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Can innovation predict regional resilience? An econometric exploration of Brazilian municipalities during the Covid-19 pandemic

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Authors' Notes

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Abstract

Objective: This article examines the relationship between innovation and regional economic resilience in an emerging economy.

Method: This is a quantitative and descriptive research that uses a logistic regression based on socio-economic indicators of the 101 most populous Brazilian municipalities and considers regional resilience through employment data.

Originality/relevance: Although innovation has been identified as a source of regional economic resilience, the context of emerging economies has often been overlooked, resulting in a narrow view of this relationship.

Results: The findings show that innovation did not act as a classification variable for (non-)resilient regions. Municipalities characterized by greater proximity to ports, greater per capita Internet access, and the presence of technology parks showed less resilience during the Covid-19 pandemic compared to the national average performance, which is counterintuitive. In addition, a positive relationship was found between lower tax burden and regional resilience.

Theoretical contribution: The empirical research conducted helps to understand the specific impact of a crisis such as the pandemic in an emerging economy. The results also suggest that innovation is not a sufficient condition for regional resilience in the short run.

Practical contributions: The article points to the need to strengthen innovation capacities in regions of an emerging economy, which, if underdeveloped, are unable to act as an immune system in the face of a pandemic shock.

Keywords: regional resilience, innovation, shock, logistic regression, Covid-19

A inovação pode prever a resiliência regional? Uma exploração econométrica dos municípios brasileiros durante a pandemia de COVID-19

Resumo

Objetivo: Este artigo verifica a relação entre inovação e resiliência econômica regional, em uma economia emergente.

Método: Esta é uma pesquisa quantitativa e descritiva, que utiliza uma regressão logística a partir de indicadores socioeconômicos dos 101 municípios brasileiros mais populosos e considera a resiliência regional por meio de dados de emprego.

Originalidade/Relevância: Embora a inovação tenha sido identificada como uma fonte de resiliência econômica regional, o contexto das economias emergentes tem sido frequentemente negligenciado, resultando em uma visão estrita dessa relação.

Resultados: Os achados mostram que a inovação não atuou como variável de classificação para regiões (não-)resilientes. Municípios caracterizados por maior proximidade de portos, maior quantidade *per capita* de acesso à internet e pela existência de parques tecnológicos apresentaram menor resiliência durante a pandemia de COVID-19 quando comparadas ao desempenho médio nacional, o que se mostra contraintuitivo. Além disso, foi encontrada relação positiva entre menor carga tributária e resiliência regional.

Contribuição teórica: A exploração empírica realizada ajuda a compreender os efeitos específicos de uma crise como a gerada pela pandemia em uma economia emergente. Os achados também indicam que a inovação não seja condição suficiente para a resiliência das regiões no curto prazo.

Contribuições práticas: O artigo aponta para a necessidade de fortalecer as capacidades de inovação em regiões de uma economia emergente, que, se subdesenvolvidas, são incapazes de atuar como um sistema imunitário diante de um choque pandêmico.

Palavras-chave: resiliência regional, inovação, choque, regressão logística, COVID-19

¿Puede la innovación predecir la resiliencia regional? Una exploración econométrica de los municipios brasileños durante la pandemia de COVID-19

Resumen

Objetivo: Este artículo verifica la relación entre innovación y resiliencia económica regional, en una economía emergente.

Método: Se trata de una investigación cuantitativa y descriptiva, que utiliza una regresión logística basada en indicadores socioeconómicos de los 101 municipios brasileños más poblados y considera la resiliencia regional a través de datos de empleo.

Originalidad/Relevancia: Aunque la innovación ha sido identificada como una fuente de resiliencia económica regional, a menudo se ha descuidado el contexto de las economías emergentes, lo que ha resultado en una visión estrecha de esta relación.

Resultados: Los hallazgos muestran que la innovación no actuó como una variable de clasificación para las regiones (no) resilientes. Los municipios caracterizados por una mayor proximidad a los puertos, un mayor acceso a Internet per cápita y la existencia de parques tecnológicos mostraron menos resiliencia durante la pandemia de COVID-19 en comparación con el desempeño promedio nacional, lo que parece contradictorio. Además, se encontró una relación positiva entre una menor carga fiscal y la resiliencia regional.

Aporte teórico: La exploración empírica realizada ayuda a comprender los efectos específicos de una crisis como la generada por la pandemia sobre una economía emergente. Los hallazgos también indican que la innovación no es una condición suficiente para la resiliencia de las regiones en el corto plazo.

Contribuciones prácticas: El artículo señala la necesidad de fortalecer las capacidades de innovación en regiones de una economía emergente que, si están subdesarrolladas, son incapaces de actuar como un sistema inmunológico ante un shock pandémico.

Palabras clave: resiliencia regional, innovación, shock, regresión logística, COVID-19

Introduction

Fostering the ability to cope with the negative effects of economic shocks has been the goal of different organizations of various types. Initiatives such as the Rockefeller Foundation's 100 Resilient Cities and the United Nations' Sustainable Development Goals (SDGs) (2015) are confirming instances of this idea (Wang & Li, 2022). This ability has been tested in events such as the global financial crisis of 2008–2010, the crisis resulting from the COVID-19 pandemic, and more recently put to the test again with the impacts of the war in Ukraine. In this context, a challenge for managers is to comprehend how and why some regions are resilient (or not), adapting or transforming according to changes (Filippetti et al., 2020). This understanding may provide more effective responses for regions regarding different contexts and types of shocks.

One of the potential sources of regional (economic) resilience is innovation, a phenomenon recognized in the economic and strategy literature as a driver of growth and productivity (Nelson & Winter, 1982; Schumpeter, 1934; Wenzel et al., 2020). At the macro level, Archibugi and Filippetti (2011) found that the most innovative countries in the European Union (EU) were less affected by the 2008–2010 financial crisis. At the micro level, research shows that innovative companies had better economic performance during the same crisis (e.g. Cefis et al., 2020; Nemlioglu & Mallick, 2021). In events of shocks, the gains from pre-crisis innovations enable the "survival premium," which emerges even when financial conditions are controlled (Cefis et al., 2020, p. 64).

Despite these initial notes, the understanding of innovation as a source of regional resilience is limited. What is known about this relationship in the short term derives mainly from studies on the 2008–2010 crisis in developed countries (Viana et al., 2023). The findings have shown that the most innovative regions performed better regarding employment or wealth creation (Viana et al., 2023), despite some exceptions (e.g., Calignano & De Siena, 2020; Romão, 2020; Tuysuz et al., 2022). This specific approach demands analyzing different contexts, especially in regions of economies that are not seen as innovation leaders (Calignano & De Siena, 2020).

For instance, Brazil is marked by scarce public investment in innovation, low commitment to innovative actions, and a lack of relationships between companies and institutions that support business activity, such as universities and research centers (Esteves & Feldmann, 2016). Moreover, the role of the economic actors in fighting COVID-19 has been asymmetrical among macro-regions (Miranda et al., 2022), thus making it possible to question pre-existing capacities. So, even in this scenario, can there be a positive connection between innovation and regional resilience?

To fill this gap, this paper aims to examine the relationship between innovation and regional economic resilience in an emerging economy. To achieve this, we used secondary data from the 101 most populous municipalities in Brazil, encompassing a period of shock and gradual recovery. Data on patents, intellectual property, and employment in science and technology (S&T) were used as innovation proxies. Variables related to the capacity to innovate were also employed: distance to ports, exporting companies, human capital, and technological infrastructure. In addition, the level of wealth created, economic growth, and economic specialization, as well as the tax burden were included in the analysis.

This paper adds to the debate on the possible determinants of regional resilience by addressing the role of innovation in regions of an emerging economy and the shock of the COVID-19 pandemic. This addition is timely since reviews of the literature have identified a Eurocentric perspective of regional resilience (Miranda & Hoffmann, 2021; Sutton et al., 2023; Viana et al., 2023). Another contribution refers to the analysis, which considered the relationships among variables in a probabilistic rather than deterministic way, as suggested by Bristow and Healy (2018). Besides, this paper presents counterintuitive results on proximity to ports, fast internet access, and technology parks, and prompts reflection on tax burden and regional resilience.

In addition to this Introduction, the paper is made up of four other sections. The second one presents an overview of the innovation–regional resilience relationship and develops the hypotheses to be tested. The third section shows the choices and procedures followed to carry out the empirical exploration. In the fourth section, the models are developed, and the results are analyzed and discussed. Lastly, in the fifth section, the limitations of the research are defined, possible paths for future research are explored, and the theoretical and practical repercussions are highlighted.

Innovation and Regional Resilience

An overview of innovation as a determinant of regional resilience

Regional resilience and innovation are concepts marked by the lack of consensual terms (Fröhlich & Hassink, 2018; Kahn, 2018). Regional resilience is seen as a phenomenon encompassing (Ferrão et al., 2023; Martin et al., 2016; Martin & Sunley, 2015, 2020): vulnerability (degree of exposure and susceptibility to shocks), resistance (degree and extent of initial impacts of shocks), adaptability (ability to adapt/transform to economic change), and recovery (degree and extent of post-shock regional development). Thus, regional resilience can be understood as the ability of a regional economy to react to shocks by boosting resilience or recovery. Innovation can be defined as the implementation of new or improved products or processes (OECD, 2018). In this paper, it is assumed that setting the concepts apart makes it possible to determine the effects of innovation on performance (Arancegui et al., 2012).

Some of the first texts on the theoretical framework of regional resilience referred to the role of innovation. Clark et al. (2010) suggested that industrial districts with a larger number of innovative companies are more resilient, especially those formed by small, locally connected companies. Wolfe (2010) wrote that the allocation of specialized regional assets affects the capacity to innovate and respond to shocks, as resilient regions foster coordinated relationships to produce change. The papers by Clark et al. (2010) and Wolfe (2010) are part of The Resilient Region issue of the Cambridge Journal of Regions, Economy and Society. In its editorial, Christopherson et al. (2010) list among the potential sources of regional resilience: a developed regional innovation system; an innovative, entrepreneurial and skilled workforce; and modern productive infrastructure (including a transportation system and high-speed internet).

However, theoretical and empirical research addressing the intersection of these topics did not develop quickly over the next five years. In a review of the book Innovation, Global Change, and Territorial Resilience, Sunley (2013) criticized the implicit assumption of a positive link between innovation and economic resilience and the lack of empirical evidence. Martin and Sunley (2015) classified the sources of resilience into four interrelated subsystems: i) industrial and business structure; ii) labor market; iii) financial; and iv) governance. In this framework, a clear mention was made of the capacity to innovate as an element of the industrial and business subsystem.

Similarly, Evenhuis (2017) highlighted five areas that gather sources of resilience: i) economic basis; ii) labor market; iii) built environment; iv) institutional arrangements; and v) sense-making and politics. In this case, innovation was mentioned as an effect of other sources of resilience. Later, based on Martin and Sunley's (2015) suggestion, Miranda and Hoffmann (2021) analyzed papers on regional resilience published between 2010 and 2017 and indexed by the Web of Science. They included innovation as a variable of the industrial and business structure subsystem.

At the end of the second decade of the 21st century, interest in researching the innovation–regional resilience nexus was boosted. For instance, Bristow and Healy (2018) supported Sunley's (2013) point about the lack of results on this relationship in the short term. Moreover, based on an exploratory analysis, these authors showed that European regions with greater innovation capacity also showed greater resistance or recovery in facing the 2008–2010 financial crisis (see Bristow & Healy, 2018). In addition, several studies have revealed a positive association between the constructs, when operating innovation, or the capacity to innovate, by the proxies: patents, brands, spending on research and development (R&D), or employment in a knowledge-intensive activity (KIA) (e.g. Filippetti et al., 2020; Pinto et al., 2019; Rizzi et al., 2018).

Despite the mostly positive associations between innovation—or the capacity to innovate—and regional resilience while facing the 2008–2010 financial crisis, some studies have presented different results (see Viana et al., 2023 for a review). For instance, in Calignano and De Siena (2020), the rate of change of employment in high-tech sectors was (non-significantly) negatively related to the regional economic resilience of Italian provinces (NUTS3) in 2008–2014. In the research by Muštra et al. (2020) concerning EU regions, despite the positive link between an index of innovation and regional resilience, higher levels of human capital were associated with a lower likelihood of a region belonging to more resilient groups. Furthermore, in Romão's (2020) research on European regions with tourism as a main economic activity, R&D spending and human capital were negatively associated with resilience.

Concerning COVID-19, the results have been more mixed. Hu et al. (2022) highlighted innovation—measured by patents *per capita*—as a source, but dependence on foreign markets as a barrier to the resilience of cities in northeast China. Besides, Sargento and Lopes (2023) showed a positive relationship between research and innovation organizations that cooperate with companies on innovation projects and the economic resilience of Portuguese municipalities. On the other hand, Tuysuz et al. (2022) showed that both the number of patents *per capita* and export levels *per capita* predicted negatively the resilience of Turkish regions. In the same vein, employing a cluster analysis based on industrial production and retail turnover indices, Chernova and Gridnev (2023) suggested that the least resilient regions in Russia were those with higher levels of economic openness, more urbanized, and with a higher number of innovation-investing companies.

In short, the previous results support the view that in resilience research, some issues must be considered, such as resilience of what and to what (see Davoudi, 2012). The first refers to the scope of analysis and how resilience is measured (Martin & Sunley, 2015), such as concerning employment or wealth, since different results may be attained depending on the variables used (see Crescenzi et al., 2016; Sensier et al., 2016). The second refers to the shock under analysis, which can be of an economic, institutional, technological, environmental, pandemic, or anthropogenic nature (Sutton et al., 2023) since different shocks require different reactions (Miranda et al., 2023). In this scenario, it should be pointed out that a review by Viana et al. (2023) highlighted the role of context and operationalization when addressing the relationship between innovation and regional resilience, suggesting that it should be examined from different loci and shocks.

Developing hypotheses

The assumption of innovation as a crucial determinant of regional resilience comes from an evolutionary perspective, which sees socioeconomic systems as dynamic (Bristow & Healy, 2018; Filippetti et al., 2020; Pinto & Guerreiro, 2019). As it emerges from a collective process, innovation functions as a mechanism of adaptation or economic change (Pinto & Guerreiro, 2019), influencing resistance and recovery (Simmie, 2014). The reasoning is that innovative regions are better prepared to address shocks because they can combine activities, take risks, and have players with different attitudes concerning change (Bristow & Healy, 2018). In the long term, a recursive process occurs, with innovative regions being able to attract investment, connect with foreign markets, and muster internal abilities, aspects that shape adjustments in times of crisis (Crescenzi et al., 2016). As such, innovative performance does not stem from an accident during the path of economic development but is the result of an incremental process, which enables a creative response in the event of a shock (Filippetti et al., 2020). Therefore, we present the first hypothesis of this research:

H1: The higher the level of pre-shock innovation, the greater the likelihood of regional resilience.

Hypotheses were also formulated about the capacity to innovate as a determinant of regional resilience. This capacity was broken down into variables to provide greater detail. Given this, one proxy for innovation capacity is human capital, with the educational level of the workforce seen as a source of regional resilience (Di Caro, 2017; Duschl, 2016). Human capital fosters creativity and flexibility, driving process innovations in response to shocks, whereas, for instance, prior investment in R&D may not be associated with regional needs in the short term (Crescenzi et al., 2016). This human capital effect is expected for both small and large regional economies, with investment in education leading to higher quality of the labor force and increased productivity (Giannakis & Bruggeman, 2017). This positive result has been confirmed by different studies in developed countries when addressing the 2008–2010 crisis (e.g., Crescenzi et al., 2016; Giannakis & Bruggeman, 2017; Rios & Gianmoena, 2020; Rizzi et al., 2018) or COVID-19 (e.g., Sargento & Lopes, 2023). Thus, one expects that it will also be corroborated at different levels of economic development, leading to the second hypothesis:

H2: The larger the human capital, the greater the likelihood of regional resilience.

The relationship between regions and foreign markets—through exports—was listed as a second proxy for the capacity to innovate. On the one hand, several positive features of exports are highlighted, such as access to new resources and markets (Bathelt et al., 2013; Walther et al., 2011), incentive for companies to maintain innovation efforts in times of crisis (Holl & Rama, 2016), and protection from shocks restricted to the national level (Martin & Gardiner, 2019). On the other hand, dependence on exports is related to the vulnerability of a region, due to greater exposure to shocks coming from other countries (Diodato & Weterings, 2015; Du et al., 2019; Eraydin, 2016a; Martin et al., 2016; Martin & Gardiner, 2019; Tuysuz et al., 2022). There is even a suggestion that small export-oriented economies may have a pattern of economic resilience depending more on extra-regional factors than on the internal context and endogenous capacities (Ženka et al., 2019). In this scenario, it is worth considering the nature of the shock, since efforts to prevent the spread of COVID-19 have resulted in the halting of production, the closure of ports, and the disruption of supply chains (Caballini et al., 2022). Thus, more globally connected regions tend to show less economic resistance to these impacts (Hu et al., 2022; Sargento & Lopes, 2023; Tuysuz et al., 2022). We therefore suggest:

H3a: The larger the number of exporting companies, the lower the likelihood of regional resilience; and
H3b: The closer to ports, the lower the likelihood of regional resilience.

Technological infrastructure is also related to the capacity to innovate. One proxy is broadband access, one of the variables distinguishing resilient-transforming Turkish regions in the face of the 2008–2010 crisis (Eraydin, 2016b), and whose expansion suggests high development potential (Stognief et al., 2019). While only the availability of passive information and communication technology (ICT) infrastructure (e.g., mail service, radio, television) may not be related to innovation, there are signs that the use of active (e.g., cell phones, broadband internet) and passive ICT infrastructure promotes adaptability, thus easing the implementation of new technologies and innovations (van Aswegen & Retief, 2020). During the COVID-19 pandemic, digitalization and high-speed internet functioned as the basis for developing several new business models (see Gong et al., 2020). In addition, another potential proxy is the existence of science and technology parks, seen as environments that foster innovation, for instance, through exchanges between companies and universities (Díez-Vial & Montoro-Sánchez, 2016). The deployment of such parks has been proposed as a means of seeking economic adaptation or transformation (see David, 2018). We therefore suggest that:

H4: The more developed the technological infrastructure, the greater the likelihood of regional resilience.

Thus, except for H3a and H3b, a positive association is expected for the other hypotheses. Having presented the research preceding this paper, the next section addresses the method used to achieve the proposed goal.

Method

Analysis unit and sample

We used region as the analysis unit and collected data from the 101 most populous municipalities in Brazil, representing 41% of the country's estimated population in 2021 according to the Brazilian Institute of Geography and Statistics (IBGE, 2022). These municipalities are spread across the five Brazilian macro-regions: Southeast (48.5%), Northeast (19.8%), South (14.9%), North (9.9%), and Midwest (6.9%). A key point when exploring potential sources of regional resilience is determining the spatial scale of analysis (Martin, 2012). In this study, the availability of systematized data for the independent variables justified the scale used and the limited number of regions.

Variables and data

The selection of variables was based on the literature on regional resilience and innovation and is seen in Figure 1. A resilience index was calculated as the dependent variable (Giannakis & Bruggeman, 2017; Lagravinese, 2015):

$$res = [(\Delta E_r/E_r) - (\Delta E_n/E_n)]/|\Delta E_n/E_n|$$

where $(\Delta E_r/E_r)$ and $(\Delta E_n/E_n)$ represent the rate of change in employment at the regional and national levels, respectively. This is a measure whose positive values show that a given region has been more resilient than the national economy, while negative values indicate less relative resilience. Regarding the drop in employment in March 2020, February of the same year was set as the initial period (peak) and February 2022 as the final period—the latest data available at the time of writing. Due to this time frame, this study addresses particularly the resistance dimension, as also done by Hu et al. (2022). Moreover, employment data was chosen since it is more readily available than the Gross Domestic Product (GDP) (Sensier et al., 2016). This data is available on the website of the *Cadastro Geral de Empregados e Desempregados* [General Register of Employed and Unemployed – CAGED] (Brasil, 2022a).

Figure 1

Variables used in the study

Code	Variable	Description	Source
Dependent variable			
res	Resilience	Regional employment increase rate, subtracted from the national rate, with the result divided by the national rate's module.	CAGED (Brasil, 2022a)
Independent variables			
ipr	Intellectual property	Number of intellectual property contract deposits divided by the number of companies (2016 and 2017). Unit: thousand contracts/companies	ENAP (2022)a
kia	Employment in S&T	Workers in S&T divided by total employment in the municipality (2019). Unit: %	ENAP (2022)a
pat	Patents	Total number of patents for innovation, added innovation, and utility models in the last two years divided by the number of companies (2019). Unit: thousand patents/companies	ENAP (2022)a
hcp1	Secondary school	Percentage (%) of adults with completed secondary education: average of the ratio of fathers and mothers who declared they had completed secondary education by those enrolled in ENEMb	ENAP (2022)a

Continues on the next page

hcp2	Technical education	Number of people enrolled in technical education divided by the estimated population aged over 15. Unit: ln(%)	ENAP (2022)a
hcp3	Graduates in high-quality courses	Students with a score of 4 or 5 in ENADEc from 2017 to 2019 divided by the total number of graduates. Unit: %	ENAP (2022)a
exp	Exporting companies	Number of exporting companies divided by the total number of companies in the municipality (2019). Unit: ln(%)	ENAP (2022)a
port	Distance from port	Euclidean distance from the nearest port to the municipality. Unit: km	ENAP (2022)a
inf1	Fast internet access	Number of internet points above 12Mbps, weighted by the population estimate (2020). Unit: accesses/inhabitants	ENAP (2022)a
inf2	Technology park	Dummy variable if the municipality is listed or not in the Parques Tecnológicos [Technology Parks] project (2018).	ENAP (2022)a
Control variables			
gdp1	GDP growth	Average actual GDP growth (2014 to 2018). Unit: %	ENAP (2022)a
gdp2	GDP per capita	Municipal GDP per capita in R$/BRL (2018). Unit: ln	ENAP (2022)a
hhi	Herfindahl-Hirschman index	The sum of the squares of the municipal employment shares in each industry sector (CNAE 2.0 sections) related to the total municipal employment rate (2019).	Relação Anual de Informações Sociais [Annual Social Information Report – RAIS] (Brasil, 2022b)
trib	Tax burdend	State revenue from the Imposto sobre Circulação de Mercadorias e Serviços [Tax on Goods and Services – ICMS] in 2018 weighted by the 2017 state GDP. Unit: Inverse of % x 10	ENAP (2022)a

Source: prepared by the authors. Note: [a] Data compiled or processed by the *Escola Nacional de Administração Pública* [National School of Public Administration – ENAP] (https://ice.enap.gov.br/opendata); [b] ENEM – *Exame Nacional do Ensino Médio* [National Secondary School Exam]; [c] ENADE – *Exame Nacional de Desempenho dos Estudantes* [National Student Performance Exam]; [d] Inversion carried out, affecting interpretation.

The data for the independent and control variables were provided mainly from a database compiled by ENAP (2022) together with Endeavor. As for innovation, due to the unavailability of data at the municipal level regarding new or improved products or processes, the proxies patents, intellectual property contract deposits, and the ratio of S&T workers were used. Variables related to innovation capacity were also listed and are defined below.

We used as proxies for human capital the proportion of adults with completed secondary education, the logarithm of the ratio of people enrolled in technical education in the population aged over 15, and the proportion of graduates from high-quality courses (score 4 or 5 in ENADE). The use of different proxies for human capital allows us to check Viana et al.'s (2023) suggestion that the level of qualification is relevant when analyzing regional resilience, in this case, when addressing a shock other than the 2008–2010 financial crisis. Regarding external connectivity with regions in other countries as a potential source of regional resilience, we used the ratio of exporting companies based in the region and the distance to the nearest port (public ones or in the Amazon River). Furthermore, technological infrastructure was employed using *per capita* access points to fast internet and a dummy variable for regions listed in the Technology Parks project. Although the last two variables alone are insufficient to capture the regions' technological infrastructure, considering them can provide insights to inform further debates and policies (see ENAP, 2022).

Four control variables were also included in the analysis. Average actual GDP growth and GDP *per capita* capture economic growth and the wealth created, respectively. The Herfindahl-Hirschman index estimates specialization, with higher values suggesting a concentration of regional economic activity in a few industries, and is calculated by the formula (Doran & Fingleton, 2018): $herf_{rt} = \sum_i (E_{ir}^t / E_r^t)^2$, where E_{ir}^t represents formal employment in the industry i in region r at time t, and E_r^t is the total employment in region r in the same period. Data from the RAIS was used for the calculation, based on the national classification of economic activities (CNAE 2.0) per section (Brasil, 2022b), as suggested by Tupy et al. (2021). The considered period *t* was the last day of the year 2019. In addition, the state's ICMS tax revenue weighted by GDP was used as a proxy for the tax burden.

Data processing and statistical technique

We analyzed the data using descriptive statistics and logistic regression, a multivariate analysis technique suitable when the dependent variable is a categorical one (Hosmer & Lemeshow, 2000). Regional resilience studies frequently use logistic regression because relative or counterfactual measures offer binary results (e.g. Giannakis & Bruggeman, 2017; Wang & Li, 2022). Two models were estimated, one with forced entry and a thriftier one. The analyses were performed using the R language (R Core Team, 2021), RStudio (RStudio Team, 2022), and libraries such as *car* (Fox & Weisberg, 2019), *dlookr* (Ryu, 2022), *psych* (Revelle, 2021), *pROC* (Robin et al., 2011), *questionr* (Barnier et al., 2022), *ResourceSelection* (Lele et al., 2019), and *tidyverse* (Wickham et al., 2019).

To assess the models, firstly we used the likelihood logarithm (2log-likelihood, -2loglikehood, or -2LL), which is fitter the smaller it is (Hair et al., 2018). The -2LL of the null (with no independent variables) and proposed models were estimated, and their difference was assessed using a chi-square test. Three measures were then calculated: the pseudo R^2 of Hosmer and Lemeshow based on the -2LL, the R^2 of Cox-Snell, and the R^2 of Nagelkerke, with higher values suggesting a better fit (Hair et al., 2018). We also used the Akaike Information Criterion (AIC), which considers the fit of the penalized model. Although the AIC's magnitude is not our focus, the smaller it is, the thriftier the model and the greater the data support (Fox, 2016). The following processing methods were used for the thriftiest model obtained.

After the adjustment assessment, we verified the logistic regression requirements (Fernandes et al., 2020; Field et al., 2012; Fox, 2016; Hair et al., 2018; Tabachnick & Fidell, 2013): i) the absence of influential extreme cases; ii) the independence of errors; iii) the absence of multicollinearity; and iv) the linearity of each predictor with the dependent variable's logit.

Once the assumptions had been met, the predictive capacity was assessed using a confusion matrix, resulting from cross-tabulating the dependent variable with the probabilities the logistic regression model had estimated. To prepare that matrix and lower the overfitting effect, the sample was divided into a training (analysis) set and a test set in a ratio of 70:30, respectively. The cut-off point set for the estimated probabilities was 0.5, which is the value normally used (Fernandes et al., 2020; Hosmer & Lemeshow, 2000). Based on this grading, model evaluation measures were calculated, such as: accuracy, sensitivity, specificity, false positive rate, true positive predictive value (precision), true negative predictive value, and F-measure (F1) (Altman & Bland, 1994a, 1994b; Fawcett, 2006).

We also used the area under the curve (AUC) of the ROC (Receiver Operating Characteristic) curve to evaluate the model's prediction. The AUC estimates the model's ability to differentiate between cases marked by the dependent variable or not, with the interpretation rule being (Hosmer & Lemeshow, 2000): i) AUC = 0.5: no discrimination; ii) 0.5 < AUC < 0.7: poor; iii) 0.7 ≤ AUC < 0.8: reasonable; iv) 0.8 ≤ AUC < 0.9: excellent; v) AUC ≥ 0.9: exceptional.

Innovation and Regional Resilience in Brazilian Municipalities

Examining the innovation–regional resilience relationship

Of the municipalities sampled, 38 were classified as resilient and 63 as non-resilient. An imbalance can produce a classification bias in the logistic regression towards the most ordinary class. However, the resilience of the studied municipalities is not a rare event, in which case there would be a difference of tens or thousands of times between the binary classes (see King & Zeng, 2001). Thus, we did not need to use bias correction methods. The potential sources of resilience should then be addressed.

Table 1 shows descriptive statistics for the quantitative variables. The low percentage of exporting companies based in the municipalities demonstrates the potential to be explored. These exporting companies are mostly located in the Brazilian Southeast and South Regions, with nine of the top ten municipalities not being state capitals. As for the results or impacts of innovation, patents and employment in S&T showed positive asymmetry (on the right), with a gathering of regions sampled at the lowest levels determined in these variables.

Table 1

Descriptive statistics of quantitative variables

Variables	Minimum	Average	Median	Maximum	St. deviation	Asymmetry	Kurtosis
ipr	21.56	99.10	95.76	222.34	43.36	0.71	0.25
kia	2.41%	7.36%	5.81%	25.76%	4.40%	1.64	2.90
pat	0.38	5.70	5.18	29.74	4.18	2.43	10.59
hcp1	23.55%	54.95%	55.07%	69.59%	8.27%	-0.73	1.41
hcp2	-1.22	0.15	0.17	1.55	0.50	-0.26	0.78
hcp3	0.00%	21.17%	18.10%	72.07%	14.96%	0.89	0.80
exp	-3.04	-0.58	-0.47	1.54	1.03	-0.26	-0.58
port	5.00	200.71	70.00	1,142.00	270.27	1.83	2.72
inf1	0.02	1.93	1.78	4.34	0.88	0.18	-0.60
trib	24.11	106.41	108.31	171.96	31.39	0.11	-0.62
gdp1	-8.23%	-0.39%	-0.47%	14.31%	2.85%	1.49	7.48
gdp2	9.42	10.42	10.40	11.61	0.49	0.07	-0.45
hhi	0.11	0.16	0.15	0.31	0.04	1.67	3.14

Source: prepared by the authors. Note: St. deviation = standard deviation.

The correlations (Table 2) and boxplots are also presented, with the data separated according to the classes of the dependent variable (Figure A1). We found Pearson's correlations between -0.37 and 0.69, suggesting no multicollinearity between the possible determinants of resilience (see Tabachnick & Fidell, 2013). The boxplots showed overlapping classes for some variables (e.g., *gdp1*, *exp*, *pat*, *kia*), indicating that these variables add little to the logistic regression model. The exploratory analysis also suggests that the more socio-economically developed municipalities and those with a higher tax burden were less resilient to the shock and that innovation did not function as a variable to distinguish classes.

Table 2

Correlation matrix of quantitative variables

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	*ipr*	1												
2	*kia*	0.26	1											
3	*pat*	0.37	0.26	1										
4	*hcp1*	0.50	0.18	0.23	1									
5	*hcp2*	0.16	0.05	0.30	0.35	1								
6	*hcp3*	0.42	0.15	0.37	0.35	0.42	1							
7	*exp*	0.42	0.62	0.14	0.24	-0.05	0.07	1						
8	*port*	-0.06	-0.20	-0.16	0.06	-0.22	-0.03	-0.18	1					
9	*inf1*	0.69	0.17	0.35	0.63	0.28	0.53	0.23	-0.01	1				
10	*trib*	-0.29	-0.07	0.20	-0.21	0.00	0.10	-0.21	0.15	-0.20	1			
11	*gdp1*	-0.05	0.01	0.01	0.06	-0.03	0.05	0.02	0.11	0.11	0.14	1		
12	*gdp2*	0.63	0.52	0.26	0.58	0.36	0.41	0.42	0.06	0.64	-0.26	0.17	1	
13	*hhi*	-0.33	0.21	-0.11	-0.23	-0.32	-0.22	0.15	0.12	-0.37	0.18	0.02	-0.21	1

Source: prepared by the authors.

Regarding the logistic regression analysis, we present the calculated univariate models in the Appendix (Table A1). The 0.25 p-value limit was used as a cutoff, so the variables *gdp1* and *kia* were excluded from the modeling (see Bendel & Afifi, 1977). It should be noted we expected these variables to add little, according to the descriptive analysis performed. Table 3 shows the forced entry model with the variables kept in the analysis. The change in the amount of information clarified by the model (compared to the null model) is significant: $\chi^2(12) = 42,39$ ($p < 0,0001$). When analyzing the pseudo R^2 measures, the results suggest that the model would account for 31.6% to 46.7% of the variation in resilience prediction. However, when assessing the coefficients' statistical significance, p-values > 0.05 were obtained. The only significant predictors were *port* and *trib*, with positive relationships. We therefore sought a thriftier model.

Table 3

Estimation of logistic regression (model 1)

Variables	Coefficient	Standard error	2.5% (CI)	Odds ratio	97.5% (CI)
(Intercept)	-0.961	8.746	0.000	0.382	1.5E+07
ipr	-0.004	0.011	0.973	0.996	1.018
pat	0.019	0.068	0.884	1.019	1.172
hcp1	-0.064	0.045	0.853	0.938	1.021
hcp2	-0.343	0.691	0.173	0.710	2.702
hcp3	0.011	0.023	0.964	1.011	1.058
exp	0.026	0.320	0.547	1.027	1.948
port	0.003**	0.001	1.001	1.003	1.006
inf1	-0.588	0.548	0.179	0.556	1.575
inf2sim	-1.036	0.858	0.056	0.355	1.760
trib	0.021**	0.010	1.002	1.022	1.044
gdp2	0.168	0.889	0.200	1.182	6.954
hhi	3.597	8.033	0.000	36.502	6.8E+08

Measures of the model's quality of fit

-2LL null	-2LL model	Pseudo R^2	R^2 Cox & Snell	R^2 Nagelkerke	AIC
133.76	91.38	0.31	0.34	0.46	117.38

Source: prepared by the authors. Note: *p < 0.1; ** p < 0.05; *** p < 0.01; CI = confidence interval.

The final model encompassed the intercept and four predictors (Table 4): *inf1*, *inf2*, *trib*, and *port*. The coefficients and odds ratio suggest that the first two variables are negatively associated with resilience, while the others have a positive association. Thus, the lower the ICMS tax burden (inverse transformation, as shown in Figure 1), the more likely a region is to have been more resilient than the country as a whole. Moreover, the nearer a region is to ports, the larger the number of fast internet access points *per capita*, or due to the presence of technology parks, the more likely it is to have shown lower relative resilience. The confidence intervals (CIs) support the results for *inf1*, *port*, and *trib*. However, the CI for *inf2* ranged from -1 to +1, suggesting that the relationship between this variable and economic resilience may be positive or negative when considering other regions. For point estimates, the model shows some significance for these coefficients. However, for interval estimation, there are caveats for the *inf2* variable.

Table 4

Estimation of logistic regression (model 2)

Variables	Coefficient	Standard error	2.5% (CI)	Odds ratio	97.5% (CI)
(Intercept)	-2.035*	1.182	0.012	0.131	1.250
Port	0.003**	0.001	1.001	1.003	1.006
inf1	-0.874**	0.351	0.201	0.417	0.804
inf2sim	-1.320*	0.774	0.049	0.267	1.105
Trib	0.025***	0.009	1.009	1.026	1.046

Measures of the model's quality of fit

-2LL Null	-2LL model	Pseudo R^2	R^2 Cox & Snell	R^2 Nagelkerke	AIC
133.76	94.86	0.29	0.32	0.43	104.86

Source: prepared by the authors. Note: *p < 0.1; ** p < 0.05; *** p < 0.01; CI = confidence interval.

It should be noted that this model meets the logistic regression assumptions. Cook's distance suggests that there are no outliers (Figure A2). Five potential points of influence were determined, whose studentized residuals were more or less than 2. However, this amount is less than 5%, which is considered reasonable (Field et al., 2012). Secondly, the result of the Durbin-Watson test was 2.27 (p-value = 0.23), implying no autocorrelation between residuals and independence of errors. Thirdly, we see no multicollinearity, with the predictors showing VIF < 2, average VIF of 1.12, and tolerance higher than 0.8. Fourthly, the linearity assumption was met, with a non-significant ($p > 0.05$) interaction term between predictors and the respective logarithmic changes, as Table A2 shows.

As for the model's predictive capacity, Table 5 presents the confusion matrix. Considering the test sample, the level of accuracy was 83.3%, with 25 of the 30 regions classified correctly. Regarding the predictions for non-resilient regions, 17 were classified correctly and three incorrectly, i.e., a true negative predictive rate of 85%. For the resilient group, there were eight correct gradings and two wrong ones, i.e., an accuracy of 80%. An F1 score of 76.2% was also obtained, a measure estimated from sensitivity and precision.

Table 5

Confusion matrix

	Actual			
	Analysis sample		Test sample	
Predicted	Resilient	Non-resilient	Resilient	Non-resilient
Resilient	17	5	8	2
Non-resilient	10	39	3	17

Source: prepared by the authors. Note: test model measures (analysis): accuracy = 0.83 (0.79); sensitivity = 0.73 (0.63); specificity = 0.89 (0.89); false positive rate = 0.11 (0.11); true positive predictive = 0.8 (0.77); true negative predictive = 0.85 (0.80); F1 score = 0.76 (0.69).

Still, regarding prediction performance, the ROC Curve for the test sample shows an AUC of 0.847 (Figure A3), pointing out the model's excellent discriminatory capacity (see Hosmer & Lemeshow, 2000).

Particulars of an emerging economy?

An evolutionary perspective suggests a positive relationship between pre-crisis innovation and regional economic resilience (Bristow & Healy, 2018). This idea has been confirmed by different studies addressing the 2008–2010 crisis in European or Chinese regions (e.g. Filippetti et al., 2020; Li et al., 2019; Wang & Li, 2022), or the COVID-19 crisis (Hu et al., 2022). However, the results presented here do not support this understanding. The regressions with just one predictor for the proxies patents, employment in S&T, and intellectual property were non-significant for the first two and negatively significant for the last one. However, when considering the saturated model, we found no significant coefficients for innovation. Consequently, none of these proxies remained in the final, thriftier model.

Thus, we could not corroborate innovation as a determinant of resilience in Brazil's most populous regions facing the COVID-19 crisis, with insufficient evidence to support H1. This finding is consistent with Calignano e De Siena's (2020) research on the 2008–2010 crisis in regions of Italy, seen as a moderate innovator country by EU standards. This paper is also in line with the results of Tuysuz et al. (2022) on regions in Turkey, and with Chernova and Gridnev (2023) on regions in Russia, which addressed the effects of the COVID-19 pandemic. In such context, this study adds by ascertaining this relationship in the most populous regions of an emerging economy that is not regarded as a leader in global innovation rankings. Thus, we question pre-shock innovation based on the listed proxies as a sufficient determinant for regional resilience.

Furthermore, the non-significant associations for human capital do not support H2, in contrast to previous studies on the 2008-2010 crisis (e.g., Crescenzi et al., 2016; Giannakis & Bruggeman, 2017) or the COVID-19 pandemic (e.g., Sargento & Lopes, 2023). The level of human capital has been frequently suggested as a key determinant of economic resistance and recovery while facing a shock (see Miranda & Hoffmann, 2021; Sutton et al., 2023; Viana et al., 2023 for reviews). However, Viana et al. (2023) emphasized that the use of different variables can lead to distinct results when addressing the relationship between innovation (or the capacity to innovate) and regional resilience, which may help to explain the non-significant relationships obtained in this study. In addition, it is worth noting that Sargento and Lopes (2023) found a significant relationship between human capital and economic resistance (at a 10% significance level) but not between this predictor and economic recovery, which suggests a more in-depth study of this relationship regarding different types of shocks and dimensions of regional resilience.

Regarding the relationship between regions and foreign markets, this study showed that the further away from ports, the higher the likelihood of economic resilience to the effects of COVID-19, which supports H3b. While trade transactions with other countries provide access to new markets and resources (Bathelt et al., 2013; Walther et al., 2011), greater dependence on exports can also increase a region's vulnerability (Diodato & Weterings, 2015; Du et al., 2019; Eraydin, 2016a; Martin et al., 2016; Martin & Gardiner, 2019). In this context, it should be noted that the crisis resulting from the COVID-19 pandemic has suddenly impacted supply chains, causing the retention of containers and a decrease in sea transport activities (Notteboom et al., 2021), with a resulting decrease in imports and exports (Xu et al., 2021). Thus, the findings of this paper confirm previous research and highlight the particulars of the examined shock, which had a greater impact on the more globally connected regions (see Hu et al., 2022; Sargento & Lopes, 2023; Tuysuz et al., 2022). As such, this study adds by considering the proximity of ports, while the studies by Hu et al. (2022), Sargento and Lopes (2023), and Tuysuz et al. (2022) focused on export or import levels.

Moreover, technological infrastructure was negatively related to resilience, thus refuting H4. In addition to the results of the models with just one predictor and the exploratory analysis, the results suggest that the more socioeconomically developed regions were more impacted by the crisis. It is known that the presence of ICT infrastructure *per se* may not yield technological advantages (van Aswegen & Retief, 2020). The findings of the present paper add to this understanding, demonstrating that ICT infrastructure alone does not predict economic resilience either. Concerning technology parks, while the point estimate showed significance, the interval estimate encompassed both negative and positive association results. This suggests that the behavior of this variable may differ when considering other regions, which could be analyzed in other studies. This caveat is supported by examples in the regional resilience literature of technology parks as a means of seeking adaptation or structural change (e.g. David, 2018; Simmie & Martin, 2010).

On the other hand, we found a positive association between a lower tax burden and resilience. Examples of other determinants of resilience related to financial arrangements are tax incentives (Davies, 2011), fiscal austerity (Bell & Eiser, 2016), opening up credit to specific sectors (Hoffmann et al., 2017), and public financing funds (Arbolino & Di Caro, 2021). In the case of negative effects resulting from the COVID-19 pandemic, one form of reaction was to postpone collecting interest or taxes so that financial resources could be channeled to measures to mitigate the shock's impacts (see Gong et al., 2020). In this context, the results of this study showed that municipalities with a lower tax burden on GDP also had a higher likelihood of regional resilience. Furthermore, we highlight the proxy used is at the state level, which is broader than that of municipalities.

Conclusion

This study assessed the relationship between innovation and regional economic resilience. In addition, we tested other variables relating to the capacity to innovate, with control for economic structure, economic growth and development, and tax burden. The rationale of this analysis was the interest of public managers and researchers in why some regions resist or recover more quickly than others. To operate it, data on the 101 most populous municipalities in Brazil was examined using descriptive statistics and binary logistic regression.

The empirical exploration showed that in Brazil's most populous municipalities, pre-shock innovation did not function as a determinant of regional resilience, considering the negative economic effects of the COVID-19 pandemic. This result implies that the capacity to innovate is not a sufficient condition for regional resilience in the short term, especially considering the resistance dimension. By addressing this relationship, this research sheds light on the context of an emerging country that is not a leader in global innovation rankings and on the particulars of a pandemic shock.

As a result of the findings, we sought practical recommendations. The first is to strengthen regional innovation capacities—which, if underdeveloped, do not seem to increase the likelihood of resilience in the short term. Moreover, the consolidation of the government's public data can foster scientific research and analyses that produce information for managerial decision-making. This availability will allow addressing the sources of regional resilience in a predictive and not just descriptive way. In addition, the association between a lower tax burden and regional resilience can inform debates on taxation and the use of public resources in the country.

Finally, it is worth highlighting the limits of this study. Firstly, due to access to systematized data, we considered the 101 most populous Brazilian municipalities. Given that urban regions, rural regions, and former industrial regions have different levels of resilience to economic shocks (Ženka et al., 2019), future studies could expand the sample, or consider regions in other emerging economies. Secondly, there is a suggestion that the relationship between innovation and regional resilience should come with a warning about the variables used since different results were found depending on the operationalization and context (Viana et al., 2023). In this case, the relationship may also be reviewed using other proxies.

Thirdly, due to the time frame considered, we did not separate the result of regional resilience into performance-related dimensions. Thus, we recommend future studies that analyze the relationship between innovation and regional resilience, taking into account economic resistance and recovery. Fourthly, the actions taken to combat COVID-19 spreading enabled some sectors to continue trading, while others had to halt their activities. Sector-specific variables can shed light on these relationships. Moreover, other databases could be used to search for models with a greater capacity to explain variations in regional resilience. Fifth, despite the association between a lower tax burden and regional resilience, the relationship between the variables needs to be further explored. Finally, this research did not delve into regional dynamics during the shock. An open issue refers to innovation as a response to crises, as a means of subverting existing practices and shaping more resilient regions.

AUTHORS' CONTRIBUTIONS

Contribution	Viana, L. F. C.	Hoffmann, V. E.	Pinto, H.
Conceptualization	X	–	–
Methodology	X	–	–
Software	X	–	–
Validation	X	–	–
Formal analysis	X	–	–
Investigation	X	–	–
Resources	X	X	X
Data curation	X	X	X
Writing – original draft	X	–	–
Writing – review & editing	X	X	X
Visualization	X	X	X
Supervision	–	X	X
Project administration	X	X	X
Funding acquisition	X	X	–

References

Altman, D. G., & Bland, J. M. (1994a). Statistics notes: diagnostic tests 1: sensitivity and specificity. *British Medical Journal*, *308*(6943), 1552. https://doi.org/10.1136/bmj.308.6943.1552

Altman, D. G., & Bland, J. M. (1994b). Statistics notes: diagnostic tests 2: predictive values. *British Medical Journal*, *309*(6947), 102. https://doi.org/10.1136/bmj.309.6947.102

Arancegui, M. N., Martíns, J. J. G., Rodríguez, S. F., & Alonso, A. M. (2012). Territorial benchmarking methodology: the need to identify reference regions. In P. Cooke, M. D. Parrilli, & J. L. Curbelo (Eds.), *Innovation, global change and territorial resilience*. Edward Elgar Publishing.

Arbolino, R., & Di Caro, P. (2021). Can the EU funds promote regional resilience at time of Covid-19? Insights from the Great Recession. *Journal of Policy Modeling*, *43*(1), 109–126. https://doi.org/10.1016/j.jpolmod.2020.10.001

Archibugi, D., & Filippetti, A. (2011). Is the economic crisis impairing convergence in innovation performance across Europe? *Journal of Common Market Studies*, *49*(6), 1153–1182. https://doi.org/10.1111/j.1468-5965.2011.02191.x

Barnier, J., Briatte, F., & Larmarange, J. (2022). *questionr: functions to make surveys processing easier*. https://cran.r-project.org/package=questionr

Bathelt, H., Munro, A. K., & Spigel, B. (2013). Challenges of transformation: innovation, re-bundling and traditional manufacturing in Canada's Technology Triangle. *Regional Studies*, *47*(7), 1111–1130. https://doi.org/10.1080/00343404.2011.602058

Bell, D. N. F., & Eiser, D. (2016). Migration and fiscal policy as factors explaining the labour-market resilience of UK regions to the Great Recession. *Cambridge Journal of Regions,* *Economy and Society*, *9*(1), 197–215. https://doi.org/10.1093/cjres/rsv029

Bendel, R. B., & Afifi, A. A. (1977). Comparison of stopping rules in forward "stepwise" regression. *Journal of the American Statistical Association*, *72*(357), 46–53. https://doi.org/10.2307/2286904

Brasil. Ministério da Economia. (2022). *Novo CAGED*. http://pdet.mte.gov.br/novo-caged

Brasil. Ministério da Economia. (2023). *Relação Anual de Informações Sociais (RAIS)*. https://bi.mte.gov.br/bgcaged

Bristow, G., & Healy, A. (2018). Innovation and regional economic resilience: an exploratory analysis. *The Annals of Regional Science*, *60*(2), 265–284. https://doi.org/10.1007/s00168-017-0841-6

Caballini, C., Ghiara, H., & Persico, L. (2022). Analysis of the impacts of COVID-19 on selected categories of goods passing through the ports of Genoa and Savona, Italy. *Case Studies on Transport Policy*, *10*(2), 851–869. https://doi.org/10.1016/j.cstp.2022.03.002

Calignano, G., & De Siena, L. (2020). Does innovation drive economic resistance? Not in Italy, at least! *Rivista Geografica Italiana*, *3*, 31–49. https://doi.org/10.3280/RGI2020-003002

Cefis, E., Bartoloni, E., & Bonati, M. (2020). Show me how to live: firms' financial conditions and innovation during the crisis. *Structural Change and Economic Dynamics*, *52*, 63–81. https://doi.org/10.1016/j.strueco.2019.10.001

Chernova, O. A., & Gridnev, D. S. (2023). Resilience of Russian regions in the face of COVID-19. *Regional Statistics*, *13*(1), 76–93. https://doi.org/10.15196/RS130104

Christopherson, S., Michie, J., & Tyler, P. (2010). Regional resilience: theoretical and empirical perspectives. *Cambridge Journal of Regions, Economy and Society*, *3*(1), 3–10. https://doi.org/10.1093/cjres/rsq004

Clark, J., Huang, H.-I., & Walsh, J. P. (2010). A typology of "innovation districts": what it means for regional resilience. *Cambridge Journal of Regions, Economy and Society*, *3*(1), 121–137. https://doi.org/10.1093/cjres/rsp034

Crescenzi, R., Luca, D., & Milio, S. (2016). The geography of the economic crisis in Europe: National macroeconomic conditions, regional structural factors and short-term economic performance. *Cambridge Journal of Regions, Economy and Society*, *9*(1), 13–32. https://doi.org/10.1093/cjres/rsv031

David, L. (2018). Agency and resilience in the time of regional economic crisis. *European Planning Studies*, *26*(5), 1041–1059. https://doi.org/10.1080/09654313.2018.1448754

Davies, S. (2011). Regional resilience in the 2008-2010 downturn: comparative evidence from European countries. *Cambridge Journal of Regions, Economy and Society*, *4*(3), 369–382. https://doi.org/10.1093/cjres/rsr019

Davoudi, S. (2012). Resilience: a bridging concept or a dead end? *Planning Theory & Practice*, *13*(2), 299–333. https://doi.org/10.1080/14649357.2012.677124

Di Caro, P. (2017). Testing and explaining economic resilience with an application to Italian regions. *Papers in Regional Science*, *96*(1), 93–113. https://doi.org/10.1111/pirs.12168

Díez-Vial, I., & Montoro-Sánchez, Á. (2016). How knowledge links with universities may foster innovation: The case of a science park. *Technovation*, *50–51*, 41–52. https://doi.org/https://doi.org/10.1016/j.technovation.2015.09.001

Diodato, D., & Weterings, A. B. R. (2015). The resilience of regional labour markets to economic shocks: exploring the role of interactions among firms and workers. *Journal of Economic Geography*, *15*(4), 723–742. https://doi.org/10.1093/jeg/lbu030

Doran, J., & Fingleton, B. (2018). US Metropolitan Area Resilience: Insights from dynamic spatial panel estimation. *Environment and Planning A*, *50*(1), 111–132. https://doi.org/10.1177/0308518X17736067

Du, Z., Zhang, H., Ye, Y., Jin, L., & Xu, Q. (2019). Urban shrinkage and growth: measurement and determinants of economic resilience in the Pearl River Delta. *Journal of Geographical Sciences*, *29*(8), 1331–1345. https://doi.org/10.1007/s11442-019-1662-6

Duschl, M. (2016). Firm dynamics and regional resilience: an empirical evolutionary perspective. *Industrial and Corporate Change*, *25*(5), 867–883. https://doi.org/10.1093/icc/dtw031

Enap. (2022). *Índice de cidades empreendedoras: Dados abertos*. https://ice.enap.gov.br/opendata

Eraydin, A. (2016a). Attributes and characteristics of regional resilience: defining and measuring the resilience of Turkish regions. *Regional Studies*, *50*(4), 600–614. https://doi.org/10.1080/00343404.2015.1034672

Eraydin, A. (2016b). The role of regional policies along with the external and endogenous factors in the resilience of regions. *Cambridge Journal of Regions*, *Economy and Society*, *9*(1), 217–234. https://doi.org/10.1093/cjres/rsv026

Esteves, K., & Feldmann, P. R. (2016). Why Brazil does not innovate: a comparison among nations. *Revista de Administração e Inovação*, *13*(1), 29–38. https://doi.org/10.11606/rai.v13i1.110635

Evenhuis, E. (2017). New directions in researching regional economic resilience and adaptation. *Geography Compass*, *11*(11), e12333. https://doi.org/https://doi.org/10.1111/gec3.12333

Fawcett, T. (2006). An introduction to ROC analysis. *Pattern Recognition Letters*, *27*, 861–874. https://doi.org/10.1016/j.patrec.2005.10.010

Fernandes, A. A. T., Figueiredo Filho, D. B., Rocha, E. C. da, & Nascimento, W. da S. (2020). Read this paper if you want to learn logistic regression. *Revista de Sociologia e Política*, *28*(74), e006. https://doi.org/10.1590/1678-987320287406en

Ferrão, J., Pinto, H., Caldas, J. M. C., & Carmo, R. M. do. (2023). Vulnerabilidades territoriais, pandemia e emprego: Uma análise exploratória de perfis socioeconómicos municipais e impactos da COVID-19 em Portugal. *Revista Portuguesa de Estudos Regionais*, *63*, 161–182.

Field, Z., Field, A., Miles, J., & Field, Z. (2012). *Discovering statistics using R*. SAGE Publications. https://doi.org/10.5860/choice.50-2114

Filippetti, A., Gkotsis, P., Vezzani, A., & Zinilli, A. (2020). Are innovative regions more resilient? Evidence from Europe in 2008–2016. *Economia Politica*, *37*(3), 807–832. https://doi.org/10.1007/s40888-020-00195-4

Fox, J. (2016). *Applied regression analysis and generalized linear models* (3rd ed.). Sage Publications.

Fox, J., & Weisberg, S. (2019). *An {R} companion to applied regression* (3rd ed.). SAGE Publications.

Fröhlich, K., & Hassink, R. (2018). Regional resilience: a stretched concept?*. *European Planning Studies*, *26*(9), 1763–1778. https://doi.org/10.1080/09654313.2018.1494137

Giannakis, E., & Bruggeman, A. (2017). Determinants of regional resilience to economic crisis: a European perspective. *European Planning Studies*, *25*(8), 1394–1415. https://doi.org/10.1080/09654313.2017.1319464

Gong, H., Hassink, R., Tan, J., & Huang, D. (2020). Regional resilience in times of a pandemic crisis: the Case of COVID-19 in China. *Tijdschrift Voor Economische En Sociale Geografie*, *111*(3), 497–512. https://doi.org/10.1111/tesg.12447

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2018). *Multivariate data analysis* (8th ed.). Cengage Learning. https://doi.org/10.1002/9781119409137.ch4

Holl, A., & Rama, R. (2016). Persistence of innovative activities in times of crisis: the case of the Basque Country. *European Planning Studies*, *24*(10), 1863–1883.

https://doi.org/10.1080/09654313.2016.1204426

Hosmer, D. W., & Lemeshow, S. (2000). *Applied logistic regression* (2nd ed.). John Wiley & Sons.

Hu, X., Li, L., & Dong, K. (2022). What matters for regional economic resilience amid COVID-19? Evidence from cities in Northeast China. *Cities*, *120*, 103440. https://doi.org/10.1016/j.cities.2021.103440

IBGE – Instituto Brasileiro de Geografia e Estatística. (2022). *População: Estimativas da popuçação*. https://www.ibge.gov.br/estatisticas/sociais/populacao.html

Kahn, K. B. (2018). Understanding innovation. *Business Horizons*, *61*(3), 453–460. https://doi.org/10.1016/j.bushor.2018.01.011

King, G., & Zeng, L. (2001). Logistic regression in rare events data. *Political Analysis*, *9*(2), 137–163. https://doi.org/10.1093/oxfordjournals.pan.a004868

Lagravinese, R. (2015). Economic crisis and rising gaps North-South: Evidence from the Italian regions. *Cambridge Journal of Regions, Economy and Society*, *8*(2), 331–342. https://doi.org/10.1093/cjres/rsv006

Lele, S. R., Keim, J. L., & Solymos, P. (2019). *ResourceSelection: resource selection (probability) functions for use-availability data*. https://cran.r-project.org/package=ResourceSelection

Li, L., Zhang, P., & Li, X. (2019). Regional economic resilience of the old industrial bases in China - a case study of Liaoning Province. *Sustainability*, *11*(3), 723. https://doi.org/10.3390/su11030723

Martin, R. (2012). Regional economic resilience, hysteresis and recessionary shocks. *Journal of Economic Geography*, *12*(1), 1–32. https://doi.org/10.1093/jeg/lbr019

Martin, R., & Gardiner, B. (2019). The resilience of cities to economic shocks: a tale of four recessions (and the challenge of Brexit). *Papers in Regional Science*, *98*(4), 1801–1832. https://doi.org/10.1111/pirs.12430

Martin, R., & Sunley, P. (2015). On the notion of regional economic resilience: conceptualization and explanation. *Journal of Economic Geography*, *15*(1), 1–42. https://doi.org/10.1093/jeg/lbu015

Martin, R., & Sunley, P. (2020). Regional economic resilience: evolution and evaluation. In G. Bristow & A. Healy (Eds.), *Handbook on regional economic resilience* (pp. 10–35). Edward Elgar Publishing.

Martin, R., Sunley, P., Gardiner, B., & Tyler, P. (2016). How regions react to recessions: resilience and the role of economic structure. *Regional Studies*, *50*(4), 561–585. https://doi.org/10.1080/00343404.2015.1136410

Miranda, N. da S. J., & Hoffmann, V. E. (2021). Regional resilience: a bibliometric study from the Web of Science. *Gestão & Regionalidade*, *37*(111), 23–41. https://doi.org/10.13037/gr.vol37n111.6093

Miranda, N. da S. J., Hoffmann, V. E., & Filgueiras, R. C. (2023). How does a region react to different types of shocks? The case of a Brazilian T&C industrial region. *Innovation and Management Review*, *20*(2), 103–118. https://doi.org/10.1108/INMR-11-2021-0214

Miranda, N. da S. J., Viana, L. F. C., Carneiro, D. K. de O., Filgueiras, R. C., & Goulart, G. da S. (2022). Initial actions of the Brazilian regional innovation ecosystem against the COVID-19 pandemic. *International Journal of Innovation*, *10*(2), 291–318. https://doi.org/10.5585/iji.10i2.21576

Muštra, V., Šimundić, B., & Kuliš, Z. (2020). Does innovation matter for regional labour resilience? The case of EU regions. *Regional Science Policy and Practice*, *12*(5), 949–964. https://doi.org/10.1111/rsp3.12348

Nelson, R. R., & Winter, S. G. (1982). *An evolutionary theory of economic change*. The Belknap Press of Harvard University Press. https://doi.org/10.2307/2232409

Nemlioglu, I., & Mallick, S. (2021). Effective innovation via better management of firms: The role of leverage in times of crisis. *Research Policy*, *50*(7), 104259. https://doi.org/10.1016/j.respol.2021.104259

Notteboom, T., Pallis, T., & Rodrigue, J. P. (2021). Disruptions and resilience in global container shipping and ports: the COVID-19 pandemic versus the 2008–2009 financial crisis. *Maritime Economics and Logistics*, *23*, 179–210. https://doi.org/10.1057/s41278-020-00180-5

OECD. (2018). *Oslo Manual 2018: guidelines for collecting, reporting and using data on innovation* (4th ed.). OECD Publishing. https://doi.org/10.1787/9789264304604-en

ONU. (2015). *Agenda 2030*. Organização das Nações Unidas (ONU). https://nacoesunidas.org/pos2015/agenda2030/

Pinto, H., & Guerreiro, A. (2019). Resilience, innovation, and knowledge transfer. In *The Role of Knowledge Transfer in Open Innovation* (pp. 281–299). IGI Global. https://doi.org/10.4018/978-1-5225-5849-1.ch014

Pinto, H., Healy, A., & Cruz, A. R. (2019). Varieties of capitalism and resilience clusters: An exploratory approach to European regions. *Regional Science Policy & Practice*, *11*(6), 913–933. https://doi.org/https://doi.org/10.1111/rsp3.12183

R Core Team. (2021). *R: a language and environment for statistical computing*. https://www.r-project.org/

Revelle, W. (2021). *psych: procedures for psychological, psychometric, and personality research*. https://cran.r-project.org/package=psych

Rios, V., & Gianmoena, L. (2020). The link between quality of government and regional resilience in Europe. *Journal of Policy Modeling*, *42*(5), 1064–1084. https://doi.org/10.1016/j.jpolmod.2020.02.005

Rizzi, P., Graziano, P., & Dallara, A. (2018). A capacity approach to territorial resilience: the case of European regions. *Annals of Regional Science*, *60*(2), 285–328. https://doi.org/10.1007/s00168-017-0854-1

Robin, X., Turck, N., Hainard, A., Tiberti, N., Lisacek, F., Sanchez, J.-C., & Müller, M. (2011). pROC: an open-source package for R and S+ to analyze and compare ROC curves. *BMC Bioinformatics*, *12*, 77.

Romão, J. (2020). Tourism, smart specialisation, growth, and resilience. *Annals of Tourism Research*, *84*(June), 102995. https://doi.org/10.1016/j.annals.2020.102995

RStudio Team. (2022). *RStudio: Integrated Development Environment for R*. http://www.rstudio.com/

Ryu, C. (2022). *dlookr: Tools for Data Diagnosis, Exploration, Transformation*. https://cran.r-project.org/package=dlookr

Sargento, A., & Lopes, A. S. (2023). Territorial resilience on the aftermaths of COVID-19 crisis—An exploratory analysis on the role of innovation. *Regional Science Policy & Practice*. https://doi.org/10.1111/rsp3.12697

Schumpeter, J. A. (1934). The fundamental phenomenon of economic development. In *The theory of economic development* (2nd ed.). Harvard University Press.

Sensier, M., Bristow, G., & Healy, A. (2016). Measuring regional economic resilience across Europe: operationalizing a complex concept. *Spatial Economic Analysis*, *11*(2), 128–151. https://doi.org/10.1080/17421772.2016.1129435

Simmie, J. (2014). Regional economic resilience: a Schumpeterian perspective. *Raumforschung Und Raumordnung*, *72*(2), 103–116. https://doi.org/10.1007/s13147-014-0274-y

Simmie, J., & Martin, R. (2010). The economic resilience of regions: Towards an evolutionary approach. *Cambridge Journal of Regions, Economy and Society*, *3*(1), 27–43. https://doi.org/10.1093/cjres/rsp029

Stognief, N., Walk, P., Schöttker, O., & Oei, P.-Y. (2019). Economic resilience of German lignite regions in transition. *Sustainability*, *11*(21), 5991. https://doi.org/10.3390/su11215991

Sunley, P. (2013). Innovation, global change and territorial resilience. *Regional Studies*, *47*(4), 644–645. https://doi.org/10.1080/00343404.2013.781754

Sutton, J., Arcidiacono, A., Torrisi, G., & Arku, R. N. (2023). Regional economic resilience: A scoping review. *Progress in Human Geography*, *47*(4), 500–532. https://doi.org/10.1177/03091325231174183

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Pearson.

Tupy, I. S., Silva, F. F., Amaral, P. V. M., & Cavalcante, A. T. M. (2021). The spatial features of recent crises in a developing country: analysing regional economic resilience for the Brazilian case. *Regional Studies*, *55*(4), 693–706. https://doi.org/10.1080/00343404.2020.1851025

Tuysuz, S., Baycan, T., & Altuğ, F. (2022). Economic impact of the COVID-19 outbreak in Turkey: Analysis of vulnerability and resilience of regions and diversely affected economic sectors. *Asia-Pacific Journal of Regional Science*, *6*(3), 1133–1158. https://doi.org/10.1007/s41685-022-00255-6

van Aswegen, M., & Retief, F. P. (2020). The role of innovation and knowledge networks as a policy mechanism towards more resilient peripheral regions. *Land Use Policy*, *90*, 104259. https://doi.org/10.1016/j.landusepol.2019.104259

Viana, L. F. C., Hoffmann, V. E., & Miranda, N. da S. J. (2023). Regional resilience and innovation: Paper profiles and research agenda. *Innovation & Management Review*, *20*(2), 119–131. https://doi.org/10.1108/INMR-11-2021-0225

Walther, O., Schulz, C., & Dörry, S. (2011). Specialised international financial centres and their crisis resilience: the case of Luxembourg. *Geographische Zeitschrift*, *99*(2–3), 123–142.

Wang, X., & Li, M. (2022). Determinants of regional economic resilience to economic crisis: Evidence from Chinese economies. *Sustainability*, *14*(2), 809. https://doi.org/10.3390/su14020809

Wenzel, M., Stanske, S., & Lieberman, M. B. (2020). Strategic responses to crisis. *Strategic Management Journal*, *42*(2), 16–27. https://doi.org/10.1002/smj.3161

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., … Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

Wolfe, D. A. (2010). The strategic management of core cities: path dependence and economic adjustment in resilient regions. *Cambridge Journal of Regions, Economy and Society*, *3*(1), 139–152. https://doi.org/10.1093/cjres/rsp032

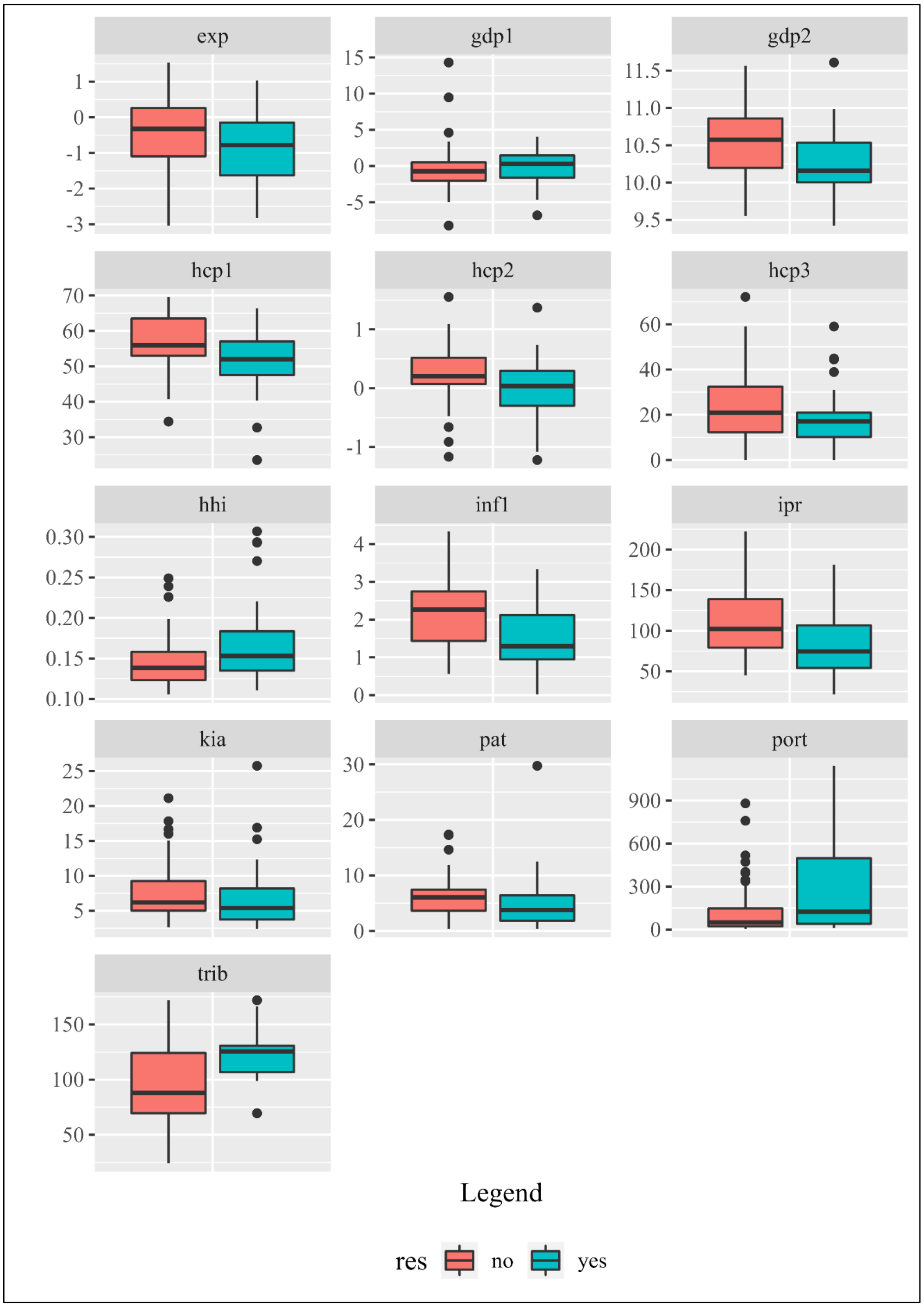
Xu, L., Yang, S., Chen, J., & Shi, J. (2021). The effect of COVID-19 pandemic on port performance: Evidence from China. *Ocean & Coastal Management*, *209*, 105660. https://doi.org/10.1016/j.ocecoaman.2021.105660

Ženka, J., Slach, O., & Pavlík, A. (2019). Economic resilience of metropolitan, old industrial, and rural regions in two subsequent recessionary shocks. *European Planning Studies*, *27*(11), 2288–2311. https://doi.org/10.1080/09654313.2019.1638346

APPENDIX

Figure A1

Boxplot of independent quantitative variables



Source: prepared by the authors

Table A1

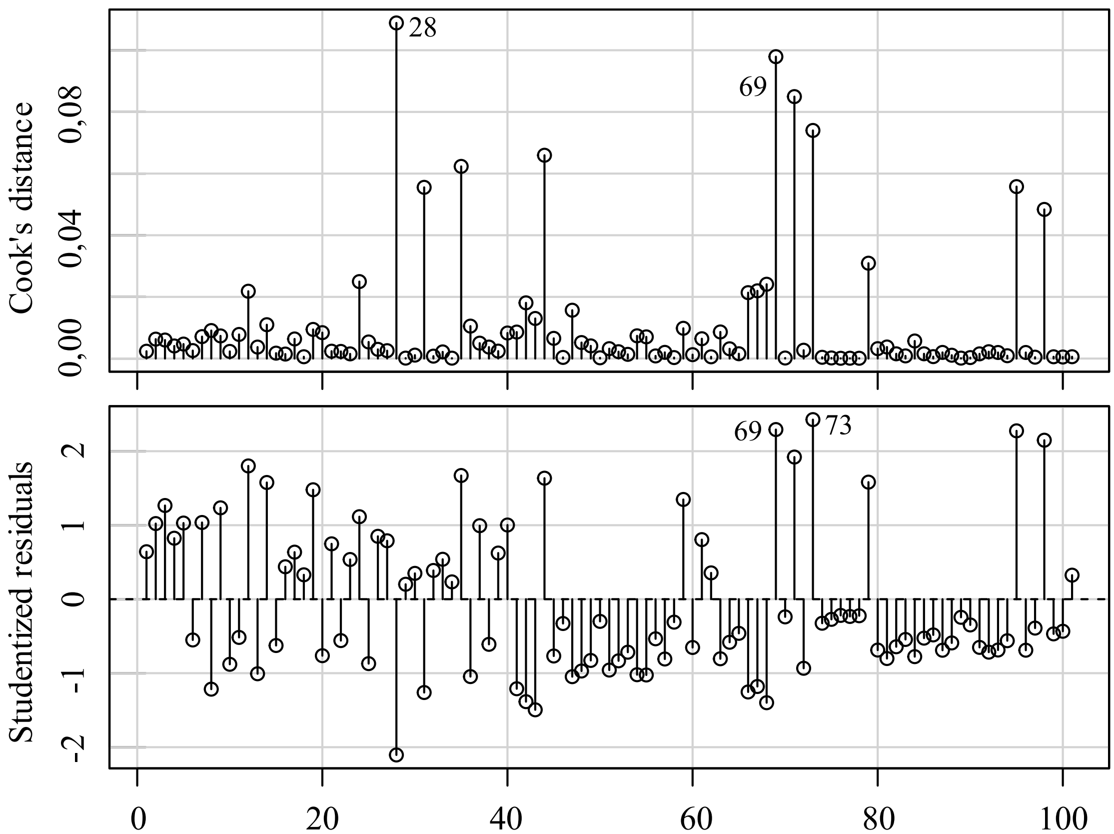
Univariate analyzes

Variable	Coefficient	Standard error	z-value	p-value
ipr	-0.020	0.006	-3,223	0.001
kia	-0.045	0.050	-0.910	0.363
pat	-0.082	0.060	-1.376	0.169
hcp1	-0.099	0.030	-3.227	0.001
hcp2	-1.103	0.454	-2.429	0.015
hcp3	-0.025	0.015	-1.651	0.099
exp	-0.348	0.206	-1.686	0.092
port	0.003	0.001	3.016	0.003
inf1	-1.013	0.286	-3.536	0.000
inf2sim	-1.540	0.663	-2.323	0.020
trib	0.027	0.008	3.438	0.001
gdp1	0.037	0.072	0.519	0.604
gdp2	-1.272	0.472	-2.696	0.007
hhi	15.101	5.672	2.662	0.008

Source: prepared by the authors.

Figure A2

Cook distance and studentized residuals



Source: prepared by the authors.

Table A2

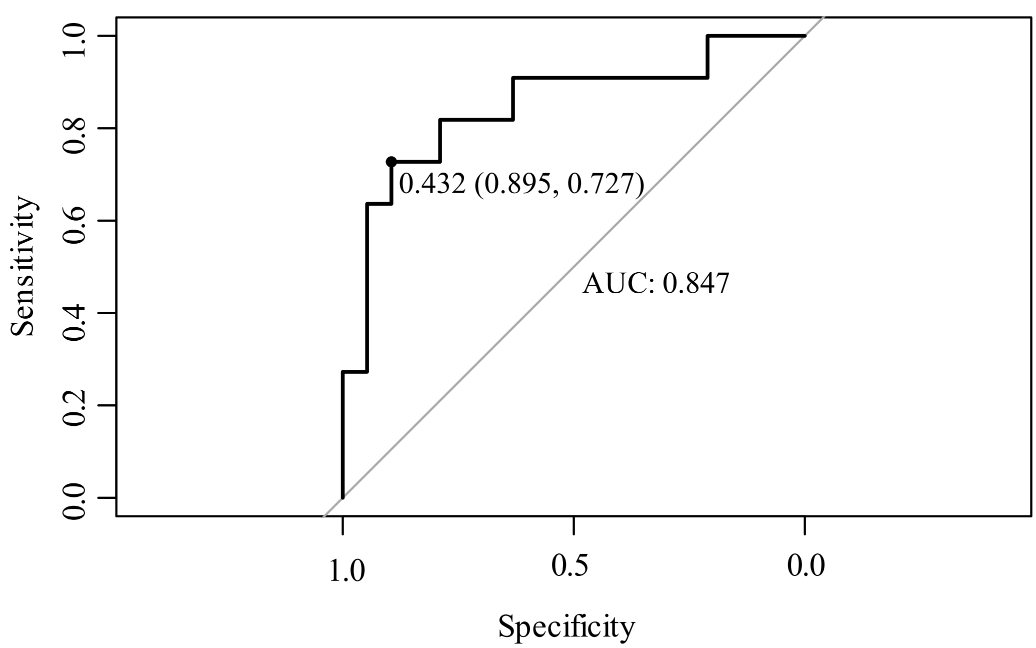
Estimation of logistic regression (model 3) to verify linearity

Variable	Coefficient	Standard error	z-value	p-value
(Intercept)	-5.977	7.542	-0.793	0.428
port	0.005	0.017	0.315	0.752
inf1	-2.871	2.119	-1.355	0.175
inf2sim	-1.212	0.785	-1.544	0.122
trib	0.351	0.371	0.947	0.343
port_int[1]	0.000	0.003	-0.139	0.889
inf1_int[1]	1.262	1.282	0.984	0.325
trib_int[1]	-0.057	0.065	-0.884	0.377

Source: prepared by the authors. Note: [1]interaction between the predictor and its respective log.

Figure A3

ROC curve



Source: prepared by the authors.