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The survival effects of non-R&D induced innovation during crisis

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A B S T R A C T

Using firm-level data from 41 countries, this study investigates how resource-constrained firms can strengthen their resilience to resist the COVID-19 crisis through non-R&D induced innovation. The empirical results show that firms in Middle- and Low-income countries, where access to government aid is often constrained, can enhance their survival prospects by internally upgrading their learning and adaptive capabilities. Specifically, non-R&D induced innovation can effectively substitute for insufficient government financial support by enabling firms to adjust operations and maintain competitiveness during the Covid-19 pandemic. The findings emphasise the importance of jointly considering government support and innovation in firm survival analyses, as omitting either factor may introduce potential omitted variable bias. To address this, supervised learning approaches are employed to predict whether firms that exited had received government support prior to closure. In addition, this study advances the literature by uncovering the complementary roles of innovation and government financial interventions, and highlights context-specific strategies that policymakers should adopt to improve firm resilience amid external shocks.

1. Introduction

Economic and financial crises have historically tested the resilience of firms, but the COVID-19 pandemic revealed vulnerabilities on an unprecedented scale and disrupted global business operations across all sectors. Traditional economic models often view government support as an effective response during a crisis if targeted fiscal and monetary interventions can help businesses steer through temporary shocks (Chetty et al., 2024). Nonetheless, the pandemic revealed significant constraints in their reach and effectiveness, particularly in Middle- and Low-income Countries (MLICs), where limited fiscal space and weaker institutional capacities hindered the timely and adequate provision of financial assistance (Devereux and Yu, 2020; Lane and Milesi-Ferretti, 2011). Firms in these countries tend to be particularly vulnerable to prolonged disruptions due to both internal and external financial constraints and the absence of comprehensive safety nets available in advanced economies. This raises a critical, yet underexplored question: how can firms enhance their survival prospects when conventional government intervention proves inadequate or unattainable?

Unlike conventional government intervention, innovation enhances firms' ability to adapt to crises by enabling them to reconfigure supply chains, optimize cost structures, and address shifted customer demands (Masso and Tiwari, 2024; Moilanen et al., 2014). Due to insufficient technological capability and budget constraints, non-R&D induced innovation, frequently associated with "doing, using, and interacting", is widely adopted as a primary source of innovation among firms in developing countries (Jensen et al., 2007; Santamaría et al., 2009). In contrast to firms engaged in formal R&D, non-R&D innovators face fewer financial burdens from long-term investments, allowing them to focus on practical, incremental solutions during crises. While the role of non-R&D induced innovation in enhancing innovation performance (Hervas-Oliver et al., 2011; Lee and Walsh, 2016), competitiveness (Battisti et al., 2022; Heidenreich, 2009) and productivity growth (Hou and Mohnen, 2013) is well-documented, its function as a crisis-response tool for improving firm resilience remains underexplored in the literature.

This study uses the COVID-19 pandemic as a unique lens to examine whether non-R&D induced innovation can serve as an effective survival mechanism for firms in MLICs, especially where internal R&D capabilities and external government interventions are limited (Chetty et al., 2024). Here, the non-R&D induced innovation refers to product or process innovations arising from non-R&D activities. For example, this includes innovations achieved by purchasing technology-embedded machinery, leveraging expertise from customers through standardized solutions, and disseminating experience-based knowledge via training and worker mobility. Rather than generalising to all external shocks and crises, this study treats the COVID-19 pandemic as a unique and exogenous disruption to explore internal adaptive capabilities under adverse

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conditions. Specifically, we intend to address the following key questions: can innovation substitute for government support in safeguarding firm survival, particularly for firms in MLICs with limited fiscal policy space? to what extent does non-R&D induced innovation affect the survival prospects of firms in MLICs that are disproportionately affected by the COVID-19 pandemic, and how do these effects vary across manufacturing and non-manufacturing sectors? do innovation-driven internal capabilities and external government interventions complement each other, strengthening firms' resilience?

To investigate these issues, this study draws on firm-level data from the World Bank Enterprise Survey (WBES), consisting of 41 countries across different income levels. A notable limitation in much of the existing COVID-19 firm survival literature is the use of static survival indicators that measure only whether a firm remains in operation at a given point in time. Such an approach typically ignores the dynamics of exit over time and the duration of survival (Muzi et al., 2023). To address this gap, the Cox Proportional Hazards (Cox PH) model is adopted to assess firms' hazard ratios as an evolving process. Another challenge frequently encountered in firm-level survival studies during the pandemic period is missing information on firms that exited the market, particularly regarding whether they had access to government support prior to closure (Chetty et al., 2024). Omitting key survival covariates could introduce bias if they are correlated with other explanatory variables. To mitigate this bias, supervised learning approaches are used to account for incomplete information on firms' access to government supports during the pandemic.

This study advances the theoretical understanding of crisis resilience by highlighting the previously underexplored role of non-R&D induced innovation. While the role of innovation in firm resilience is well-documented (Aga and Maemir, 2022; Aghion et al., 2005; Archibugi et al., 2013), there is a gap in understanding how non-R&D induced innovation contributes to survival during crises (Cirera et al., 2021). In the absence of adequate financial policy tools among MLICs, it is crucial to examine whether and to what extent non-R&D induced innovation can substitute for government support in enabling firms to effectively respond to crises. The results are expected to provide empirical evidence that the effectiveness of non-R&D induced innovation depends on economic and sector contexts, contributing to the literature on innovation and firm survival in MLICs.

Moreover, the analysis refines the existing models of firm resilience by incorporating the interplay between internal adaptive capacity (innovation) and external fiscal capacity (government intervention). The findings contribute to the innovation and survival framework by emphasizing a dual strategy: combining government support where feasible with firm-level innovation-driven resilience. The results suggest that the synergy between government support and innovation depends on the type of innovation and the country's income level. Tailored policy design not only needs to be aligned with firms' innovation capacities and the fiscal capabilities of their respective governments but also consider the potential of adopting an integrated framework that fosters synergies.

2. Relevant literature

2.1. Government intervention, innovation and firm survival during COVID-19 pandemic

The COVID-19 pandemic saw a clear shift away from the neoliberal policy paradigm to Keynesian economic principles (Hay, 2004). To support economies while managing a public health crisis, many governments implemented unprecedented fiscal support measures, such as direct transfers, wage subsidies, and loan guarantees, to protect employment and prevent mass business failures (Davies and Gane, 2021; Wood et al., 2023). Empirical evidence shows that these direct financial interventions have been vital in sustaining firms that might otherwise have exited due to a lack of competitiveness or financial resilience (Gourinchas et al., 2025). Although similar evidence was found across developing countries (Muzi et al., 2023), governments normally face significant constraints in implementing large-scale fiscal and monetary interventions due to limited fiscal space, high debt levels, and less developed financial markets (Cull and Xu, 2005; Ding et al., 2021). As a result, government support in these countries was often insufficient to offset the economic damage, leaving firms more vulnerable to the crisis's impacts (Beck et al., 2005).

Innovation is widely recognized as an important source of resilience. Theoretically, the Schumpeterian tradition views innovation as a mechanism for creative destruction, where firms that fail to innovate are more likely to be displaced during crises (Archibugi et al., 2013; Cefis et al., 2022; Schumpeter, 1939; Sidorkin and Srholec, 2014). Rather than being passively "cleansed" by crises, innovative firms proactively adjust and transform to survive. This is further supported by endogenous growth theory, which emphasises the central role of innovation in boosting productivity, sustaining competitiveness, and ensuring long-term survival (Aghion and Howitt, 1992; Klette and Kortum, 2004; Romer, 1990). Complementing these views, evolutionary theory (Nelson and Winter, 2004) suggests that firms in technologically dynamic environments are more likely to engage in adaptive, non-routinized behaviours to promote market share and strengthen a firm's operational resilience.

A growing body of empirical evidence supports a causal link between innovation and firm survival, particularly during crises. Krammer (2022) found that firms with prior investments in innovation adapted better to the disruptions caused by the COVID-19 pandemic. Similarly, Cefis et al. (2020) reported that innovation significantly contributed to firm survival during the pandemic by enabling businesses to adjust operations. Comparable patterns have been observed in Sub-Saharan Africa, where innovation served as an effective strategy coping with adverse economic conditions (Aga and Maemir, 2022; Aidoo et al., 2021). These studies strengthen the argument that innovation enhances firms' capacity to respond to shocks and recover more effectively. However, the strength of this relationship may be contingent on industry-specific characteristics and firm-level absorptive capacity (Cefis et al., 2022; Ugur and Vivarelli, 2021).

2.2. Non-R&D induced innovation and firm survival

In developing economies, firms often engage in imitative and incremental innovation rather than pioneering radical innovations (Fagerberg et al., 2018; Fu et al., 2011). Due to resource constraints, firms from these countries rely on informal learning, experiential knowledge, and incremental improvements that do not involve structured Science, Technology and Innovation (STI) mechanism (Singh et al., 2022). In addition, weak legal systems, inadequate intellectual property rights protection, and insufficient infrastructure require firms to rely on informal mechanisms and adaptive strategies rather than formal R&D processes (Perri and Quadrini, 2018).

Non-R&D induced innovation is frequently associated with learning and adaptive modes, which emphasises experiential learning and knowledge sharing across functions (Brouwer and Kleinknecht, 1997; Jensen et al., 2007; Lee and Walsh, 2016; Masso and Tiwari, 2024). The concept of Doing, Using and Interacting (DUI) was introduced to describe the role played by non STI based activities which facilitate knowledge acquisition and transfer for problem-solving and learning (Jensen et al., 2007). It includes practices such as design, use of advanced machinery, employee training, and leveraging external knowledge sources. These practices are especially significant in developing country firms operating in resource-constrained environment.

A growing body of literature recognizes the significance of non-R&D induced innovation in fostering firm-level innovation and competitiveness. Lee and Walsh (2016) argue that non-R&D activities like learning-by-doing, and employee engagement are key drivers of innovation where formal R&D capabilities are limited. Employees innovate through routine interactions and incremental process improvements, which

makes non-R&D innovation a practical substitute or complement to formal R&D. Masso and Tiwari (2024) argue that R&D activities are essential for sustained productivity growth in advanced firms while non-R&D induced innovation significantly boosts productivity in catching-up economies. Moilanen et al. (2014) further emphasise that these practices are more common among firms with budget constraints and are crucial in enhancing their innovative performance, particularly those in peripheral regions that benefit from external knowledge due to limited internal resources.

Firms adopting non-R&D innovation tend to be more resilient, able to quickly adjust to market shifts and exploit opportunities without incurring substantial fixed or sunk costs associated with formal R&D (Arqué-Castells and Mohnen, 2015). Unlike firms in developed economies that commit substantial investment to long-term R&D projects, these firms rely on informal, incremental approaches that reduce financial stress and allow rapid responses to demand shifts triggered by external shocks (Hervas-Oliver et al., 2011; Lee and Walsh, 2016). Moreover, the economic and institutional environments in MLICs, for example rapid changes in market conditions, consumer preferences, and regulatory frameworks, require higher levels of adaptability and flexibility among firms (Lane and Milesi-Ferretti, 2011). Therefore, non-R&D innovative firms in MLICs build resilience and adaptability into their operations, supporting a flexible approach to business that aligns with the dynamic conditions of their markets.

Reflecting differences in technological intensity and capital requirements, the survival effects of R&D and non-R&D induced innovations vary significantly across industries. In capital- and scale-intensive manufacturing sectors, R&D-induced innovation plays a more prominent role in enhancing firm resilience. Such firms typically operate within formal innovation systems, possess greater absorptive capacity, and are better positioned to translate R&D investments into productivity gains and competitive advantages during crises (Filippetti and Archibugi, 2011). Empirical evidence shows manufacturing firms with established R&D capabilities are more likely to survive shocks by reconfiguring production and adapting to market changes (Bartelsman et al., 2013; Cirera et al., 2021). In contrast, service sectors rely more on non-R&D induced innovation, such as organizational changes, digital adoption, and customer-driven process improvements, that are incremental and practice-based. These DUI featured innovation are critical for survival where formal R&D is either inaccessible or less effective (Jensen et al., 2007; Lee and Walsh, 2016; Masso and Tiwari, 2024).

2.3. Potential synergy in enhancing survival

Although prior studies have extensively examined the role of innovation and government funding in firm survival, the interplay between external support and internal effort remains underexplored (Hou and Mohnen, 2013). Both innovation and government intervention enhance firms' resilience and enable them to overcome the risks of closure during crises. According to the absorptive capacity theory, firms with strong innovation capabilities are better positioned to absorb and utilize government support effectively (Cohen and Levinthal, 1990). These firms are also able to coordinate resources more efficiently to optimize operations and adjusting business models in response to external shocks.

Prior study shows that external subsidies are more effective when firms have prior experiences with in-house R&D (Branstetter et al., 2006). During the pandemic, innovative firms strengthen their resilience by transforming and adapting new business models e.g., remote working and digital transformation (Battisti et al., 2022). Innovative firms were able to utilize government support to scale up such transformations and enhance their survival prospects (Brown et al., 2020). Similarly, government financial support enhances firm performance during crises not only by alleviating immediate liquidity pressures but also by enabling firms to upgrade adaptability and resilience (Guerrieri et al., 2022).

3. Empirical model and data

3.1. Model specification

To examine the determinants of firm survival, we employ the Cox Proportional Hazards model (Audretsch and Mahmood, 1995). Survival is defined as the time from the initial survey period until the firm exits the market. The Cox PH model is particularly suited for firms' survival data as it accommodates right-censored nature, where some firms may not exit by the end of the observation period. The hazard function $\lambda(t|X_i, Z_i)$ for firm i at time t is specified as:

$$\lambda(t|Inno_i, Gov_i, Productivity_i, Z_i) = \lambda_0(t)\exp(\beta_1 Inno_i + \beta_2 Gov_i + \beta_3 Inno_i{*}Gov_i + \beta_4 Productivity_i + \beta_k Z_i), \quad (1)$$

$$Inno_i \in [RnDInno_i, NRnDInno_i]$$

$$Z_i \in [Cashflow_i, Age_i, Import_i, Export_i, EduWorker_i, Training_i, KPI_i, SOE_i, Subsidiary_i, Stringency_c, IDI_c]$$

where $\lambda_0(t)$ represents the hazard function. Firm i's survival is a function of innovation ($Inno_i$) and government support (Gov_i), together with productivity ($Productivity_i$) and a vector of controls Z_i. $\beta_1, \beta_2, \ldots \beta_k$ are the corresponding coefficients to be estimated. Subscript c refers to the country c. Innovation will be distinguished by its type, R&D induced innovation ($RnDInno$) and non-R&D induced innovation ($NRnDInno$). λ is the hazard rate of firm i at time t. The log-hazard function is given as:

$$ln\lambda(t|Inno_i, Gov_i, Productivity_i, Z_i) = ln\lambda_0(t) + \sum_{k=1}^{i}(\beta_1 Inno_i + \beta_2 Gov_i + \beta_3 Inno_i{*}Gov_i + \beta_4 Productivity_i + \beta_k Z_i) \quad (2)$$

Where $\sum_{k=1}^{i}(.)$ represent the linear combination of covariates. Hazard ratio can be obtained from $exp(\beta_k)$, which measures the relative risk of firm exit associated with each covariate.

Gov_i enters the Eq. (1) as explanatory variable because government interventions are essential at protecting economic stability and employment during crises. They may also compensate for the lack of internal resilience, and temporarily sustain firms that would otherwise exit the market. Meanwhile, firms with stronger internal innovative capability and resilience may utilize the external funding better than those with relatively weaker resilience. Therefore, interaction between them ($Inno_i{*}Gov_i$) is included.

3.2. Data and variables

The World Bank Enterprise Survey (WBES)[1] provides comprehensive and standardized firm-level data on business and investment climates across 151 countries. The survey focuses on a wide range of topics, including firm performance, innovation activities, access to finance, infrastructure, competition, and the business environment. During the pandemic, the COVID Follow-up Surveys (CFS)[2] were conducted in 46 countries between 2020 and 2022 to capture changes in firm operations, sales, employment, innovation, and government support. The CFS builds upon the original WBES by following the same firms through up to three additional waves. Combining the pre-pandemic Enterprise Standard Survey (ESstand) with CFS data allows firms to be observed up to four times: once before the pandemic and up to three times during the pandemic.

The combined ESstand and CFS data makes this a unique resource for studying firm performance and resilience during crises. It enables researchers to link pre-crisis firm characteristics with pandemic impacts and provides insights into firm resilience and survival. Studies have shown that poor business climates, characterized by inadequate infrastructure, burdensome regulations, and macroeconomic instability, significantly impede firm survival across MLICs (Goel and Nelson, 2023; Krammer, 2022; Muzi et al., 2023). For instance, research focusing on Nigeria revealed that a one-unit increase in business constraints increased the likelihood of firm exit by 11 percentage points, emphasizing the importance of fostering a conducive business environment through improved policies and investment (Orjiakor, 2022). Similarly, research in Eastern Europe and Central Asia demonstrated that firms in regions with stronger competitive environments were better able to reallocate resources from less productive to more productive entities during the pandemic (Özşuca, 2023).

The sample in the current research is constructed by combining the latest pre-pandemic standardized Enterprise Surveys (ESstand) with the CFS. It includes firms that meet two criteria: (a) they appear at least once in the follow-up surveys to ensure continuity in tracking firms' survival status, and (b) they participated in the baseline ESstand conducted between 2017 and 2019. After applying these criteria, the sample included 22,326 firms, which was further reduced to 17,418 observations after removing missing values. Table 1 provides the full list of countries and the number of firms sampled, categorized by income levels.

Table 1
Sample country list.

Country Name	Freq.	Income Levels	Country Name	Freq.	Income Levels
Albania	338	Upper-middle	Lebanon	478	Upper-middle
Azerbaijan	68	Upper-middle	Lithuania	321	High
Belarus	526	Upper-middle	Malta	215	High
Bosnia and Herzegovina	230	Upper-middle	Moldova	341	Lower-middle
Bulgaria	627	High	Mongolia	353	Upper-middle
Chad	106	Low	Montenegro	117	Upper-middle
Croatia	394	High	Morocco	858	Lower-middle
Cyprus	195	High	Mozambique ES	533	Low
Czech Republic	478	High	Nicaragua	262	Lower-middle
El Salvador	469	Lower-middle	Niger	52	Low
Estonia	326	High	North Macedonia	300	Upper-middle
Georgia ES	491	Upper-middle	Poland	638	High
Greece	586	High	Portugal	944	High
Guatemala	213	Lower-middle	Romania	745	Upper-middle
Guinea	53	Low	Russian Fed.	1155	Upper-middle
Honduras	196	Lower-middle	Serbia	266	Upper-middle
Hungary	744	High	Slovenia	321	High
Italy	615	High	Togo	66	Low
Jordan	308	Upper-middle	Zambia	554	Lower-middle
Kazakhstan	1069	Upper-middle	Zimbabwe ES	566	Lower-middle
Latvia	301	High			
Total	17,418				

3.2.1. Dependent variable

Firm exit is constructed from the survey question: *"Currently, is this establishment open, temporarily closed (suspended services or production), or permanently closed?"*. The *exit* variable is assigned a value of 1 to firms reporting permanent closure. To maintain consistency, firms that later reappeared in subsequent waves after initially being reported as permanently closed were excluded. Consistent with prior studies (Goel and Nelson, 2023; Muzi et al., 2023), firms were also classified as having exited if they were uncontactable during the follow-up waves. Approximately 25.96 % of the sample (4521 firms) falls into the exit category.

3.2.2. Time variable

To capture the dynamics of survival during crises instead of treating exit as a static outcome, the time variable (*Months*) is constructed to measure the number of months firm has survived until its closure since the start of the pandemic. This variable is constructed by using the 'exit time' recorded in the three waves of CFS.[3]

[1] The Enterprise Surveys (ESstand) provide nationally representative data on formally registered firms with a minimum of five employees. To ensure consistency, a standardized questionnaire and a uniform implementation strategy are applied, using a stratified random sampling approach based on industry, firm size, and geographic location within each country. Survey weights are included to adjust for sampling imbalances and non-eligibility. The 2017–2019 round of ES data serves as a pre-pandemic baseline survey for this study. The COVID-19 Follow-up Surveys (CFS) extend the original ES design and maintain cross-country comparability. More information on the ES methodology is available at: https://www.enterprisesurveys.org/en/methodology.

[2] The CFS survey comprises three waves. The initial follow-up wave and Round 2 were conducted during 2020–2022 to capture firms' initial responses to the pandemic. The third wave (Round 3) revisited a subset of the countries surveyed in previous rounds during 2021–2022 to provide a more longitudinal dimension. As a result, some firms were surveyed in all three waves while others were included in only one or two waves. To construct the CFS data, each round was first processed separately and appended across countries. These rounds were then combined into a single dataset, which was subsequently matched with the WBES standardized data using the unique firm identifier '*idstd*'.

[3] Out of 4521 exited firms, 948 reported the exact year and month of closure. If an exit firm participated in the interview but did not provide information on the date of closure, the month when the interview was conducted or the response was received (via email) is used instead. In total, 1116 firms fall into this group. Given that exited firms are unlikely to continue operations much beyond their last interaction with the survey, the survey response month serves as a reasonable proxy for the actual closure time. Additionally, 597 firms participated and survived in the first wave of the CFS but were uncontactable in subsequent waves. For these firms, the timing of their previous survey participation is recorded as the exit time. For the remaining firms, including those assumed to have exited (uncontactable firms), the industry- and country-level average survival time is used to fill in the missing values.

3.2.3. Explanatory variables

The ESstand survey was used to capture firm-specific characteristics and innovation activities. $Inno_i$ is a binary equal to 1 if a firm introduced either a new product or process innovation within the three years preceding the survey. Innovation is assumed to enhance resilience and be positively associated with firm survival. Approximately 36.82 % of firms reporting an innovation outcome (*Inno*).

Following the prior literature (Pellegrino et al., 2019), innovation is further classified by its input source. First, R&D-induced innovation (*RnDInno*) is a binary variable set to 1 if a firm engaged in R&D activities and introduced a product or process innovation within the past three years. This captures innovation stemming from formal, structured knowledge creation processes. Second, the binary variable, non-R&D induced innovation (*NRnDInno*), equals 1 if a firm introduced product or process innovations without reporting any R&D expenditure during the same period.[4] This reflects innovation emerging from learning and adoption channels, particularly relevant in MLICs where firms often innovate through DUI modes (Jensen et al., 2007; Pellegrino et al., 2019). About 26.13 % reported having non-R&D induced innovation whereas about 10.07 % indicating having innovation accompanied with R&D activities.[5]

Labour productivity (*Productivity*) is measured by the ratio of total sales to the total number of employees. Several studies show a positive association between productivity and firms' survival (Bruhn et al., 2023; Muzi et al., 2023). Their findings highlight that higher pre-pandemic productivity has been associated with greater operational agility. This also allows firms to better absorb demand shocks and supply disruptions. Other scholars argue that the survival impact of productivity is not always confirmed. For example, Bosio et al. (2020) find that, during extreme economic distress, productivity is not consistently associated with longer survival times across various sectors and countries. Even highly productive firms are vulnerable to liquidity constraints and disrupted operations during crises.

3.2.4. Government support

To alleviate the immediate financial pressures faced by firms during the crisis, many governments adopted a range of support measures, including the deferral of financial obligations, reductions in operational costs such as payroll expenses, and the provision of credit support through loan guarantees (Belghitar et al., 2022). In the CFS, firms were asked whether they had received any government support during the pandemic. The survey identified five primary forms of government support: (1) direct cash transfers for businesses (*Cash*), (2) deferral of credit payments, utility bills, rent, or mortgage, including suspension of interest payments (*Defer*), (3) access to new credit (*Credit*), (4) fiscal exemptions or reductions (*Tax*), and (5) wage subsidies (*Wage*). Separate binary indicators are created for each type of assistance, assigned a value of 1 if the firm reported receiving that specific support. In addition, variable Gov_i is a dichotomous measure, given the value of 1 if any of the above support was reported and 0 otherwise.

As discussed above, excluding exited firms with no information on government support risks introducing sample selection bias. To fill in the missing government support data, we employ the non-parametric approaches to predict whether an exited firm had received government support and identifies the types of assistance they may have accessed.[6] Specifically, Random Forest (RF) and Extreme Gradient Boosting (XGboost) are performed. The comparison between their accuracies is given in Table 2. In general, XGboost performed better than RF.

Table 3 presents hazard ratios across income levels, innovation types, and government support. Exit statistics are summarised for two groups: firms in MLICs and the pooled sample firms.[7] The following interpretations are based on the pooled sample. Firms in high-income countries exhibit the lowest exit rates, about 16.48 % of innovative firms in this group exited the market at the last interview point. The relatively low exit rate reflects greater resilience of high-income country firms compared to those in lower-middle-income and low-income countries, 22.23 % and 68.77 % respectively.

Regarding innovation types, R&D innovators demonstrate a stronger survival prospect compared to non-R&D innovators. The exit rates are 18.19 % vs. 22.19 %. Meanwhile, firms receiving cash transfers show the lowest exit rates with 6.52 % exit rate, followed by those with wage subsidies with 7.51 % exit rate and credit access with 10.17 % exit rate. Deferrals of payment and fiscal exemptions are slightly less effective, 10.50 % and 11.3 % respectively. As MLICs sample excludes high-income firms, exit rates are generally higher across different innovation and government support categories compared to the pooled sample. The Log Rank test also suggests that all observed differences in exit rates are statistically significant at the 1 % level.

3.2.5. Firm specifics and other controls

A set of control variables are included to account for firm-level characteristics, macroeconomic factors, and sector-specific factors. *Cashflow* measures the proportion of inputs financed through internal funds or retained earnings. Following prior studies (Almeida et al., 2004; Carpenter and Petersen, 2002), cash flow is used as an objective proxy for firms' internal financing flexibility, capturing their ability to self-finance operations and absorb short-term shocks. This capacity is particularly relevant in crisis context such as the COVID-19 pandemic. A healthy internal financing enables firms to mitigate the impacts of temporary shocks by providing essential liquidity to maintain operations and absorb disruptions. Conversely, difficulty in accessing finance significantly increases the likelihood of financial distress and bankruptcy, as observed during the COVID-19 crisis (Ding et al., 2021; Gourinchas et al., 2025).

Age, measured as the natural logarithm of the number of years since establishment, reflects a firm's experience and market presence. Older firms often benefit from established networks, operational experience, and customer loyalty. These factors can contribute to firms' resilience to external disruptions and shocks (Chen et al., 2025; Özşuca, 2023). In

[4] As discussed in previous research (Cirera and Muzi, 2020), self-reported innovation measures in developing countries are often affected by framing and cognitive biases, leading to inconsistent reporting. Meanwhile, the absence of R&D expenditure over a three-year window does not fully capture a firm's long-term R&D trajectory. Firms may have engaged in R&D prior to this period or maintain residual capabilities. Nonetheless, this approach aligns with existing literature that emphasises the role of short-run, observed R&D behaviour as a key determinant of firm innovation (Pellegrino et al., 2019).

[5] It is worth noting that R&D innovation firms are non-exclusive, and they may also use non-R&D activities to source innovation. Therefore, the categorisation might slightly underreport the non-R&D innovative firms.

[6] To predict the government support variables with the classification tree, a set of covariates were chosen based on the best subset model. In total 15 variables were considered to fit into the best selection model: *Age, Size (number of employees, in* log*), Total sales, Productivity, SOE, Subsidiary, Export, Import, R&D induced innovation, Non-R&D induced innovation, Cashflow, Stringency Index, IDI, industry dummies, Income group dummies*. Please see Table 4 for the detailed variable definitions. Based on the result, models including the following 12 variables produced the best predictive performance: *Age, Size (number of employees, in* log*), Productivity, SOE, Subsidiary, Export, Import, R&D induced innovation, Non-R&D induced innovation, Cashflow, Stringency Index, industry dummies*.

[7] The estimated firm exit rate of 25.96 % in this study is higher than those reported in WBES-based analyses. Muzi et al. (2023) found an average rate of 16.5 % based solely on firms explicitly reported permanent closure, while Goel and Nelson (2023) reported about 22 % when including both confirmed and apparent closures. The higher rate in this study likely reflects: 1) a different sample composition; 2) the broader definition of exit, which treats uncontactable firms as closures; and 3) the exclusion of permanently closed firms that reappeared in later CFS waves, 113 firms in total, to avoid misclassification.

Table 2
Prediction accuracies: Comparison between Random Forest and XGboost.

	Cash	Defer	Credit	Tax	Wage	Gov.
Random Forest	0.83254	0.84277	**0.88948**	**0.82890**	0.74399	0.75405
XGboost	**0.84108**	**0.84367**	0.88759	0.82328	**0.76294**	**0.75709**
No. Predictions	6,011	6,345	6,874	6,114	4,772	4,031

Note: Figures in bold indicate the higher prediction accuracy between Random Forest and XGboost. The corresponding approach is therefore considered superior in performance. Number of observations: the pooled sample includes 17,418 firms. The Random Forest and Extreme Gradient Boosting (XGboost) were estimated by using R packages: rf and xgb. Training and testing splits are 70 versus 30 of the sample with 50 folds cross validations. The number of trees was set to 1000. Prediction accuracy is defined as the proportion of outcomes correctly predicted by each approach.

Table 3
Hazard ratio across income levels, innovation types, and government support types.

Sample groups	Middle- and Low- Income			Pooled Sample Firms		
	No. of Firms	Exit Rate	Log Rank Test chi2 (1)	No. of Firms	Exit Rate	Log Rank Test chi2 (1)
Total sample	10,713	31.89 %		17,418	25.96 %	
Income level						
High Income				6705	16.48 %	490.47*
Upper Middle	6444	32.43 %	3.97*	6444	32.43 %	230.91*
Lower Middle	3459	22.23 %	224.1*	3459	22.23 %	35.84*
Low	810	68.77 %	686.15*	810	68.77 %	1059.93*
Innovation Type						
Innovator	3819	26.26 %	72.64*	6306	21.08 %	112.09*
Non-R&D Innovator	2946	26.10 %	52.11*	4552	22.19 %	39.89*
R&D Innovator	873	26.80 %	9.62*	1754	18.19 %	57.47*
Government Support						
Cash Transfer	565	14.16 %	37.61*	2899	6.52 %	378.79*
Deferral of Payment	953	17.21 %	35.53*	2372	10.50 %	151.42*
Credit Access	584	17.47 %	19.14*	1505	10.17 %	95.21*
Fiscal Exemption	1273	16.26 %	68.15*	2672	11.30 %	152.65
Wage Subsidy	1800	13.44 %	149.95*	5686	7.51 %	832.91*

Note: * denotes the Pr > chi2 is less than 0.001 in Log Rank Tests. Non-R&D innovator includes exclusively firms reported to have either product and/or process innovation but no investment in R&D; R&D innovator includes innovators invested in R&D, non-exclusively. The differences in Chi2 statistics for Upper Middle-, Lower Middle- and Low-income groups between two samples are due to the different sample sizes, which affect the weight each sample contributes to the χ^2 calculation.

contrast, younger firms may benefit from adaptability and innovation, which can also play a critical role in survival (Huergo and Jaumandreu, 2004; Krammer, 2022).

As defined by Cohen and Levinthal (1990), absorptive capacity is a firm's ability to identify, assimilate, and exploit external knowledge. It is a key determinant of innovation and adaptability during times of crisis. Especially in MLICs, where innovation often occurs through non-R&D channels, R&D engagement alone may not fully capture firms' learning capabilities. To address this, two proxies are used. The first is *EduWorker*, a dummy variable equal to 1 if the firm reports an inadequately educated workforce as a moderate, major, or very severe obstacle. This variable serves as a negative proxy for the firm's cognitive capacity to absorb and utilize external information (Vega-Jurado et al., 2008). The second is *Training*, a binary variable equal to 1 if a firm provides formal training to its permanent staff. This variable reflects the firm's internal efforts to build human capital, enhance knowledge assimilation, and support adaptive learning (Keller, 1996; Stentoft et al., 2023). Both proxies align with the conceptual distinction between potential and realized absorptive capacity (Zahra and George, 2002), with training supporting the transformation and application of knowledge, and education enabling its acquisition and assimilation.

To measure the management quality, a binary variable *KPI* is included. It equals 1 if the firm reports having a formalized, written business strategy with clearly defined key performance indicators (KPI). KPI practices are associated with more effective performance monitoring, risk assessment, and adaptive decision-making which are all important elements for surviving during crisis. Firms with better-defined management practices tend to innovate more, grow faster, and respond better to shocks (Commander and Svejnar, 2011; Copestake et al., 2024).

SOE and *Subsidiary* are binary variables identify firms with state ownership and those operating as subsidiaries. SOEs may gain preferential access to government assistance and are protected by soft budget constraints (Kornai et al., 2003; Qian and Roland, 1998), while subsidiaries can get access to the financial and managerial resources of their parent companies (Cull and Xu, 2005). Evidence shows that SOEs performed better compared to firms with other ownership structures, although they exhibited lower adaptability in responding to the crisis, such as increasing online activity and adopting remote work practices (Bruhn et al., 2023). Yet, firms with government ownership may suffer greater pressure due to competing objectives, such as prioritizing employee welfare over profitability (Goel and Nelson, 2023). *Subsidiaries* demonstrated greater resilience during the crisis because of intra-group lending mechanisms, which effectively provide financial and managerial support to affiliates facing external credit constraints (Kolasa et al., 2010). Such relationship with headquarter may also lead to disadvantages during crises, as headquarter decisions are often tailored to meet national priorities across multiple countries where parent firms operate, reducing the local responsiveness of their crisis strategies (Krammer, 2022).

Firms heavily reliant on import and exports often face additional financial pressure when trade collapses (Aga and Maemir, 2022; Bosio et al., 2020; Orjiakor, 2022). *Import* and *Export* are binary variables indicate whether a firm engages in import or export activities. Exporting firms benefit from diversified markets but are also exposed to global demand shocks, while importing firms face risks associated with supply chain disruptions and exchange rate volatility (Bas and Berthou, 2012). Yet, trade engagement often enhances firms' adaptability and resilience during crises, as exporting and importing firms tend to be more competitive and globally connected compared to those operating solely in domestic markets (He et al., 2024; Kasahara and Rodrigue, 2008). Additionally, they benefit from diversified sourcing strategies and stronger institutional access, enabling them to manage supply shocks

more effectively than non-importers (Todo et al., 2023).

The complex dynamics of firm survival suggests that external factors such as demand shocks and institutional conditions can offset resilient advantages. Thus, while government support, innovation and productivity remain important determinants, their protective impacts may be affected by macro and systemic challenges (Bosio et al., 2020). The Oxford COVID-19 Policy Stringency Index (*Policyindex*) quantifies the extent of government restrictions, such as lockdowns and travel bans, aimed at containing the pandemic. While stringent policies may disrupt business operations, they can also create safer conditions for recovery (Goel and Nelson, 2023; Hale et al., 2021). The ICT Development Index (*IDI*) measures a country's digital infrastructure, reflecting its capacity for technological adaptation. Prior studies demonstrated how digital tools enabled these businesses to navigate the challenges posed by the COVID-19 pandemic in developing and emerging countries (Bürgel et al., 2023; Klöckner et al., 2023). Firms in regions with advanced digital infrastructure can leverage remote working solutions and digital tools to maintain operations during crises (Kharlamov and Parry, 2021).

Finally, *Industry* dummies account for heterogeneity. For example, sectors like healthcare and technology may benefit from increased demand, while tourism and hospitality are disproportionately affected (Belitski et al., 2022). Country's *income*-level *dummies* (Low-, Lower Middle-, Upper Middle- and High-income) capture structural differences in economic conditions. High-income countries typically offer more robust government support, infrastructure, and financial markets, enhancing firms' ability to withstand economic shocks (Chen et al., 2025; Cirera et al., 2021). The summary of variables is listed in Table 4.

Table 4
Summary statistics of variables.

Variable	Definition	Middle- and Low-income		All Sample Firms		Survey
		Mean	S.D.	Mean	S.D.	
Exit	Firms confirmed closure or uncontactable in the latest survey	0.319	0.466	0.260	0.438	CFS*
Govsupport						
Cash	Dummy variable: 1 if firm received cash support from government	0.058	0.233	0.179	0.493	CFS
Defer	Dummy variable: 1 if firm was allowed payment deferral	0.097	0.297	0.147	0.384	CFS
Credit	Dummy variable: 1 if firm received government credit access	0.060	0.237	0.093	0.354	CFS
Tax	Dummy variable: 1 if firm received fiscal exemption from government	0.130	0.336	0.165	0.291	CFS
Wage	Dummy variable: 1 if firm received wage subsidies from government	0.184	0.387	0.352	0.372	CFS
Gov	Dummy variable: 1 if a firm received any of the above government supports	0.249	0.433	0.435	0.478	CFS
Innovation and Productivity						
Inno	Dummy variable: 1 if firm introduced either product or process innovation in past three years	0.356	0.479	0.368	0.482	ESstand
R&D Inno	Dummy variable: 1 if firm engaged in R&D and introduced product or process innovation in past three years	0.081	0.274	0.101	0.301	ESstand
Non-R&D Inno	Dummy variable: 1 if firm introduced product or process innovation without engaging in R&D in past three years	0.275	0.447	0.261	0.439	ESstand
Productivity, ln	Logarithm of total sales divided by total number of employees; sales in 2017 USD	9.777	1.604	10.327	1.580	ESstand
Firm Specifics						
Age, ln	Logarithm of years since firm's formal registration	2.772	0.738	2.879	0.717	ESstand
Import	Percentage of inputs that were imported	35.468	38.197	34.892	37.455	ESstand
Export	Dummy variable: 1 if firm exports to foreign markets	0.080	0.223	0.112	0.257	ESstand
Cashflow	Percentage of investment financed through firm's internal cash or savings	0.723	0.333	0.722	0.335	ESstand
EduWorker	Dummy variable: 1 if firm reports inadequately educated workforce as moderate or severe obstacle	0.444	0.497	0.456	0.498	ESstand
Training	Dummy variable: 1 if firm provides formal training programs to permanent, full-time employees	0.326	0.469	0.346	0.476	ESstand
KPI	Dummy variable: 1 if firm has a formalized written business strategy with clear KPIs	0.305	0.460	0.367	0.482	ESstand
SOE	Dummy variable: 1 if firm is state-owned	0.020	0.140	0.015	0.120	ESstand
Subsidiary	Dummy variable: 1 if firm belongs to a foreign company group	0.132	0.339	0.145	0.352	ESstand
MacroFactors						
Stringency	Oxford COVID-19 Policy Stringency Index (2020–2022), country-level, time-invariant	44.299	10.234	43.076	9.040	OX[1]
IDI	ICT Development Index, published in 2024	71.23	19.24	77.96	18.53	IDI[2]
Industry	Dummy variables based on 4-digit industry codes from United Nations ISIC Rev. 3.1 classification					ESstand
Income level	Dummy variables for country income groups based on World Bank classification: High, Upper-Middle, Lower-Middle, and Low income					World Bank
No. observation		10,713		17,418		

Note: ESstand comprises data from the WBES conducted prior to the pandemic during 2017–2019. CFS denotes the COVID Follow-up Surveys conducted between 2020 and 2022. To construct the CFS data, each round was first processed separately and appended across countries. These rounds were then combined into a single dataset, which was subsequently matched with the WBES standardized data using the unique firm identifier '*idstd*'.

[1] Published by the University of Oxford, the Oxford COVID-19 Government Response Tracker systematically records government policy responses to the pandemic across countries and time using standardized indicators and composite indices. It provides open-access, time-series data to support analysis of how different interventions have influenced public health, economic outcomes, and policy decisions (Hale et al., 2021). For more details on the index composition and calculation, please see: https://www.bsg.ox.ac.uk/research/covid-19-government-response-tracker.

[2] Published by the International Telecommunication Union (ITU), the ICT Development Index (IDI) is a composite index to measure and compare the level of Information and Communication Technology (ICT) development across countries. It assesses the degree of digital connectivity and aims to track progress in ICT adoption and usage. Please see more details via: https://www.itu.int/itu-d/reports/statistics/idi2024/

4. Results and discussion

4.1. Determinants of firm survival in MLICs during the COVID-19 crisis

The Kaplan-Meier curves provide a visual trend of survival probabilities over the survey period. Generally, a steeper slope indicates a higher closure rate, while a flatter slope reflects lower exit rates and greater survival. Figs. 1 illustrates how survival prospects differ according to firms' innovation types and receipt of government support across MLICs.

Firms receiving government support exhibit flatter survival curves which indicates lower exit rates and higher survival probabilities over time. Similarly, both R&D and Non-R&D induced innovations appear to play a critical role in enhancing firm survival. Firms with R&D induced innovation demonstrate slightly better survival outcomes than those with non-R&D induced innovation.

The following discussion draws on results from Cox proportional hazard regressions using the MLICs sample. Hazard ratios are reported in Table 5, with values less than one indicating a reduced likelihood of firm exit and values greater than one suggesting an increased risk of exit. Robust standard errors are included in parentheses. All models include industry and income level effects. Unless otherwise noted, coefficients discussed are significant at the 10 % level or lower.

Among firms from MLICs, government support (*Gov*) significantly reduces the risk of firm exit, with hazard ratio of 0.36. Firms that received government support experienced a 64 % lower risk of exit compared to those that did not. Consistent with the existing literature, this finding highlights the critical role of government interventions in enhancing firm survival during crises (Muzi et al., 2023; Özşuca, 2023). External intervention via providing fiscal supports to firms can effectively mitigate insolvency risks stemming from disrupted operations, demand shocks, and liquidity constraints. Such interventions serve not only as an immediate pressure relief but also as a safety net, enabling firms to strategically plan and compete during and after crises.

Non-R&D induced innovation emerges as a key resilience factor across firms from MLICs while R&D induced innovation doesn't show a significant effect on survival.[8] As shown from the estimated hazard ratio of 0.84, non-R&D induced innovation lowered the risk of exit by approximately 16 %. Non-R&D innovators possess the ability to rapidly adapt to disruptions, such as reorganizing supply chains, optimizing cost structures, and addressing altered customer demands (Masso and Tiwari, 2024; Moilanen et al., 2014). Another advantage is that, unlike firms heavily reliant on formal R&D activities, non-R&D innovators are less financially burdened by long-term investments, allowing them to focus on practical, immediate solutions during crises.

Higher productivity levels yield a protective effect, as the estimated hazard ratios show by a 1 % increase in productivity reduces the likelihood of exit by approximately 4 % for firms from MLICs. More productive firms are better equipped to adapt to adverse conditions by mitigating the risk of closure. These findings align with literature emphasizing the resilience of productive firms (Aga and Francis, 2017; Bruhn et al., 2023; Hopenhayn, 1992; Muzi et al., 2023).

Several firm-level controls exhibit the expected associations with exit likelihood during the crisis. *Cashflow* shows a hazard ratio of 0.91, indicating a 9 % higher survival likelihood for each 1 % increase in investment financed through firm's internal fund. Stable internal financing allows firms to meet short-term obligations, maintain operations, and mitigate the risk of insolvency (Aga and Maemir, 2022; Özşuca, 2023). The result confirms that firms with healthy cash flow are better equipped to manage temporary shocks and maintain operations under challenging environments. Firms' age (*Age*) also significantly affects exit risk, with a hazard ratio of 0.83 suggesting that a 1 % increase in age lowers the hazard of exit by 17 %. Older firms benefit from accumulated experience, learning by doing, and stronger market presence, which essentially enhance resilience (Aga and Francis, 2017; Huergo and Jaumandreu, 2004).

Import shows a marginal but significant protective effect. The hazard ratio is close to 1, indicating slightly lower exit risk for importing firms. While reliance on imported inputs may intuitively suggest greater exposure to supply chain disruptions, the negative and significant estimated coefficient indicates that importing firms tend to be more innovative, better managed, and globally connected (He et al., 2024; Kasahara and Rodrigue, 2008). Moreover, diversified sourcing and stronger institutional access may also help importing firms better cope with shocks (Todo et al., 2023). In contrast, *Export* does not show a significant association with survival.

Firms' absorptive capacity is proxied by *EduWorker* and *Training*. Consistent with theory (Cohen and Levinthal, 1990), higher absorptive capacity enables firms to better assimilate and learn during external shocks. *EduWorker* is significantly associated with a higher risk of firm exit, highlighting the negative effect of lacking qualified staff. Formal training programs (*Training*) exhibit a protective effect, but this is not statistically significant.

Ownership structure also matters. *SOE* and *Subsidiaries* report a hazard ratio ranging from 0.56 and 0.87 respectively, reflecting a 44 % and 13 % reduction in exit risk. SOEs may benefit from preferential access to resources and implicit government support. This finding is consistent with existing studies showing that SOEs outperformed privately-owned firms in terms of sales during crises (Bruhn et al., 2023) and maintained relative stability in performance and liquidity (Fang et al., 2022). *Subsidiaries* also enjoy a survival advantage, potentially due to support from parent companies or better integration into international production networks.

Turning to macro variables, the policy stringency index (*Stringency*) is positively associated with firm exit risk across MLICs. The result suggests that stricter containment measures slightly increase the likelihood of exit. Although necessary for public health reasons, lockdowns, travel restrictions, and social distancing can disrupt normal business operations, imposing additional financial stress (Fang et al., 2022; Goel and Nelson, 2023). Conversely, the *IDI* exhibits a hazard ratio of 0.99, suggesting that better digital infrastructure offers modest but statistically significant resilience benefits by enabling remote work, online marketing, and e-commerce in less technologically mature markets.

4.2. Findings across different income levels

To investigate the distinct patterns in how government support, innovation, and firm characteristics influence survival probabilities across High-, Upper-Middle-, and Lower-Middle and Low-(LM&L) income countries, the pooled sample is divided into the corresponding subsamples based on the World Bank country classifications. Table 6 compares the estimated hazard ratios across different groups.

In High-income countries, government support shows a strong protective effect, significantly lowering the risk of firm exit. The hazard ratio of 0.116 implies an 88.4 % reduction in exit risk for supported firms. By contrast, while government support still enhances survival probabilities in MLICs, its effect is somewhat reduced. In upper-middle and LM&L countries, the effects are weaker and corresponding to 58.1 % and 73.6 % reductions in exit risk respectively. These differences likely reflect variations in fiscal capacity, the efficiency of policy implementation, and the overall effectiveness of government interventions. High-income countries, with their stable financial

[8] Both R&D and non-R&D induced innovation are treated as explanatory variables (causal relationship with firm survival) for two reasons: (1) the COVID-19 pandemic was an exogenous and unanticipated shock, which reduces concerns about reverse causality and provides a quasi-experimental setting for the analysis; and (2) innovation activities are measured prior to the crisis during the WB standard survey, while survival outcomes are observed in subsequent follow-up survey waves. This temporal ordering further mitigates concerns about reverse causality.

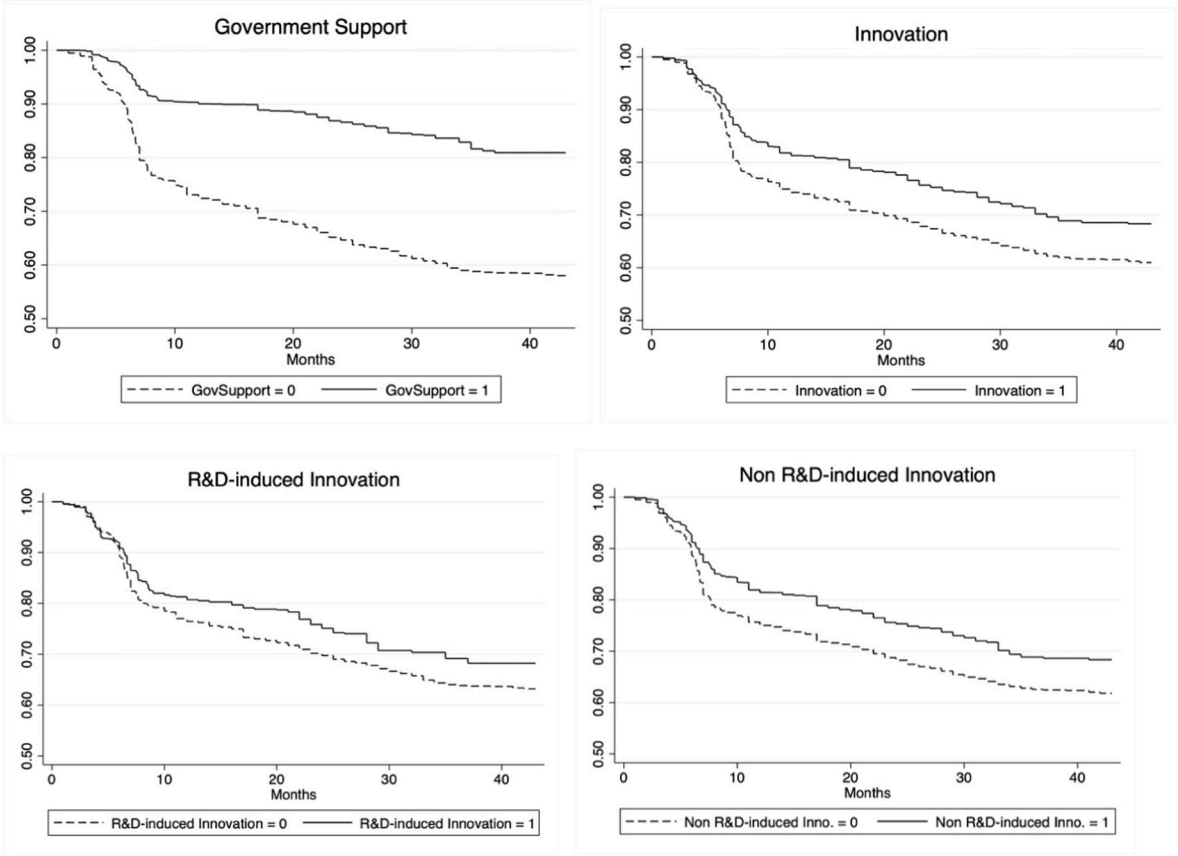
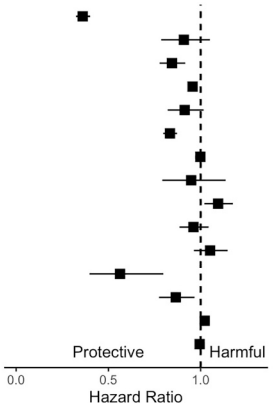


Fig. 1. Kaplan-Meier survival curves among MLIC firms.
Note: Number of observations: MLICs sample includes 10,713 firms.

Table 5
The effect of innovation and government support on Middle- and Low-income countries' firm survival, Cox HP results.
Note: Hazard Ratio (exponentiated coefficients); Robust Standard errors in parentheses. Number of observations: MLICs sample includes 10,713 firms. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Variable	Hazard R. (S.E.)	P-value
Gov	0.36 (0.054)***	<0.001
RnDInno	0.91 (0.074)	0.195
NRnDInno	0.84 (0.042)***	<0.001
Productivity	0.96 (0.013)***	<0.001
Cashflow	0.91 (0.054)*	0.096
Age	0.83 (0.023)***	<0.001
Import	1.00 (0.000)***	<0.001
Export	0.95 (0.092)	0.566
EduWorker	1.09 (0.036)**	0.012
Training	0.96 (0.042)	0.343
KPI	1.05 (0.044)	0.263
SOE	0.56 (0.178)***	0.001
Subsidiary	0.87 (0.057)**	0.010
Stringency	1.02 (0.002)***	<0.001
IDI	0.99 (0.001)***	<0.001



institutions and predictable market environments, can deliver timely and well-targeted support (Aga and Maemir, 2022; Fang et al., 2022; Özşuca, 2023). In contrast, MLICs face constraints such as limited fiscal space and weaker institutions, which reduce the impact of government aid (Cirera et al., 2021).

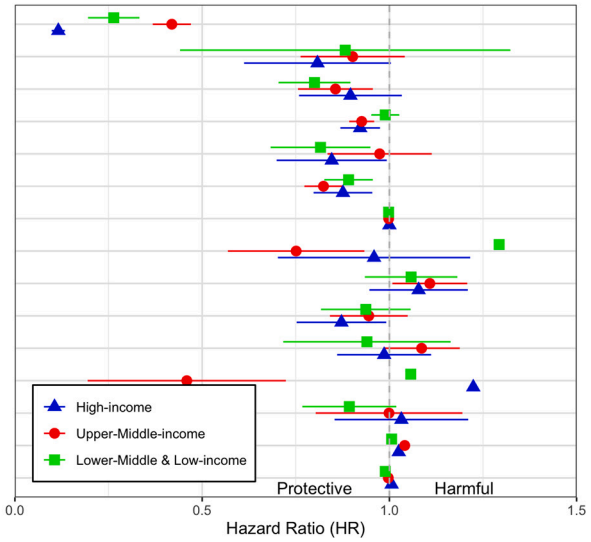
The role of innovation exhibits notable differences across income levels. In high-income countries, where formal R&D infrastructure and advanced innovation ecosystems are readily available, R&D-based innovation proves beneficial. Firms can employ technological sophistication, skilled labour, and protective intellectual property rights to translate research investments into tangible survival advantages. The hazard ratio of *RnDInno* is 0.808, albeit significant at 10 % level, suggesting that research-driven innovation improves survival prospects in well-developed innovation ecosystems and reduces the likelihood of firm closure by 15 % across high-income countries. This indicates that pre-COVID R&D induced innovation enhances firm survival by equipping firms with dynamic capabilities to adapt and maintain competitiveness in rapidly evolving environments (Teece, 1986). Superior managerial diligence often accompanies innovative firms. Such characteristic is expected to further boost their crisis responsiveness (Eggers and Kaplan, 2009). These findings are consistent with prior literature showing a positive effect of innovation on survival and performance during crisis in the context of Europe (Sidorkin and Srholec, 2014; Özşuca, 2023). Notably, non-R&D induced innovation is not significant in high-income contexts, possibly overshadowed by more advanced innovation forms.

In upper-middle income countries, non-R&D induced innovation emerges as a key resilience strategy. The hazard ratio of 0.856 suggests that non-R&D induced innovation reduces the closure risk among upper-middle income firms by 14.4 %. Firms operating in these environments benefit from adopting incremental improvements. The reduced significance of R&D induced innovation in this group indicates that while these economies may have developed some formal R&D capabilities, firms still find more immediate value in practical, cost-effective adaptation strategies, given their institutional and infrastructural constraints.

In LM&L countries, non-R&D induced innovation proves even more crucial to enhance survival prospect. Firms engaging in the adoptive and learning innovation benefited from nearly 20 % higher survival

Table 6
Cox HP regression across income levels.
Note: Hazard Ratio (exponentiated coefficients); Robust Standard errors in parentheses. Number of observations: the pooled sample includes 17,418 firms; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

	High	Upper-Middle	Lower-Middle & Low
Gov	0.116 ***	0.419 ***	0.264 ***
RnDInno	0.808 *	0.902	0.882
NRnDInno	0.896	0.856 ***	0.800 ***
Productivity	0.922 ***	0.926 ***	0.989
Cashflow	0.846 *	0.974	0.816 **
Age	0.876 ***	0.824 ***	0.891 ***
Import	1.000	0.998 ***	0.998 ***
Export	0.959	0.751 **	1.293 *
EduWorker	1.078	1.108 **	1.058
Training	0.872 *	0.945	0.937
KPI	0.986	1.086 *	0.940
SOE	1.224	0.459 ***	1.057
Subsidiary	1.032	0.999	0.893
Stringency	1.025 ***	1.041 ***	1.006 **
IDI	1.006	0.997	0.989 ***



likelihood compared to firms that did not engage in non-R&D innovation activities. With underdeveloped research ecosystems and scarce resources for formal R&D, firms rely heavily on incremental, DUI modes of innovation. This type of innovation enables firms to adapt quickly to the market without the financial commitments that R&D-based innovation entails. In these contexts, non-R&D induced innovation functions as an effective survival tool, compensating for the limited returns from formal R&D activities.

Productivity and *Cashflow* significantly enhanced survival. In High-income contexts, a 1 % increase in productivity lowered exit risk by about 7.8 %, while the same improvement reduced exit risk by only 7.4 % in Upper Middle-income countries. *Cashflow* had a stronger protective effect in LM&L income countries than in Upper-Middle and High-income contexts. A 1 % rise in cash flow reduced exit risk by 15.4 % and 18.4 % in High- and LM&L income groups respectively. The estimated hazard ratio is insignificant among firms in Upper Middle-income countries. These differences may be explained by the greater availability of external financing and more efficient liquidity management in developed economies (Aga and Maemir, 2022). Yet, due to limited external financial channels, internal liquidity can compensate for underdeveloped capital markets and credit constraints.

Age consistently reduced exit risk across all income groups but played a more pronounced role in upper-middle income countries than the other groups. Older firms, especially in resource-constrained environments, may benefit from accumulated market knowledge, established networks, and adaptive strategies developed over time (Krammer, 2022; Muzi et al., 2023). Similar effect is found for the absorptive capacity proxy *EduWorker*. In Upper-Middle income firms, a one-unit rise in perceiving such obstacle increases exit risk by 10.8 %. The other proxy (*Training*) positively affects survival but is statistically significant only in high-income countries, suggesting returns to capability-building depend on broader institutional support. Management quality (*KPI*) improves survival likelihood, particularly in upper-middle-income countries. This supports the view that structured management enhances firms' shock responsiveness by improving decision-making and monitoring (Flammer and Ioannou, 2021).

Exporting reduces exit risk in upper-middle-income countries, suggesting international market integration helps mitigate closure risks. However, in LM&L countries, exporting appears to increase exit risk, possibly due to market volatility, limited diversification, or weaker global competitiveness. *SOEs* perform well in Upper-Middle income countries, likely due to preferential access to resources and stability. This advantage is less evident in High-income countries and not as pronounced in Lower-income subsamples.

At the macro level, COVID-19 policy stringency (*Stringency*) is positively associated with exit risk across all income groups, reflecting the economic trade-offs of containment measures. Conversely, digital infrastructure (*IDI*) provides modest but meaningful survival benefits, especially in lower-income settings, where even incremental digital improvements enhance resilience through enabling remote work and online-economy.

4.3. Sectoral differences in the determinants of firm survival

To explore how firm survival dynamics differ by sector, the sample was divided into manufacturing and non-manufacturing groups. Table 7 presents hazard ratios along with their significance levels for both sectors.

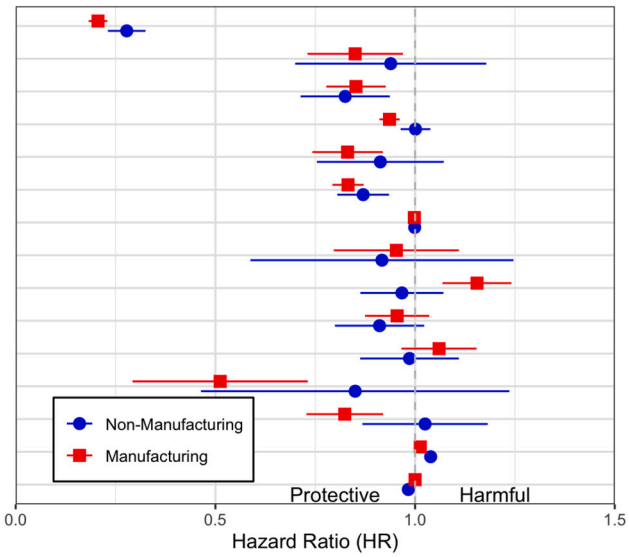
Overall, government support (*Gov*) significantly reduces exit risk in both sectors, with a slightly stronger protective effect observed in non-manufacturing firms. This likely reflects the higher vulnerability of service-oriented firms to pandemic-related disruptions such as mobility restrictions and demand collapses, which increased their reliance on government interventions (Ge et al., 2023).

Both R&D induced and non-R&D induced innovation exhibit significant protective effects across sectors. The hazard ratios for *NRnDInno* are comparable between sectors, 0.825 for non-manufacturing and 0.852 for manufacturing. Interestingly, R&D induced innovation only demonstrates a robust reduction in exit risk for manufacturing firms. This likely reflects that stronger integration of formal R&D activities into manufacturing processes is positively associated with greater resilience to external shocks (Cefis and Marsili, 2012).

Productivity plays a substantial role in manufacturing, where a 1 % increase is associated with a 6.4 % reduction in exit risk. However, this effect is statistically insignificant in non-manufacturing. This supports prior literature showing that productivity is more critical to survival in capital- and scale-intensive sectors (Bartelsman et al., 2013). *Cashflow* is significant among manufacturing firms while *Age* is an important

Table 7
Cox HP regression across manufacturing and non-manufacturing sector.
Note: Hazard Ratio (Exponentiated coefficients); Robust Standard errors in parentheses. Number of observations: the pooled sample includes 17,418 firms; Sample firms are classified into manufacturing and non-manufacturing sectors using the 4-digit ISIC Rev. 3.1. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

	Non-Manufact.	Manufact.
Gov	0.278 ***	0.206 ***
RnDInno	0.939	0.850 **
NRnDInno	0.825 ***	0.852 ***
Productivity	1.001	0.936 ***
Cashflow	0.913	0.831 ***
Age	0.870 ***	0.832 ***
Import	0.999	0.998 ***
Export	0.917	0.953
EduWorker	0.967	1.155 ***
Training	0.911	0.955
KPI	0.986	1.060
SOE	0.850	0.512 **
Subsidiary	1.025	0.824 ***
Stringency	1.039 ***	1.013 ***
IDI	0.983 ***	1.000



predictor of resilience in both sectors, though with greater magnitude and significance in non-manufacturing. Importing firms might belong to essential manufacturing sectors, such as pharmaceuticals, food, or industrial inputs, that received priority for operational continuity during lockdowns. This is reflected by the significant estimated coefficient and protective effects in the manufacturing sample. An inadequately educated workforce (*EduWorker*) significantly increases the risk of exit in manufacturing but has no significant effect in non-manufacturing. Similarly, *Training* and *KPI* are not significantly associated with survival in both groups. The SOE status and subsidiary affiliation are associated with better survival outcomes, but only in manufacturing. Policy stringency increases exit risk in both sectors, but the harmful effect is stronger on non-manufacturing firms. Well-developed ICT infrastructure (*IDI*) significantly reduces exit risk only in non-manufacturing, suggesting that digital readiness was a more important enabler for continuity in service and retail sectors during lockdown.

4.4. Joint effects of innovation and government support

Table 8 presents the Cox Proportional Hazards (Cox PH) regressions across different income levels, with three different specifications: (1) omitting government support (Models 1–3), (2) excluding interaction

Table 8
Cox HP regression results across different income levels, non-Hazard Ratio.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	High	Upper Middle	LM&Low	High	Upper Middle	LM&Low	High	Upper Middle	LM&Low
Gov				−2.153***	−0.871***	−1.331***	−2.181***	−0.801***	−1.290***
				(0.075)	(0.062)	(0.131)	(0.091)	(0.075)	(0.145)
R&DInno	−0.434***	−0.154*	0.084	−0.214*	−0.103	−0.126	−0.287*	−0.038	−0.091
	(0.118)	(0.079)	(0.253)	(0.123)	(0.079)	(0.255)	(0.147)	(0.086)	(0.257)
NR&DInno	−0.199***	−0.205***	−0.183***	−0.110	−0.155***	−0.223***	−0.115	−0.134**	−0.217***
	(0.075)	(0.060)	(0.062)	(0.078)	(0.060)	(0.062)	(0.088)	(0.067)	(0.063)
Gov*R&DInno							0.241	−0.342*	−43.336[1]
							(0.250)	(0.190)	(0.000)
Gov*NR&DInno							0.018	−0.120	−0.165
							(0.180)	(0.146)	(0.323)
Productivity	−0.107***	−0.074***	−0.041**	−0.081***	−0.077***	−0.011	−0.081***	−0.077***	−0.011
	(0.032)	(0.018)	(0.018)	(0.029)	(0.018)	(0.019)	(0.029)	(0.018)	(0.019)
Control Var.	Included	Included	Included	Included	Included	Included	Included	Included	Included
Log pseudo LH	−9447.18	−17,524.02	−10,279.39	−8925.33	−17,408.90	−10,205.59	−8924.89	−17,407.13	−10,204.89
No. of failures	1105	2090	1326	1105	2090	1326	1105	2090	1326
Observations	6705	6444	4269	6705	6444	4269	6705	6444	4269

Robust standard errors in parentheses; *** p < 0.01, ** p < 0.05, * $p < 0.1$. The control variable list include: *Cashflor, Age, Import, Export, EduWorker, Training, KPI, SOE, Subsidiary, Stringency, and IDI.* Industry dummies are also included in the regressions.

[1] The unusually large magnitude of the estimated coefficient for *Gov*R&DInno* may be caused by the potential multicollinearity between the interaction term and the main effect *R&DInno*. The pairwise correlation between these two variables is relatively high, 0.3170. Such strong correlation may have inflated the coefficient's standard error and lead to the extreme value. Nevertheless, this estimated coefficient is insignificant.

terms (Models 4–6), and (3) including interaction terms between government support and innovation (Models 7–9). Positive coefficients indicate increased exit risk, while negative coefficients reflect protective effects.

Models excluding government support (Models 1–3, Table 8) reveal that omitting external financial assistance biases the estimated impact of innovation, typically overestimating its protective effect. This highlights the importance of accounting for external financial assistance when assessing the role of innovation in firm survival. Models with interaction terms (Models 7–9, Table 8) allow for an examination of potential synergies between innovation and government support across different income levels. Models without interaction terms (Models 4–6, Table 8) show minor changes in the estimated coefficients compared to the ones with interactions. This consistency indicates that the direct effects of innovation and other factors on firm survival remain robust regardless of the inclusion of interaction terms.

In Upper-Middle income countries, the interaction between government support and R&D-based innovation is negative and statistically significant. When R&D firms receive government assistance, they experience an even greater reduction in exit risk compared to relying on either R&D or non-R&D induced innovation alone. In other words, R&D innovators in these environments can more effectively translate external financial aid into resilience capability building and enhancing the protective effect on survival. Yet, certain level of innovation capability is needed to foster such synergy as the interaction terms become insignificant in LM&L income countries. The interaction with non-R&D induced innovation is not statistically significant, implying that while incremental, practice-based innovations remain valuable, they may not sufficiently enhance the survival impact of public support as effectively as formal R&D innovations do. In High-income countries, both government support and R&D innovation independently reduce exit risk, but their interaction is not statistically significant. This may reflect that firms in these environments already possess the absorptive capacity and managerial expertise to fully exploit government support without additional synergy effects.

5. Concluding remarks

Whereas previous global financial crises typically originate from systemic issues within the financial sector, the COVID-19 crisis was an exogenous health shock that disrupted global supply chains and sharply reduced demand (Guerrieri et al., 2022). This dual impact affected countries across all income levels, yet developing economies faced unique challenges due to limited fiscal space, high debt burdens, and less developed financial markets, which constrained their ability to implement large-scale government interventions. Consequently, government support in these countries was often insufficient to fully mitigate the economic damage, leaving firms more vulnerable.

This study advances the understanding of firm survival in the context of an unprecedented crisis by analysing firm-level data from the World Bank. The findings highlight the critical role of non-R&D induced innovation in enhancing firm resilience. At the same time, direct financial support, such as cash transfer and wage subsidy, significantly enhanced firms' survival rates by providing essential liquidity to sustain operations, mitigate insolvency risks, and avoid closures. Importantly, the results show that innovation and government support interact in complex ways. Omitting government support from COVID-19 firms survival analyses may lead to biased estimates and an overestimation of the relationship between innovation and firm survival. The results emphasises that direct financial support is essential to prevent firm closures during the Covid-19 crisis. This finding aligns with theories that emphasise the liquidity needs of firms as central to survival during economic shocks. By focusing on liquidity-enhancing measures, governments can provide immediate relief that addresses the external shock more effectively than other tools.

While innovation, government support, productivity, and firm characteristics such as cashflow and firm age consistently contribute to survival, their relative importance varies across economic context. High-income countries benefit from advanced financial systems and institutions, which reinforce the impact of government support and formal R&D-based innovation. In contrast, firms in MLICs rely more heavily on incremental and practice-based non-R&D induced innovation to build resilience. The sectoral analysis reveals important differences between manufacturing and non-manufacturing firms. Manufacturing firms benefit more from R&D-induced innovation and productivity improvements whereas non-manufacturing firms derive greater survival benefits from non-R&D induced innovation and digital infrastructure.

These findings suggest that policy initiatives should prioritise innovation not only as a strategy for long-run growth but also as a stabilising mechanism against economic shocks. This is consistent with macroeconomic theories highlighting how innovation-related policies can reduce market volatility while fostering productivity (Aghion and Saint-Paul, 1998; Massari and Shadmani, 2025). Moreover, policy interventions must be context and sector sensitive. In resource-constrained environments, fostering non-R&D innovation through training, collaboration platforms, and capability-building may provide a more feasible and cost-effective pathway to resilience than focusing on formal R&D. Recognising that R&D is not the sole driver of innovation broadens the scope of knowledge creation and dissemination.

In addition, the findings reveal that the synergy between government support and innovation depends on the type of innovation and income level context. In MLICs, the combination of government support and R&D induced innovation significantly reduces the risk of firm exit, indicating that such support enhances the effectiveness of R&D activities. In contexts where R&D induced innovation is relatively underdeveloped or difficult to sustain due to limited resources, government intervention can act as a critical catalyst. By providing the necessary capital, stability, or market signals, state support enables R&D active firms to convert innovative ideas into tangible crisis-response strategies, thereby enhancing their survival likelihoods. On the other hand, the absence of a strong interaction effect for non-R&D induced innovation does not diminish the importance of incremental, adaptive innovations. Therefore, policy measures in MLICs might need to be more tailored if the goal is to achieve synergy. Improving absorptive capacities, training, and knowledge networks could help non-R&D innovators derived greater benefit from government support. In High-income countries, both government support and R&D innovation independently contribute to firm resilience, but their interaction does not produce additional benefits, likely because firms in these settings already possess the capacity to utilize support effectively.

Looking ahead, a promising avenue for future research is to differentiate the exits caused by short-term pandemic shocks from those driven by productivity-based reallocation or ‘cleansing’ effects. Longitudinal data covering both pre- and post-pandemic periods would be particularly valuable for this purpose. Investigating the causal mechanisms underlying different types of innovation also requires firm-level data with detailed information on specific innovation inputs. Such data would enable a more precise classification of non-R&D induced innovation, especially since some firms currently categorized as non-R&D innovators may possess prior R&D experience and retained capabilities that significantly contribute to absorptive capacity and resilience. Additionally, Non-R&D induced innovation in catching-up economies remains an underexplored topic within the innovation literature, particularly regarding its diverse forms in MLICs. Another important research direction is to examine how non-R&D innovation fosters absorptive capacity and technological capabilities during the early stages of transitioning toward knowledge-based economies. Key questions include whether non-R&D innovations in these contexts correspond to the DUI modes observed in advanced economies, and to what extent innovation frameworks developed for High-income settings are applicable.

CRediT authorship contribution statement

Jun Hou: Writing – review & editing, Writing – original draft, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this paper, the author used ChatGPT for proofreading the text. Following the use of this tool, the author reviewed and edited all content as necessary and accepts full responsibility for the final version of the manuscript.

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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Data availability

Data will be made available on request.

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