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How and when adversity breeds ingenuity in an emerging market: Environmental threats, co-innovation, and frugal innovation

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ABSTRACT

Despite burgeoning research on frugal innovation, there is limited understanding of how environmental threats shape frugal innovation, the mechanisms underlying this relationship and its boundary conditions. To address these gaps, we propose a moderated mediation model based on the strategy tripod perspective to examine the impact of environmental threats on frugal innovation through the mediating mechanism of co-innovation capability. Moreover, we investigate how legal incompleteness can moderate this relationship. We tested our model empirically with data from 301 manufacturing firms in an emerging market of Ghana, using a time-lagged research design. The results of our analysis largely support the proposed hypotheses in the model, revealing a more nuanced understanding of the indirect impact of environmental threats on frugal product innovation to contribute to the existing body of knowledge in the field of innovation.

1. Introduction

Firms in emerging markets often face highly price-sensitive consumers (e.g., Ernst et al., 2015; Halme et al., 2012). A significant portion of firms in these economies operate in the informal sector, where unbranded products and services pose competition (Adomako et al., 2024a, 2024b; Hart et al., 2004; Prahalad, 2012). These environmental threats in emerging markets present substantial opportunities for frugal innovation (Ernst et al., 2015). As emerging markets continue to grow, many firms are shifting to adopt the strategy of frugal innovation, as an emerging solution to address societal challenges, thus stimulating local entrepreneurship and inclusive development (Economist, 2010; Saraf, 2009).

The concept of frugal innovation reflects a resource-scarce solution that leverages low-technological opportunities to meet local market needs (Hossain, 2018; Lim and Fujimoto, 2019). This approach often requires firms to reconfigure products and processes from scratch to meet consumer demands while also concurrently striving to reduce the resources used or the costs (Radjou et al., 2012). The literature introduces a spectrum of terms that denote some notions of frugality, such as "cost innovations", which refers to cost-effective product or service modifications, "affordable value innovation", indicating innovation with low cost yet still having values, and "jugaad", a term used primarily in India to describe a flexible approach to problem-solving and innovation with limited resources (Christensen et al., 2013).

Recent studies have explored various drivers of frugal innovation, such as knowledge sources, institutional environment, and reverse engineering (Cai et al., 2019; Dost et al., 2019; Ernst et al., 2015). However, there is a dearth of research on how specific environmental conditions can trigger frugal innovation. Environmental threats refer to top executives' assessment of potential business losses within their operating environment (Adomako et al., 2024b; Kreiser et al., 2020; Staw et al., 1981; Voss et al., 2008). The strategy tripod perspective postulates that industry conditions, institutional factors, and resources or capabilities shape a firm's strategic behaviors (Esteve-Pérez and Mañez-Castillejo, 2008; Peng et al., 2008, 2009).

High environmental threats, such as economic volatility or market uncertainties, pose resource constraints to firms in emerging markets (Ernst et al., 2015; Zhu et al., 2019). Constantly constrained firms are more likely to turn to frugal innovation, which emphasizes achieving more with fewer resources and thereby offering high value (Ray and Ray, 2010; Williams and van Triest, 2009; Williamson, 2010). Emerging market firms can acquire and utilize resources and capabilities external to the firm (Adomako et al., 2024a; Esteve-Pérez and Mañez-Castillejo,

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2008), such as by establishing partnerships between businesses and their stakeholders to play a pivotal role in the firm's frugal innovation activities known as co-innovation (Adomako & Nguyen, 2023; Chang et al., 2022). Indeed, consistent with the resource–capability view of the strategy tripod, co-innovation serves as a critical capability for emerging market firms by facilitating value creation through joint resource allocation and utilization. Lastly, the institutional-based view of the strategy tripod suggests that firm outcomes in emerging markets are constrained by the institutional framework or the lack of it. In particular, legal incompleteness, gaps or deficiencies in formal institutions, such as regulations and infrastructure (Bruton et al., 2013; Doh et al., 2017), often require creative and resource-efficient solutions. In environments where institutions are weak or absent, firms may be compelled to engage in frugal innovation to navigate and thrive in the absence of established norms and support structures.

Using the strategy tripod view as an integral framework, we propose a model integrating industrial conditions (i.e., environmental threats), firm-specific capabilities (i.e., co-innovation), and institutional factors (i.e., legal incompleteness). Specifically, we ask whether co-innovation capability can serve as a critical intermediary in the relationship between environmental threats and frugal innovation, and how legal incompleteness can moderate this relationship. By integrating institution, capability and industry factors, this proposed model helps to advance our scholarly understanding of how top managers in volatile environments proactively achieve frugal innovation through collaborative co-innovation under weak institutional settings. The way managers and entrepreneurs interpret their environment has substantial managerial consequences (Daft & Weick, 1984; Zhang et al., 2021). This perspective is particularly relevant in our study, as we seek to understand how firm leaders perceived environmental threats and institutional voids impact frugal innovation through co-innovation capabilities.

This research makes several contributions to the existing body of knowledge on frugal innovation, specifically when and how firms conduct frugal innovation in emerging markets. First, our investigation puts forward a view that external environmental pressures are not just hurdles but also catalysts for strategic ingenuity. Diverging from the traditional focus on environmental threats as impediments, we unearth how firms in emerging markets use looming threats not as a signal to retreat but as a cue for strategic action, leveraging the threatening environment to fuel their innovative endeavors (Adomako et al., 2024b; Kahneman and Tversky, 2013; Voss et al., 2008). This reframing of environmental threats as a potent source of innovation disrupts the existing narrative, paving the way for a newer understanding of the forces that shape innovation in constrained contexts.

Second, we cast new light on co-innovation's role as a strategic fulcrum in resource-limited settings, elucidating how perceived environmental adversities do not dampen but ignite collaborative innovation efforts (Bossink, 2002; Lee et al., 2012). This counters the conventional belief that scarcity curtails resource and capability development towards collaboration, suggesting instead that it galvanizes firms to seek strength through partnerships (Lafuente et al., 2023).

Third, we contribute to institutional theory by illustrating how legal incompleteness, an aspect often seen as a barrier, unexpectedly serves as an impetus for innovation (Khanna et al., 2005; Sheng et al., 2011). This advances our understanding of how firms adapt their innovation strategies within such institutional voids (Anderlini et al., 2013; Wei et al., 2020).

Lastly, we challenge and redefine the perception of frugal innovation, positioning it not as a simplistic, reactive approach to resource scarcity but as a strategic and nuanced orchestration shaped by a confluence of environmental, collaborative, and institutional factors (George et al., 2012; Meyer et al., 2017). This aligns with the call for a more nuanced appreciation of innovation in resource-constrained environments (Prahalad and Mashelkar, 2010; Ray and Ray, 2011), encouraging a more integral view that integrates the environment, firm capabilities, and institutional context to better understand firm behaviors in emerging economies.

2. Theoretical background and hypotheses

2.1. Strategy tripod view

The strategy tripod view encompasses three fundamental perspectives in strategy: industry-based, institution-based, and resource-based views. First, the industry-based view argues that a firm's performance is significantly influenced by the industry conditions (Porter, 1980; Wijekoon et al., 2021). Second, the institution-based view focuses on the significance of the specific institutional framework in shaping firm strategy and performance including innovation (Peng, 2002, 2006; Tang et al., 2024). This is particularly relevant in emerging economies with weak or underdeveloped institutional infrastructure (Deng et al., 2023; Sheng et al., 2011). Third, the resource-based or capability-based view suggests that a firm's sustainable competitive advantage primarily stems from its valuable, rare, inimitable, and non-substitutable resources or capabilities (Barney, 1991; Barney et al., 2021; Teece et al., 1997). This perspective emphasizes the internal strengths and weaknesses in terms of the resources or capabilities developed in individual firms (Barney, 1991; Chen et al., 2021; Wernerfelt, 1984).

Although each of the three perspectives provides valuable insights, they concentrate on distinct levels of analysis. The industry-based view concentrates on external forces operating at the industry level, the institution-based view underscores the constraints imposed at the societal level (Peng et al., 2008; Su et al., 2016), and the resource-based view examines internal aspects at the firm level (Barney, 1991; Esteve-Pérez and Mañez-Castillejo, 2008; Mahoney and Pandian, 1992). Alone, none of these perspectives provides an integrated understanding of the complex phenomenon; rather, the integration of their insights provides a more insightful understanding (Gao et al., 2010; Peng et al., 2009; Zhu et al., 2019). Thus, it is critical for a holistic theory to integrate the three perspectives.

One particular theory that offers an integrative insight into all three perspectives is the strategy tripod view. This perspective is well-suited to our research as it allows us to capture the multifaceted influences on frugal innovation. This theory posits that a firm's industry conditions, institutional factors, and resources or capabilities collectively influence firm strategic choices and performance. This theoretical framework aligns with previous research (e.g., Oliver, 1997) that posits competitive advantage is fundamentally influenced by how firms navigate the industrial and institutional contexts through rent-generating capabilities. The strategy tripod view is particularly relevant for studying emerging markets like Ghana, which are characterized by dynamic industry conditions, resource constraints, and evolving institutional frameworks (Adomako et al., 2024b; Peng et al., 2008; Zhu et al., 2019). These markets present unique challenges and opportunities, making the strategy tripod view particularly valuable. The industry-based view helps us understand how firms in Ghana navigate environmental threats and competitive pressures (Adomako et al., 2024b; Sun et al., 2021). The institution-based view sheds light on the impact of legal incompleteness and regulatory changes, which are common in emerging markets (Bu et al., 2024). Finally, the resource-based view emphasizes the importance of co-innovation and the development of unique capabilities that can provide firms with a competitive edge despite resource limitations. By integrating these three perspectives, the strategy tripod view allows us to capture the dynamic nature of doing business in emerging markets, offering insights that are theoretically sound and practically relevant (Lahiri et al., 2020; Zhu et al., 2019).

Building on this tripod view, our study asserts that the heterogeneity of environmental threats as industry conditions contribute to variations in firm capabilities, such as frugal innovation for firms operating in emerging markets. We further argue that in emerging markets such as Africa, co-innovation capability is a key and necessary firm capability to

serve as an underlying mechanism through which firms can translate industry conditions such as threat perceptions into frugal innovation. Additionally, we identify the effect of environmental threats, an institutional factor, as the boundary condition. In doing so, we integrate these three perspectives based on the three pillars of the strategy tripod (environmental threats as industry conditions), legal incompleteness as an institution condition, and co-innovation as the resource or capability developed). Fig. 1 shows our conceptual model.

2.2. Environmental threats and co-innovation

The strategy tripod view suggests that a firm's strategic decisions are influenced by the interplay of its resources or capabilities, institutional factors, and industry conditions. One of the three perspectives of the strategy tripod framework is the industry-based view. According to the industry-based view (Porter, 1985), differences in competitive advantages and performance among organizations are attributed to industry conditions or the task environment. Changes within the industry present both opportunities and challenges that impact a firm's ability to generate profits.

In our study, environmental threats represent industry conditions that can drive firms to engage in co-innovation activities. Threat perceptions refer to executives' perceptions regarding the potential losses in a firm's operating environment that can lead to unfavorable outcomes by disrupting the normal operations of firms (Adomako et al., 2024b; Noltemeyer and Bush, 2013; Staw et al., 1981). We emphasize environmental threats as a predictor of frugal innovation because research has demonstrated that it is a crucial factor contributing to environmental uncertainty as well as entrepreneurial opportunities (Staw et al., 1981). When faced with challenges such as technological disruptions, or competitive pressures, firms may find it beneficial to collaborate with other firms (Mascia et al., 2017). These co-innovation activities allow them to pool resources, share knowledge, and develop innovative solutions more effectively than they could alone.

Moreover, when firms perceive potential losses resulting from volatile environments, they tend to exhibit a willingness to take risks (Kahneman and Tversky, 2013; Voss et al., 2008). This implies that firm leaders, recognizing the erosion of a firm's strategic position by threats, are more likely to consider developing innovative capabilities as a strategic means to counteract these challenging environments. Furthermore, the perception of risk in a strategic decision becomes less prominent when compared to a threatening environment rather than an environment filled with opportunities (Adomako et al., 2024b; Noltemeyer and Bush, 2013; Voss et al., 2008), resulting in a higher probability of risk-seeking behavior in response to environmental threats. For instance, when the environment is perceived as being abundant with opportunities, firms tend to rely on existing capabilities as an adequate response (Schilke, 2014; Teece et al., 1997) in order not to risk disruptions. By contrast, to mitigate or capitalize on threatening environments, these firms are more willing to invest in product exploration, even if it involves taking risks (Voss et al., 2008).

Furthermore, threatening environments create a sense of urgency within firms to address potential losses and risks. This motivation prompts them to consider cost innovation in emerging economies. By identifying cost-saving measures, optimizing processes, and minimizing resource consumption, firms can develop more efficient practices. As environmental threats often drive changes in consumer preferences, regulatory requirements, and market conditions (Freel, 2005; Matanda and Freeman, 2009), firms that perceive these threats can better recognize the need to offer affordable solutions to adapt to the evolving demands of customers and the market. These firms can develop products or services that provide more "value for the buck" and cost optimization that better meet the essential requirements of price-sensitive consumers (Halme et al., 2012).

Furthermore, heightened environmental threats serve as catalyst for segmenting the market for frugal innovation. Simply put, when there is greater variability in the external environment, established firms are more likely to introduce new products or processes as a means of safeguarding their market position. Essentially, the more threatening or complex the environment becomes, the stronger the motivation to innovate, leading firms to move towards engaging in innovation (Freel, 2005; Miller and Friesen, 1982). For example, when customer preferences or expectations fluctuate, or when competitors introduce new products, firms face heightened pressure to innovate.

Besides, environmental threats often require firms to adapt and make more out of their limited resources in emerging markets (Adomako et al., 2024b; Singh et al., 2022; Verdu et al., 2012). Firms perceiving these threats are more inclined to explore collaborative approaches for joint resource utilization by collaborating on innovation. This co-innovation approach not only helps them overcome resource constraints but also provides a competitive advantage (Frow et al., 2015; Tsou et al., 2015). This is particularly salient in emerging markets because a significant portion of these economies operate within the informal sector, where competition arises from unbranded products and services (London and Hart, 2004). Consequently, firms operating in such resource-constrained conditions, which perceive a greater degree of environmental threats, are more inclined to co-innovate to achieve significantly lower costs for their consumers (Wilden et al., 2016). Thus, we suggest that:

H1. Perceived environmental threats have a positive influence on co-innovation capability.

2.3. Leveraging co-innovation capability for frugal innovation

The resource and capability view posits that strategic advantages are garnered through the ability to adapt, integrate, and reconfigure

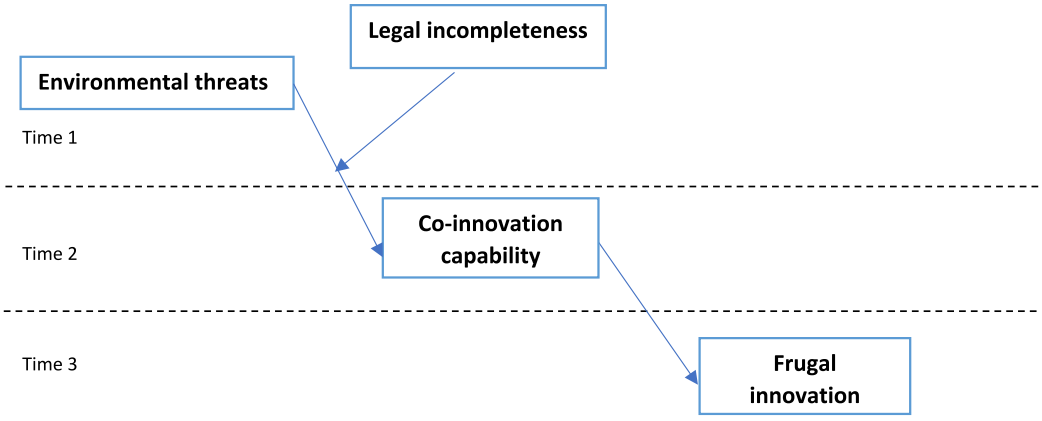

Fig. 1. Conceptual model.

internal and external competencies to address rapidly changing environments (Barney, 1991; Teece et al., 1997). In emerging markets, the capability of firms to develop and co-innovate with other firms constitutes a distinctive resource that is unique, irreplaceable, and difficult to replicate. Co-innovation capability, defined as the ability to synergistically combine and utilize resources and capabilities with external partners to create and implement value (Adomako and Nguyen, 2023; Chang et al., 2022; Schilke and Lumineau, 2018), is particularly salient for frugal innovation, which requires novel and agile approaches to resource utilization in the face of resource constraints to be able to reduce prices for customers (Wilden et al., 2016) and enhanced speed to market (van Blokland et al., 2008). The utilization of external resources helps these firms achieve frugal innovation within stringent budgetary and material constraints in emerging markets (Hossain, 2017, 2020).

In emerging markets, a firm's capacity to engage in co-innovation is a testament to its resourcefulness to sense and seize opportunities in a constrained setting to adapt to environmental challenges, and hence the ability to pivot and innovate frugally in response to such challenges is a clear demonstration of a firm's development of unique resources and capability in action (Teece, 2014; Wang and Ahmed, 2007). The capability to co-innovate is not merely about resource acquisition; it is fundamentally about value creation through joint strategic resource orchestration and recombination (Sirmon et al., 2007). This value creation is especially pertinent in the development of frugal innovations, where the essence is in maximizing resource utility and customer value (George et al., 2012). Such resources and capabilities to co-innovate are difficult to imitate due to the unique historical development and social complexity of the partnering firms' networks (Eisenhardt and Martin, 2000; Esteve-Pérez and Mañez-Castillejo, 2008). Firms with the ability to co-innovate effectively have a resource that sets them apart.

Based on this resource–capability view of the tripod framework, we propose a hypothesis that ties co-innovation to frugal innovation. This relationship, grounded in the resource–capability view, suggests that well-honed co-innovation serves as a key resource or capability for firms to be more adept at developing frugal innovations. We argue that co-innovation capability allows firms to better meet basic needs efficiently, which is crucial for developing frugal innovation (Ray and Ray, 2010; Williams and van Triest, 2009). The capability to co-innovate can lead to the development of products or services that stand out in terms of cost-effectiveness and functionality. Based on these arguments, we suggest that:

H2. Co-innovation capability has a positive influence on frugal innovation.

2.4. Mediating role of co-innovation capability

Although the current body of literature on innovation often indicates that as environmental threats intensify, firms are more likely to embrace proactive and aggressive strategies (Freel, 2005; Özsomer et al., 1997), the underlying mechanisms of this relationship remain unclear. In this study, we propose that the capability of co-innovation serves as a mechanism linking environmental threats and frugal innovation for firms in emerging markets.

First, environmental threats pose significant challenges and uncertainties for firms in emerging markets (Adomako et al., 2021; Story et al., 2015). These threats can range from shifting market conditions to disruptive technological advancements or regulatory changes. In response to such threats, firms recognize the need for collaborative problem-solving. Co-innovation signifies that firms' innovation endeavors are accomplished through cooperation with external partners and stakeholders. This collaborative approach yields various benefits, such as knowledge creation within firms, improved innovation practices and learning outcomes (Westerlund and Rajala, 2010), and a faster timeline to market (van Blokland et al., 2008). By engaging in co-innovation with external partners and stakeholders, firms can pool their resources, expertise, and perspectives to address complex environmental challenges more effectively (Lafuente et al., 2023; Yeniyurt et al., 2014). The shared understanding of the threats and collective efforts enable firms to develop innovative solutions with significantly lower costs to cater for resource-constrained consumers that may not have been possible through individual efforts. Moreover, previous studies have suggested that a diverse set of resources, knowledge, and capabilities is often required to address environmental threats effectively (Adomako et al., 2021; Voss et al., 2008). Co-innovation allows firms to leverage the complementary resources and expertise of their partners. Therefore, firms with strong capabilities in co-innovation can adapt and respond effectively to changing environments (Bogers et al., 2019; Lee et al., 2012) in a frugal manner.

Through collaboration with external stakeholders who have unique knowledge, technologies, or market access, firms can enhance their capabilities to navigate threats and develop frugal innovative solutions that prioritize cost and value considerations for customers with limited resources. This proactive collaboration under environmental threats facilitates the exchange of ideas, access to new markets, and integration of complementary technologies, which can lead to frugal innovations. Additionally, environmental threats that heighten uncertainty can disrupt existing market dynamics and create opportunities for firms to co-innovate and gain a competitive advantage frugally (John et al., 2003; Roper and Tapinos, 2016). Under environmental threats, co-innovation enables firms to tap into each other's resources to enter new market segments, expand their customer base, or develop innovative products and services that address emerging customer needs (Bossink, 2002; Dawson et al., 2014). By partnering with external stakeholders, firms can access new markets, distribution channels, or customer segments that they may not have been able to reach on their own (Wang et al., 2023). As such, co-innovation serves as a means for firms to capitalize on the opportunities presented by environmental threats, leading to frugality.

Additionally, in the context of emerging economies, where firms are active but have limited resources, co-innovation which involves collaborative partnerships and knowledge sharing among firms and their stakeholders can help firms pool resources, expertise, and capabilities to optimize their resource allocation and enhance operational efficiency (Adomako and Nguyen, 2023) to co-innovate. This collaborative approach enables firms to identify cost-saving opportunities, streamline processes, and reduce inefficiencies, thereby driving co-innovation. The shared knowledge and expertise from external partners can contribute to the identification of innovative ways to reduce costs and improve product functionalities and features that are tailored to meet the specific needs of consumers without compromising quality or value (Lafuente et al., 2023; Yeniyurt et al., 2014). Taken together, we reason that co-innovation represents one of the means that firms under environmental threats can use to deliver frugal innovation:

H3. Perceived environmental threats have a positive influence on frugal innovation through co-innovation capability (a partial mediation).

2.5. Moderating role of legal incompleteness

In most emerging markets, the legal system often remains underdeveloped (Peng, 2003) which exemplifies institutional voids (Julian and Ofori-Dankwa, 2013; Tracey and Phillips, 2011) reflecting “institutional arrangements that support markets are weak or fail to accomplish the role expected of them” (Mair and Marti, 2009, p. 422). This underdevelopment is characterized by a high level of legal incompleteness, where clear rules and legal codes to guide businesses are lacking (Wei et al., 2017). When legal codes are incomplete, it leads to uncertainty in the business environment and the risk-taking behaviors of agent firms. This is because increasing investments in innovative competencies is a strategic response to threatening environments (Kahneman and Tversky,

2013), through which firms can enhance their ability to navigate uncertainties, protect their strategic position, and capitalize on emerging opportunities. Proactive investment in innovation enables firms to stay ahead of the curve in the face of threats compounded by legal incompleteness.

First, when managers perceive high environmental threat levels under legal incompleteness, they are likely to face higher levels of uncertainty and risk. In such situations, the preference to innovate products and services that prioritize cost and value considerations for customers with limited resources becomes more pronounced as traditional approaches may not suffice to address the challenges. The combination of environmental threats and perceived legal incompleteness creates a heightened need for innovative solutions. Co-innovation capability, which involves collaborating with external partners and stakeholders, can help firms pool resources, knowledge, and expertise to co-innovate under a complex and uncertain environment.

Second, emerging markets often face resource constraints, including limited financial resources, technological capabilities, and access to global markets. These resource constraints become even more prominent in the presence of environmental threats and perceived legal incompleteness (Voss et al., 2008; Wei et al., 2017). Under environmental threats and perceived legal incompleteness, co-innovation capability provides an avenue for firms to tap into external resources, such as government R&D funding, expertise, and networks, to overcome resource limitations (Lafuente et al., 2023). By leveraging collaborative partnerships to innovate, firms can pool their resources and capabilities with external stakeholders to develop and implement frugal innovations that address the challenges posed by the environment.

Third, high environmental threats and perceived legal incompleteness contribute to increased risk and uncertainty for firms operating in emerging markets, and therefore firms may hesitate to invest in innovation on their own due to the potential risks involved and the lack of clear regulatory guidelines (Adomako et al., 2023). In such a context, leveraging co-innovation capability becomes more attractive, because firms can distribute and share the risks associated with innovation initiatives among multiple partners in a more frugal manner. Collaborative efforts allow for the complementarity of diverse perspectives, knowledge, and resources, which can help mitigate risks and uncertainty. Thus, engaging in co-innovation can help navigate the hostile and uncertain environment more effectively, leading to the development of frugal innovation. Taken together, we hypothesize that:

H4a. The relationship between perceived environmental threats and co-innovation capability is greater (more positive) under higher perceived legal incompleteness.

H4b. The strength of the mediated effect of perceived environmental threats on frugal innovation via co-innovation varies by the degree of legal incompleteness, such that the mediated effect will be stronger when legal incompleteness is higher than lower.

3. Method

3.1. Study setting

The study focused on firms located in Ghana, which represents a suitable context for studying frugal innovation in emerging economies for two key reasons. First, the Ghanaian business environment, as in many African countries, is characterized by pronounced environmental uncertainty, which subjects firms to resource constraints, intense competition, and rapid market and technological changes (Adomako et al., 2021; Matanda and Freeman, 2009). Collectively, these factors contribute to a setting replete with environmental threats (Adomako et al., 2021; Cowden et al., 2022). Second, Ghana embodies the resource limitations commonly found in developing nations, including limited access to capital, technology, and skilled labor (Amankwah-Amoah and Hinson, 2019; Robson and Obeng, 2008). Meanwhile, much like many parts of Africa, Ghana has a young and rapidly growing population with its own particular market needs. Consequently, frugal innovation becomes highly relevant in this resource-constrained context. Thus, the Ghanaian context provides a suitable context to study environmental threats and frugal innovation in a resource-constrained environment.

3.2. Sample and data collection

We conducted a survey drawing a sample from a database of 7980 registered manufacturing firms obtained from the Registrar General's Department in Ghana. We focused on manufacturing firms because of the prevalent environmental threats they encounter in Ghana, such as resource scarcity and regulatory fluctuations (Ahir et al., 2022; Sampath, 2016). The study targeted: (1) independent entities not affiliated with any company group or chain, (2) firms employing between 5 and 500 full-time employees, (3) manufacturers of tangible products engaged in productive business activities, and (4) firms with complete contact information of the chief executive officer (CEO) or a senior management officer (Story et al., 2015). Of the initial pool, 800 independent firms met the selection criteria and were chosen for participation.

The CEOs of these firms were contacted and invited to participate in the study (Chin et al., 2021). The questionnaire used in the study was developed in English because the official business language in Ghana is English. To ensure the validity and relevance of the questionnaire to firms in Ghana, we conducted pilot testing through in-depth group interviews with 14 CEOs (not included in the current study). A trained interviewer scheduled appointments with key informants, administered the questionnaire on-site and provided clarification when needed. Each interview session lasted approximately 2 h. The main informants of each firm identified and described a minimum of two new frugal products launched in the market within the last three years. To mitigate selection bias, the interviewer subsequently randomly chose one of the newly described products as the focal point for the interview. This ensured that each product had an equal chance of being selected, enhancing the objectivity and fairness of the study (Atuahene-Gima and Li, 2004).

Data collection occurred in three waves. First (T1), we contacted the CEOs of the 800 firms to gather data on the independent, moderating, and control variables. At T1, we obtained a complete survey from 366 firms. Four weeks later in the second survey (T2), top managers in areas such as engineering and business development were approached in person to fill out a survey on the mediator (co-innovation). After removing incomplete responses, we obtained 314 complete responses at T2. Consistent with the best practice in conducting mediation analysis (MacKinnon et al., 2012; Michaelis et al., 2020), and to attenuate common method variance (Podsakoff et al., 2012), we contacted the product development managers or marketing managers in person 12 months later after T1 (i.e., T3) to gather information on the dependent variable (i.e., frugal innovation) and the control variables. A total of 301 firms (response rate: 37.62 %) provided complete and matched responses.

Table 1 presents the descriptive statistics of the sample. On average, these firms had been operating for 9 years, employed over 160 full-time staff members, and generated an average annual turnover of U.S.$ 423,456. The sampled firms operated in high-tech (31.6 %) and low-tech (68.4 %) industries. Approximately 43 % of the firms reported that export sales accounted for >50 % of their total sales. The average age of CEOs was 42 years, and 61.5 % were males and 38.5 % were females.

To assess the potential influence of non-response bias, we conducted a comparative analysis between early and late respondents from our

Table 1
Descriptive statistics.

Variables	Obs	Mean	Std. Dev.	Min	Max	p1	p99	Skew.	Kurt.
Frugal innovation	301	1.594	0.296	0.847	2.306	0.944	2.181	−0.012	2.488
Environmental threats	301	4.891	0.939	1.333	7	2.667	6.667	−0.266	3.059
Co-innovation	301	4.680	0.874	2	6.750	2.750	6.750	0.280	2.782
Legal incompleteness	301	2.9634	0.894	8	27	9	26	0.005	2.556
Start-up	301	0.671	0.471	0	1	0	1	−0.728	1.531
CEO age	301	42.296	7.877	28	68	30	64	0.658	3.352
CEO education	301	2.362	1.216	1	5	1	5	0.373	1.992
CEO gender (male)	301	0.615	0.487	0	1	0	1	−0.471	1.222
Export orientation	301	0.429	0.496	0	1	0	1	0.289	1.083
Technology capability	301	2.386	0.651	12	25	13	25	−0.016	2.764
Environmental munificence	301	2.938	0.795	6	21	8	20	−0.044	2.655
Firm size (logged)	301	4.606	1.075	1.609	6.215	1.609	6.215	−0.619	3.558
Firm age (logged)	301	2.036	0.603	0.693	3.219	1.099	3.135	0.054	1.934
Industry (low-tech)	301	0.684	0.466	0	1	0	1	−0.793	1.630

final sample, considering late responses as being more similar to non-responses (Kanuk and Berenson, 1975). Using Pearson's chi-square test for categorical variables (Greenwood and Nikulin, 1996), our analysis indicated no significant differences between early and late respondents in terms of firm age, firm size, and industry type (low-tech vs high-tech). As such, non-response bias does not pose a significant concern for the validity of our results (Rogelberg and Stanton, 2007).

3.3. Measures

For all multi-item constructs, unless stated otherwise, a seven-point Likert scale was used for measurement, with scale anchors ranging from 1 = strongly disagree to 7 = strongly agree. Our study assesses perception measures for several critical reasons. First, perceptual measures offer valuable insights that extend beyond financial metrics, capturing nuanced aspects of frugal innovation that objective indicators may overlook. These measures are typically more readily available and have demonstrated strong reliability and validity (Adomako and Ahsan, 2022; Dess and Robinson Jr., 1984). Second, managers' perceptions significantly influence their strategic decisions and actions (Daft & Weick, 1984; Kraus et al., 2012; Wang et al., 2017).

The way managers interpret their environment has substantial managerial consequences (Boso et al., 2013). Third, in emerging markets like Ghana, secondary data are often scarce or inconsistent, making perception-based data essential for analyzing firm leaders' actions (Adomako and Ahsan, 2022; Zhang et al., 2021). Studying perceptual variables also facilitates cross-industry comparisons amidst diverse economic and market contexts, as secondary data can face challenges due to contextual differences (Beard and Dess, 1981). Thus, the use of perception measures in our study provides a practical and insightful approach to understanding frugal innovation in emerging markets. The items, along with their validity and reliability measures, are presented in Table 2.

Environmental threats (t1). We measured environmental threats with a three-item scale from Voss et al. (2008) and Adomako et al. (2021, 2024a). The scale evaluates the current environmental conditions in the business operating environment.

Legal incompleteness (t1). The scale measuring legal incompleteness was taken from Wei et al. (2017). Four items were used to capture the legal incompleteness construct, highlighting the absence of formal institutional elements such as laws, policies, and their interpretation in implementations.

Co-innovation capability (t2). Following Chang et al. (2022), we captured a firm's co-innovation capability with four items, which provide an evaluation of the firm's co-innovation practices.

Frugal innovation (t3). We measured frugal innovation with five items from previous studies (Cai et al., 2019; Ernst et al., 2015). These items focus on firms that create high-quality, cost-effective solutions that are well-suited to resource-constrained environments or low-income customer segments.

Control variables. To account for various factors that could potentially influence our research model, we included several control variables. These variables encompassed firm size, firm age, industry type, export market orientation, start-up, technological capability, environmental munificence and CEOs' age and gender. We control for firm size, age, and industry, as these factors may be associated with frugal innovation (e.g., Adomako et al., 2024a). Firm size was quantified by log transformation of the number of full-time employees in each firm. Firm age was measured as the log transformation of the number of years of the firm since its establishment. The industry type was categorized into low-tech (coded as 0) and high-tech (coded as 1). Additionally, we controlled for export market orientation because it has the potential to influence innovation activities (Boso et al., 2013; Damijan et al., 2010). Export market orientation was evaluated by asking respondents to indicate whether the firm's export sales accounted for >50 % of its total sales.

We controlled for start-up status because previous research suggests that the first five years of a new venture's existence is a critical period for its development (Shrader et al., 2000) and innovation activities. In line with the approach taken by Zhou et al. (2017), we used a binary variable to determine whether a firm was established as a new venture within the past five years (1 = yes; 0 = no). We also controlled for technological capability as it could affect how firms engage in innovation (Lozada et al., 2019). Technological capability was measured using five items derived from Zhou and Wu (2010). Finally, environmental munificence was included in our model as the task environment factors have the potential to cause omitted variable bias and it may influence frugal innovation (Farooq, 2017; Welter et al., 2016). Environmental munificence was assessed using three items adapted from Baum and Locke (2004).

We controlled for two individual-level variables (i.e., CEO age, and gender) considering that they are potential indicators of decision-making confidence, which may matter for innovation initiatives (Oesterle et al., 2016). For example, older CEOs might have accumulated more experience throughout their professional careers, which could also influence decisions related to frugal innovation activities (Adomako et al., 2024a). CEO age was measured as the number of years of the CEO while gender was captured as 0 = female and 1 = male.

3.4. Reliability and validity assessment

We used the LISREL 8.5 statistical software with maximum likelihood estimation to conduct a confirmatory factor analysis (CFA) on all items. The model's adequacy was assessed using the conventional chi-square test, along with other approximate fit indicators (Bagozzi and Yi, 2012). The results indicated a good fit for the model, with a non-significant chi-square value ($\chi2 = 192.72$, d.f. = 159, normed $\chi2$ [$\chi2$/d.f.] = 1.21, $p > 0.05$) and acceptable values for other fit indices (root mean square error of approximation [RMSEA] = 0.05, non-normed fit

Table 2
Constructs, reliability, and validity.

Details of measurement items	Factor loading	Cronbach's α	CR	AVE	HSV
Environmental threat (Voss et al., 2008)		0.81	0.81	0.60	0.17
Please indicate your level of agreement with these statements related to your current business environment					
The current operating environment is particularly hostile	0.65				
The current overall business environment is an opportunity (r)	0.89				
The venture's economic environment is promising (r)	0.77				
Frugal innovation (Cai et al., 2019; Ernst et al., 2015)		0.91	0.92	0.71	0.22
Please indicate your level of agreement with these statements related to your company's innovation activities					
The innovation product has a drastically lower price compared to the mainstream products in the market	0.77				
The innovation product offers similar functionalities compared to the mainstream products in the market	0.89				
The innovation product is at lower costs for resource-constrained customers	0.80				
The innovation product provides new value to low-income customers	0.87				
The innovation product is affordable for the low-income population	0.88				
Legal incompleteness (Wei et al., 2017)		0.82	0.83	0.55	0.17
Please indicate your level of agreement with these statements related to your company's business context. In the past 3 years:					
The laws and regulations have been incomplete	0.77				
Voids in the laws and regulations have persisted	0.74				
The regulations and policies have not been specific enough to rely on	0.75				
The regulations and policies have not been specific enough to guide practices	0.72				
Co-innovation capability (Chang et al., 2022)		0.86	0.87	0.62	0.20
Please indicate your level of agreement with these statements related to your company's co-innovation activities					
Our company has integrated the needs of partner organizations in developing new products or services.	0.78				
We frequently apply advice from partner organizations in co-creating new products or services.	0.80				
We frequently integrate stakeholder needs into our innovation process.	0.77				
We receive advice from external stakeholders in our R&D activities	0.81				
Technological capability (Zhou and Wu, 2010)		0.87	0.88	0.60	0.09
Compared to your major competitors, how would you evaluate your firm's capabilities in the following areas					
Acquiring important technology information	0.79				
Identifying new technology opportunities	0.80				
Responding to technology changes	0.76				
Mastering the state-of-art technologies	0.82				
Developing a series of innovations constantly	0.83				
Environmental munificence (Baum and Locke, 2004)		0.87	0.88	0.71	0.12
Rate the following in terms of their impact on your current business situation					
Level of market demand	0.85				
Degree of community support	0.89				
Availability of financial resources	0.80				

Note: AVE = average variance extracted; CR = composite reliability; HSV = highest shared variance.

index [NNFI] = 0.94, comparative fit index [CFI] = 0.95, standardized root mean square residual [SRMR] = 0.06). Reliability, convergent validity, and discriminant validity assessments were conducted for all constructs. Significant factor loadings at the 1 % level were observed for each item, indicating convergent validity (Table 2). Furthermore, the composite reliability (CR) values for each construct exceeded the recommended threshold of 0.70, confirming construct reliability (Fornell and Larcker, 1981). Discriminant validity was evaluated using Fornell and Larcker's (1981) test, comparing the average variance extracted (AVE) for each construct against the highest shared variance (HSV) between construct pairs. The results demonstrated discriminant validity in both samples, as the AVE for each construct exceeded the HSV between construct pairs.

3.5. Common method variance assessment

We took several additional steps to mitigate common method bias concerns. First, we separately collected data on the independent, mediating, and dependent variables in a 3-wave data collection effort. Podsakoff et al. (2012) suggest that this time separation helps to reduce biases such as consistency patterns and illusion correlations. Second, the data were not significantly correlated using Harman's (1967) single-factor test. In addition, we conducted a general factor covariate test following Podsakoff et al. (2012). We found our results to be consistent with the main findings when we included the first unrotated factor in our models as a control. Lastly, based on Siemsen et al. (2010), common method variance bias does not present a problem for the interaction effect, as it tends to make the testing of the interaction effect more conservative.

4. Results

Table 3 presents the pairwise correlations. The results in column 1 show that environmental threats ($\beta = 0.29, p < 0.01$), co-innovation

Table 3
Correlations of the variables.

	Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1	Frugal innovation	1.000													
2	Environmental threats	0.293***	1.000												
3	Co-innovation	0.573***	0.521***	1.000											
4	Legal incompleteness	0.527***	0.290***	0.535***	1.000										
5	Start-up	−0.238***	−0.169***	−0.309***	−0.292***	1.000									
6	CEO age	−0.023	−0.037	−0.086	0.102*	−0.080	1.000								
7	CEO education	−0.284***	−0.276***	−0.277***	−0.229***	0.279***	−0.067	1.000							
8	CEO gender (male)	0.079	−0.038	0.033	0.000	−0.191***	0.028	−0.079	1.000						
9	Export orientation	−0.014	0.074	0.037	0.001	0.035	−0.022	0.090	−0.004	1.000					
10	Technology capability	0.220***	0.039	0.122**	0.127**	−0.098*	0.060	−0.073	0.005	−0.072	1.000				
11	Environmental munificence	0.493***	0.291***	0.573***	0.562***	−0.293***	−0.031	−0.228***	0.070	0.029	0.092	1.000			
12	Firm size (logged)	−0.035	0.172***	0.116**	0.048	0.050	0.049	−0.007	−0.046	−0.076	0.126**	0.050	1.000		
13	Firm age (logged)	−0.143**	−0.104*	−0.187***	−0.149***	0.500***	−0.005	0.198***	−0.143**	0.093*	−0.044	−0.228***	0.067	1.000	
14	Industry	0.145**	−0.157***	−0.185***	0.117**	0.011	−0.053	0.102*	−0.053	0.126**	0.065	−0.144**	0.024	−0.008	1.000

*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

capability ($\beta = 0.57, p < 0.01$), and legal incompleteness ($\beta = 0.53, p < 0.01$) have significant positive correlations with frugal innovation. Relating to a few control variables, technology capability ($\beta = 0.22, p < 0.01$) and environmental munificence ($\beta = 0.49, p < 0.01$) are also positively correlated with frugal innovation. Also, in column 2, environmental threats have a significant positive effect on co-innovation ($\beta = 0.52, p < 0.01$). Legal incompleteness also correlates with co-innovation capability ($\beta = 0.54, p < 0.01$). The mean-variance inflation factor (VIF) is 1.46, significantly below the acceptable threshold of 10 (Belsley et al., 2005; Neter et al., 1985). This indicates that there is no significant concern regarding multicollinearity.

Table 4 shows the baseline results. In Models 6–10, we followed previous studies (see Jha et al., 2023) to winsorize our dependent variable to mitigate concerns about outliers. The results after winsorization were identical to the estimations in Models 1–5 (Table 4), ruling out concerns that any findings may be a result of a few outliers. Table 5 shows the mediation coefficients including the confidence interval from the estimation by SEM and Medsem, in addition to the Sobel-Monte-Carlo test based on Baron and Kenny (1986). Table 6 presents the path coefficients of the moderated mediation estimation. Table 6 also reports the biased-corrected confidence interval (Model 7) of the mediation effect, including the parametric mediation coefficients that test for a causal effect of the controlled direct, natural indirect and total effects of Model 6. We report the moderated-mediated bootstrap confidence interval in Table 7.

We performed several robustness tests to assess the sensitivity of our findings to different specifications and to address potential endogeneity concerns. First, we split our sample into firm structure or status (start-up and established firms). We also split our sample into SMEs and large firms, following the World Bank to benchmark both firm sizes. Finally, we report in Fig. A1 the distribution of items within the sample, which was relatively balanced and complemented with the covariances between dimensions (see Table A4). The supplementary analyses for firm status are in Tables A1 and A2, and a three-way interaction to ascertain the robustness of our main estimations is in Table A3.

4.1. Hypothesis testing

We tested H1, H2 and H4a using Ordinary Least Squares (OLS) with cluster robust standard errors in a stepwise order (Chen et al., 2022). The mediation and moderated mediation (H3 and H4b) were tested with structural equation modelling with predictive margins using Stata 16. In H1, we proposed that environmental threats would be positively associated with co-innovation. Results in Model 2 in Table 4 show that environmental threat was positively related to co-innovation capability ($\beta = 0.32, p < 0.001$), supporting H1. In H2, we hypothesized that co-innovation has a positive relationship with frugal innovation. The results in Model 3 (Table 4) show that co-innovation has a positive and significant effect on frugal innovation ($\beta = 0.84, p = 0.001$), supporting H2.

In H3, we predicted that co-innovation capability mediates the positive relationship between perceived environmental threats and frugal innovation. We build on Wang et al. (2022) to estimate our mediation effect. Hence, we performed a mediation estimation using Stata 16. To estimate this, SEM and Medsem were run simultaneously (Table 5) to estimate the mediation effect and the 95 % confidence interval. The results show that the indirect effects were positive and significant, supporting H3—Sobel ($\beta = 0.273, SE = 0.061, p = 0.001$) and Monte-Carlo ($\beta = 0.274, SE = 0.062, p = 0.001$). In addition, the ratio of indirect to total effects (RIT) indicates about 93 % of the effect of environmental threats on frugal innovation was mediated by co-innovation capability. The proportion of the indirect effect to direct effect (RID) reveals that the mediated effect of co-innovation capability was 13.3 times as large as the direct effect between environmental threats and frugal innovation. To further validate our results, we performed a causal mediation analysis (see Liu et al., 2014). While the

Table 4
Regression results.

	Frugal innovation	Co-innovation	Co-innovation	Frugal innovation	Frugal innovation	Frugal innoW	Co-innoW	Co-innoW	Frugal innoW	Frugal innoW*
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
	−0.005	−0.010**	−0.014***	0.006	−0.004	−0.008	−0.009**	−0.012***	0.000	−0.008
CEO age	(0.010)	(0.005)	(0.004)	(0.009)	(0.009)	(0.008)	(0.004)	(0.004)	(0.008)	(0.007)
	−0.235***	−0.037	−0.050	−0.159***	−0.165***	−0.215***	−0.048*	−0.057**	−0.152***	−0.160***
CEO education	(0.066)	(0.030)	(0.031)	(0.061)	(0.061)	(0.058)	(0.027)	(0.026)	(0.054)	(0.054)
	0.075	−0.018	−0.021	0.132	0.160	0.064	−0.056	−0.056	0.111	0.129
CEO gender (male)	(0.167)	(0.078)	(0.073)	(0.154)	(0.147)	(0.143)	(0.065)	(0.061)	(0.132)	(0.127)
	0.094	0.034	−0.021	0.005	−0.035	0.044	−0.002	−0.047	−0.030	−0.076
Export orientation	(0.168)	(0.076)	(0.070)	(0.152)	(0.144)	(0.142)	(0.065)	(0.061)	(0.129)	(0.123)
	0.121***	0.021	0.017	0.103***	0.098***	0.110***	0.012	0.008	0.095***	0.091***
Technology capability	(0.035)	(0.017)	(0.018)	(0.032)	(0.030)	(0.031)	(0.014)	(0.014)	(0.028)	(0.027)
Environmental	0.239***	0.127***	0.077***	0.115***	0.047	0.215***	0.119***	0.074***	0.111***	0.056*
munificence	(0.032)	(0.016)	(0.018)	(0.033)	(0.038)	(0.028)	(0.013)	(0.014)	(0.029)	(0.032)
	−0.119	0.033	0.044	−0.188***	−0.171**	−0.090	0.020	0.029	−0.148**	−0.133**
Firm size (logged)	(0.088)	(0.045)	(0.043)	(0.069)	(0.067)	(0.076)	(0.036)	(0.034)	(0.060)	(0.059)
	0.227	0.094	0.042	0.142	0.062	0.131	0.084	0.037	0.061	−0.004
Firm age (logged)	(0.201)	(0.081)	(0.070)	(0.186)	(0.174)	(0.166)	(0.071)	(0.062)	(0.155)	(0.148)
	−0.440*	−0.313***	−0.155	−0.126	0.066	−0.293	−0.267***	−0.129	−0.031	0.133
Start-up	(0.265)	(0.108)	(0.095)	(0.242)	(0.230)	(0.221)	(0.096)	(0.085)	(0.204)	(0.196)
	0.274	0.147*	0.121	0.078	0.070	0.276*	0.144**	0.122*	0.113	0.103
Industry (low-tech)	(0.179)	(0.085)	(0.080)	(0.167)	(0.153)	(0.150)	(0.072)	(0.068)	(0.139)	(0.128)
Environmental threats (		0.316***	−0.570***		−0.761*		0.241***	−0.482***		−0.777**
H1)		(0.055)	(0.211)		(0.404)		(0.040)	(0.156)		(0.349)
				0.843***	0.622***				0.703***	0.510***
Co-innovation (H2)				(0.110)	(0.129)				(0.093)	(0.115)
			−0.191***		−0.110			−0.149***		−0.140
Legal incompleteness			(0.051)		(0.114)			(0.039)		(0.099)
Environmental threats			0.048***		0.044*			0.039***		0.045**
* legal										
incompleteness (H4)			(0.011)		(0.022)			(0.008)		(0.019)
	5.107***	1.392***	5.833***	2.792***	6.969***	5.780***	2.117***	5.715***	3.849***	8.144***
Constant	(0.920)	(0.525)	(1.221)	(0.969)	(2.371)	(0.797)	(0.399)	(0.880)	(0.828)	(2.074)
Observations	301	301	301	301	301	301	301	301	301	301
R-squared	0.327	0.499	0.563	0.445	0.495	0.353	0.514	0.581	0.463	0.509
RMSE	1.379	0.63	0.59	1.255	1.203	1.164	0.532	0.496	1.062	1.021
Adj R2	0.304	0.48	0.544	0.423	0.47	0.331	0.495	0.562	0.443	0.485
F-stat	16.659***	30.593***	33.609***	25.069***	28.00***	20.337***	40.25***	45.816***	30.591***	35.704***
Ll	−518.326	−281.92	−261.167	−489.382	−475.162	−467.303	−231.18	−208.837	−439.117	−425.773

Note: W = the dependent variable was winsorized in case of outliers. Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table 5
Mediation of co-innovation on frugal innovation with bootstrap confidence interval.

	Delta	Sobel	Monte Carlo
Indirect effect	0.273	0.273	0.274
Std. Err.	0.065	0.061	0.062
z-Value	4.19	4.472	4.418
p-Value	0.0000	0.0000	0.0000
Conf. Interval	[0.145, 0.401]	[0.153, 0.393]	[0.159, 0.398]

controlled direct effect was not significant, the natural indirect effect was positive and significant ($\beta = 0.206, SE = 0.06, p = 0.001$). Similarly, the total effect was also positive and significant ($\beta = 0.208, SE = 0.09, p = 0.021$). The bias-corrected confidence interval supported our natural indirect and total effects (Table 6, Models 6 and 7). Also, with the parametric estimation, we found the effect of environmental threats on co-innovation capability—H1 ($\beta = 0.71, SE = 0.11, p = 0.001$) to follow the same statistical pattern as our baseline estimation, including the effect of co-innovation capability on frugal innovation—H2 ($\beta = 0.29, SE = 0.042, p = 0.001$).

In H4a, we proposed that the effect of environmental threats on co-innovation is higher under more legal incompleteness. In Model 4 (Table 4), we tested the moderating effect of legal incompleteness on the relationship between environmental threats and on co-innovation capability. The moderating coefficient was positive and significant in Model 4 ($\beta = 0.048, SE = 0.01, p = 0.001$), supporting the first part of H4a. The moderating effect of legal incompleteness is conceivably best illustrated with the help of a visual representation as in Fig. 2. As observed in Fig. 2, at a high level of legal incompleteness, the relationship between environmental threats and co-innovation was larger compared to when legal incompleteness was low. This confirmed the overall effect of H4a.

Finally, we tested the moderated mediation hypothesis in H4b. We predicted that the positive relationship between environmental threats and frugal innovation is mediated by co-innovation capability when legal incompleteness is high rather than low. To test this first-stage moderated mediation, we first examined the moderating effect of legal incompleteness on the relationship between environmental threats and frugal innovation, after which we ran the moderated mediation, using SEM. First, in Model 5, Table 4, we can confirm the first-stage moderating effect holds ($\beta = 0.044, SE = 0.02, p = 0.051$). We further visualized the relationship in Fig. 3. We showed that the relationship between environmental threats and frugal innovation is stronger at a higher level of legal incompleteness, especially when observed at the tail of the slope.

We further assessed the moderated mediation in Table 6, Models 1–5. The *environmental threats*legal incompleteness* coefficients were significantly positive on co-innovation ($\beta = 0.057$, $SE = 0.01$, $p =$

Table 6
Moderated-mediation and robustness for mediation effects.

	Frugal inno	Co-inno	Co-inno	Frugal inno	Paramed	Bias-corrected CI
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Co-innovation	0.843***			0.735***		
	(0.129)			(0.127)		
Environmental threats	0.021	0.324***	−0.652***	−0.726*		
	(0.093)	(0.053)	(0.198)	(0.395)		
var(e.Frugal innovation)	1.514***			1.520***		
	(0.153)			(0.123)		
var(e.Co-innovation)		0.391***	0.394***			
		(0.035)	(0.039)			
Legal incompleteness			−0.204***	−0.078		
			(0.052)	(0.115)		
Environmental threats * legal incompleteness			0.057***	0.042*		
			(0.010)	(0.022)		
Controlled direct effect (cde)					0.002	[−0.169, 0 0.188]
					(0.093)	
Natural indirect effect (nde)					0.206***	[0.108, 0.336]
					(0.058)	
Total effect(te)					0.208**	[0.038, 0.382]
					(0.089)	
Constant	2.677***	1.290**	6.447***	7.308***		
	(0.993)	(0.515)	(0.959)	(2.165)		
Observations	301	301	301	301	301	

Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table 7
Bootstrapped moderated-mediation results.

Coefficient		Bias	Std. Err.	[95 % Confidence Interval]		
Index of moderation mediation	0.0204	0.0003	0.0063	0.0095	0.0338	(P)
−1SD	0.0449	0.0026	0.0308	−0.0165	0.1061	(P)
Mean	0.1308	0.0015	0.0330	0.0699	0.1985	(P)
+1SD	0.2166	0.0004	0.0512	0.1219	0.3224	(P)

(P): percentile confidence.

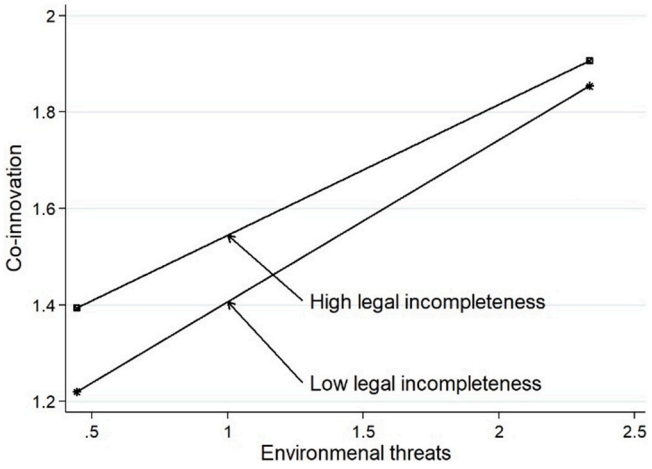

Fig. 2. Predicted co-innovation at different combinations of legal incompleteness and environmental threats (moderating effects).

0.001) and frugal innovation ($\beta = 0.042$, $SE = 0.02$, $p = 0.061$), respectively. The estimated variance coefficients for frugal innovation and co-innovation were also positive and significant, confirming the strength of these results. The bootstrap moderated-mediation coefficients with 10,000 replications (Table 7) reveal the estimated

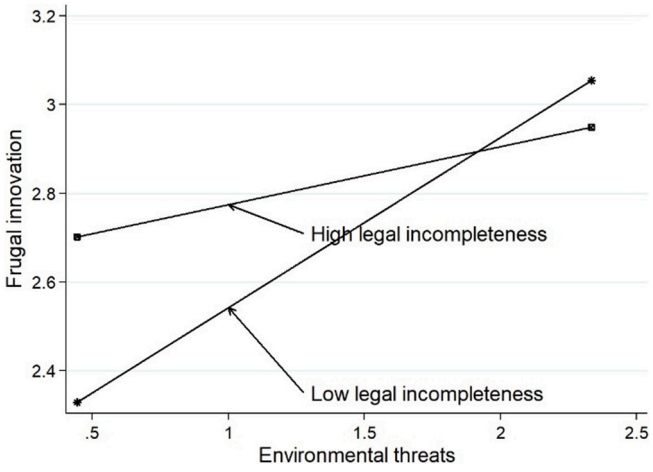

Fig. 3. Predicted frugal innovation at different combinations of legal incompleteness and environmental threats (moderating effects).

coefficients across various levels of the moderator. In addition to the bootstrap replications and the core coefficients reported, we generated the predictive margins of the moderated mediation (Fig. 4). As shown in the figure, at a higher level of legal incompleteness via co-innovation, the slopes were steeper upward, confirming H4b.

4.2. Test for omitted variable bias

To assess if our model suffered from omitted variable bias, we used the Ramsey reset test that employed the powers of the fitted values of frugal innovation. Our test was first carried out on the effect of environmental threats on frugal innovation, including all covariates. The test statistics indicated that our model was free from omitted variable bias, with the following test values: *F-statistics = 17.09, p-value = 0.001*. In addition, to ensure the relationship was not driven by either the linear or non-linear relationship, we further generated the squared and cubed terms of environmental threats (primary independent variable). The

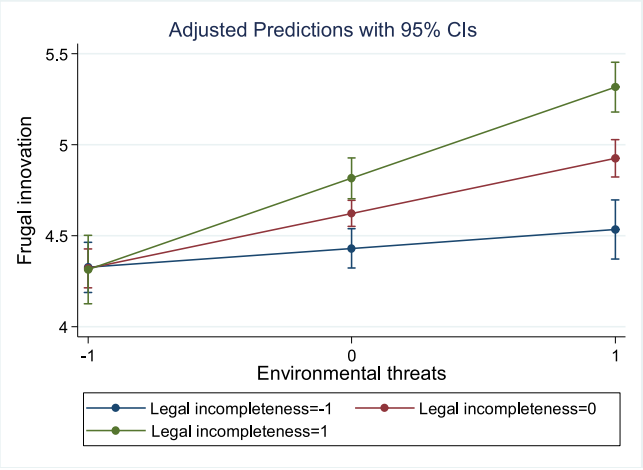

Fig. 4. Predicted frugal innovation at different combinations of legal incompleteness and environmental threat via co-innovation (moderated-mediation).

non-linear variables were plugged into our model, including the linear terms of environmental threats and tested with the Ramsey reset test for omitted variable bias. We ran the regression and tested the three terms in the equation for omitted variable bias (Cinelli and Hazlett, 2020; Feigenberg et al., 2023).

The test statistics confirm that our model was free from omitted variable bias *(F-statistics = 13.13, p-value = 0.001)* after regressing frugal innovation on environmental threats, its second-order and third-order terms and the covariates. We used the same step to test for our mediator and frugal innovation. The test statistics confirm that our model did not suffer from omitted variable problems. We observed the following test values on the linearity of co-innovation capability, including the control variables: *F-statistics = 92.34, p-value = 0.001*. For co-inno, co-inno^2, co-inno^3 and co-variates, the test values were *F-statistics = 61.60, p-value = 0.001*. To further confirm the results of the Ramsey reset test, we visualized the estimated fitted values of the squared and cubed terms. Subsequently, we grouped them by the average of each variable (i.e., environmental threats and co-innovation). The visualization suggests the model is unlikely to suffer from omitted variable bias (Figs. A1 & A2), confirming the initial test statistics.

4.3. Instrumental variable tests

Following previous studies (e.g., Semadeni et al., 2014; Zhang et al., 2021) that breakdown firms based on industries and use each industry average as instruments to test for endogeneity concerns, we obtained the industry averages of our independent variables as possible instruments on co-innovation and frugal innovation. In Table A5, Model 1, we observed that the environmental threats at the industry level was positively related to individual firms' environmental threats ($\beta = 0.51$, $SE = 0.04$, $p = 0.001$). Similarly, the industry average of co-innovation capability at the industry level is positively related to individual firms' co-innovation in Model 2 ($\beta = 0.39$, $SE = 0.04$, $p = 0.001$). The F-statistics for each model confirmed the relevance of the instrument. We further probed whether our instruments were relevant to the IV diagnostic tests. The first-stage F-statistics in Models 3–6 were 191.04, 77.43, 22.84, and 99.81, all exceeding 10. Thus, the instruments used in this study are deemed strong for checking endogeneity concerns.

Furthermore, we tested the instruments to ascertain how the results converge with our baseline hypothesis analysis (Table 4). In Model 3, we regressed co-innovation capability on environmental threats, and the results were positive and significant ($\beta = 0.24$, $SE = 0.067$, $p = 0.001$). This finding confirms H1. In Model 4, we regressed frugal innovation on co-innovation capability. The coefficient was positive and significant ($\beta = 0.67$, $SE = 0.23$, $p = 0.001$). Further, we tested how legal incompleteness moderates the link between environmental threats and co-innovation. The results in Model 5 ($\beta = 0.086$, $SE = 0.039$, $p = 0.026$) confirm the moderation effect of legal incompleteness. Additionally, in Model 6, we checked the moderating effect of legal incompleteness on the relationship between co-innovation and frugal innovation ($\beta = 0.025$, $SE = 0.006$, $p = 0.001$). These results confirm both moderation effects in the main findings (Table 4).

We tested for the exogeneity of the instruments. Table A5 shows that our choice of instruments was adequate, and all instruments were exogenous without rejecting the null hypothesis that our instruments were exogenous. For the exogeneity test of environmental threats in Model 3, the Durbin ($\beta = 2.129$, $p = 0.145$) and Wu-Hausman ($\beta = 2.051$, $p = 0.3153$) tests were not significant, confirming the exogeneity of the instrument. We also confirmed the exogeneity of co-innovation capability in Model 4 (Durbin—$\beta = 0.719$, $p = 0.340$; Wu-Hausman—$\beta = 0.690$, $p = 0.407$), and environmental threats in Model 5 (Durbin—$\beta = 1.099$, $p = 0.295$; Wu-Hausman—$\beta = 1.048$, $p = 0.309$), and in Model 6 (Durbin—$\beta = 0.382$, $p = 0.536$; Wu-Hausman—$\beta = 0.363$, $p = 0.549$). Finally, in the first stage, the results of the instruments on the potentially endogenous variable(s) are, by and large, significant, suggesting the relevance of the instruments. Also, Cragg–Donald F-statistics show that the instruments are relatively strong in all models. Moreover, Sargan statistics suggest that the instruments are exogenous in all models ($p > 0.10$) (Zhang et al., 2021). Moreover, neither Durbin nor Wu–Hausman tests can be rejected in any model ($p > 0.10$), suggesting that the relationship between environmental threats and co-innovation on frugal innovation is not significantly biased due to endogeneity (Zhang et al., 2021).

4.4. Split sample tests and further moderating tests

First, we split our sample into firm status (start-ups and established firms). The results of these analyses are in line with our main findings (Table A1). We found a significantly positive relationship between environmental threats and co-innovation for both start-ups (Model 2: $\beta = 0.22, SE = 0.06, p = 0.000$) and established firms (Model 7: $\beta = 0.47, SE = 0.1, p = 0.001$), as well as co-innovation capability and frugal innovation for both start-ups (Model 3: $\beta = 0.79, SE = 0.16, p = 0.001$) and established firms (Model 8: $\beta = 0.96, SE = 0.14, p = 0.001$). The coefficient of the moderating effect of environmental threats and legal incompleteness on co-innovation capability for start-ups (Model 4: $\beta = 0.045, SE = 0.02, p = 0.008$) and established firms ($\beta = 0.037, SE = 0.019, p = 0.063$) are similar.

Furthermore, we split our sample into SMEs and large firms (Table A2), using the traditional scale from the World Bank to benchmark both firm sizes. SMEs are categorized as firms with employees <249 and large firms with employees >249. In comparing the effects using both firm sizes, we found environmental threats to positively relate to co-innovation for SMEs in Model 2 ($\beta = 0.37, SE = 0.06, p = 0.001$) but not large firms. We observed a positive effect of co-innovation capability on frugal innovation for both firm sizes (Models 3 & 8). Regarding the interaction of environmental threats and legal incompleteness, the results were positive and significant on co-innovation capability for SMEs in Model 4 ($\beta = 0.053, SE = 0.011, p = 0.001$) as well as for large firms in Model 9 ($\beta = 0.054, SE = 0.026, p = 0.043$).

To further assess if the sub-group differences are statistically significant, we performed a three-way regression on our mediation and moderated-mediation effects (Table A3). There were no observed significant effects across the moderated variables, confirming the robustness of our main findings.

Finally, to check if the type of collaborators may significantly alter our findings, we performed an additional analysis to examine the role of university collaboration. First, we identified whether the focal firm was located in a city with at least one research-driven university. Not all cities in Ghana are home to research-driven universities. Consequently,

it is understandable that firms in these cities might find it more challenging to form partnerships with research-intensive universities as collaborators. To explore whether our findings would differ based on the presence of research-driven universities, we used cohabitation with such universities in the same city as a variable. Our hand-collected data includes the location of each firm, and we compiled a database indicating whether those cities have research-driven universities. We then conducted an additional analysis comparing our findings between firms located in cities with and without research-driven universities. The results in Table A4 suggest that the differences are not statistically significant, indicating that the roles of university collaboration, a type of collaboration, may not significantly alter the main findings.

5. Discussion

We draw on the strategy tripod view, which integrates the industry-based, resource-based, and institution-based perspectives into a comprehensive theoretical framework (Peng et al., 2009) to theorize the relationship between environmental threats and frugal innovation. We further investigate the boundary conditions of this relationship in legal incompleteness as well as the mediating role of co-innovation capability. The empirical results of our study support the main proposition. Specifically, we found that firms facing higher levels of environmental threats conduct more frugal innovation. This relationship between environmental threat and frugal innovation is mediated by co-innovation capability and is amplified under high perceived legal incompleteness. Together, these findings carry important theoretical and practical implications for understanding the impact of environmental threats on frugal innovation in emerging markets.

We first discuss the contrasting findings of our study, compared to previous research on the impact of environmental threats and institutional voids on innovation, which can be attributed to our specific focus on frugal innovation facilitated by co-innovation capabilities. Unlike general innovation efforts that may be hindered by resource constraints and institutional deficiencies, frugal innovation is a strategic response to such challenges, leveraging resource-scarce approaches and collaborative partnerships to meet local market needs (Ernst et al., 2015; Hossain, 2018). Our results suggest that environmental threats and institutional voids can serve as catalysts for firms to engage in frugal innovation through co-innovation, as a means of navigating and thriving in constrained contexts.

5.1. Implications for theory

Our research contributes to the existing literature in several ways. First, this study extends the scope of the frugal innovation literature (Agnihotri, 2015; Hossain, 2020; Neumann and Gassmann, 2022; Vesci et al., 2021) by exploring how environmental threats as a specific source of environmental uncertainty foster frugal innovation. Previous studies have failed to adequately address the influence of different sources of environmental uncertainty on frugal innovation activities (Freel, 2005; Van Rijnsoever et al., 2012). Our research advances this line of inquiry by specifically examining environmental threats as a major source of environmental uncertainty for frugal innovation. This extension is crucial because previous studies have primarily focused on weak R&D capabilities as major drivers of frugal innovation in emerging markets (Adomako et al., 2024a; Zeschky et al., 2014). Consequently, our research underscores the importance of threat perceptions in shaping frugal innovation activities. We demonstrate that environmental threats, conventionally viewed as external pressures, are strategic determinants that mold a firm's innovative trajectory. Our evidence suggests that these threats are not merely factors to which firms react defensively but are critical elements that can be leveraged to proactively enhance co-innovation capabilities. This is counter to the prevailing belief that environmental pressures serve only to constrain firm behavior; instead, we reveal that they can act as catalysts for strategic innovation development. Our view counters the conventional wisdom that advocates for a reactive stance towards environmental threats, especially in contexts where R&D capabilities are inherently limited; instead, our findings suggest that such threats can spur firms to adopt a proactive and risk-embracing posture, echoing individual-level studies (e.g., Kahneman and Tversky, 2013). The implications of our study challenge the prevailing understanding by reframing environmental threats from risk factors to strategic levers that can enable firms to pull together their limited R&D capabilities and foster frugal innovation. This strategic response to environmental threats is not just a survival tactic but a deliberate, strategic choice to navigate and exploit environmental threats to the firm's advantage.

Second, our study sheds light on the significance of co-innovation as a possible means for firms in emerging economies to innovate frugally under environmental threats. Our finding reveals that in emerging economies, the presence of environmental threats is not solely a barrier but can be a powerful instigator for the development of co-innovation capabilities, which in turn drives frugal innovation activities. This nuanced understanding extends the dialogue in the co-innovation literature by unveiling how environmental challenges can be transformed into innovative opportunities (Bossink, 2002; Lee et al., 2012). We discover that when firms perceive the environment as threatening, rather than retracting to themselves, they are likely to seek collaboration, pooling resources and capabilities with others, thereby enhancing their co-innovation potential (Lafuente et al., 2023). The role of co-innovation as a mediator is critical in identifying a deliberate adaptation mechanism by which firms navigate and counter adverse environmental conditions in emerging markets. By engaging in co-innovation, firms can assimilate diverse resources and knowledge, which is essential for fostering frugal innovations that are well-suited to the constraints of emerging markets. The mediating role of co-innovation can be counterintuitive in the context of emerging markets, where it is often assumed that limited resources and capabilities stifle innovative endeavors. On the contrary, our research suggests that limitations in these markets may incentivize firms to engage more deeply in co-innovation practices, leveraging the collective strength of partnerships to counteract the paucity of resources and institutional voids. In other words, the very environmental threats that are assumed to limit a firm's strategic maneuverability are revealed to incubate the capability for co-innovation (Bossink, 2002; Lee et al., 2012). In conclusion, by positing co-innovation as a mediating force emerging from environmental adversity, our study identifies and highlights a new pathway for firms in emerging economies to innovate in the face of environmental threats.

Third, our study adds to the existing literature on the institutional conditions under which environmental threats have a pronounced impact on frugal innovation. Our findings on the role of legal incompleteness as a moderator in the relationship between environmental threats and frugal innovation introduce a compelling twist that institutional voids, such as legal incompleteness, may not always inhibit innovation but can inadvertently stimulate it. In contexts characterized by legal incompleteness, the conventional expectation is that innovation will be stifled due to increased uncertainty and the reduced ability to observe signals related to firms' innovation activities (Anderlini et al., 2013; Wei et al., 2020). While past literature has often portrayed institutional voids as barriers to firm action (Mair et al., 2012), our findings reveal that these voids can stimulate firms to engage in innovative activities as a means of navigating and compensating for institutional deficiencies (Khanna et al., 2005). This is because the absence of robust legal frameworks often pushes firms from protecting their innovation capabilities to finding ways to utilize external capabilities. The presence of legal incompleteness can thus act as a catalyst (Sheng et al., 2011), urging firms to focus less on being protective and more proactive in their co-innovation strategies when developing affordable value products. Thus, our findings suggest that these challenges do not necessarily deter innovation; rather, they can prompt firms to engage more in co-innovation as a means of adapting and thriving in an emerging

market, offering a fresh perspective that enriches the institutional based-view literature (Peng et al., 2009, 2018). This insight challenges the traditionally held belief that robust institutional structures are a precondition for innovation, instead positing that the absence of such structures can be a driving force for innovation (Bruton et al., 2010).

Fourth, our study offers a fundamental departure from the prevalent notion of frugal innovation as a simplistic, linear and reactive behavior (George et al., 2012; Zeschky et al., 2014). We posit that frugal innovation emerges as a complex strategic outcome based on the strategy tripod view, intricately woven from the fabric of environmental threats, co-innovation capabilities, and institutional frameworks. Contrary to the simplistic notion of frugal innovation as a stopgap or makeshift innovation under resource constraints, our findings suggest that it is a more nuanced strategic response that firms harness collective intelligence and capabilities in co-innovation to create value-focused solutions. Moreover, the nuanced role of institutional frameworks, particularly legal incompleteness, as both a constraint and a catalyst, advances our scholarly understanding of what leads to frugal innovation in emerging markets (Meyer et al., 2017). Our more nuanced development on frugal innovation aligns with recent calls for a more fine-grained view of innovation in emerging markets (Prahalad and Mashelkar, 2010; Ray and Ray, 2011), moving beyond the notion of frugal innovation as a mere artifact of resource scarcity to consider the environment, the capability underpinning it, and the institutional settings in an integrated manner.

Lastly, our study enriches the strategy tripod perspective by providing new insights into the paradoxical interplay among environmental threats, co-innovation capabilities, and institutional voids in driving frugal innovation by revealing counterintuitive effects that defy traditional expectations. Specifically, we demonstrate how environmental threats, typically seen as industry constraints, can paradoxically foster the development of co-innovation capabilities, enabling firms to leverage external partnerships and pool scarce resources innovatively. Moreover, institutional voids like legal incompleteness, often portrayed as hindrances to firm actions, unexpectedly emerge as catalysts that compel firms to engage in frugal innovation through collaborative efforts as an adaptive response. This paradoxical convergence of environmental pressures, collaborative capabilities, and institutional deficiencies propels some firms to turn perceived constraints into opportunities for frugal innovation. By uncovering these counterintuitive dynamics that challenge traditional assumptions, our study provides a new understanding from the strategy tripod view, redefining our understanding of how firms can harness synergies among threats, capabilities, and voids in resource-constrained emerging markets to drive strategic innovation proactively.

5.2. Implications for policy and practice

Our study has two implications for practice. As firms international increasingly find emerging markets appealing, domestic firms need to concentrate on developing and introducing frugal innovation to capture the large price-sensitive segments in these markets. The findings of our study demonstrate that in a context characterized by environmental threats, frugal innovation can flourish through co-innovation capability. This finding underscores the significance of firm capabilities acting as a mechanism between environmental threats and frugal innovation in emerging markets. Thus, firms should consider co-innovation in such contexts. They should also reconsider their future business models to incorporate frugal innovation into their overall strategy (Markides, 2006; Williamson, 2010). This may entail a more comprehensive integration of the low-income market strategy into the core operations of firms and a heightened commitment to serving this expanding market segment, despite it being relatively new and unfamiliar (Adomako et al., 2023; Ernst et al., 2015; Prahalad, 2005). The results of this study also indicate that the impact of environmental threats on frugal innovation through co-innovation capability is influenced by both institutional and industry conditions. This implies that firms should consider the external business environment when allocating resources for frugal innovation under environmental threats. The varying effects of the institutional context on different types of frugal innovations suggest that firms should account for the institutional contexts when investing in capabilities in emerging markets.

In terms of policy, the study suggests that co-innovation capability plays a mediating role in the relationship between environmental threats and frugal product innovation. Policymakers can focus on policies and initiatives that enhance collaboration and co-innovation among different stakeholders, such as through industry–academia partnerships, public–private collaborations, and knowledge-sharing platforms. Creating a platform that facilitates knowledge exchange, technology transfer, and collaborative problem-solving can boost co-innovation capability and ultimately promote frugal innovation in emerging markets. It is important to note that while environmental threats and institutional voids may stimulate frugal innovation through co-innovation capabilities, as our findings suggest, these factors could also potentially impede external investments and overall innovation-associated revenues. Future research should explore this potential trade-off in relevant policy discussions.

5.3. Limitations and future research

Our study has identified several limitations that present opportunities for future research. First, despite employing various strategies such as theoretically derived controls, establishing theoretical and contextual boundaries, implementing survey design steps, conducting statistical tests, and employing validation surveys and time-lag to address common method bias (Podsakoff et al., 2012) and alternative explanations, we acknowledge that these limitations cannot be eliminated. We encourage future research on frugal innovation to explore the influence of additional contextual factors such as environmental dynamism and macro hostility (Kreiser et al., 2020; Michaelis et al., 2020; Zahra and Neubaum, 1998), and develop mixed-research designs.

Second, our results may be constrained to the specific empirical setting we selected, which may differ significantly from those encountered in other contexts such as developed markets. Therefore, future studies should consider using diverse samples of firms. Future research in frugal innovation must prioritize diversity in research settings, where regions like Africa remain underrepresented (Howell et al., 2018; Lange et al., 2023). The deliberate selection of Ghana as an African country in our study underscores the importance of addressing this gap and fostering a more diverse array of settings to enrich the literature. This choice not only contributes valuable evidence to the existing body of knowledge but also serves as an inspiration for future studies, encouraging the initiation of a robust stream of research on frugal innovation in Africa. Researchers are encouraged to explore various African contexts to further broaden the understanding of frugal innovation phenomena and contribute to a more inclusive and comprehensive literature. To enhance the external validity of our findings, it would be valuable to expand this study to include other emerging markets such as other parts of Africa, India, and China.

Third, the scope of our current study, while broadening the understanding of co-innovation's role in fostering frugal innovation, does have certain limitations that open avenues for future research. Notably, our analysis, with its focus on the overall level of co-innovation, does not dissect the subtleties and strategic variations that different co-innovation partnerships can offer, particularly in the nuanced landscape of a developing economy. We invite future studies to explore the rich tapestry of co-innovation types, such as collaborations with peer firms, universities, suppliers, and end-users. An in-depth comparative analysis of how these relationships differ in impact under different levels of environmental threats and different institutional settings would lay a robust foundation for an ambitious and comprehensive research agenda.

Finally, we acknowledge that we have not yet examined potential

influencing factors such as institutional support and barriers to frugal innovation. For instance, in emerging markets like Ghana, where market failures are prevalent and environmental threats are high (Adomako et al., 2023), it is common for firms to exhibit opportunistic behaviors that aim to benefit from the spillovers of innovation without making equivalent investments or assuming corresponding risks (Boeing, 2016; Cai et al., 2019). To further deepen our understanding of the potential effect of frugal innovation in emerging markets, future studies should assess the level of assistance provided by public institutions in terms of financial resources and knowledge access, as well as the barriers encountered by firms in their innovation endeavors. For example, if the barriers are minimal and public support is significant, firms may be more inclined to engage in frugal innovation, even in the face of environmental threats. We encourage future researchers to join us in exploring the dynamics and interplay of these variables to enhance our understanding of this complex relationship.

5.4. Conclusion

Our study makes an important contribution to understanding how firms in emerging markets can turn environmental threats into a springboard for innovation. Our theoretical model and empirical evidence challenge the view that environmental threats merely constrain firms, showing instead that they can drive frugal innovation through co-innovation. This research moves the conversation forward by demonstrating that such threats, coupled with the lack of protection from legal frameworks, can spur alternative innovation pathways through co-innovation. This more nuanced understanding of frugal innovation, as a strategic orchestration rather than a mere reaction to limited resources, calls for scholars and practitioners alike to embrace this complexity, as it holds the key to a more grounded scholarly understanding of innovation in emerging markets.

CRediT authorship contribution statement

Samuel Adomako: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Data curation. **Stephen Kehinde Medase:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **Stephen X. Zhang:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that there is no conflict of interest to disclose for the submitted manuscript titled "How and When Adversity Breeds Ingenuity in an Emerging Market: Environmental Threats, Co-Innovation, and Frugal Innovation" to ***Research Policy***. The authors have no financial or non-financial interests that could be perceived as influencing the content or outcome of this research. This declaration is made in accordance with the policies and guidelines set forth by **Research Policy**.

Data availability

Data will be made available on request.

Appendix A

Table A1
Regression results by firm status (start-up vs. established).

	Start-up firms					Established firms				
Variables	Frugal inno	Co-inno	Co-inno	Frugal inno	Frugal inno	Frugal inno	Co-inno	Co-inno	Frugal inno	Frugal inno
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
CEO age	−0.009	0.004	−0.001	−0.011	−0.021*	0.001	−0.022***	−0.026***	0.024*	0.013
	(0.013)	(0.006)	(0.006)	(0.012)	(0.012)	(0.015)	(0.006)	(0.006)	(0.014)	(0.013)
CEO education	−0.202***	−0.017	−0.029	−0.157**	−0.170**	−0.277**	−0.091	−0.088	−0.142	−0.144
	(0.076)	(0.036)	(0.038)	(0.071)	(0.073)	(0.132)	(0.058)	(0.056)	(0.117)	(0.115)
CEO gender (male)	0.047	−0.099	−0.073	0.174	0.256	0.187	−0.036	−0.074	0.202	0.173
	(0.200)	(0.098)	(0.095)	(0.190)	(0.178)	(0.256)	(0.134)	(0.116)	(0.237)	(0.245)
Export orientation	0.011	0.111	0.048	−0.129	−0.177	0.293	0.051	−0.010	0.190	0.147
	(0.219)	(0.102)	(0.098)	(0.204)	(0.196)	(0.267)	(0.107)	(0.094)	(0.233)	(0.233)
Technology capability	0.123***	0.036*	0.033	0.094**	0.093**	0.096	−0.015	−0.023	0.117**	0.099**
	(0.042)	(0.020)	(0.021)	(0.041)	(0.038)	(0.061)	(0.027)	(0.027)	(0.047)	(0.050)
Environmental munificence	0.169***	0.104***	0.068***	0.083**	0.009	0.394***	0.156***	0.092***	0.176***	0.127**
	(0.042)	(0.021)	(0.024)	(0.039)	(0.047)	(0.041)	(0.026)	(0.027)	(0.052)	(0.062)
Firm size (logged)	−0.105	0.068	0.079	−0.181**	−0.154*	−0.111	−0.084	−0.071	−0.150	−0.142
	(0.100)	(0.056)	(0.054)	(0.076)	(0.078)	(0.163)	(0.070)	(0.060)	(0.150)	(0.145)
Firm age (logged)	0.199	0.034	−0.006	0.182	0.075	0.214	0.142	0.130	0.017	0.035
	(0.231)	(0.094)	(0.087)	(0.217)	(0.202)	(0.347)	(0.151)	(0.115)	(0.304)	(0.314)
Industry (low-tech)	0.118	0.255**	0.207**	0.152	0.232	0.595**	0.004	0.024	0.548**	0.605**
	(0.229)	(0.105)	(0.101)	(0.225)	(0.202)	(0.252)	(0.129)	(0.113)	(0.231)	(0.235)
Environmental threats		0.222***	−0.558*		−1.042*		0.467***	−0.304		−0.516
		(0.060)	(0.288)		(0.555)		(0.096)	(0.448)		(0.665)
Co-innovation				0.789***	0.621***				0.957***	0.750***
				(0.159)	(0.165)				(0.141)	(0.212)
Legal incompleteness			−0.189**		−0.196			−0.119		−0.029
			(0.077)		(0.161)			(0.097)		(0.166)
Environmental threats * legal incompleteness			0.045***		0.062*			0.037*		0.024
			(0.017)		(0.032)			(0.019)		(0.033)
Constant	5.623***	0.999	5.075***	3.969***	9.393***	3.099*	1.877**	5.727**	0.403	3.698
	(1.197)	(0.642)	(1.687)	(1.257)	(3.368)	(1.585)	(0.736)	(2.273)	(1.477)	(3.685)
Observations	202	202	202	202	202	99	99	99	99	99

(*continued on next page*)

Table A1 (*continued*)

	Start-up firms					Established firms				
Variables	Frugal inno	Co-inno	Co-inno	Frugal inno	Frugal inno	Frugal inno	Co-inno	Co-inno	Frugal inno	Frugal inno
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
R-squared	0.19	0.355	0.402	0.305	0.373	0.512	0.704	0.768	0.627	0.652
RMSE	1.383	0.632	0.612	1.285	1.23	1.307	0.546	0.489	1.149	1.13
Adj R2	0.152	0.321	0.364	0.268	0.329	0.463	0.671	0.735	0.585	0.599
F-stat	5.093***	9.717***	11.006***	8.5***	9.936***	21.665***	28.442***	36.983***	30.439***	21.544***
Ll	−346.99	−188.305	−180.579	−331.598	−321.184	−161.695	−74.712	−62.74	−148.381	−145.004

Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table A2
Regression results by firm size (SMEs vs. large firms).

	Small and medium enterprises (SMEs)					Large firms				
Variables	Frugal inno	Co-inno	Co-inno	Frugal inno	Frugal inno	Frugal inno	Co-inno	Co-inno	Frugal inno	Frugal inno
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
CEO age	−0.012	−0.013**	−0.016***	0.002	−0.006	0.038	0.007	−0.000	0.032	−0.006
	(0.010)	(0.006)	(0.005)	(0.009)	(0.009)	(0.024)	(0.009)	(0.010)	(0.025)	(0.025)
CEO education	−0.284***	−0.030	−0.054	−0.180**	−0.216***	−0.116	−0.058	−0.076	−0.065	−0.100
	(0.074)	(0.035)	(0.036)	(0.069)	(0.069)	(0.179)	(0.060)	(0.060)	(0.172)	(0.173)
CEO gender (male)	0.022	0.033	0.012	0.047	0.046	0.053	−0.123	−0.033	0.165	0.437
	(0.186)	(0.094)	(0.088)	(0.169)	(0.164)	(0.373)	(0.145)	(0.147)	(0.363)	(0.366)
Export orientation	0.045	0.069	−0.004	−0.084	−0.135	0.285	−0.029	−0.037	0.309	0.486
	(0.183)	(0.087)	(0.079)	(0.164)	(0.156)	(0.425)	(0.147)	(0.149)	(0.413)	(0.407)
Technology capability	0.134***	0.034*	0.032*	0.102***	0.102***	0.058	−0.038	−0.042	0.092	0.073
	(0.036)	(0.018)	(0.018)	(0.032)	(0.031)	(0.103)	(0.031)	(0.033)	(0.097)	(0.090)
Environmental munificence	0.211***	0.114***	0.061***	0.103***	0.040	0.324***	0.182***	0.128***	0.161*	−0.007
	(0.036)	(0.019)	(0.021)	(0.035)	(0.042)	(0.085)	(0.026)	(0.041)	(0.090)	(0.115)
Firm age (logged)	0.010	0.023	0.103***	−0.034	−0.094	0.500	0.265*	0.223	0.266	0.277
	(0.226)	(0.097)	(0.035)	(0.209)	(0.195)	(0.501)	(0.151)	(0.149)	(0.529)	(0.503)
Start-up	−0.244	−0.300**	−0.198**	0.071	0.185	−0.580	−0.392**	−0.044	−0.227	0.176
	(0.303)	(0.128)	(0.085)	(0.271)	(0.254)	(0.675)	(0.189)	(0.203)	(0.724)	(0.776)
Industry (low-tech)	0.281	0.148	0.113	0.066	0.052	0.008	−0.110	−0.091	0.107	−0.162
	(0.200)	(0.097)	(0.092)	(0.184)	(0.169)	(0.448)	(0.137)	(0.134)	(0.473)	(0.432)
Environmental threats		0.376***	−0.601***		−1.008**		0.012	−0.943**		1.060
		(0.057)	(0.214)		(0.418)		(0.087)	(0.460)		(1.696)
Co-innovation				0.830***	0.656***				0.888**	0.559
				(0.114)	(0.141)				(0.367)	(0.423)
Legal incompleteness			−0.217***		−0.182			−0.222		0.446
			(0.051)		(0.117)			(0.135)		(0.473)
Environmental threats * legal incompleteness			0.053***		0.054**			0.053**		−0.042
			(0.011)		(0.024)			(0.026)		(0.090)
Constant	5.596***	1.373**	6.310***	2.853***	8.310***	1.334	2.632***	7.540***	−1.040	−4.877
	(0.997)	(0.572)	(1.288)	(1.020)	(2.515)	(2.296)	(0.931)	(2.687)	(2.355)	(9.948)
Observations	235	235	235	235	235	66	66	66	66	66
R-squared	0.34	0.521	0.59	0.474	0.518	0.348	0.598	0.65	0.405	0.514
RMSE	1.32	0.638	0.592	1.181	1.139	1.56	0.522	0.496	1.504	1.397
Adj R2	0.314	0.5	0.569	0.451	0.489	0.243	0.525	0.571	0.297	0.393
F-stat	16.702***	29.36***	36.333***	28.664***	30.873***	4.13***	10.071***	12.359***	4.307***	6.054***
Ll	−393.498	−222.162	−204.105	−366.849	−356.742	−117.561	−44.7	−40.157	−114.564	−107.86

Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table A3
Three-way interaction of industry, start-up, size and environmental threats, legal incompleteness on frugal innovation.

	Industry		Start-up		Size	
	Co-inno	Frugal inno	Co-inno	Frugal inno	Co-inno	Frugal inno
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
CEO age	−0.013***	−0.003	−0.014***	−0.004	−0.015***	−0.005
	(0.005)	(0.009)	(0.005)	(0.009)	(0.005)	(0.008)

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Table A3 (*continued*)

	Industry		Start-up		Size	
	Co-inno	Frugal inno	Co-inno	Frugal inno	Co-inno	Frugal inno
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
CEO education	−0.054*	−0.169***	−0.049	−0.165***	−0.038	−0.161**
	(0.030)	(0.061)	(0.030)	(0.061)	(0.030)	(0.063)
CEO gender (male)	−0.015	0.154	−0.038	0.146	−0.004	0.097
	(0.073)	(0.147)	(0.075)	(0.147)	(0.073)	(0.145)
Export orientation	−0.020	−0.054	−0.023	−0.041	−0.014	−0.016
	(0.070)	(0.147)	(0.070)	(0.146)	(0.069)	(0.149)
Technology capability	0.015	0.097***	0.016	0.097***	0.020	0.091***
	(0.017)	(0.031)	(0.017)	(0.031)	(0.017)	(0.029)
Environmental munificence	0.078***	0.045	0.075***	0.048	0.079***	0.038
	(0.018)	(0.039)	(0.019)	(0.038)	(0.018)	(0.039)
Firm size (logged)	0.050	−0.163**	0.045	−0.168**		
	(0.042)	(0.070)	(0.044)	(0.068)		
Firm age (logged)	0.069	0.082	0.044	0.068	0.062	−0.031
	(0.072)	(0.173)	(0.070)	(0.174)	(0.074)	(0.181)
Co-innovation		0.613***		0.607***		0.660***
		(0.129)		(0.133)		(0.130)
Environmental threats	−0.108	−0.166	−0.316	−0.760	−0.455	0.946
	(0.427)	(0.695)	(0.440)	(0.719)	(0.450)	(1.298)
Legal incompleteness	−0.107	0.059	−0.121	−0.082	−0.063	0.380
	(0.107)	(0.194)	(0.098)	(0.182)	(0.129)	(0.372)
Environmental threats * legal incompleteness	0.029	0.016	0.037*	0.043	0.027	−0.038
	(0.021)	(0.036)	(0.020)	(0.035)	(0.024)	(0.066)
Industry (low-tech)	2.839	4.354	−0.140*	−0.089	−0.132*	−0.069
	(2.265)	(4.501)	(0.078)	(0.158)	(0.079)	(0.154)
Start-up	−0.173*	0.017	1.916	0.851	−0.194*	0.132
	(0.096)	(0.238)	(2.416)	(4.549)	(0.100)	(0.242)
Industry * environmental threats	−0.672	−0.730				
	(0.451)	(0.831)				
Industry * legal incompleteness	−0.119	−0.209				
	(0.114)	(0.237)				
Industry * environmental threats * legal incompleteness	0.028	0.033				
	(0.022)	(0.044)				
Start-up * environmental threats			−0.309	−0.010		
			(0.500)	(0.884)		
Start-up * legal incompleteness			−0.088	−0.043		
			(0.120)	(0.241)		
Start-up * environmental threats * legal incompleteness			0.012	0.001		
			(0.025)	(0.046)		
Firm size					0.839	11.390
					(2.542)	(7.603)
Firm size * environmental threats					−0.103	−1.825
					(0.496)	(1.362)
Firm size * legal incompleteness					−0.146	−0.527
					(0.139)	(0.390)
Firm size * environmental threats * legal incompleteness					0.024	0.086
					(0.026)	(0.069)
Constant	3.656	3.473	4.310*	6.577*	5.078**	−3.917
	(2.261)	(3.891)	(2.257)	(3.676)	(2.340)	(7.308)
Observations	301	301	301	301	301	301
R-squared	0.573	0.499	0.572	0.497	0.584	0.514
RMSE	0.587	1.204	0.588	1.207	0.579	1.186
Adj R^2	0.549	0.469	0.547	0.466	0.561	0.485
F-stat	30.3***	23.1***	33.9***	24.6***	30.6***	23.5***
Ll	−257.779	−473.819	−258.347	−474.558	−253.84	−469.232

Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table A4
The role of university collaboration.

	Frugal inno	Co-inno	Frugal inno	Co-inno	Frugal inno	Frugal inno	Frugal inno
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
CEO age	−0.001	−0.006	0.005	−0.008**	−0.002	−0.004	−0.003
	(0.010)	(0.004)	(0.009)	(0.004)	(0.009)	(0.009)	(0.009)
CEO education	−0.202***	−0.007	−0.163***	−0.021	−0.171***	−0.170***	−0.153**
	(0.064)	(0.026)	(0.060)	(0.026)	(0.061)	(0.061)	(0.063)
CEO gender (male)	0.122	0.030	0.123	0.019	0.145	0.148	0.062
	(0.165)	(0.067)	(0.153)	(0.064)	(0.144)	(0.146)	(0.149)

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Table A4 (*continued*)

Variables	Frugal inno Model 1	Co-inno Model 2	Frugal inno Model 3	Co-inno Model 4	Frugal inno Model 5	Frugal inno Model 6	Frugal inno Model 7
Export orientation	0.157 (0.168)	0.129* (0.066)	−0.017 (0.158)	0.078 (0.062)	−0.050 (0.147)	−0.058 (0.147)	−0.027 (0.142)
Technology capability	0.124*** (0.034)	0.025* (0.015)	0.101*** (0.032)	0.020 (0.015)	0.095*** (0.030)	0.095*** (0.031)	0.099*** (0.031)
Environmental munificence	0.204*** (0.033)	0.087*** (0.015)	0.117*** (0.033)	0.052*** (0.016)	0.051 (0.038)	0.049 (0.038)	0.038 (0.039)
Firm size (logged)	−0.147* (0.085)	0.009 (0.038)	−0.185*** (0.070)	0.024 (0.036)	−0.157** (0.068)	−0.167** (0.068)	−0.149** (0.068)
Firm age (logged)	0.176 (0.200)	0.032 (0.072)	0.150 (0.186)	0.012 (0.064)	0.098 (0.174)	0.067 (0.175)	0.069 (0.173)
Start-ups	−0.316 (0.261)	−0.169* (0.097)	−0.139 (0.244)	−0.073 (0.089)	0.030 (0.231)	0.055 (0.233)	0.004 (0.236)
Industry (low-tech)	0.170 (0.214)	0.395*** (0.090)	−0.183 (0.188)	0.357*** (0.088)	−0.177 (0.181)	−0.199 (0.183)	−0.221 (0.178)
University collaboration	0.739*** (0.226)	0.933*** (0.077)	−0.195 (0.250)	−0.007 (0.464)	−1.865** (0.821)	−0.784 (1.396)	−5.501 (4.203)
Co-innovation			0.895*** (0.136)		0.639*** (0.145)	0.581* (0.295)	0.594*** (0.145)
Environmental threats		0.247*** (0.050)		−0.423** (0.185)	−0.738* (0.389)	−0.750* (0.404)	−0.497 (0.608)
Legal incompleteness				−0.125** (0.050)	−0.059 (0.113)	−0.107 (0.114)	−0.060 (0.181)
Co-innovation * university collaboration						0.131 (0.321)	
Environmental threats * legal incompleteness				0.031*** (0.011)	0.033 (0.022)	0.043* (0.023)	0.019 (0.037)
Environmental threats * university collaboration				0.178 (0.094)	0.355 (0.166)		0.649 (0.826)
Legal incompleteness * university collaboration							0.208 (0.236)
Environmental threats * legal incompleteness * university collaboration							−0.017 (0.047)
Constant	4.719*** (0.919)	1.198** (0.494)	2.749*** (0.987)	4.565*** (1.098)	6.795*** (2.283)	7.307*** (2.590)	7.192** (3.237)
Observations	301	301	301	301	301	301	301
R-squared	0.35	0.629	0.446	0.672	0.504	0.496	0.518
RMSE	1.357	0.543	1.256	0.513	1.197	1.206	1.183
Adj R^2	0.326	0.614	0.423	0.655	0.476	0.468	0.488
F-stat	16.623***	49.235***	22.744***	44.607***	24.392***	25.248***	24.21***
Ll	−512.954	−236.651	−489.064	−218.065	−472.493	−474.634	−467.961

Robust standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table A5
Instrumental variable estimations.

Variables	Environmental threats Model 1	Co-innovation Model 2	Co-innovation Model 3	Frugal innovation Model 4	Co-innovation Model 5	Frugal innovation Model 6
CEO age	−0.006 (0.005)	−0.009* (0.004)	−0.010** (0.005)	0.004 (0.010)	−0.016*** (0.005)	−0.004 (0.009)
CEO education	−0.081** (0.034)	−0.050 (0.030)	−0.050 (0.033)	−0.174*** (0.066)	−0.071* (0.037)	−0.163*** (0.063)
CEO gender (male)	−0.070 (0.079)	−0.022 (0.072)	−0.030 (0.076)	0.120 (0.150)	−0.048 (0.077)	0.171 (0.143)
Export orientation	0.258*** (0.078)	0.152** (0.072)	0.051 (0.076)	0.023 (0.150)	−0.062 (0.083)	0.003 (0.143)
Technology capability	−0.007 (0.015)	0.020 (0.014)	0.021 (0.015)	0.107*** (0.029)	0.017 (0.014)	0.095*** (0.028)
Environmental munificence	0.052*** (0.015)	0.122*** (0.014)	0.132*** (0.015)	0.140*** (0.044)	0.066*** (0.019)	0.040 (0.036)
Firm size (logged)	0.086** (0.036)	0.054 (0.033)	0.045 (0.036)	−0.174** (0.070)	0.056 (0.035)	−0.166** (0.068)
Firm age (logged)	−0.062 (0.089)	0.060 (0.081)	0.096 (0.084)	0.159 (0.169)	0.031 (0.081)	0.051 (0.162)
Start-up	0.005 (0.119)	−0.217** (0.109)	−0.327*** (0.113)	−0.191 (0.239)	−0.100 (0.122)	0.067 (0.221)
Industry (low-tech)	−2.646*** (0.188)	−2.053*** (0.217)	−0.167** (0.081)	−0.119 (0.167)	−0.115 (0.076)	−0.085 (0.154)
Environmental threats (industry average-t1)	0.508***					

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Table A5 (*continued*)

	Environmental threats	Co-innovation	Co-innovation	Frugal innovation	Co-innovation	Frugal innovation
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	(0.036)					
		0.392***				
Co-innovation (industry average-t1)		(0.044)				
			0.240***		−1.286*	−0.504**
Environmental threats (main)			(0.067)		(0.726)	(0.228)
				0.670***		0.656***
Co-innovation (main)				(0.230)		(0.117)
					−0.380**	
Legal incompleteness					(0.193)	
					0.086**	0.025***
Environmental threats * legal incompleteness					(0.039)	(0.006)
	4.592***	2.961***	1.718***	3.267***	9.579**	5.370***
Constant	(0.465)	(0.425)	(0.527)	(1.083)	(3.820)	(1.269)
First-stage F-Statistics (IV)			191.042***	77.428***	22.844***	99.81***
R-squared (IV)			0.5151	0.5315	0.9687	0.71
Adjusted R (IV)			0.4967	0.5137	0.9673	0.6971
Partial R (IV)			0.398	0.2113	0.0737	0.258
Observations	301	301	301	301	301	301
R-squared	0.515	0.532	0.493	0.44	0.543	0.491
RMSE	0.653	0.597	0.621	1.235	0.589	1.177
Adj R^2	0.497	0.514	0.474	0.418	0.523	0.468
Chi^2	319.803***	341.481***	253.944***	183.989***	366.176***	285.579**

Standard errors in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

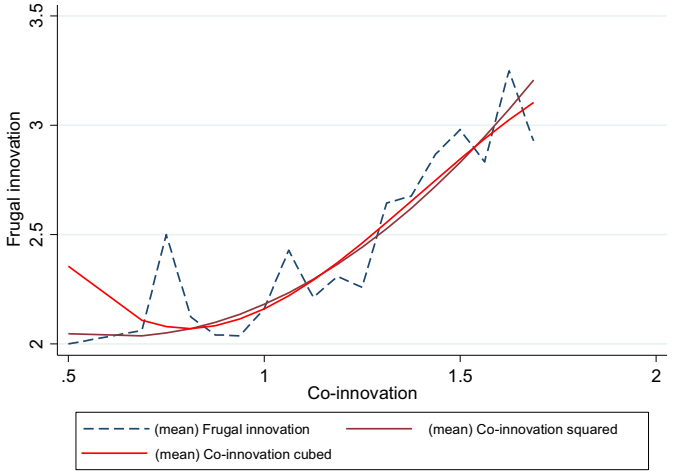

Fig. A1. Omitted variable bias (OVB) test for co-innovation.

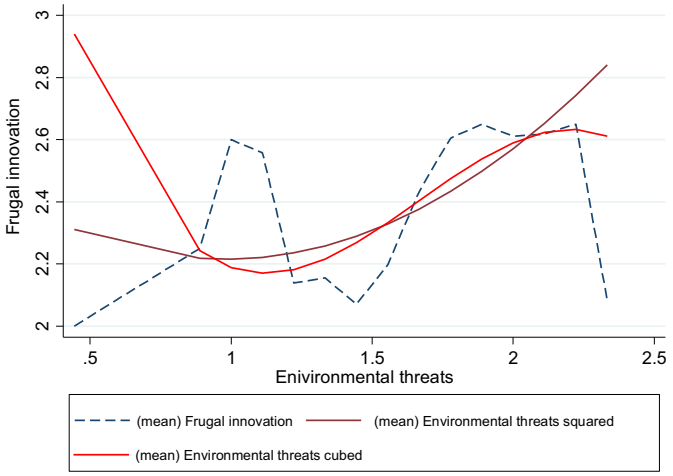

Fig. A2. Omitted variable bias (OVB) test for environmental threats.

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