distribution

Variables	(1) Exports	(2) Imports
<i>Deaths per thousand</i>		
Q1	−9.822 (5.993)	−2.366 (5.601)
Q2	−25.618*** (6.000)	−20.206*** (5.613)
Q3	−26.815*** (6.647)	−27.562*** (5.896)
Q4	−36.561*** (6.896)	−43.427*** (7.557)
<i>Stringency</i>		
Q1	−0.088** (0.037)	−0.024 (0.035)
Q2	−0.095** (0.039)	−0.147*** (0.035)
Q3	−0.195*** (0.040)	−0.208*** (0.037)
Q4	−0.204*** (0.039)	−0.145*** (0.040)
Constant	24.649*** (1.765)	12.982*** (1.728)
Observations	447,535	522,687
R-squared	0.139	0.145
Firm FE	YES	YES
Country FE	YES	YES
Time FE	YES	YES

The quartiles of the firms distribution are defined according to their average unit value in the reference period (2017, 2018 and 2019) by trade flow. The dependent variable corresponds to the rate of change of the value of exports and imports, respectively, by each firm for and from a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average value of firm's exports and imports, respectively, for and from that country in the corresponding months of 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Figure 6 plots the coefficients associated with the lockdown stringency index for the main manufacturing industries in terms of export flows. In the horizontal axis, sectors are ordered from the highest to the lowest import content, as reported in Rua and Cardoso (2019). The coefficient estimated for “transport equipment” is by far the most negative. This industry posts a high import content (71.2 percent) and has been widely identified as highly integrated in GVCs (e.g. Blázquez and González-Díaz 2016 and Sturgeon and Biesebroeck 2011). Conversely, industries such as “agriculture”,

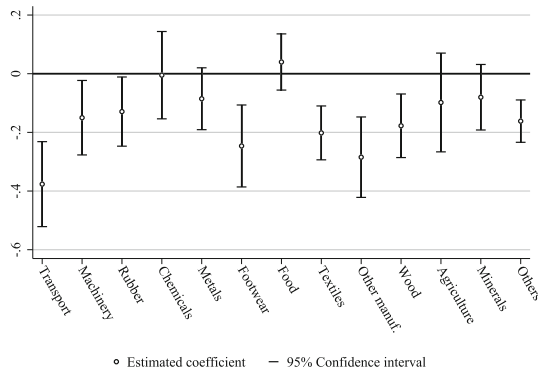


Fig. 6 Impact of lockdowns on exports by sector. *Notes:* Estimation results in Table 11. The industries represented are, respectively, Transport equipment; Machinery; Rubber and plastics; Chemicals; Metals; Footwear; Food and beverages; Textiles and wearing apparel; Other manufacturing; Wood and paper; Agriculture, forestry and fishing and Other minerals. The correspondence between these manufacturing industries and NACE Rev.2 is presented in Table 10. Industries are ordered from the highest to the lowest import content, as reported in Rua and Cardoso (2019)

“food” and “chemicals” present coefficients that are not statistically different from zero. In the latter case, although there is a high import content (50.4 percent), the industry includes pharmaceutical products, whose demand has not been affected by containment measures.⁴ It is also relevant to note that industries like “footwear” and “textiles”, whose import content is lower (40.6 and 38.1 percent, respectively), post coefficients for the stringency index that are negative and statistically significant. These sectors produce on the basis of clear seasonal patterns and have been quite affected by the stringency measures, notably the closure of retail trade, i.e. the access of consumers to new clothing and footwear collections was limited. In addition, these industries are more labour-intensive and thus more affected by the absence of workers due to containment measures.

The analysis was replicated for firm-level import flows, and results are presented in Fig. 7. In this case, many industries post coefficients that are not statistically different from zero. Nevertheless, the coefficient for the “transport equipment” is again the most negative and statistically significant. The “textiles” industry also present a negative and significant coefficient, signalling that containment measures adopted in partner countries led to lower imports of these products, probably due to disruptions in foreign production.

The analysis at the partner country level follows the same approach adopted above for industries. We include in the regression a set of categorical variables that identify important trade partners, over and above the firm-level, country and time fixed effects. Results for exports and imports with the main Portuguese trade partners are presented in figures 8 and 9, respectively. In both figures, the countries in the horizontal axis are ordered from the highest to the lowest weight as sources of value added embodied in Portuguese exports, as reported by Hale (2005). The analysis of the coefficients

⁴ We estimate our main regressions excluding medical goods and the results remain qualitatively unchanged, with the coefficient associated with the stringency index slightly increasing both for exports and imports.

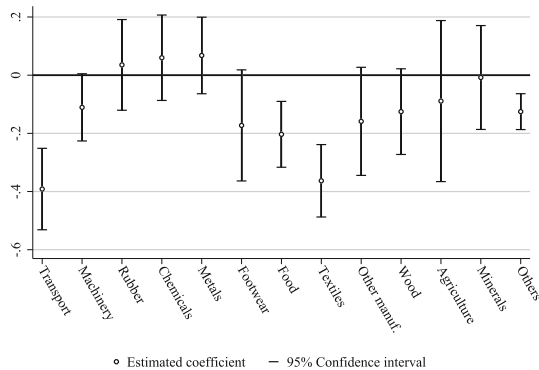
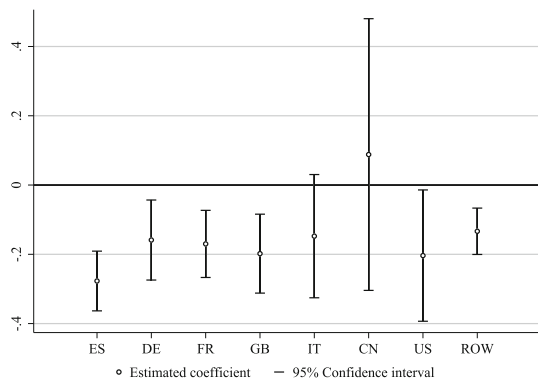


Fig. 7 Impact of lockdowns on imports by sector. *Notes:* Estimation results in Table 11. The industries represented are, respectively, Transport equipment; Machinery; Rubber and plastics; Chemicals; Metals; Footwear; Food and beverages; Textiles and wearing apparel; Other manufacturing; Wood and paper; Agriculture, forestry and fishing and Other minerals. The correspondence between these manufacturing industries and NACE Rev.2 is presented in Table 10. Industries are ordered from the highest to the lowest import content, as reported in Rua and Cardoso (2019)

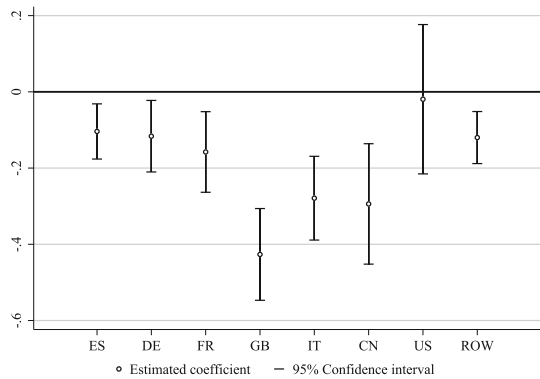
Fig. 8 Impact of stringency of lockdowns on export flows by destination country. *Notes:* Estimation results in Table 12. Countries in the horizontal axis are ordered from the highest to the lowest weight as sources of value added embodied in Portuguese exports, as reported by Hale (2005). “ES” stands for Spain, “DE” for Germany, “FR” for France, “GB” for UK, “IT” for Italy, “CN” for China, “US” for USA and “ROW” for Rest of the World



estimated for the impact of the stringency measures on exports shows that they are more negative and statistically significant in Spain, Germany, France and UK. These are the four main Portuguese export partners, but they are also key suppliers of intermediate products necessary for Portuguese exporters. Spain is the largest Portuguese trade partner, its single land border and there are strong supply chains linking the two Iberian countries. One German automotive multinational accounts for an important share of Portuguese exports and Amador and Stehrer (2014) has also documented the Iberian GVCs as important. Results for the stringency coefficient are not significantly different from zero in the cases of Italy and China. The number of Portuguese firms exporting to China is relatively small, which implies the widening of the confidence intervals.

The analysis concerning import partners conveys a somewhat different message (Fig. 9). The coefficients are more negative and statistically significant in the UK, Italy and China. Given our interpretation of the coefficients, containment measures

Fig. 9 Impact of stringency of lockdowns on import flows by origin country. *Notes:* Estimation results in Table 12. Countries in the horizontal axis are ordered from the highest to the lowest weight as sources of value added embodied in Portuguese exports, as reported by Hale (2005). “ES” stands for Spain, “DE” for Germany, “FR” for France, “GB” for UK, “IT” for Italy, “CN” for China, “US” for USA and “ROW” for Rest of the World



imposed in these countries affected their ability to meet Portuguese orders, possibly due to tighter border controls or disturbances in their production.

4.5 Time-varying effects

As the pandemics evolved up to the first half of 2021, one salient feature was the recovery of international trade flows, which raised the hypothesis of adaptation by firms to prevailing restrictions. The time-varying impact of lockdowns was estimated using our preferred specification and a set of categorical variables that identify each of the six quarters between the beginning of 2020 and the first half of 2021 and interact with the stringency index. The rich set of firm, country and time fixed effects is maintained.

The estimated coefficients and the 95 percent confidence interval for exports are plotted in Fig. 10. Results show that the impact of lockdowns was strongest in the first two quarters of 2020. In the last two quarters of 2020, the upper bound of the confidence interval is above zero, i.e. the coefficients are not statistically significant at a 5 percent significance level. The negative impact seems to emerge again with the third wave of the pandemics, but it is not statistically different from zero at a 1 percent significance level and remains non-significant in the second quarter of 2021. This path suggests that firms adapted their activities in order to export under the effect of containment measures. The result is even more visible when we take quantities exported rather than values (Fig. 12).

Conversely, lockdowns in the origin countries contributed negatively to the growth rate of firms' imports in the first quarter of 2021, both in terms of values and quantities (Figs. 11 and 13, respectively). Berthou and Stumpner (2022) uses French country-level bilateral trade data up to the end of 2020 and also finds that exports adapted more quickly to new conditions than imports.

As for the impact of health conditions on firm-level trade flows, although there are differences in terms of relative magnitude, the quarterly pattern is close to the one registered for the stringency of lockdowns in the case of exports. However, it remains negative and significant in the third quarter of 2020 and non-significant in the first quarter of 2021 at a 5 percent significance level. As for imports, health conditions

Fig. 10 Quarterly impact of lockdowns on exports in 2020 and first half of 2021. *Note:* Estimation results in Table 8

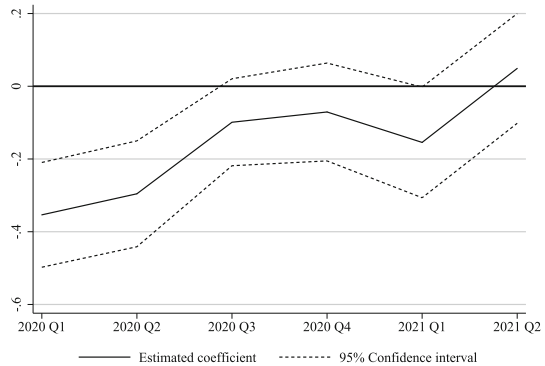
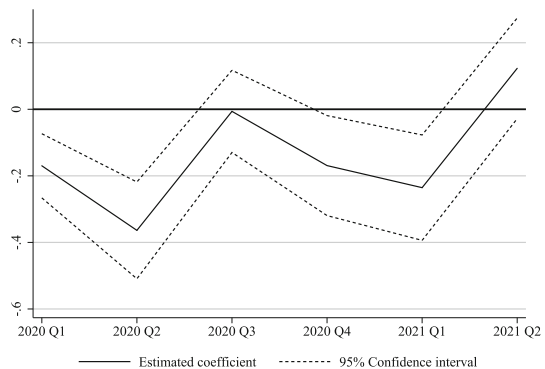


Fig. 11 Quarterly impact of lockdowns on imports in 2020 and first half of 2021. *Note:* Estimation results in Table 8



did not impact on the last two quarters of 2020 at a 5 percent significance level and got negative and significant in the first quarter of 2021. As previously mentioned, interpreting the impact of foreign health conditions in imports is not straightforward. These results are presented in Table 8 in [Appendix B](#).

5 Concluding remarks

The impact of the COVID-19 pandemics in international trade flows was strong, mostly due to the difficulties imposed by the lockdowns targeted at limiting infections. It is important to quantify the overall impact of these restrictions and detail along firms' heterogeneity dimensions and along time. Understanding how firm's size and geographical concentration of trade flows interact with restrictions to mobility is relevant to design policy responses, while knowledge about the differential impact associated with the existence of foreign capital, the unit value of products exported, industries and trade partners, hints at the interplay between lockdowns and the operation of international supply chains. Lastly, knowledge about the ability demonstrated by international traders to adapt to the measures underpinning lockdowns is also valuable because such restrictions may be implemented under different future contexts.

We conclude that the effects of lockdowns on trade flows are sizeable and broadly similar for exports and imports. The detrimental impact of lockdowns increases with firm size and with the geographical concentration of trade flows, both in exports and imports. Moreover, firms with foreign capital and those in the upper quartiles of the unit value distribution are also those where the negative impact of lockdowns on trade is estimated to be larger. The same applies to industries with high import content and to trade partners that are more important as sources of value added to be embodied in exports. The quarterly impact of lockdowns on trade has diminished as of the second half of 2020 in case of exports, suggesting that Portuguese exporters adapted to operate under adverse mobility and working conditions.

The future of international trade is likely to be affected by the pandemic crisis. Firstly, the pre-existing protectionist trends may be reinforced by some governments' drive to promote domestic production as a shield against prolonged and severe supply chain disruptions. These concerns do not seem to be supported by our results. Although the most affected firms are those typically linked to GVCs, international traders evidenced a strong degree of adaptation and managed to operate with containment measures. Nevertheless, after this experience, firms may have decided to re-optimize production and supply chains, a development that will be interesting to assess empirically in the near future. Secondly, the pandemic has been reinforcing the upward trend in international trade of non-tourism services, notably those associated with communications and data. The quantitative impact of lockdowns in international trade of non-tourism services is a dimension not analysed in this paper, but it stands as an interesting path for research going forward.

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Declarations

Conflicts of interest Authors confirm that there are no conflicts of interest and research did not involve human participants and/or animals.

Appendix A Summary statistics

Table 6 Description of the firm-level trade data used for the period January 2020–June 2021. Source: Authors' calculations using International Trade Data (Statistics Portugal)

Firm-level	Exports	Imports
Number of firms	35,731	130,760
Number of partner countries		
- Mean	3.4	1.8
- Standard deviation	6.8	2.5
- Median	1.0	1.0
Flows (Thousand Euros)		
- Mean	2,293.6	755.0
- Standard deviation	34,067.2	20,813.2
- Median	6.2	0.3

Table 7 Key statistics on deaths and stringency index for the period January 2020–June 2021

Exports	Mean	SD	P25	Median	P75
Deaths per thousand	0.0733	0.0996	0.00309	0.0265	0.114
Stringency index	56.23	22.46	49.10	61.92	71.30
Imports	Mean	SD	P25	Median	P75
Deaths per thousand	0.0785	0.0994	0.00327	0.0367	0.131
Stringency index	58.66	22.04	51.87	63.84	73.45

These statistics are obtained in the sample underlying our main econometric specification, as presented in the third column of Tables 1 and 2, respectively

Appendix B Time-varying effects

Table 8 Impact of stringency of lockdowns on export and import flows for each quarter of 2020 and 2021. Notes: These results are graphically represented in Figs. 10 and 11. The dependent variable corresponds to the rate of change (in log differences) of the value of exports/imports, respectively, of each firm for/from a given country in a given month of 2020 and of the first half of 2021 in relation to the reference period (average value of each firm exports/imports, respectively, for/from that country and month in 2017, 2018 and 2019)

Variables	(1) Exports	(2) Imports
<i>Deaths per thousand</i>		
2020		
1st Quarter	−46.275*** (15.070)	−31.929*** (11.032)
2nd Quarter	−71.659*** (7.502)	−45.318*** (6.917)
3rd Quarter	−67.651*** (24.487)	9.857 (25.287)
4th Quarter	0.249 (7.239)	12.079* (6.857)
2021		
1st Quarter	−12.986* (7.514)	−38.022*** (7.600)
2nd Quarter	−0.621 (9.316)	9.312 (9.569)
<i>Stringency</i>		
2020		
1st Quarter	−0.354*** (0.073)	−0.170*** (0.049)
2nd Quarter	−0.296*** (0.074)	−0.364*** (0.074)
3rd Quarter	−0.099 (0.061)	−0.006 (0.063)
4th Quarter	−0.071 (0.069)	−0.169** (0.077)
2021		
1st Quarter	−0.154** (0.078)	−0.235*** (0.081)
2nd Quarter	0.049 (0.077)	0.123 (0.077)
Constant	23.538*** (1.919)	13.248*** (2.020)
Observations	447,535	522,687
R-squared	0.139	0.145
Firm FE	YES	YES
Country FE	YES	YES
Time FE	YES	YES

Robust standards errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Appendix C Size of traders

Table 9 Impact of stringency of lockdowns on export and import flows by firm size

Variables	(1) Exports	(2) Imports
<i>Deaths per thousand</i>		
Micro	−20.608* (10.969)	−30.448*** (7.934)
Small	−32.259*** (6.439)	−42.046*** (5.302)
Medium	−32.542*** (5.494)	−22.312*** (5.963)
Large	−10.662 (7.033)	17.634** (7.362)
<i>Stringency</i>		
Micro	−0.093* (0.052)	−0.108** (0.043)
Small	−0.091** (0.039)	−0.043 (0.035)
Medium	−0.121*** (0.038)	−0.149*** (0.037)
Large	−0.209*** (0.043)	−0.287*** (0.043)
Constant	22.517*** (1.846)	11.008*** (1.825)
Observations	413,110	477,112
R-squared	0.134	0.137
Firm FE	YES	YES
Country FE	YES	YES
Time FE	YES	YES

These results are graphically represented in Figs. 4 and 5. The dependent variable corresponds to the rate of change (in log differences) of the value of exports/imports, respectively, of each firm for/from a given country in a given month of 2020 and of the first half of 2021 in relation to the reference period (average value of each firm exports/imports, respectively, for/from that country and month in 2017, 2018 and 2019) Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Appendix D Manufacturing industries

Table 10 Manufacturing breakdown in descending order of the imported content of exports

Rank	Sector	NACE Rev. 2	Subsector
1	Transport equipment	29	Manufacture of motor vehicles, trailers and semi-trailers
		30	Manufacture of other transport equipment
2	Machinery	26	Manufacture of computer, electronic and optical products
		27	Manufacture of electrical equipment
		28	Manufacture of machinery and equipment n.e.c.
3	Rubber and plastics	22	Manufacture of rubber and plastic products
4	Chemicals	20	Manufacture of chemicals and chemical products
		21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
5	Metals	24	Manufacture of basic metals
		25	Manufacture of fabricated metal products, except machinery and equipment
6	Footwear	15	Manufacture of leather and related products
7	Food and beverages	10	Manufacture of food products
		11	Manufacture of beverages
8	Textiles and wearing apparel	13	Manufacture of textiles
		14	Manufacture of wearing apparel
9	Other manufacturing	31	Manufacture of furniture
		32	Other manufacturing
10	Wood and paper	16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
		17	Manufacture of paper and paper products
		18	Printing and reproduction of recorded media
11	Agriculture, forestry and fishing	01	Crop and animal production, hunting and related service activities
		02	Forestry and logging
		03	Fishing and aquaculture
12	Other minerals	23	Manufacture of other non-metallic mineral products
		05	Mining of coal and lignite
		06	Extraction of crude petroleum and natural gas
		07	Mining of metal ores
		08	Other mining and quarrying

Industries are organized in descending order of the imported content of exports, according to the most recent input–output matrices published by Statistic Portugal (with reference to the year 2017)

Table 11 Impact of stringency of lockdowns on export and import flows by activity sector

Variables	(1) Exports	(2) Imports
<i>Deaths per thousand</i>		
Transport equipment	9.240 (14.825)	33.371*** (12.925)
Machinery	−8.811 (13.061)	26.379** (12.199)
Rubber and plastics	−20.082* (11.537)	−26.477 (16.623)
Chemicals	9.870 (15.527)	2.438 (16.263)
Metals	−21.577** (10.049)	−22.815 (14.299)
Footwear	−23.662 (17.791)	−73.546*** (21.887)
Food and beverages	−38.991*** (8.789)	22.080* (12.272)
Textiles and wearing apparel	−45.696*** (8.952)	−20.725 (14.331)
Other manufacturing	−50.619*** (14.190)	−57.442*** (22.221)
Wood and paper	−4.636 (10.617)	2.334 (16.968)
Agriculture, forestry and fishing	−27.436 (21.293)	−8.082 (31.838)
Other minerals	−41.330*** (11.315)	−1.878 (20.479)
Other sectors	−26.152*** (6.160)	−34.705*** (4.346)

Table 11 continued

Variables	(1) Exports	(2) Imports
<i>Stringency</i>		
Transport equipment	−0.376*** (0.074)	−0.391*** (0.071)
Machinery	−0.150** (0.065)	−0.111* (0.059)
Rubber and plastics	−0.129** (0.060)	0.035 (0.080)
Chemicals	−0.005 (0.076)	0.060 (0.075)
Metals	−0.085 (0.054)	0.068 (0.067)
Footwear	−0.246*** (0.071)	−0.173* (0.097)
Food and beverages	0.040 (0.049)	−0.203*** (0.058)
Textiles and wearing apparel	−0.202*** (0.047)	−0.363*** (0.064)
Other manufacturing	−0.285*** (0.070)	−0.159* (0.095)
Wood and paper	−0.178*** (0.055)	−0.125* (0.075)
Agriculture, forestry and fishing	−0.098 (0.086)	−0.089 (0.141)
Other minerals	−0.080 (0.057)	−0.008 (0.091)
Other sectors	−0.162*** (0.037)	−0.125*** (0.031)
Constant	24.777*** (1.765)	13.004*** (1.727)
Observations	447,535	522,687
R-squared	0.139	0.145
Firm FE	YES	YES
Country FE	YES	YES
Time FE	YES	YES

These results are graphically represented in Figs. 6 and 7. The dependent variable corresponds to the rate of change (in log differences) of the value of exports/imports, respectively, of each firm for/from a given country in a given month of 2020 and of the first half of 2021 in relation to the reference period (average value of each firm exports/imports, respectively, for/from that country and month in 2017, 2018 and 2019) Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Appendix E Partner countries

Table 12 Impact of stringency of lockdowns on export and import flows by destination and origin country, respectively

Variables	(1) Exports	(2) Imports
<i>Deaths per thousand</i>		
Spain	−61.733*** (8.366)	−49.388*** (6.281)
Germany	−0.066 (15.117)	−2.626 (11.409)
France	−63.969*** (11.010)	−27.830** (12.615)
UK	−40.177*** (10.279)	−10.226 (11.815)
Italy	−29.406* (17.843)	−13.897 (10.016)
China	1,882.189 (6,637.550)	4,877.553* (2,684.030)
USA	2.262 (23.885)	−33.094 (26.820)
Rest of the World	−10.302** (4.640)	−8.406* (4.888)
<i>Stringency</i>		
Spain	−0.277*** (0.044)	−0.104*** (0.037)
Germany	−0.159*** (0.059)	−0.116** (0.048)
France	−0.170*** (0.049)	−0.158*** (0.054)
UK	−0.198*** (0.058)	−0.427*** (0.061)
Italy	−0.148 (0.091)	−0.279*** (0.056)
China	0.088 (0.200)	−0.294*** (0.081)

Table 12 continued

Variables	(1) Exports	(2) Imports
USA	−0.204** (0.097)	−0.019 (0.100)
Rest of the World	−0.134*** (0.034)	−0.120*** (0.035)
Constant	26.033*** (1.795)	14.900*** (1.818)
Observations	447,535	522,687
R-squared	0.139	0.145
Firm FE	YES	YES
Country FE	YES	YES
Time FE	YES	YES

These results are graphically represented in Figs. 8 and 9. The dependent variable corresponds to the rate of change (in log differences) of the value of exports/imports, respectively, of each firm for/from a given country in a given month of 2020 and of the first half of 2021 in relation to the reference period (average value of each firm exports/imports, respectively, for/from that country and month in 2017, 2018 and 2019) Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Appendix F Robustness tests

Appendix F.1 Lags of the stringency index and google mobility indicators

Table 13 Stringency of lockdowns, retail and transit-station Google mobility and firms' exports

Variables	(1) HDFE	(2) HDFE	(3) HDFE	(4) HDFE
Deaths per thousand	−29.957*** (3.842)	−30.252*** (3.856)	−20.645*** (4.171)	−15.843*** (4.345)
Stringency-1 month lag	−0.069** (0.032)			
Stringency-2 months lag		0.058* (0.032)		
Transit-station mobility			0.211*** (0.033)	
Retail mobility				0.231*** (0.031)
Constant	20.330*** (1.681)	13.513*** (1.772)	21.708*** (0.910)	20.997*** (0.720)
Observations	447,529	420,868	435,041	435,037
Adjusted R-squared	0.117	0.119	0.119	0.119
Firm FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES

The dependent variable corresponds to the rate of change (in log differences) of the value of exports of each firm to a given country in a given month of 2020 and the first half of 2021 in relation to the reference period (average value of each firm exports for that country and month in 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 14 Stringency of lockdowns, retail and transit-station Google mobility and firms' imports

Variables	(1) HDFE	(2) HDFE	(3) HDFE	(4) HDFE
Deaths per thousand	−24.736*** (3.708)	−29.394*** (3.721)	−11.551*** (4.234)	−14.279*** (4.385)
Stringency-1 month lag	−0.218*** (0.029)			
Stringency-2 months lag		−0.025 (0.030)		
Transit-station mobility			0.237*** (0.033)	
Retail mobility				0.143*** (0.030)
Constant	17.538*** (1.619)	6.724*** (1.710)	9.021*** (0.891)	6.085*** (0.722)
Observations	522,684	492,133	490,684	490,682
Adjusted R-squared	0.120	0.122	0.120	0.120
Firm FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES

The dependent variable corresponds to the rate of change (in log differences) of the value of imports of each firm from a given country in a given month of 2020 and of the first half of 2021 in relation to the reference period (average value of each firm imports from that country and month in 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 15 Correlation between the stringency index and the transit-station and retail mobility (in percentage)

	Transit-station mobility	Retail mobility
All countries	−60.34	−62.62
Portugal	−86.81	−67.66
Spain	−73.06	−70.98
Germany	−85.48	−75.26
France	−84.70	−83.18
UK	−94.63	−80.58
USA	−91.74	−72.87

There is no information for China in Google Mobility Reports

Appendix F.2 Sub-indices of the stringency index

Table 16 Alternative indices of lockdowns' stringency

Variables	(1) Exports	(2) Exports	(3) Imports	(4) Imports
Deaths per thousand	−24.951*** (4.032)	−28.730*** (3.898)	−19.164*** (3.960)	−24.426*** (3.739)
C1, C2, C5, C6, C7, C8 index	−0.128*** (0.028)		−0.152*** (0.026)	
C6, C7, C8 index		−0.061*** (0.023)		−0.087*** (0.021)
Constant	22.001*** (1.213)	19.498*** (1.075)	12.229*** (1.188)	9.915*** (1.068)
Observations	447,535	447,535	522,687	522,687
R-squared	0.139	0.139	0.145	0.145
Firm FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Time FE	YES	YES	YES	YES

The C1, C2, C5, C6, C7, C8 index comprises school closures (C1), workplace closing (C2), public transportation (C5), stay at home order (C6), restrictions on internal movement (C7) and international travel controls (C8). The C6, C7, C8 index includes the last three indicators. These sub-indices are constructed with the methodology of the overall stringency index (https://github.com/OxCGRT/covid-policy-tracker/blob/master/documentation/index_methodology.md). The dependent variable corresponds to the rate of change (in log differences) of the value of exports/imports, respectively, of each firm for/from a given country in a given month of 2020 and of the first half of 2021 in relation to the reference period (average value of each firm exports/imports, respectively, for/from that country and month in 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Appendix F.3 Growth rate of the quantities as dependent variable

Table 17 Stringency of lockdowns and firms' quantities exported

Variables	(1) HDFE	(2) HDFE	(3) HDFE
Deaths per thousand	-30.952*** (4.299)		-25.606*** (4.522)
Stringency index		-0.199*** (0.035)	-0.134*** (0.037)
Constant	8.857*** (0.413)	17.771*** (1.977)	16.010*** (2.002)
Observations	447,594	447,594	447,594
Adjusted R-squared	0.125	0.125	0.125
Firm FE	YES	YES	YES
Country FE	YES	YES	YES
Time FE	YES	YES	YES

Estimates obtained in the sample of our main econometric specification presented in the third column. The dependent variable corresponds to the rate of change (in log differences) of the quantities exported by each firm to a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average of firm's quantities exported for that country in the corresponding months of 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

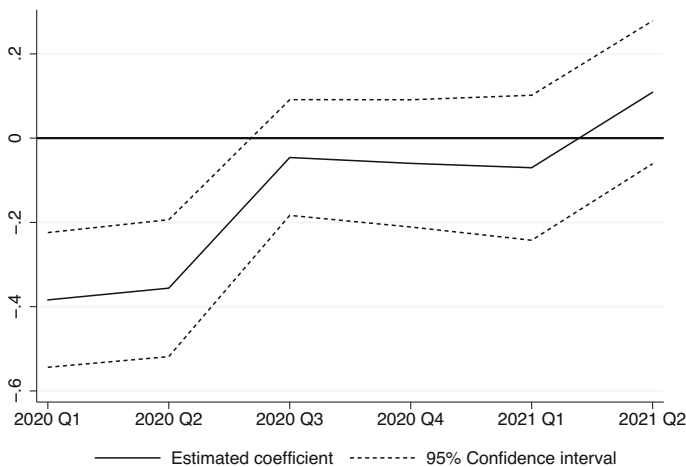


Fig. 12 Quarterly impact of lockdowns on quantities exported in 2020 and first half of 2021. *Note:* This result is analogous to the one presented in Fig. 10 but using as dependent variable the rate of change (in log differences) of the quantities exported by each firm to a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average of firm's quantities exported for that country in the corresponding months of 2017, 2018 and 2019)

Table 18 Stringency of lockdowns and firms' quantities imported

Variables	(1) HDFE	(2) HDFE	(3) HDFE
Deaths per thousand	-30.280*** (4.828)		-25.441*** (5.130)
Stringency index		-0.175*** (0.038)	-0.103** (0.040)
Constant	-8.592*** (0.472)	-0.703 (2.244)	-2.912 (2.279)
Observations	522,693	522,693	522,693
Adjusted R-squared	0.109	0.109	0.109
Firm FE	YES	YES	YES
Country FE	YES	YES	YES
Time FE	YES	YES	YES

Estimates obtained in the sample of our main econometric specification presented in the third column. The dependent variable corresponds to the rate of change (in log differences) of the quantities imported by each firm from a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average of firm's quantities imported from that country in the corresponding months of 2017, 2018 and 2019)

Robust standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

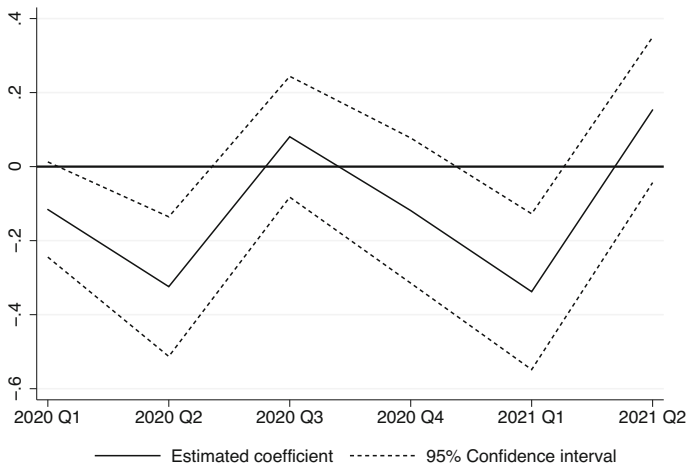


Fig. 13 Quarterly impact of lockdowns on quantities imported in 2020 and first half of 2021. *Note:* This result is analogous to the one presented in Fig. 11 but using as dependent variable the rate of change (in log differences) of the quantities imported by each firm from a given country in a given month of the period January 2020–June 2021 relatively to the reference period (average of firm's quantities imported from that country in the corresponding months of 2017, 2018 and 2019)

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