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Measuring systemic risk during the COVID-19 period: A TALIS$^3$ approach

Massimiliano Caporin$^{a,*,1}$, Laura Garcia-Jorcano$^{b,1}$, Juan-Angel Jimenez-Martin$^{c,1}$

$^a$Department of Statistical Sciences, University of Padova, Padova, Italy
$^b$Department of Economic Analysis and Finance (Area of Financial Economics), Facultad de Ciencias Jurídicas y Sociales, Universidad de Castilla-La Mancha, Toledo, Spain
$^c$Instituto Complutense de Análisis Económico (ICAE) and Department of Economic Analysis, Facultad de Ciencias Económicas y Empresariales, Campus de Somosaguas, Universidad Complutense, Madrid, Spain

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**A B S T R A C T**

The rapid spread of COVID-19 has had severe impacts on financial markets. We analyzed the systemic impact of the COVID-19 pandemic in different supersectors of STOXX600 North America and the STOXX600 Europe, using the Traffic Light System for Systemic Stress (TALIS$^3$) approach which provides a comprehensive color-based classification for grouping sectors according to system and sector stress level. We contrasted the financial markets’ reaction in North America and Europe, noticing that in Europe the systemic impact has been more persistent during March–May 2021. By evaluating the sectorial contribution to market risk, we observed heterogeneity between North America and Europe.

**1. Introduction**

The diffusion of the COVID-19 pandemic severely hit both the real economy and financial markets at a global level. The real effects of the pandemic have tended to emerge with a lower speed than the impact of COVID-19 on financial markets. This is a consequence of the speed at which financial markets react and the ease of accessing financial data compared to the time needed to observe structural macroeconomic indicators, which are not available in real-time, and it may take more than one month for preliminary estimates of, for example, quarterly Gross Domestic Product to be released after the end of the reference quarter. Consequently, financial markets’ reaction to the pandemic has been faster and has also accounted for all the information that has been released over time and transferred to the real economy state. Therefore, by studying the financial market response to the COVID-19 diffusion we may detect relevant insights into how this peculiar crisis produces effects.

A possible approach to tackling this objective is to focus on systemic risk indicators, tracing the market reaction to a global shock like COVID-19. Few papers have addressed this issue (Rizwan et al., 2020, among others). Among the possible indicators (see Adrian and Brunnermeier, 2016; Acharya et al., 2017, among others, and Bisias et al., 2012 for a survey), we chose the systemic risk indicators.

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$^*$Correspondence to: University of Padova, Department of Statistical Sciences, Via C. Battisti 241, 35121 Padova, Italy.

E-mail addresses: massimiliano.caporin@unipd.it (M. Caporin), Laura.Garcia@uclm.es (L. Garcia-Jorcano), juanangel@ccce.ucm.es (J.-A. Jimenez-Martin).

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measure TrAffic Light System for Systemic Stress (TALIS$^3$), introduced in Caporin et al. (2021). TALIS$^3$ combines the information contained in the ΔCoVaR and the sector shortfalls (the realized losses of an economic sector are larger than the expected VaR) to provide accurate systemic risk rankings. Therefore, TALIS$^3$ identifies the contribution of each super-sector to the whole market systemic risk by combining signals from two different sources. This approach has some advantages compared to other indicators. First, TALIS$^3$ uses appropriate and well-known loss functions to quantify the level of an asset’s stress (squared deviations between an asset’s equity returns and the corresponding VaR) and the system stress (the ΔCoVaR measure of Girardi and Ergün, 2013). Then, to analyze the severity of such stress states, these loss functions are dynamically analyzed, leading to a color-based classification of the assets that includes four possible states. TALIS$^3$ also allows the derivation of an aggregated index on the basis of an asset’s risk classification, which is a promising way to move beyond the isolated categorization of each financial instrument and gain a complete understanding of the dynamics of the system. Caporin et al. (2021) discuss in greater detail the flexibility of TALIS$^3$ and the advantages of using this approach compared to other systemic risk indices and classification criteria.

Using TALIS$^3$, we analyzed financial market stress in the months before the COVID-19 diffusion and the market reaction to the first wave of the pandemic until February 2021. By exploiting the informative content of TALIS$^3$, we contrasted the reaction of the European and North American financial markets at the aggregate level and by focusing on sectoral equity indices, thus decomposing market risk into the contribution coming from various economic sectors. Therefore, this paper challenges and takes advantage of the applicability of TALIS$^3$ to measure the impact of COVID-19 on the whole financial system.

We observed that both Europe and North America reacted to the pandemic diffusion at both the aggregated and sectorial level. However, heterogeneity emerged in the second half of 2020, with Europe characterized by a larger aggregated risk level while North American risk indicators showed more volatility.

The paper proceeds as follows: In Section 2, we describe the data and review the methodology used. Section 3 presents the empirical results, and Section 4 sets out conclusions.

2. Data and methodology

We considered the STOXX 600 North America and the STOXX 600 Europe indices. These indices are used as proxies for the two financial systems. We evaluated the systemic risk focusing on the super-sector decomposition of the indices. For Europe, we worked with the Hedged STOXX600 index, thus excluding currency risk from the analysis. We used daily log returns from January 1, 2016 to February 7, 2021, for a total of 1339 observations. All data were downloaded from Thomson Reuters EIKON.

Building TALIS$^3$ involved the evaluation two loss functions. The first function was the magnitude of the distressed state at the system level, defined as the expected loss conditional on the event that the system is in distress:

$$M D^i_{t+1} = E[L^i_{t+1} | I^i_{t+1} = 1].$$

(1)

where $L^i_{t+1} = \Delta CoVaR^i_{t+1}$ is the loss function for the system measured with the ΔCoVaR defined by Girardi and Ergün (2013) ($q$ being a quantile, usually on the left tail), and $I^i_{t+1}$ is the indicator function of system distress. The latter builds on the system’s VaR, leading to a value of 1 if $R^i_{t+1} \leq V aR^i_{t+1}$ and 0 otherwise. We assumed $q = 5\%$ for ΔCoVaR, and $V aR$ of the system. For evaluating ΔCoVaR$^j$, we adopted a semi-parametric approach combining a bivariate DCC-GJR-GARCH model, borrowing from Glosten et al. (1993) and Engle (2002), with the Filtered Historical Simulation (FHS) of Barone-Adesi et al. (1998), Barone-Adesi and Giannopoulos (1996), and Barone-Adesi et al. (1999). We adopted a 250-day rolling window approach for model estimation.

The second loss function, the magnitude of the distressed state in the $j$th super-sector, was the sector’s expected loss conditional on the event that the sector is in distress:

$$M D^j_{t+1} = E[L^j_{t+1} | I^j_{t+1} = 1].$$

(2)

where $L^j_{t+1} = (R^j_{t+1} - V aR^j_{t+1})^2$ is the loss function for the $j$th sector, defined as a quadratic numerical score that evaluates the sector’s excess returns when it is in distress; $I^j_{t+1}$ is the indicator function of the sector, which is equal to 1 if $R^j_{t+1} \leq V aR^j_{t+1}$ and 0 otherwise. Similarly to the system’s case, we assumed $q = 5\%$ for the $V aR$ of the sector, and we evaluated the $V aR$ with a GJR-GARCH with FHS.

To properly monitor the sector’s risk, high or low financial stress was identified by contrasting the value taken by the distress magnitudes in (1) and (2) with respect to threshold values, denoted by $z^j_{r,t+1,m}$ for $i = j, s$, where $j$ is the sector and $s$ is the system. We defined the thresholds as:

$$z^j_{r,t+1,m} = \max \left\{ \text{median} \left\{ M D^i_{r,t+1,k} \right\}_{k=1}^{k=m}, \text{median} \left\{ M D^j_{r,t+1,m} \right\}_{k=1}^{k=m} \right\}.$$

(3)

2 Being an empirical paper, this work is not intended to provide a methodological contribution; interested readers are referred to Caporin et al. (2021).

3 The super-sectors are: Auto and Parts; Banks; Basic Resources; Chemicals; Construction and Materials; Consumer Goods and Services; Energy; Financial Services; Food, Beverages, and Tobacco; Health Care; Industrial Goods and Services; Insurance; Media; Retail; Technology; Telecommunications; Travel and Leisure; Utilities; and Real Estate.

4 We generated 10,000 simulations in FHS to uncover the future evolution of the system and sector returns. For additional details on the methodology, the specification and implementation choices, we refer the reader to Caporin et al. (2021).

5 Readers interested in additional details on TALIS$^3$, namely, the size of the window, the MGARCH model and assumptions about the probability distributions, should refer to Section 3.5 and the Supplementary Material of Caporin et al. (2021).
where $i = j, s$. The threshold is the maximum of two arguments: the median of the full history of expected losses and the median of the last $m$-day window. We selected $m = 60$ days (roughly three months).

Given the thresholds, when $\Delta Cov aR_{t+1,m} > \zeta^{i}_{t+1,m}$ the $j$th sector faces losses with magnitudes that are larger than the threshold, and the sector is said to be in a relatively severe state of stress. In contrast, when $\Delta Cov aR_{t+1,m} \leq \zeta^{i}_{t+1,m}$ the $j$th sector faces losses with magnitudes that are smaller than the threshold, and the sector lies in a relatively minor stress state. The magnitude of the system’s losses can be similarly defined, for example, $\Delta Cov aR_{t+1,m} > \zeta^{i}_{t+1,m}$ implies that the impact of the super-sector on the whole system measured by $\Delta Cov aR_{t+1,m}$ is more severe than it used to be in the past.

$TALIS^3$ provides a ranking of sectors on the basis of the comparison of loss magnitudes with respect to the thresholds. For ease of interpretation, the ranking uses different colors depending on whether the sector and the system are in a relatively low or high state of stress. $TALIS^3$ ranks sectors according to four different possible states:

$$
TALIS^3_{j,t+1,m} = \begin{cases} 
\text{red} & \text{when } \Delta Cov aR_{t+1,m} > \zeta^{i}_{t+1,m} \text{ and } \Delta Cov aR_{t+1,m} > \zeta^{s}_{t+1,m} \\
\text{amber} & \text{when } \Delta Cov aR_{t+1,m} \leq \zeta^{i}_{t+1,m} \text{ and } \Delta Cov aR_{t+1,m} > \zeta^{s}_{t+1,m} \\
\text{yellow} & \text{when } \Delta Cov aR_{t+1,m} > \zeta^{i}_{t+1,m} \text{ and } \Delta Cov aR_{t+1,m} \leq \zeta^{s}_{t+1,m} \\
\text{green} & \text{when } \Delta Cov aR_{t+1,m} \leq \zeta^{i}_{t+1,m} \text{ and } \Delta Cov aR_{t+1,m} \leq \zeta^{s}_{t+1,m}.
\end{cases}
$$

The $TALIS^3$ for sector $j$, at time $t + 1$, using a window of size $m$ can be labeled using the traffic light signals for high (red), medium-high (amber), medium-low (yellow), and low (green) risk. Sectors currently in a relatively high stress state and with a severe impact on the system have a red label, indicating the highest risk. Red sectors should be under strict monitoring, as they could lead to a large impact on the entire system in case of losses. A sector with a green label, indicating the lowest risk, has a low stress state accompanied by a limited impact on the system. Amber and yellow sectors are in a middle position: an amber sector has a severe impact on the system even when it is in a minor stress state, while sectors in a severe stress state but with limited impact on the system are labeled yellow. We rank amber as riskier than yellow, as our focus is at the system level.

Using the time-varying sector-specific $TALIS^3$ classification, we calculated a time-varying aggregated version of $TALIS^3$. It is an aggregated $\Delta Cov aR$-related index, which uses the absolute value of the loss at the system level and sector-specific weights derived on the basis of the $TALIS^3$ ranking. Following a strategy similar to Aikman et al. (2017), we defined the aggregated index as a weighted geometric mean, which is robust to outliers and large differences between sector $\Delta Cov aR$ values (see Caporin et al., 2021, for more details):

$$
A_TALIS^3_{t+1,m} = \prod_{j=1}^{N} |\Delta Cov aR_{t+1,m}^{j}|^{w_{j,t+1,m}} \left(\frac{1}{(\sum_{j=1}^{N} w_{j,t+1,m})}\right),
$$

where $w_{j,t+1,m}$, the quantitative weight, is assigned to each state of distress according to the $TALIS^3$ classification in (4), $w_{j,t+1,m} = 1$ for red sectors and decreases to 0.75, 0.50, and 0.25 for amber, yellow, and green sectors, respectively. Note that weights induce a larger role for sectors in a riskier state.

By applying the $TALIS^3$ methodology, we recovered 970 one-day-ahead $TALIS^3$ rankings and aggregated index values7 from January 6, 2017 to the end of the sample, February 7, 2021, thus spanning the COVID-19 outbreak and part of the second wave of infections.

3. Results

Figs. 1 and 2 show daily $TALIS^3$ heat maps for the 19 North American and European super-sectors, respectively. Each row represents a super-sector, and the dates are on the x-axis. The aggregate $TALIS^3$ index is also included at the top of both figures. As expected, periods of high stress, in which the redness in the heat map is more intense for all the super-sectors, show a larger aggregate $TALIS^3$. The redness of $TALIS^3$ is more intense in Europe than in North America in almost the entire sample except at the outset of COVID-19 in March 2020, where both Europe and North America seem to have a similar red intensity. $TALIS^3$ identifies four periods that were apparently more turbulent, namely, January 2018, October 2018, August 2019, and the COVID-19 period. In January 2018, the S&P 500 index fell more than 10% between January 26 and February 9, after rallying more than 27% between the start of 2017 and January 2018. In October 2018, world stock markets lost 7.8% in US dollar terms over the month, based on the broadest measure of global equity performance. October 2018 ranks as the 22nd worst month for stocks since 1970, in the bottom 3.8% of all months. The US Federal Reserve Chair Jerome Powell’s statement that “we’re a long way from neutral on interest rates” (Woodruff, 2018), indicated that they would raise rates further than expected by the market, which led to higher bond yields. At the same time, expectations for economic growth appear to have declined somewhat, even though US growth indicators remained robust. In August 2019, $TALIS^3$ reports more intense redness, in particular in Europe, signaling high stress in

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6 A longer rolling window size, for example, $m = 120$, yields a weaker signal, and a shorter one, $m = 20$, produces a signal contaminated by noise. For robustness analysis on $TALIS^3$ performances with $m = 20$ and $m = 120$, see Caporin et al. (2021).

7 We lost 250 observations in the first window, 60 observations for computing the signal coming from the system and sector, and another 60 for computing the threshold.
Fig. 1. Aggregated TALIS\(^3\) in logarithm terms (top panel) and daily TALIS\(^3\) for the 19 selected sectors (bottom panel) belonging to STOXX 600 North America for the considered period (06/01/2017-02/17/2021).

Note: Each row in the bottom panel of the figure shows 60-day TALIS\(^3\) for all considered sectors. For example, the first row from the top corresponds to the Auto and Parts Sector, and the nineteenth from the bottom to the Real Estate sector. To better understand the labeled color for each day, let + (-) sign stand for a high (low) stress state. Red (+ system, + sector), amber (+ system, - sector), yellow (- system, + sector), and green (- system, - sector) mean that during that day this sector was labeled as an EXTREMELY, VERY, MODERATELY, or SLIGHTLY systemic sector, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the financial system. Euro-zone shares ended lower in August. Weak economic data from Germany contributed to increased worries over global growth. Shares fell in the UK, although defensive areas, such as Health Care and Utilities, outperformed. The prospect of a no-deal Brexit rose with the UK government unveiling plans for a lengthy prorogation of parliament. Finally, in late February 2020, the European aggregate TALIS\(^3\) index rallied to the top on March 13, and on March 17, the North American aggregate index reached a peak. The turbulence and stress of the market between late February and mid-March 2020 are shown in Figs. 1 and 2 by a strong redness intensity for every super-sector.

To analyze which sectors are the most systemic, we divided the sample into two periods: before the COVID-19 pandemic until February 28, 2020 and from Feb 29, 2020 to the end of the sample. For each sector, we computed the average of the TALIS\(^3\) time series which is then used to rank the 19 super-sectors from the largest, as the most systemic, to the lowest. During the pre-COVID-19 period, the top three most systemic sectors in Europe (North America) were Financial Services, Travel and Leisure, and Media (Travel and Leisure, Basic Resources, and Utilities). TALIS\(^3\) ranks the Travel and Leisure sector as one of the most systemic sectors in the pre-COVID-19 period in both regions, with North America first and Europe second. While Financial Services ranks first for Europe, it ranks last in North America. During the COVID-19 pandemic, Technology, Auto and Parts, and Energy (Health Care, Chemicals, and Food, Beverage and Tobacco) turned out to be the most systemic sectors in Europe (North America). A noteworthy result reported by TALIS\(^3\) is that Banks, Financial Services and Insurance did not rank highly during the COVID-19 pandemic, while Technology and Health Care rank first in Europe and North America, respectively. Financial sectors, that played a leading role during the 2008 financial crisis, do not seem have contributed significantly to the systemic risk of the whole stock market in the considered sample. TALIS\(^3\) also shows that the main contributors to the stress of the systems in Europe and North America during the COVID-19 pandemic have been rather different.

Fig. 3 shows the aggregated TALIS\(^3\) indices. For the sake of comparison we normalize the two aggregated indices plotted in the top panel. We follow the same strategy than Aikman et al. (2017) of using the Normal cumulative distribution function to normalize them on the 0, 1 interval. The top panel reports that from February 25, 2020 to the peak, the European index in red increased by 229% in 13 days and the North American index increased by 329% in 15 days, sending a strong signal that systemic risk was drastically increasing during that short period of time. Later, the level of financial stress decreased faster in North America than in Europe remaining higher until middle June 2020 when a new spike is observed in North America. As in Caporin et al. (2021), we also follow Aikman et al. (2017) and include the heat maps associated with each aggregated index in the middle (NA) and bottom (EU) panels.\(^8\) The heat map is a continuous color ramp assigning a color to each daily observation of the aggregated index. Low values of the index appear “cool”(deep blue), indicating a low level of distress for the entire system, whereas large values appear “hot”(dark red), indicating a high level of distress for the system. According to Fig. 3, the more severely adverse scenarios seemed

\(^8\) For details on the methodology, see Caporin et al. (2021).
Fig. 2. Aggregated $\text{TALIS}^3$ in logarithm terms (top panel) and daily $\text{TALIS}^3$ for the 19 selected sectors (bottom panel) belonging to STOXX 600 Europe for the considered period (06/01/2017–02/17/2021).

Note: Each row in the bottom panel of the figure shows 60-day $\text{TALIS}^3$ for all considered sectors. For example, the first row from the top corresponds to the Auto and Parts Sector, and the nineteenth from the bottom to the Real Estate sector. To better understand the labeled color for each day, let + (−) sign stand for a high (low) stress state. Red (+ system, + sector), amber (+ system, − sector), yellow (− system, + sector), and green (− system, − sector) mean that during that day this sector was labeled as an EXTREMELY, VERY, MODERATELY, or SLIGHTLY systemic sector, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3. Aggregated $\text{TALIS}^3 (A_{\text{TALIS}^3}^{(t+1), 60})$, for STOXX 600 North America (black line) and STOXX 600 Europe (red line) [top panel], and its corresponding heat map for STOXX 600 North America [middle panel] and STOXX 600 Europe [bottom panel].

Note: The top panel of the figures shows aggregated $\text{TALIS}^3$ computed using a weighted geometric mean according to Eq. (5), where the weights corresponding to the 19 selected sectors belonging to STOXX 600 North America (black line) and STOXX 600 Europe (red line) are based on $\text{TALIS}^3$ according to each state of distress. The middle and bottom panels show the heat map of each index, a continuous color ramp assigning a color for each daily observation of the aggregated index. Colors are associated with the percentile of the distribution of aggregated $\text{TALIS}^3$. Low values of the index appear “cool” (deep blue), indicating a low level of distress in the system, while large values appear “hot” (dark red), indicating a high level of distress in the system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

to happen during the COVID-19 pandemic: aggregate $\text{TALIS}^3$ reports that the pandemic might have had a more intense effect on the European market than in North America between early March and middle June of 2020, when the red line is above the black. The intensity of the impact is extremely strong in March 2020, when $A_{\text{TALIS}^3}$ reports an average values of 0.376 (0.409) for
Europe (North America), around three times the average value for the full COVID-19 period, 0.12 (0.15) and well over the average value for the pre-COVID-19 period of 0.02 (0.06).

4. Conclusion

By using a novel approach for systemic risk monitoring, TALIS\textsuperscript{3}, we evaluated the systemic impact of the COVID-19 pandemic on the North American and European financial markets. TALIS\textsuperscript{3} extracts, and processes signals generated by underlying risk metrics, providing a visual and automatic classification of economic sectors according to their marginal contributions to systemic risk, and permitting the management of two individual signals to provide more information than the original one individually does. We observed that the reaction of the markets at the onset of the virus diffusion was similar, but the impact on Europe has been more persistent during the first half of 2020. At sector levels, we clearly observed that financial sectors have not been the drivers of the risk, and there exists heterogeneity between North America and Europe. TALIS\textsuperscript{3} and its aggregated version, which turns out to be reliable for predicting stress states of financial markets (see Caporin et al., 2021), provide valuable insights into the impact of the COVID-19 on the financial markets; this evidence suggests that TALIS\textsuperscript{3} can be used for regulators to gauge and more precisely assess the cost for the whole economy associated with systemic events.

CRediT authorship contribution statement

Massimiliano Caporin: Conceptualization, Methodology, Formal analysis, Writing, Supervision. Laura Garcia-Jorcano: Conceptualization, Methodology, Formal analysis, Writing, Supervision. Juan-Angel Jimenez-Martin: Conceptualization, Methodology, Formal analysis, Writing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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