Sustainability Strategies and Firm Value

Abstract

Despite the diffusion of sustainability as a legitimate strategic logic, scholarly evidence of its impact on firm value remains tentative. The prevailing emphasis on a "local business case", which focuses on proximate mechanisms, provides limited strategic guidance on how firms should adapt their behavior as systemic boundaries become more salient. This paper bridges this gap by developing a framework, grounded in complexity theory, that links the value of sustainability strategies to their ability to manage a multi-level feedback loop between firm operations and systemic outcomes. We posit that firms must develop strategic complexity, the degree of sophistication of their strategies in terms of the breadth of implied sustainability behaviors, to match the systemic complexity of the environment they are embedded in. Due to cognitive and organizational costs, this relationship is not linear but follows an inverted U-shape. Furthermore, we hypothesize that this curve shifts when exogenous shocks alter systemic complexity. To test these predictions, we develop a novel methodology, applying a hierarchical Bayesian model to a dataset of over 200,000 corporate sustainability initiatives by 1,186 firms to measure the complexity of their enacted strategies. Our empirical design leverages the European Union's "Fit for 55" policy as a quasi-natural experiment in a continuous treatment, triple difference-in-differences framework. Our results support both hypotheses: we find a curvilinear relationship between strategic complexity and firm financial value, and show that the curve shifts toward higher complexity for EU firms following the regulatory shock.

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1 Introduction

The idea of building a strategic advantage, through a combination of cost efficiencies and differentiation approaches, from the pursuit of sustainability-related opportunities to innovate and improve products, processes, and business models, has emerged and is diffusing as a legitimate strategic logic (Schaltegger et al. 2016). However, scholarly evidence of the impact of this diverse set of strategic commitments on firm value creation remains tentative. Research grounds the business case for sustainability investments by pointing to customer preferences and product differentiation (Albuquerque et al. 2019), reduced cooperation costs with local communities (Franks et al. 2014), reduced regulatory risk and exposure to policy failures (Cuervo-Cazurra et al. 2023, Kim et al. 2024), employee satisfaction (Bode et al. 2015, Edmans et al. 2024), and cheaper cost of capital (Chava 2014). Yet, this emphasis on the *local* business case, in its attempt to find proximate mechanisms, overlooks the need to embed these results in a *systemic* theory of sustainability strategy. This has long been recognized as a gap in corporate corporate sustainability research and practice (Ostrom 1990, Bansal and Song 2017), but strategic guidance on how individual firms should adapt their behavior to pursue value creation as systemic boundaries become more salient remains limited.

In this paper, we argue that the value of sustainability strategy depends on its effectiveness in controlling a three-step, multi-level feedback loop: the focal firm's choices, their effect on systemic outcomes, and the subsequent consequences back at the firm level. To isolate and clarify the role of strategic choices, scholars have developed thought experiments or simulations where their effect on performance can be directly observed. A popular "microworld" that can be extended to include both traditional strategy and sustainability concerns involves a fishing boat operating in the sea and selling seafood for profit (Gifford and Gifford 2000). Even in this reduced problem, the fishing boat needs to make a series of general strategic decisions, including where to fish (exploration/exploitation), which crew to hire to get the best skillset (human capital management), whether to invest in larger nets (corporate finance), whether to specialize in particular seafood (market segmentation), or whether to compete or join forces with other boats (growth strategy).

A key lens to understand corporate sustainability consists of grand challenges (George et al. 2016). Grand challenges are complex, large-scale problems that pose significant threats to human wellbeing and planetary systems. By their nature, grand challenges are a collective action problem. They are not solvable by any individual actor, their resolution entails the understanding of systemic and intertwined causal webs, the grievances that they cause are felt broadly but disproportionately, and agents can free-ride on the contributions of others. In the fishing microworld, a grand challenge can appear with a small modification: instead of the wide open sea, the fishing boat now operates in a relatively small lake. The main consequence of this change is that the fish population is not virtually infinite anymore, and its ability to replenish itself becomes a crucial consideration. If the boat is not conscious about the amount of fish it catches today, it might permanently damage its future performance. Furthermore, if rival boats resort to overfishing to get ahead, the focal boat itself might still suffer the consequences. With the move from the open sea to a small lake, the planetary boundaries of the microworld become salient (Bansal et al. 2025). In the real world, we have overwhelming evidence that environmental sustainability and the associated planetary boundaries have become salient as well, not because of a change in scenario but because of the growth of the private sector overall, and in particular, that of large, multinational corporations whose activities can be directly linked to systemic environmental degradation (Franks et al. 2014, Dietz et al. 2018).

The optimal strategy for the fishing boat in the lake scenario is markedly more complex than the one in the open sea. On top of the boat's internal state (resources, capabilities), competitors' behavior, and global parameters (seafood demand, factor prices), a new *global state variable* now affects current and future performance via a previously irrelevant feedback loop. The need to consider the fish population level not only imposes further constraints on existing behavior (e.g., where and how much is most profitable to fish might be different), but also introduces new choice dimensions that would have been strategically irrelevant before (e.g., investing in fishing technologies that create less lasting damage to the lake floor). From the point of view of an external observer, the boat's behavior is much more diverse than in the open sea case, because the same boat will make a potentially different set of choices for each possible level of the fish population it faces. In complexity theory, this phenomenon is captured by the law of requisite variety, which implies that an agent's behavior ought to match increases in the complexity of the system it is embedded in with more complex, contingent behavior if it wants to maintain the same level of control in its performance outcomes (Ashby 1956, McKelvey and Boisot 2009). This effectively means that the success of the agent's strategy is directly linked with its ability to "internalize" systemic complexity into its processes, routines, and decision switches.

The environmental challenges that large public corporations face are much more diverse and intertwined than maintaining a viable fish population in a small lake, but the salience of planetary boundaries imposes similar causal loops (Rockström et al. 2009, Steffen et al. 2015). Indeed, business operations are directly responsible for multiple systemic externalities, including greenhouse gas emissions, biodiversity loss, and waste accumulation, while their current and future performance is in turn negatively affected by a combination of transition (e.g., stringent regulatory interventions, erosion of stakeholder support) and physical (e.g., increased damages from natural disasters, resource depletion) factors. The far greater complexity of the real world makes analytical solutions, akin to those available in the microworld, virtually impossible. Yet, a version of the same intuition holds in principle for the diversity of environmental policies and behavior of corporations and their consequences in terms of financial value. This paper thus develops and tests a framework that links the complexity of sustainability strategies with firm value. We propose that system-level feedback loops between firm actions and Earth system states determine the requisite strategic complexity of firm sustainability strategies. As planetary boundaries become more binding, they create systemic complexity, in terms of the degree and strength of the intertwined causal web between business operations and the environment, that firms must match with strategic complexity, in terms of diversity and richness of behavior, to preserve effectiveness and, ultimately, financial value.

However, real organizations face fundamental constraints that prevent perfectly adaptive complexity responses. Indeed, there are two points of departure from the fishing boat scenario that define the nature of this relationship. First, firms' decision-making processes are only boundedly rational (Ethiraj and Levinthal 2004). Therefore, their strategies might be suboptimal due to imperfect understanding of the systemic relationships or due to imperfect control of their own behavior, and improving in these regards is a crucial capability that can be acquired (Zollo and Winter 2002). Moreover, designing structures and routines capable of selecting and implementing increasingly complex strategies comes at steep cognitive and organizational costs, as opposed to rational agents with no information gathering costs and infinite computing power (Ocasio 1997, 2011). Second, firms pay close attention to peers and navigate a constant tension between the distinctiveness of their approach and aligning behavior in strategic groups (Sonenshein et al. 2017, Bothello et al. 2023). We therefore posit that increasing strategic sophistication improves firm value with diminishing effects as the current level of strategic complexity starts to account for most of the systemic one, while costs exponentially increase. Thus, the complexity of sustainability strategies exhibits an inverse U-shaped relationship with firm value. Importantly, the vertex of the parabola corresponds to the most efficient complexity management approach (before marginal gains of further sophistication are no longer compatible with the marginal cognitive and implementation costs). Furthermore, firms move and cluster along this curve as they develop crucial capabilities in managing for grand challenges over time.

To empirically test these predictions, we develop a hierarchical Bayesian model that interprets sustainability strategies as latent constructs that emerge from realized sustainability behavior. By analyzing more than 200,000 sustainability initiatives from 1,186 firms, we estimate which strategies guided firm activities over time, and their complexity according to the action and goal diversity they imply. Although the systemic complexity of environmental challenges is not directly observable, we exploit the introduction of the European Union's "Fit for 55" policy as an exogenous shock to systemic complexity for firms in the EU with respect to their peers in the United Kingdom, Canada, and the United States. Indeed, by selectively affecting the strategic choice space available to European corporations to hamper the feasibility of low-effort symbolic strategies, regulators can effectively reshape the competitive landscape and thus increase effective systemic complexity. We employ a continuous treatment triple difference-in-differences design that combines the indicator variable for being a firm headquartered in the EU with the continuous measure of strategic complexity identified by the model. To account for diversity on observables, we implement non-parametric covariate balancing propensity score matching and include pre-treatment Mundlak devices in the main equation. Moreover, we account for endogeneity in selection, the peculiar conditions that push some firms to disclose sustainability information and not others, and in treatment, the peculiar conditions that push some firms to choose some strategies and not others, via a double instrumentation estimated through Heckman correction and IV-GMM. Finally, to account for generated regressors, we cluster and bootstrap all standard errors at the firm level.

The results show that the complexity of sustainability strategies does indeed follow an inverted U-shaped relationship with firm value, and that the vertex of this relationship moved towards a further level of complexity after effective systemic complexity increased. Firms do cluster in strategic groups in their approach to sustainability strategies, and these groups are shaped by both experience and materiality considerations.

2 Theory and Hypotheses

2.1 The local business case for sustainability

Organizations are established to achieve a shared purpose that would not be efficient to pursue by each member independently (McGahan 2023). In the business environment specifically, modern corporations seek to create value through economic activities. In doing so, they develop routines and capabilities to make intertemporal, complex decisions aimed at ensuring their efficiency and survival. To the extent these decisions are strategic choices, we can interpret firms' behaviour as agentic and the bundle of choices they make as strategies (Dess and Davis 1984). In particular, firms adapt routines and structures to assess, control, and ultimately improve their sustainability performance (Baumgartner and Ebner 2010). The domain of corporate sustainability can therefore serve as a strategic arena where corporate initiatives and decisions are deliberate non-market tools in pursuit of value creation.

Several streams of literature have focused on the mechanisms through which sustainability generates firm value. In particular, arguments rooted in the resource-based view of the firm posit that proactive environmental and social strategies foster the acquisition and utilization of unique organizational resources that can serve as basis for competitive advantage (Barney 1991, Helfat et al. 2023). The natural resource-based view focuses on environmental constraints as endogenous drivers of competitive advantage rather than exogenous threats to firm operations (Russo and Fouts 1997, Hart and Dowell 2011). This extends the RBV logic by theorizing that ecological limits themselves fundamentally reshape capability development trajectories, creating path dependencies through pollution prevention, product stewardship, and sustainable development that generate difficult-to-imitate advantages precisely because they emerge from constraint-driven innovation. Similarly, sustainability investments generate intangible social resources, including enhanced reputation, brand equity, and organizational legitimacy, that function as strategic assets conferring competitive advantages through premium pricing, customer loyalty, and preferential access to markets and regulatory approvals (Vishwanathan et al. 2020). Beyond these static resource advantages, sustainability strategies also foster the development of higher-order dynamic capabilities that enable continuous adaptation to evolving environmental and social challenges (Teece et al. 1997, Aragón-Correa and Sharma 2003, Sharma and Vredenburg 1998). These meta-capabilities for sensing emerging sustainability issues, seizing opportunities from regulatory and market shifts, and reconfiguring resource portfolios accordingly create value not through any single resource position but through the organizational capacity to repeatedly transform in response to the rapidly changing sustainability landscape.

Firms might also use sustainability strategies to garner stakeholder support by addressing their demands and grievances (Donaldson and Preston 1995, Jones 1995, Parmar et al. 2010). This perspective recognizes that stakeholders are not merely recipients of firm value but necessary participants in its creation, contributing essential resources, legitimacy, and social license to operate (Stoelhorst 2023, McGahan 2023). Complementing the resource-based view, stakeholder theory highlights that critical resources often reside outside firm boundaries, controlled by stakeholders whose cooperation must be secured through strategies that align firm and stakeholder interests (Barney 2018, McGahan 2021, Freeman et al. 2021).

Another important stream focuses on the role of organizational purpose in driving firm value, where firms articulate and pursue integrated objectives to create multistakeholder value (Henisz 2023, Ocasio et al. 2023, Crilly and Sloan 2012). This perspective suggests that broadening organizational purpose addresses externalities and enables stronger relational contracts with stakeholders, thereby enhancing long-term value creation when traditional contracting mechanisms fail (Henisz 2023). The value creation mechanism operates through the collective understanding of the firm's relationship with society, which fundamentally shapes how firms allocate attention across competing stakeholder demands (Crilly and Sloan 2012).

These frameworks focus on the focal firm and its dyadic relationships with stakeholders. They provide a powerful toolkit for an "open sea" world but fall short in a "small lake" context, as they do not adequately account for the systemic feedback loops that are the defining feature of a world constrained by planetary boundaries (Strand 1983, Ostrom 1990, Bansal and Song 2017, Bansal et al. 2025). Sustainability, by its very nature, is a systemic issue tied to grand societal challenges that arise from the interconnectedness of social and ecological systems (George et al. 2016, Voegtlin et al. 2022). Firms' actions have consequences that reverberate through these systems, creating externalities that ultimately feed back to affect the firm itself, often in non-linear and unpredictable ways (Franks et al. 2014, Cenci et al. 2025). Investigating this requires a complexity science perspective, where firms are seen as adaptive agents on rugged fitness landscapes, whose success depends on their ability to match the complexity of their environment (Kauffman 1993, Holland 1995, Ashby 1956, McKelvey and Boisot 2009).

2.2 A systemic framework for value creation

In direct contrast with this tradition, a growing body of corporate sustainability research posits that major sustainability challenges are systemic, not firm-level, phenomena (George et al. 2016, Voegtlin et al. 2022). The foundation for this perspective lies in conceptualizing sustainability issues as collective action problems centered on the governance of common-pool resources (Ostrom 1990). In this view, the viability of individual firms becomes inseparable from the effective management of shared socio-ecological systems upon which all economic activity depends. Traditional strategy frameworks cannot adequately capture the diffuse causality and stakeholder interdependence inherent in such challenges, necessitating a lens that accounts for the firm's socio-ecological embeddedness (Strand 1983, Bansal and Song 2017). Consequently, firm-level sustainability goals are increasingly understood as derivations and operationalizations of broader, systemic-level sustainable development objectives. The value of a firm's sustainability activities, therefore, depends on its contribution to resolving these societal-level issues (McGahan and Pongeluppe 2023, Bansal et al. 2025).

Despite its more accurate reframing of sustainability through systemic lenses, this stream of corporate sustainability literature offers little guidance for the strategic behavior of individual, value-seeking firms. This creates a tension with the traditional research focus on firm performance (Margolis and Walsh 2003, Hahn et al. 2014). In order to investigate how a firm can strategically rationalize resource allocation toward systemic issues, we need to engage with this tension. We thus propose a recursive feedback process that moves from the firm to the system and back. The argument consists of four steps. First, firm-level behavior is strategic only if it affects the state of the system in which the firm is embedded (including pure internal adaptation with no environemntal shaping intent, as the firm is an integral part of the system), seeking to steer it towards states that are more beneficial to the firm itself. Second, how beneficial a state is to a firm depends both on the latter's *fitness* with respect to the system and the health of the system itself. Third, the actions of large, multinational corporations are directly capable of systemic consequences. Fourth, the goal of sustainability strategies is to preserve systemic prosperity as the firm thrives in it.

We start with the first of these claims by considering the nature of firms and purposeful action. Indeed, while a significant body of literature studies firm activities as stemming from mechanistic responses to outside institutional (DiMaggio and Powell 1983), structural (Lewin et al. 1999, Anand et al. 2013), or market pressures, firms rely on a core teleological rationale. Firms not only take deliberate competitive moves before countermoves, choose foreign market entry, select research and development avenues, but also deliberately learn and adapt to the surrounding environment in a quasi-Lamarckian fashion (Zollo and Winter 2002, Nembhard and Tucker 2011). The capacity to perform purposeful action is valuable to the extent to which it has real consequences on the recipient of that action, whether it be the environment, the firm's configuration, or the relative positioning of the firm with respect to the environment. In the natural as well as in the business worlds, costly traits can be justified only if they entail a reward in terms of greater chances of survival and prosperity (Nelson and Winter 1982). Purposeful, sophisticated decision-making processes in the population of firms are no exception. Therefore, firms maintain capabilities to act deliberately on themselves and others in the system they are embedded in (i.e., the *state* of the system), granted that at least part of the resulting actions are strategic, in the sense that their intended result (in terms of the transition from the current state to a new one modified by the action) entail a reward that is directly beneficial to themselves (Teece 2007, Teece et al. 1997).

Conversely, how much a state of the system is beneficial from the perspective of a firm depends on how effectively it can achieve its purpose under that state. Concretely, several characteristics of the system might impact firm effectiveness. For example, there might be relative abundance or scarcity of resources that the firm finds valuable in its activities, the existence of structural configurations that might enhance the effectiveness of specific firm actions via legitimacy or power, or a more favorable set of relationships the firm enjoys with other agents/stakeholders (Ghoul et al. 2017, Henisz 2023, McNamara et al. 2003, Odziemkowska and Henisz 2021). When these characteristics are agnostic of the specific traits and positioning of the firm, they tell us something about the overall prosperity that the system enjoys under that state. Conversely, if they differentially affect heterogeneous firms, they implicitly specify the contingencies needed for effective firm action. Specific system characteristics might be a mixed version of these two archetypes, the one that purely relate to the *system's health* and the one that purely modifies firms' relative *fitness*, forming a continuum of the two. In this context, the value of a firm with respect to a system (and a system's state) emerges from its activities of transformation of resources, and the firm's effectiveness in doing so (Stoelhorst 2023, Chen et al. 2021, Wood 2010).

Therefore, the health of the system the firm is embedded in, where resources are acquired and discharged, has direct consequences for its operations in an indissoluble way. This fact has been historically overlooked in business academia since the traditional understanding of firms stems from a world of perfect competition, where each individual entity was too small to affect global conditions via its choices. However, this representation has become more and more outdated in its attempt to describe the modern economic systems. The rise of large, multinational conglomerates has brought market power (Tirole 1988), corporate political activities (Hiatt and Park 2013), integration choices (Williamson 1975, Grossman and Hart 1986), and social movements (McDonnell 2016) to the forefront of business/economics research. These streams of literature acknowledge the possibility of firms to shape the system they are embedded in, whether in market, geographic, political, or social environments, and study it as a competitive means. Even regarding the natural environment, planetary boundaries have now become a salient barrier firms have to engage with (Bansal et al. 2025). Indeed, not only do we have conclusive evidence that private economic activities are a key driver for climate change (Rockström et al. 2009, Dietz et al. 2018), but we can also name individual large firms in their non-trivial contribution to global damages through emissions (Callahan and Mankin 2025).

Finally, the paradigmatic shift where externalities are no longer a shout in empty space, but rather one trapped in a large but finite room where sound reverberates on the walls (in the microworld language, moving from an open-sea to a small lake scenario), introduces a new set of challenges and strategic opportunities. Not only is the long-term sustainability of the system ultimately intertwined with firm value, efficiency, and survival, but firms have also reached the size and complexity to meaningfully affect it. Being able to reinforce the health of the system (or not squander it) by controlling the systemic consequences of their actions is a necessary long-term objective for firms to survive and prosper (McGahan and Pongeluppe 2023, Franks et al. 2014, Strand 1983). This is by no means a trivial endeavor, since uncontrolled externalities emerge as side consequences from very localized business decisions, while taking sustainability into account requires explicitly engaging with the systemic consequences of firm behaviors and strategically choosing them. Effectively doing so implies leveraging system thinking, operational, and dynamic capabilities (Aragón-Correa and Sharma 2003, Helfat and Winter 2011, Burato et al. 2023, Teece 2007).

This argument implies that the value of corporate sustainability behavior depends on the firms' ability to engage with the web of causal relationships and feedback loops that innervate the system they are embedded in. Yet, we lack a general understanding on a strategic mechanism that can explain what companies concretely do in this domain, and the sustained heterogeneity in sustainability strategies and their performance consequences. This paper contributes to this area by linking sustainability behavior with system complexity management, and exploring the contingencies in which firms can effectively rip the benefits of sustainability while controlling the associated organizational and cognitive costs of increasingly sophisticated approaches. We dedicate the next subsection to develop formal hypotheses.

2.3 Systemic and strategic complexity

The argument above posits that sustainability strategies are purposeful tools firms use to affect systemic outcomes in anticipation of consequent performance. To generate value, these strategies must effectively steer the system towards states that are more beneficial for the firm's long-term prosperity, which is itself tied to the system's overall health (McGahan and Pongeluppe 2023). This requires strategic behavior that actively engages with the system's underlying dynamics rather than merely reacting to localized pressures. The effectiveness of such engagement, however, hinges on a firm's ability to comprehend and navigate the inherent complexity of the systems in which it operates.

Business environments, particularly in the context of grand challenges, constitute complex adaptive systems defined by interconnected actors, non-linear relationships, and emergent properties (Holland 1995). In such systems, firms can be seen as agents adapting on rugged fitness landscapes where adaptation occurs across multiple interconnected dimensions (Kauffman 1993). The increasing salience of planetary boundaries has amplified this systemic complexity, creating new forms of interdependence between environmental, social, and economic systems that fundamentally alter the strategic landscape firms must navigate (Cenci et al.

2025, Bansal et al. 2025). Consequently, a firm's ability to create value through sustainability is conditional on its capacity to develop sophisticated internal models of this complex environment, which in turn shape its strategic choices and its capacity to interpret and respond to multifaceted sustainability challenges. From a strategic perspective, maintaining routines and capabilities that sustain sophisticated responses can be a key tool to "internalize" complexity, as opposed to accepting the more serendipitous and uncertain outcomes of rougher approaches to complex scenarios. In the microworld example, the fishing boat can develop a biodiversity strategy that would prescribe differential fishing targets contingent on the fish population level to stabilize it, rather than fishing a constant amount according to the boat capacity and thus experiencing extreme variation in outcomes for the same level of fishing (as the population level collapses). In this case, the fishing boat increases the complexity of its strategy, increasing the variety of its behavior, to effectively manage systemic complexity.

In complexity science, this dynamic is formally captured by the Law of Requisite Variety, which establishes that a system's internal regulatory mechanisms must equal or exceed the complexity it aims to manage (Ashby 1956). Applied to corporate strategy, this principle requires strategic responses that match the full spectrum of environmental complexity firms encounter (McKelvey and Boisot 2009). We propose that sustainability strategies function as interaction mechanisms calibrated to systemic complexity levels, enabling firms to achieve the requisite variety necessary for effective operation (Axelrod and Cohen 2000). Therefore, firms need to implement multiple sophisticated strategic initiatives to mount an effective behavioral response to the systemic feedback loop we described above. We define strategic complexity as the variety in realized behavior a firm has at its disposal, according to its sustainability strategy. Through strategic complexity, firms maintain a (potentially costly) capacity to generate value in increasingly complex business environments where sustainability imperatives shape competitive dynamics.

However, developing and deploying complex strategies is not costless. Real organizations, unlike idealized rational agents, face significant cognitive and organizational constraints. A key limiting factor is organizational attention, a finite resource that is strained by the need to orchestrate complex strategies (Ocasio 1997, 2011). As strategy complexity increases, the cognitive architecture required for processing interdependent sustainability initiatives becomes very costly. These attention-based constraints create non-linear barriers to implementation, as the cognitive demands of maintaining requisite variety begin to overwhelm firms' finite attention resources, forcing them to rely on selective heuristics (Blettner et al. 2015, Stevens et al. 2015).

This trade-off between the systemic rewards of variety and the organizational costs of complexity suggests a curvilinear relationship. Initially, as firms increase the complexity of their sustainability strategies, they become better equipped to manage systemic issues, leading to improved performance. However, as complexity continues to increase, the marginal benefits begin to decline while the cognitive and organizational costs mount. Eventually, a point is reached where the managerial burdens of managing additional complexity outweigh its strategic benefit, rendering the implementation of particularly complex strategies ineffective and leading to a decline in the firm's capacity to generate value. This gives rise to an inverted U-shaped relationship, formalized in our first hypothesis:

> **H1.** The complexity of firms' sustainability strategies has an inverted U-shaped relationship with firm value.

However, strategic complexity is only half of the "complexity internalization" mechanism, and firm value is also contingent upon the prevailing level of systemic complexity. An exogenous shock that increases systemic complexity, such as a significant regulatory shift or the development of a disruptive sustainable technology, fundamentally reshapes the performance curve. By increasing the systemic complexity firms face, such a shock heightens the performance penalty for simplistic strategies, which become increasingly inadequate for navigating the new landscape. This has the effect of shifting the entire curve, as a more sophisticated repertoire is now necessary to effectively manage the system's altered dynamics. This implies that the central strategic challenge for value-seeking firms is to adapt their strategic complexity in response to systemic complexity. This leads to our second hypothesis:

> **H2.** An increase in systemic complexity alters the inverted U-shaped relationship between strategic complexity and firm performance, shifting it to the right.

Therefore, our framework links firm value and sustainability strategies via the construct of systemic complexity and strategic complexity, and their relationship. While systemic complexity can be intuitively understood as K in an NK model (Kauffman 1993), strategic complexity requires further grounding. We dedicate the next subsection to formally define sustainability strategies and their complexity, and the following one to formalize the relationship between strategic complexity and systemic complexity from a theory of firm value perspective.

2.4 Sustainability strategies

In order to properly ground the construct of strategic complexity, we need to formally define what sustainability strategies are, and in what sense they can be more or less complex. Several studies have more or less explicitly acknowledged the strategic nature of particular sustainability initiatives and investigated their performance consequences (Hubbard et al. 2017, Bode et al. 2015, Bode and Singh 2018, Dimson et al. 2015).

Yet, there is a theoretical leap between micro-level constructs such as individual initiatives and firm-level strategies. In order to address this leap, we consider the exemplifying definition of sustainability initiatives (corporate social actions, in the language of the paper) of Marquis et al. (2007): "behaviors and practices that extend beyond immediate profit maximization goals and are intended to increase social benefits or mitigate social problems for constituencies external to the firm", and compare it to the seminal definition of firm-level (enterprise-level, in the language of the paper) strategy of Chandler (1962): "the determination of the basic long-term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources for carrying out these goals".

The structure of these definitions is markedly consonant. A sustainability initiative closely resembles an "atomistic" version of a strategy, with courses of action (behaviors and practices), a sustainability objective (increase social benefits or mitigate social problems), and commitment of resources (extend beyond immediate profit maximization). This suggest a direct relationship between a firm's sustainability strategy and the initiatives it implements, where the latter are the micro-level *quanta* of behavior corresponding to the macro-level choice of the former.

The idea of a sustainability initiative as a quantum of a sustainability strategy finds close consonance with the fact that strategies leave their footprint as "a pattern in a stream of decisions" (Mintzberg 1978). Indeed, firms are constantly presented with decision opportunities, a subset of which might entail the implementation of a sustainability initiative as a decision outcome (Siggelkow 2011). It is the infra-decision alignment of decision-level actions, resources, and goals towards a higher order enterprise-level objectives that constitutes the emergence, more or less deliberate, of strategies (Mintzberg and Waters 1985).

An important requirement implicit in the term pattern is that the initiatives that constitute a strategy are not a random collection, but interdependent and synergistic. Indeed, resources are indeed shared across initiatives, functions, and concurrent plans, and the actions of different initiatives can be used in complement of each other to obtain better joint results. Moreover, the objective of an individual initiative is not necessarily a long-term objective of the enterprise itself, but rather an immediate goal that enacts concretely the mechanism we outlined above for the long-term systemic one. In this sense, multiple initiatives can have their own sustainability-focused objective, but taken together they are all instrumental to the firm-level systemic prosperity goal, thus "aligned" in a unified strategy (Bansal 2002, Hahn et al. 2014, Cenci et al. 2025).

From this perspective, sustainability initiatives are implemented as an interdependent set of choices according to a strategy, and a sustainability strategy emerges from repeated patterns of co-implemented sustainability initiatives. We exemplify this two-way relationship between a strategy and its associated initiative in Figure 1 Panel **A**. A set of initiatives with different characteristics in terms of actions and goals drawn from the collective space of all potential initiatives has a unique representation in the (dimensionally smaller) strategy space.

Therefore, a firm that adopts a sustainability strategy implicitly constrains its decision-making processes to reflect the set of initiatives the strategy entails. Crucially, different strategies imply different sets of initiatives, as shown in Figure 1 Panel **B**. We can thus "observe the footprint" of sustainability strategies by analyzing the different characteristics of the initiatives they realized (cfr. Uncovering sustainability strategies), and hence derive a construct for sustainability strategies that can be effectively operationalized.

We formalize this intuition by assuming that sustainability initiatives' goals are drawn from a (arbitrarily large) set of goals G, while actions are from set A. We can therefore represent every initiative as a pair (a, g) where $a \in A$ and $g \in G$.

In order to move to higher-order constructs, we then model groupings of synergistic initiatives k as a *relevance* function over the entire initiative space $A \times G$. Since we care about what initiatives are most essential for k, rather than the "intensity" of k, we normalize it to 1, so $k : A \times G \longrightarrow [0, 1]$. Through these lenses, a group that relies exclusively on a particular initiative j, it will associate 1 with (a_j, g_j) and return 0 everywhere else. One that relies mostly on j, but requires also j' to support it, might associate 0.7 to (a_j, g_j), 0.3 to $(a_{j'}, g_{j'})$, and 0 otherwise.

In principle, there are infinitely many groupings k that can be designed over $A \times G$, but only a few are empirically relevant. In this context, we focus on those *sensible* groupings (with respect to a system), i.e., groups of initiatives that are interrelated and effectively work synergistically to achieve enterprise-level objectives via their immediate goals and actions.

Without loss of generality, we can assume that there are $|K|$ different sensible groupings of initiatives in the current system, collected in $K = \{1, \ldots, |K|\}$. Intuitively, given enough decision opportunities, the distribution of initiatives implemented by a rational firm will be proportionally related to the ones dictated by the sensible groupings, since that increases the efficiency of the overall sustainability effort.

Depending on its specific contingency, a firm might find it more fitting to pursue initiatives from a single group, more than one group at the same time, or a blended version of multiple groups. Indeed, a large multinational company could both set up measures to counter modern slavery in its supply chain (group 1) and implement asset restructurings in its facilities to abate carbon emissions (group 2). We capture this by defining sustainability strategies $\sigma \in \Sigma \coloneqq \left\{ \{\sigma_k\}_{k=1}^{|K|} : \sigma_k \in [0,1] \wedge \sum_{k=1}^{|K|} \sigma_k = 1 \right\}$ over groupings. More explicitly:

$$\sigma = \left[\sigma_1, \ldots, \sigma_k, \ldots, \sigma_{|K|}\right] \tag{1}$$

$$\sigma \geq 0 \tag{2}$$

$$\sum_{k=1}^{|K|} \sigma_k = 1 \tag{3}$$

Where (1) establishes σ as a $|K|$-vector whose each element σ_k correspond the relative proportion of $k \in K$ in strategy σ, so that per (2) and (3) all σ_k are nonnegative and sum up to one. In order to avoid confusion, below we use the term *strategic archetypes* of the system for the elements $k \in K$, while we call $s \in \Sigma$ the *pure strategy* associated with k if and only if $s_k = 1$ and 0 otherwise, while any other $\sigma \in \Sigma$ a *mixed strategy.*

Now that we have formally described sustainability strategies as elements s of a strategic menus Σ, we can establish a formalism for firm-level construct and strategic complexity. We term $\theta_i \in \Sigma$ the specific (long-term) strategy that firm i chooses, which might be a pure or mixed sustainability strategy. We further term $\vartheta_{i,t} \in \Sigma$ its strategic realization at time t. The relationship between a firm's strategy and its realization in year-on-year decisions ultimately depends on the degree of exploration of neighboring strategies the firm chooses, τ_i. Thus a dynamic component naturally emerges, where strategic pivots over time can be captured by investigating the series of strategic realizations $\{\vartheta_{i,t}\}_t = f(\theta_i, \tau_i)$ (cf. Uncovering sustainability strategies), and gauging their sensitivity to systemic complexity.

Consistently with the requisite variety argument, the complexity of firm strategies is related to the variety of contingent behavior. In our framework, this ultimately depends on the breath of activities and concurrent sustainability goals different strategic archetypes imply. We thus define the level of complexity of a strategic archetype k as the renormalized differential entropy of its implied distribution over $A \times G$, H_k (Jaynes 2003). Therefore, the strategic complexity firms deploy in a given year can be written as:

$$c(\vartheta_{i,t}) = \sum_k \vartheta_{i,t,k} H_k \tag{4}$$

Heterogeneity in $c(\vartheta_{i,t})$ is therefore a formal, manageable representation to explore the differential deployment of strategic complexity by firms over time. We can now move to tackle the question of the link between sustainability strategies and firm value more formally. In particular, we dedicate the next subsection first to set up a reduced form model to link $c(\vartheta_{i,t})$ with firm value, and then to formalize our hypotheses in parametric terms.

2.5 A formal model of firm value and complexity

The strategic positioning $\vartheta_{i,t}$ of firm i at time t over the $|K|$ sustainability strategic archetypes is a fundamental construct in order to explore the contingencies that allow firms to generate value through sustainability. Figure 1 Panel **C** visualizes this relationship by associating to each strategy in Σ an implied firm-level value. We formalize this relationship by defining firm value $\Pi_{i,t}$ as the result of a shared value function $V(\cdot)$ that leverages (a) (quasi-)immutable firm-level characteristics Z_i, e.g. sector, geography, or production technology class, (b) population wide shocks H_t, e.g. macroeconomic crises, natural disasters, and (c) the current stock of cumulated resources, technologies, and capabilities of an individual firm at a given time, which we generally term the *state* $S_{i,t}$ as follows (cf. also Hawn and Ioannou 2016):

$$\Pi_{i,t} = V(S_{i,t}, Z_i, H_t) \tag{5}$$

We further introduce the vector $x_{i,t} = [x_{1,i,t} \quad x_{2,i,t}]$ that includes the entire choice-space of firm strategic positionings, which is a superset of sustainability strategic positioning choices $x_{2,i,t} \equiv \vartheta_{i,t}$. With it, we can further refine 5 according to assumptions grounded in extant literature:

$$V(S_{i,t}, Z_i, H_t) = V_S(S_{i,t}) + V_Z(Z_i) + V_H(H_t) \tag{Strategic separability}$$

$$S_{i,t} = g_1(x_{1,i,t}, S_{i,t-1}) g_2(x_{2,i,t}, S_{i,t-1}) g_3(Z_i) g_4(H_t) S_{i,t-1} \tag{Path dependence}$$

$$V_S(S_{i,t}) = \ln S_{i,t} \tag{Diminishing returns}$$

$$\mathrm{E}\left(\ln g_k(x_{k,i,t}, S_{i,t-1}) | X_{i,t-1}, \bar{x}_{i,t}, Z_i, H_t\right) = f_k(\bar{x}_{k,i,t}, X_{i,t-1}; \beta_k) \quad k = 1, 2 \tag{Observables}$$

The Path dependence assumption describes the dynamics of the state ($S_{i,t}$) according to the flow of strategic decisions ($x_{i,t}$), firm's characteristics (Z_i), and aggregate factors (H_t). At its core, a firm's state is the result of appreciation/depreciation processes over the previous state ($S_{i,t-1}$). These processes are captured in four contributions, $g_k, k = \{1, 2, 3, 4\}$. The first two focus on the contribution of decision flows, and in neoclassical terms would be the result of maximization processes, while the last two capture the non-strategic components. Crucially, we assume multiplicative separability of sustainability with respect to remaining strategies in order to investigate their independent contribution. Building on this framework, the Strategic separability assumption implies that the firm's fixed characteristics (Z_i) or aggregate conditions (H_t) do not further affect the marginal contribution of the state to the firm's value beyond their influence on the state evolution. Concretely, this means that Z_i and H_t immediately affect value in a direct way, but their indirect contribution (i.e., through the firm's state) emerges only with a temporal lag.

With the Diminishing returns assumption, we capture the economic idea that firm value is increasing in the firm's state, but ever increasing accumulation of resources and capabilities yields smaller and smaller gains in value. In this case, the natural logarithm is a commonly used and convenient functional form to represent the class of function that satisfies this diminishing return property (namely, a positive first derivative but a negative second derivative).

Finally, the Observables assumption links theoretical quantities with observables. In particular, it requires the existence of a set of observable stocks ($X_{i,t}$) and flows ($\bar{x}_{i,t}$) that *jointly* provide an unbiased estimate on the strategic contributions g_1 and g_2 to the state transition. This assumption might sound particularly harsh, but the existence of f_k is guaranteed by the properties of conditional expectations (cf. Doob-Dynkin lemma, Doob 1953). The key component we require is that f_k is *parametrizable* by a vector of coefficient β_k that can be in principle estimated. This means that observable strategic cues ($\bar{x}_{i,t}$) can be the basis to understand the contribution of strategic choices to firm fundamentals. At the same time, even though the scalar $S_{i,t}$ is entirely unobservable, we can use a set of stock variables (potentially multiple, capturing different aspects of $S_{i,t}$) to imperfectly approximate its net contribution to the state transition process.

Taken together, these assumptions characterize (5) with the following fully-observable first difference model (see A1):

$$\pi_{i,t} = \Pi_{i,t} - \Pi_{i,t-1} = f_1(\bar{x}_{1,i,t}, X_{i,t-1}) + f_2(\bar{\vartheta}_{i,t}, X_{i,t-1}) + \delta_t + \gamma_i + u_{i,t} \tag{6}$$

Where $\bar{\vartheta}_{i,t} \equiv \bar{x}_{2,i,t}$ corresponds to the empirical vector of sustainability strategies estimated according to Uncovering sustainability strategies (cfr. also Sustainability strategies), $\bar{x}_{1,i,t}$ includes observable non-sustainability decisions (e.g., financing choices), $X_{i,t}$ is a set of stock variables, δ_t are time fixed effects, γ_i firm fixed effects, and $u_{i,t}$ is a noise term with 0 conditional mean $\mathrm{E}\left(u_{i,t} | X_{i,t}, \bar{x}_{i,t}, \gamma_i, \delta_t\right) = 0$.

Model (6) is particularly useful in our inquiry since, provided we have access to a good proxy for firm value, we can devise an identification strategy to study the value effects of sustainability strategies. Indeed, we can reframe the theoretical gap discussed above as limited knowledge of the functional form of f_2, especially regarding its distinctive features compared to more thoroughly studied phenomena that would be captured by f_1. Therefore, we dedicate the following subsection to formalizing hypotheses and refining f_2 accordingly.

In order to test the propositions we put forward in Systemic and strategic complexity, we need to formalize them as a specification for f_2 in model (6). In particular, we formalize the increasing payoff for strategic complexity in a saturated utility framework. The payoff of strategic complexity increases up to a critical point $c^*(u)$ that depends on systemic complexity u, after which the firm is fully equipped to deal with all possible contingencies the system might configure itself into. We thus model the payoff as a theoretical maximum minus a penalty that scales with the distance of $c_{i,t}$ from $c^*(u)$. Therefore:

$$r(c_{i,t}) = \begin{cases} R - \kappa_1 \left(c_{i,t} - c^*(u)\right)^2 & c_{i,t} < c^*(u) \\ R & c_{i,t} \geq c^*(u) \end{cases} \tag{7}$$

Where R represents the maximum potential reward that can be mustered from sustainability activities, and κ_1 the penalty conversion in value units. In real-world scenarios, $c_{i,t}$ will always be much lower than $c^*(u)$, so we practically restrict our analysis to the first case.

Beyond the shadow cost of being far away from the theoretical optimum $c^*(u)$, we impose further direct costs for strategic complexity, to model the tangible cognitive and implementation limits of firms:

$$l(c_{i,t}) = \kappa_2 c_{i,t} \tag{8}$$

Where κ_2 represents the per-value unit cost of strategic complexity. Finally, we control for the *quantity* of initiatives overall performed $N_{i,t}$ to normalize for the intensity of the effort. We can thus introduce the following new specification for f_2:

$$f_2 = \kappa_3 N_{i,t} + r(c_{i,t}) - l(c_{i,t}) \tag{9}$$

$$f_2 = \kappa_3 N_{i,t} + R - \kappa_1 \left(c_{i,t} - c^*(u)\right)^2 - \kappa_2 c_{i,t} \tag{10}$$

$$f_2 = \kappa_3 N_{i,t} + R - \kappa_1 c_{i,t}^2 + \kappa_1 2 c_{i,t} c^*(u) - \kappa_1 c^*(u) - \kappa_2 c_{i,t} \tag{11}$$

$$f_2 = \kappa_3 N_{i,t} + R - \kappa_1 c_{i,t}^2 + (\kappa_1 2 c^*(u) - \kappa_2) c_{i,t} - \kappa_1 c^*(u) \tag{12}$$

With this formulation, it emerges clearly how the inverted U-shape relationship (the second-degree polynomial in $c_{i,t}$) is intimately linked to systemic complexity (u) via the parameter $(\kappa_1 2 c^*(u) - \kappa_2)$. To be consistent with the formulation in Path dependence, we refactor κ_1, $2\kappa_1$,κ_2, κ_3, and R into a vector β_2 and reinstate the hypotheses as

$$f_2(\bar{\vartheta}_{i,t}; \beta_2) = \beta_{2,0} + \beta_{2,1} N_{i,t} + \beta_{2,2} c^2(\bar{\vartheta}_{i,t}) + \beta_{2,3} c(\bar{\vartheta}_{i,t}) c^*(u) + \beta_{2,4} c^*(u) + \beta_{2,5} c(\bar{\vartheta}_{i,t}) \tag{Hypotheses statement}$$

Where, as argued in Systemic and strategic complexity, we expect a negative $\beta_{2,2}$ and a positive combined influence between $\beta_{2,3}$ and $\beta_{2,5}$.

3 Data

3.1 A dataset of sustainability initiatives

Investigating sustainability strategies in the way we discussed above requires obtaining a complete account of firm-level sustainability initiatives. Incidentally, a systematic presentation of what has been done in sustainability terms over the course of a year is in the companies' interest as well. Indeed, with time ad hoc "sustainability reports" have become a standard output among major global companies (Wood 2010, Christensen et al. 2021). They are specialized disclosures produced yearly (sometimes biannually) to inform stakeholders and society at large of the firm's actions, objectives, and results within a corporate sustainability framework.

We contributed to the creation of a comprehensive dataset of sustainability reports at the Leonardo Centre at Imperial College London and the GOLDEN foundation, which systematically gathers these documents either through external purchases or web crawling. Overall, we base our analysis on $\sim$ 70000 reports for $\sim$ 12000 companies from 2010 to 2023. In order to extract sustainability initiatives from the texts of the reports, manual annotators worked on a subset of 507 sustainability reports ($\sim$ 55088 initiatives). In the annotation process, the annotators were instructed and trained to identify initiatives as actions deliberated and implemented in the fiscal year the report refers to. Crucially, commitments, vision statements, mandatory compliance, and future plans were not considered sustainability initiatives.

Once a small coherent chunk of text is recognized as an initiative, for our purposes we need to extract information about the concrete activity that was implemented and the immediate sustainability goal it pursues (see Sustainability strategies). Therefore, the annotators were also instructed and trained on mapping sustainability objectives to the most closely related goal (using the UN Sustainable Development Goals classification) and type of activities to a mutually exclusive and collectively exhaustive classification scheme (see Table A1 for action types descriptions). In Figure A1, we report both categorizations. A subset of the resulting manually annotated dataset has been used by Bettinazzi et al. (2024), who implemented an *fsQCA* design to study firm environmental behavior and media reactions.

To scale from the annotated sample to the remaining large amount of sustainability reports, a collective effort at Leonardo was put in place to develop neural-network-based machine learning approaches, train them on the manual sample, and classify the remaining documents to create the final dataset (see Harrison et al. 2023, for a similar application in the board leadership context). We use two separate machine learning systems for this task (a BERT and a RoBERTa-based model) and combine their predictions together in an ensemble model in order to achieve the best accuracy. After the algorithm identifies an initiative, the text goes through a separate system that classifies it within its context based on (1) the type of the action or activity and (2) the most closely related Sustainable Development Goal (SDG) (see Cenci et al. 2023, for a complete description). We report an overview of the empirically observed initiatives according to their action-type and SDG in Figure 2 Panel **A**.

Several diagnostic tests have been performed in order to ensure the integrity of the dataset. Inter-rater reliability tests on the manually annotated corpus were satisfactory, and the 136 reports that were included in the development and test sets of the routine were specifically annotated independently by three different annotators each, achieving an inter-rater reliability of 0.4 (moderate agreement) with a 0.7 (substantial agreement) specific agreement on the positive label (Fleiss 1966, Landis and Koch 1977). Ex-post tests on the machine output showed an initiative identification precision of 94%, while action type and SDG classification accuracy were measured at 86% and 83% respectively (conditional on the text being an initiative). Figure 2 Panel **B** and **C** report the overall coverage of the sample we matched with financial data (see also Financial and accounting variables), with respect to both different regions and with respect to the universe of large hard-to-abate firms.

3.2 Uncovering sustainability strategies

We start by observing the number, objectives, and type of initiatives in each recorded year for each recorded company in the dataset. The 14 action types together with the 17 SDGs offer a natural discretization of the initiative choice space of Figure 1. For easiness of interpretation, we further aggregate these categories across 4 objectives (climate, biodiversity, resource management, and infrastructure resilience) and 7 actions (change in current operations, innovation, human capital management, incentives, monitoring, advocacy, restructuring). Given our interpretation of realized initiatives as the footprint of adopted strategies (cf. Sustainability strategies), we adopt a hierarchical Bayesian modeling perspective to investigate what latent configuration would have a higher likelihood of having generated the observed quantities.

The initiative vector $x_{i,t}$, i.e. the 28-dimensional count vector of initiatives segmented by action-objectives made by firm i at time t, formally convey the observed information:

$$x_{i,t} = [\#\text{init with objective 1 \& type 1}, \ldots, \#\text{ init with objective 4 \& type 7}] \tag{13}$$

Exploiting the nature of count vectors, we start from the following generative process:

$$x_{i,t} \sim \text{Multinomial}(P_{i,t}, N_{i,t}) \tag{14}$$

Where $N_{i,t}$ is the total number of initiatives performed, i.e. the *intensity* of the sustainability strategic effort, and $P_{i,t}$ is a probability distribution that speaks to which actions-objectives are more likely to be chosen by firm i every time it implements a sustainability initiative at time t (make a sustainability decision).

Based on our theory, the specific characteristics of $P_{i,t}$ are induced by the sustainability strategies available to firms and the strategic mix employed by firm i at time t. In general, we assume that there are infinite but countable strategic archetypes (although the sensible, concretely observed ones are finite). Starting from the notation of Sustainability strategies, we discretize the mapping associated with generic archetypes k with a 28-dimensional vector ϕ_k, whose v^{th} element captures the relevant aspect of the associated type-SDG combination (ordered as in x) in k. We then term $\vartheta_{i,t,k}$ as the weight firm i places on archetype k at time t, so the firm-year specific probability vector is a weighted average:

$$P_{i,t} = \sum_{k=1}^{K} \vartheta_{i,t,k} \phi_k \tag{15}$$

We thus have decomposed the problem into a system-level component, the global strategic archetypes ϕ_k, and firm-level component, the specific strategy firm i pursues at time t ($\vartheta_{i,t}$). We further characterize them sequentially.

Starting from ϕ, in Sustainability strategies we assumed a countably infinite number of potential strategies, but only a finite number of sensible one. We model this by starting from a safely large number of archetypes to be considered, K^*, while building a procedure to prune them and infer how many, $|K| < K^*$, are empirically relevant. This is achieved through a stick-breaking process that defines the global prevalence, β_k, of each archetype. Unlike classic models that use a Beta distribution for stick-breaking, we employ a more flexible logistic-normal construction. For a fixed level K^*, we first draw latent variables:

$$\nu'_k \sim \mathcal{N}(0,1) \quad \forall k \in [1, \dots, K^* - 1] \tag{16}$$

These are transformed into proportions $\nu_k \in (0, 1)$ using the sigmoid function sigmoid$(\cdot)$, where the hyperparameter γ controls the concentration of the distribution:

$$\nu_k = \text{sigmoid}(\nu'_k + \ln \gamma) \tag{17}$$

The prevalences β_k are then formed by recursively breaking a "stick" of unit length:

$$\beta_k = \nu_k \prod_{j=1}^{k-1}(1 - \nu_j) \tag{18}$$

The result of this procedure is that β_k, the global prevalence of the associated archetype ϕ_k, will be meaningfully larger than zero only for some, sensible k values. At the same time, all strategic archetypes ϕ_k are linked with initiatives via another logistic-normal process:

$$\phi'_k \sim \mathcal{N}(0, \mathbf{I}_V) \tag{19}$$

$$\phi_k = \text{softmax}(\phi'_k \cdot \beta_{\text{topic}}) \tag{20}$$

Moving to $\vartheta_{i,t}$, we decompose it in two theoretically relevant parts: the multi-year, long term strategy of the firm θ_i, and its propensity to engage in exploration τ_i, which captures how likely it is to deviate from the baseline initiative composition implied by θ_i.

First, each firm's strategy θ_i is modeled starting from the global archetype distribution β, since, on aggregate, firm reliance on different archetypes constitutes the archetype global proportion by construction. This is governed by a hyperparameter α that controls how much firms can specialize away from the global norm:

$$\tilde{\theta}_i \sim \mathcal{N}(0, \mathbf{I}_{K^*}) \tag{21}$$

$$\theta_i = \text{softmax}(\tilde{\theta}_i \cdot \alpha + \log \beta) \tag{22}$$

Second, we define τ_i as a firm-specific latent parameter:

$$\tau_i \sim \text{Gamma}(\text{shape}, \text{rate}) \tag{23}$$

Then, the final firm-year strategic realization $\vartheta_{i,t}$ combines a firm-year deviation, scaled by τ_i, with their long-term strategy θ_i:

$$\tilde{\vartheta}_{i,t} \sim \mathcal{N}(0, \mathbf{I}_{K^*}) \tag{24}$$

$$\vartheta_{i,t} = \text{softmax}(\tilde{\vartheta}_{i,t} \cdot \tau_i + (\tilde{\theta}_i \cdot \alpha + \log \beta)) \tag{25}$$

Ultimately, the model optimizes for the likelihood of $x_{i,t}$ in (14) given the observed data and using uninformative Gamma priors for the hyperparameters. The model thus is forced to consider up to K^* strategic archetypes, but then allowed to globally reduce some of them to irrelevance through the stick-breaking procedure (in (16)-(18), more or less aggressively depending on γ) in order to allow the true relevant strategic archetypes K to emerge. In computations, we set $K^* = 50$.

We ran the estimation in a 2-step procedure. First, we employ Stochastic Variational Inference (SVI) with the Adam optimizer to explore reasonable parameter combinations. We ran the procedure 100 times with random initialization and retrieved samples from the best run in terms of ELBO loss, convergence and archetype distinctiveness. We then used those samples as initial parameters for Markov-Chain Monte Carlo estimation. We ran 12 parallel chains with a No-U Turn Sampler (a variant of Hamiltonian Monte Carlo), ensuring chain alignment and convergence.

This hierarchical structure allows us to simultaneously learn several quantities. The posteriors of interest are:

- $\bar{\phi}_k$: The initiative-level composition of each latent strategic archetype.

- $\bar{\theta}_i$: The firm sustainability strategy.
- $\bar{\vartheta}_{i,t}$: The firm's realized strategic mix in a given year.
- $\bar{\tau}_i$: The firm's propensity for strategic exploration.

In particular, we will use $\bar{\phi}_k$ to estimate the intrinsic complexity of each strategic archetype, and $\bar{\vartheta}_{i,t}$ to derive the level of strategic complexity firm i chose to rely upon in year t.

Most notably, the representation in equation (15) is conceptually similar to mixture models, like the Hierarchical Dirichlet Process (HDP), tipically used in topic models. In that context, each document (a firm-year) has its own mixture of topics (strategic archetypes), and each topic is a probability distribution over words (initiatives).

Our model departs from these established alternatives in three ways. First, it introduces an additional hierarchical layer that distinguishes between a firm's long-term strategy (θ_i) and its annual realization ($\vartheta_{i,t}$). Whereas a standard HDP model would learn a single strategic mixture for each firm-year, our approach models the annual strategy as a deviation from a firm-specific baseline. This structure allows the model to explicitly isolate and quantify a firm's propensity for strategic change through the latent parameter τ_i, providing a direct measure of exploration propensity. Second, our model replaces the "hard" simplex constraint of the Dirichlet distribution with the "smooth" constraint of the logistic-normal distribution. This has two major benefits: (1) it can better capture potential correlation structures between the prevalence of different archetypes, and (2) it creates a more efficient sampling environment for modern gradient-based MCMC methods, which operate more naturally in unconstrained Euclidean space. Third, the model operates on a more meaningful unit of analysis with a more parsimonious latent structure, since the information density of word-tokens is extremely low compared to classified purposeful actions.

Through this procedure, we found that 12 sustainability strategies were sufficient to explain $\sim 93\%$ of observed choices in sustainability initiatives, so in our empirical context $|K| = 12$.

We report the implied behavioral footprint of the two most prominent in Figure 3.

3.3 Systemic complexity and regulatory shaping

A central challenge in our framework is that systemic complexity is not directly observable. However, its moderating effect on the value of strategic action can be identified by exploiting exogenous shocks that alter its underlying level for a subset of firms. To this end, we leverage the European Union's "Fit for 55" legislative package, operationalized through the European Climate Law (Regulation (EU) 2021/1119). This regulation acts not as a simple constraint but as a comprehensive reshaping of the competitive environment, an instance where the government acts as a "landscape designer" to alter the fitness landscape on which firms compete (Li and Csaszar 2019). The law's announcement and subsequent adoption can be considered exogenous to the strategic choices of individual firms and thus suitable for a quasi-natural experiment.

The regulation increases systemic complexity for EU-based firms through three primary mechanisms. First, it tightens the causal web of the business environment by creating a portfolio of deeply interconnected legislative revisions. The package mandates changes to core EU climate policy instruments, including the EU Emissions Trading System (ETS), making it effectively binding, the Effort Sharing Regulation, and the framework for land use, land-use change, and forestry (LULUCF), while anticipating a Carbon Border Adjustment Mechanism (CBAM). This integration ensures that firm actions in one domain have cascading consequences across others—from operational emissions to supply chain logistics and energy sourcing—thereby amplifying the degree of interdependence that firms must manage.

Second, the framework elevates the required sophistication of corporate responses by rendering low-effort, symbolic strategies ineffective. The law establishes a legally binding trajectory toward a 55% net emissions reduction by 2030 and climate neutrality by 2050 (European Parliament and Council of the European Union 2019). Crucially, it backs these targets with a mandate for rigorous, science-based progress assessments at both the Union and Member State levels, overseen by a new European Scientific Advisory Board on Climate Change. This heightened scrutiny raises the bar for strategic action, demanding substantive, verifiable, and causally-linked initiatives over disjointed or purely communicative efforts.

Third, by making the transition "irreversible", the regulation fundamentally alters the long-term strategic calculus. It signals a permanent shift in the institutional environment, compelling firms to embed systemic feedback loops into their core decision-making processes rather than treating them as temporary pressures. The requisite variety for an effective strategic response is thus exogenously increased.

In our empirical design, firms headquartered in the EU constitute the treatment group ($Treated_i = 1$) for the period from 2021 onward ($Post_t = 1$), while the control group is constituted by firms in similarly developed countries, i.e. the United States, Canada, Japan, and the United Kingdom. Formally, we model this regulatory shock as a positive structural shift in systemic complexity, u. For any firm i at time t, this parameter is specified as:

$$u_{i,t} = u_0 + \Delta u \cdot \text{Treated}_i \cdot \text{Post}_t \tag{26}$$

where u_0 is the baseline level of systemic complexity that we consider constant in the sample period, and $\Delta \upsilon$ is the shift induced by the shock. Since we an increase in systemic complexity implies also an increase in the theoretically optimal strategic complexity response c^*, we also have:

$$c^*(u_0 + \Delta u \cdot \text{Treated}_i \cdot \text{Post}_t) = c^*(u_0) + U \cdot \text{Treated}_i \cdot \text{Post}_t \tag{27}$$

For a positive U. This specification allows us to test H2 by estimating the parameters that capture the effect of this shift in our main value equation.

3.4 Financial and accounting variables

In order to obtain a sufficiently large but comparable universe, we focus our analysis on global firms in the Industrials, Material, Energy, Consumer Staples and Discretionary, and Utilities (GICS sector codes 10,15,20,25,30, and 55) with at least 100 million dollars in total asset and revenues.

We collected data for all companies matching these criteria in Compustat North America and Compustat Global, retrieving a total of 55794 firms for years 2010 to 2023. Of these, we included in the main analysis only 1186, those which published at least 3 sustainability reports in the sample period, each with at least 5 recorded initiatives. We kept the remaining companies in the universe to account for self-selectivity in sustainability disclosure choices. Although we cannot use them to test our main hypotheses directly, we use them as first-stage model to correct for sample selection bias (see Methods).

In order to study the effect of sustainability strategies on firm value, we follow a long-standing consensus in empirical finance that relies on Tobin's Q as the main proxy for firm value (Bebchuk and Cohen 2005, Coles et al. 2008, Allayannis and Weston 2001, Daines 2001, Mackay and Moeller 2007). The choice to focus on Tobin's Q as the primary performance measure stems from its ability to capture both tangible and intangible value (Peters and Taylor 2017), which is particularly relevant when evaluating the impact of sustainability initiatives. Unlike accounting-based indicators, Tobin's Q incorporates market expectations of future earnings and places significant weight on knowledge-based assets, reputational capital, and goodwill, all of which can be strongly influenced by ESG-related activities (Hall 1993). The forward-looking nature of this metric goes beyond the current value of asset or short-term profitability and is particularly suited to capture the value generation potential of the long-term strategic orientation of the firm, including in the domain of non-market strategy or toward environmental and social objectives (Dowell et al. 2000, Awaysheh et al. 2020, Simeth and Cincera 2016, Huang et al. 2015).

We computed Tobin's Q by identifying the primary issue of common shares traded in the primary exchange of each firm in our sample. We excluded all preferred, ADR, or otherwise atypical stocks. Of the remaining ones, we relied on Compustat's primary issue flags for US, Canada, and rest of the world. If none was given, or if the current primary issue was present for less than 30% of the sample period due to recent splittings, we chose the common stock issue in the primary exchange with the highest trading volume to represent the company. We retrieved the market capitalization of each company in each year at the last business day in December, to avoid fiscal year choices bias, by multiplying closure stock price per number of shares outstanding. Finally, we assembled Tobin's Q by summing market cap and total debt, and dividing per total asset. Both stock prices and accounting variables were converted in US dollars (according to the time-relevant exchange rate) before the computation. In our main specification, we take the first difference of Tobin's Q year-on-year as proxy for $\pi_{i,t}$.

Finally, we further retrieve common structural antecedents to strategy selection and measure firm performance to populate $\bar{x}_{i,t}$ and $X_{i,t}$. Regarding stocks $X_{i,t}$, we collect revenues, tangible assets, long term debt, and EBITDA. These data are employed to build proxies for firm size (log of revenues in US dollars), tangibility (property, plants, and equipment over total asset), profitability (EBITDA over total assets), and leverage (long term debt over total asset). Conversely, we include flow data for capex, administrative expenditures, and r&d investments in $\bar{x}_{i,t}$. We converted all values in US dollars with the appropriate rate.

4 Methods

To test our hypotheses on the relationship between strategic complexity and firm value under varying levels of systemic complexity, we employ a quasi-natural experiment framework. Specifically, we leverage the introduction of the European Union's comprehensive "Fit for 55" climate policy package as an exogenous shock (cf. Systemic complexity and regulatory shaping). This regulatory event substantially increased the salience and stringency of environmental constraints for firms operating within the EU, thereby elevating the effective systemic complexity they face. Our research design uses a Difference-in-Differences (DiD) methodology. The treatment group consists of firms headquartered in the European Union, which are directly subject to the new regulatory landscape. The control group is composed of comparable firms headquartered in the United Kingdom, Canada, the United States, and Japan, which were not directly affected by this specific policy shock. The post-treatment period begins in 2021, following the announcement and initial implementation phases of the policy package.

To derive our main specification, we start from (6) and substitute f_1 and f_2 by further restricting their properties. Regarding f_1, we assume that control variables enter linearly in our equation. Since we are not explicitly theorizing on them, we are only concerned that potential non-linear effects do not bias our estimates. For completeness, we report this requirement, together with exogeneity (which we get from the previous assumptions, see A1), here below:

$$f_1(\bar{x}_{1,i,t}, X_{i,t-1}; \beta_1) = \beta_{0,1} + \beta_{1,1} X_{i,t-1} + \beta_{1,2} \bar{x}_{i,t} + X_{i,t-1} \beta_{1,3} \bar{x}_{i,t} \tag{Controls linearity}$$

$$\mathrm{E}\left(u_i | X_{i,t-1}, \bar{x}_{i,t}, \zeta_i, \eta_t\right) = 0 \tag{Exogeneity}$$

Regarding f_2, we further assume that the empirical quantity $\bar{\vartheta}_{i,t}$ is a good proxy for $\vartheta_{i,t}$ from the perspective of $c(\cdot)$ and that systemic complexity effectiveness υ, although unobservable, is constant apart from the exogenous shock described in Systemic complexity and regulatory shaping. Therefore, using the Hypotheses statement:

$$f_2(\bar{\vartheta}_{i,t}; \beta_2) = f_2(\vartheta_{i,t}; \beta_2) \tag{28}$$

$$f_2(\bar{\vartheta}_{i,t};\beta_2) = \beta_{2,0} + \beta_{2,1}N_{i,t} + \beta_{2,2}c^2(\bar{\vartheta}_{i,t}) + \beta_{2,3}c(\bar{\vartheta}_{i,t})c^*(u) \\ + \beta_{2,4}c^*(u) + \beta_{2,5}c(\bar{\vartheta}_{i,t}) \tag{29}$$

$$f_2(\bar{\vartheta}_{i,t};\beta_2) = \beta_{2,0} + \beta_{2,1}N_{i,t} + \beta_{2,2}c^2(\bar{\vartheta}_{i,t}) \\ + \beta_{2,3}c(\bar{\vartheta}_{i,t})(c^*(u_0) + U \cdot \text{Treated}_i \cdot \text{Post}_t) \\ + \beta_{2,4}(c^*(u_0) + U \cdot \text{Treated}_i \cdot \text{Post}_t) + \beta_{2,5}c(\bar{\vartheta}_{i,t}) \tag{30}$$

$$f_2(\bar{\vartheta}_{i,t};\beta_2) = (\beta_{2,0} + \beta_{2,4}c^*(u_0)) + \beta_{2,1}N_{i,t} + \beta_{2,2}c^2(\bar{\vartheta}_{i,t}) \\ + (\beta_{2,3}c^*(u_0))c(\bar{\vartheta}_{i,t}) + (\beta_{2,3}U)c(\bar{\vartheta}_{i,t}) \cdot \text{Treated}_i \cdot \text{Post}_t \\ + (\beta_{2,4}U) \cdot \text{Treated}_i \cdot \text{Post}_t + \beta_{2,5}c(\bar{\vartheta}_{i,t}) \tag{31}$$

Where, since both $c(u_0)$ and U are constant, they can be absorbed in the coefficients, so that we can arrive at the following final assumption:

$$f_2(\vartheta_{i,t};\beta'_2) = \beta'_{2,0} + \beta'_{2,1}N_{i,t} + \beta'_{2,2}c^2(\bar{\vartheta}_{i,t}) + \beta'_{2,3}c(\bar{\vartheta}_{i,t}) \\ + \beta'_{2,3}c(\bar{\vartheta}_{i,t}) \cdot \text{Treated}_i \cdot \text{Post}_t + \beta'_{2,4} \cdot \text{Treated}_i \cdot \text{Post}_t + \beta'_{2,5}c(\bar{\vartheta}_{i,t}) \tag{Observed hypotheses statement}$$

With these final assumptions, (6) becomes:

$$\pi_{i,t} = \beta'_{0,1} + \beta_{1,1}X_{i,t-1} + \beta_{1,2}\bar{x}_{i,t} + X_{i,t-1}\beta_{1,3}\bar{x}'_{i,t} + \beta'_{2,1}N_{i,t} + \beta'_{2,2}c^2_{i,t} + \beta'_{2,3}c_{i,t} \\ + \beta'_{2,3}c_{i,t} \cdot \text{Treated}_i \cdot \text{Post}_t + \beta'_{2,4} \cdot \text{Treated}_i \cdot \text{Post}_t + \beta'_{2,5}c_{i,t} + \delta_t + \gamma_i + u_{i,t} \tag{32}$$

Which is a classic triple DiD equation, with the difference that the “continuous treatment” $c_{i,t}$ also appears squared and is missing some lower order interactions.

Estimating our main equation requires a multi-stage procedure to address several significant econometric challenges that could otherwise bias the coefficients of interest. Specifically, our estimation strategy is designed to simultaneously correct for control changes that might pollute the causal path, selection on pre-treatment observables that could violate the parallel trends assumption, sample selection bias stemming from firms' voluntary decision to disclose sustainability information, and the endogeneity of a firm's strategic choice of complexity.

First, to mitigate concerns that post-treatment changes in control variables might be part of the causal pathway (i.e., bad controls) and to handle unobserved time-invariant heterogeneity, we replace the standard time-varying controls in the final equation with Mundlak (1978) devices. These are firm-specific, pre-treatment historical averages of the controls. Furthermore, to correctly specify the DiD model, we include the full set of lower-order interaction terms. Our final specification is thus a fully-saturated triple-difference model.

Second, to enhance the credibility of the parallel trends assumption, we address systematic pre-treatment differences between the treatment and control groups. We employ a non-parametric Covariate Balancing Propensity Score (CBPS) method. Using firm data from the pre-treatment period (ending 2016), we generate weights that balance the treatment and control groups on key historical observables: profitability, tangibility, leverage, and size. These weights create a pseudo-population where the observable characteristics of the two groups are statistically indistinguishable before the shock. All subsequent analyses are weighted using these CBPS weights.

Third, the sample is limited to firms that voluntarily publish sustainability reports, which is a non-random selection process. To correct for potential selection bias, we implement a procedure based on Heckman (1979). We estimate annual Probit models to predict a firm's likelihood of disclosing sustainability information in a given year. For identification, this selection model includes the average disclosure rate among industry and country peers as exclusion restriction, which is expected to influence a firm's disclosure choice but not its value directly. From these models, we compute the Inverse Mills Ratio (IMR), which is then included as a control in the main value equation to account for selection effects.

Fourth, the core of our estimation relies on an Instrumental Variable (IV) approach to address the endogeneity of strategic complexity. The final model is estimated using the Generalized Method of Moments (GMM), which is efficient under heteroskedasticity. The endogenous regressors are the complexity term ($c_{i,t}$), its square ($c_{i,t}^2$), and the interaction of strategic complexity with the DiD indicator ($c_{i,t} \cdot \text{Treated}_i \cdot \text{Post}_t$). To instrument these variables, we use the verbosity of sustainability reports among a firm's peers, measured as the number of tokenized sentences in their reports, as the base instrument. We argue that peer communication norms influence a firm's strategic communication and behavior but do not directly affect its own value, conditional on its chosen strategy and other controls. We further complement it by using interacted instruments, where we interact historical averages of controls with the shock. This approach is conceptually similar to shift-share instruments (Bartik 1991), where differential shares (here, the firm historical characteristics) are interacted with an exogenous shift (here, the policy shock).

Finally, we the strategic complexity measure, $c_{i,t}$, is a generated regressor from our initial hierarchical Bayesian model, while the inverse mills ratio is generated by the selection step. This means that meaning their estimation introduces uncertainty in the main specification that must be accounted for. Moreover, the panel nature of our data implies that errors are likely correlated within firms over time. To address both issues simultaneously, we compute bootstrapped standard errors clustered at the firm level. This procedure provides valid and conservative estimates of the statistical significance of our findings.

5 Results

This section presents the results of the analysis. We first provide descriptive statistics of our sample and the uncovered sustainability strategies. We then detail the results of the preliminary analyses required to validate our quasi-natural experiment design, including covariate balancing, the parallel trends test, and the correction for sample selection. Finally, we present the results of our main model, testing the hypothesized relationships between strategic complexity, systemic shocks, and firm value.

The final sample consists of 1,186 unique firms from 2010 to 2024 that have published at least three sustainability reports. Figure 2 provides an overview of this sample in relation to the broader Compustat universe of firms in relevant sectors. As shown in Panel **B**, the prevalence of sustainability reporting has grown substantially over our sample period. Panel **A** indicates that firms in our sample tend to have a higher valuation (average Tobin's Q of 1.49, at the 75th percentile of the universe) than the typical firm in their industries, highlighting the importance of correcting for selection bias. Panel **C** illustrates the overall distribution of sustainability initiatives, showing a primary focus on actions related to operations and structure, with climate and resource management being the most frequently cited objectives. In estimation, all variables have been normalized to have a mean of zero and a standard deviation of one, so the coefficient magnitudes can have a common interpretation.

Our Difference-in-Differences (DiD) design requires several conditions to be met for the results to be causally valid. First, we must ensure that the treatment (EU-headquartered) and control groups are comparable on pre-treatment observables. We use a non-parametric Covariate Balancing Propensity Score (npCBPS) method to re-weight the control group. Table 1 demonstrates the success of this procedure. While the unweighted regression in Model (2) shows significant differences between the groups, the weighted regression in Model (1) shows that pre-treatment observables no longer predict treatment status, with an F-statistic well below the conventional threshold for concern.

Second, the core assumption of a DiD design is that the treatment and control groups would have followed parallel trends in the outcome variable in the absence of the treatment. We test this by running a lead-lag regression, interacting the treatment indicator with a series of year dummies before and after the 2021 policy shock. The results are presented in Table 2 and visualized in Figure 4 Panel **A**. The coefficients for the pre-treatment "lag" periods are statistically insignificant, confirming that no pre-existing differential trend existed between the two groups and that the parallel trends assumption holds.

Third, since sustainability reporting is a voluntary choice, our sample of reporting firms may not be random. We address this potential sample selection bias using a two-stage Heckman (1979) procedure. We first model the firm's decision to disclose sustainability information. The results of this first-stage probit regression are shown in Table 3. The exclusion restriction—the average disclosure rate among industry and country peers—is a strong predictor of a firm's disclosure choice ($p < 0.001$), validating its use for identification. The resulting Inverse Mills Ratio (IMR) is included as a control in our main specification.

Finally, we address the endogeneity of a firm's chosen level of strategic complexity using an Instrumental Variable (IV) approach. The first-stage regression results for our three endogenous variables—strategic complexity $c_{i,t}$, its squared term $c_{i,t}^2$, and the triple interaction term $c_{i,t} \times \text{Treated}_i \times \text{Post}_t$—are reported in Table 4. Our instruments, which include peer verbosity in sustainability reports and interactions between the policy shock and historical firm characteristics, show strong predictive power for the endogenous variables, confirming their relevance.

Having established the validity of our research design, we now turn to the main results from our IV-GMM estimation, presented in Table 5 and Figure 4 Panel **B**.

Our first hypothesis (H1) predicted an inverted U-shaped relationship between the complexity of a firm's sustainability strategy and its value. This is moderately supported by our findings. In Table 5, the coefficient on Strategic Complexity Squared is negative and significant ($\beta = -1.13$, $p < 0.10$), while the coefficient on Strategic Complexity is positive and statistically significant only when interacted with the DiD term and is insignificant as a stand-alone. This configuration still retains the hypothesized curvilinear relationship: firm value initially increases with strategic complexity, but declines after an optimal point is reached due to mounting cognitive and organizational costs. This inverted U-shape is visualized by the performance curves in Figure 4 Panel C, retrieved as the fitted value over a valid range of normalized Tobin's Q.

Our second hypothesis (H2) predicted that an exogenous increase in systemic complexity would shift this inverted U-shaped relationship to the right, increasing the optimal level of strategic complexity. We test this by examining the triple interaction term, *Complexity x Treated x Post*, which captures the differential effect of strategic complexity on EU firms after the "Fit for 55" policy shock. The coefficient for this term in Table 5 is positive and highly significant ($\beta = 3.21$, $p < 0.05$). This result indicates that the value-creation potential of strategic complexity was amplified for firms facing the heightened systemic complexity induced by the new regulatory regime. As illustrated by the coefficient plot in Figure 4 Panel **B** and the performance curves in Figure 4 Panel **C**, the vertex of the parabola shifts to the right for the treatment group in the post-treatment period. This provides strong support for H2, showing that as the external environment becomes more complex, firms must adopt more sophisticated strategies to maintain performance.

6 Discussion and Conclusion

This study examines the relationship between firm-centric value creation and the growing salience of systemic environmental challenges. We developed and tested a framework arguing that in a world constrained by planetary boundaries, our 'small lake' scenario, the effectiveness of a firm's sustainability strategy is contingent on its ability to match the complexity of the surrounding socio-ecological system. This approach connects firm-level strategic choices to systemic outcomes via a multi-level feedback loop, offering a theoretical bridge between the 'local business case' for sustainability and the systemic nature of grand challenges.

Using a novel dataset of corporate sustainability initiatives and a quasi-natural experiment research design, our empirical analysis yields two primary findings. First, we identify an inverted U-shaped relationship between the complexity of a firm's sustainability strategy and its value. This suggests a trade-off: while greater strategic variety is initially beneficial for managing systemic interdependencies, it is subject to diminishing returns as the cognitive and organizational costs of implementation escalate. Second, we find that this relationship is dynamic. An exogenous shock that increases systemic complexity, the EU's 'Fit for 55' policy, shifted this curve to the right. This finding is consistent with complexity theory and the Law of Requisite Variety, indicating that a higher level of strategic complexity became optimal for firms facing a more complex regulatory and competitive environment.

This paper makes several contributions to theory. First, it contributes to strategic management by offering a new lens through which to view non-market strategy as a value creation mechanism under systemic constraints. It extends the "local" business case by moving the analytical focus from firm-centered relationships to the firm's embeddedness within a complex adaptive system. While existing theories powerfully explain how firms build competitive advantage from internal resources or stakeholder relationships (Barney 2018, McGahan 2021), our 'small lake' framework highlights a critical contingency: the overall health and complexity of the system itself. The analysis shows that in a world of binding planetary boundaries, a firm's ability to "internalize" systemic complexity becomes a source of competitive advantage in its own right.

Second, this work advances the corporate sustainability literature by bridging the gap between firm-level strategic action and systemic-level challenges (George et al. 2016, Bansal and Song 2017). We move the debate beyond whether sustainability pays to how and under what conditions it pays, identifying strategic complexity as a key mechanism. Methodologically, using a hierarchical Bayesian model offers a novel and replicable approach to operationalizing and measuring corporate strategies as latent constructs that emerge from observable patterns of corporate initiatives, answering long-standing calls to better measure and understand firms' strategic positionings in this domain.

Third, the paper contributes to complexity science in management by providing a large-scale empirical test of the Law of Requisite Variety (Ashby 1956, McKelvey and Boisot

2009). While this principle is foundational, its application in strategy has often remained at a conceptual level. The empirical demonstration of its relevance, showing that the performance implications of a firm's strategic complexity are contingent on the complexity of its environment, represents an avenue for further integration of complexity science principles into strategic management. Furthermore, by identifying an inverted U-shaped relationship, we ground this principle in the realities of organizational life, linking it to the attention-based view of the firm and the cognitive and organizational costs that constrain perfectly adaptive responses (Ocasio 1997).

Our study is not without limitations, each of which opens promising avenues for future inquiry. First, our data is based on firms' disclosed sustainability initiatives. While we correct for the selection bias of who reports, the data cannot fully capture "greenwashing" or, conversely, substantive but undisclosed actions ("greenhushing"). Future research could integrate our data with non-disclosed metrics, such as actual, externally observed emissions data, satellite imagery of land use, or supply chain audits, to explore the gap between strategic communication and operating reality.

Second, our measurement of initiatives lacks dollar figures or specific resource commitments. We capture the breadth and nature of a firm's strategic portfolio, but not the intensity of investment in each initiative. This presents an opportunity for mixed-methods research. In-depth case studies could illuminate the internal resource allocation processes and organizational structures that support the complex strategies we identify, providing a richer picture of the cognitive and implementation costs.

Third, a key avenue for future research lies in exploring heterogeneity in firm capabilities to leverage strategic complexity. Our theory posits that managing complexity is costly, but these costs likely vary. One crucial moderating capability is what has been termed organizational system thinking (OST), a firm's ability to understand and manage complex feedback loops (Burato et al. 2023). Future work could investigate whether firms with higher levels of OST face a more favorable trade-off, allowing them to manage higher levels of strategic complexity more effectively and shifting their performance curve upwards. Our latent variable τ_i, which captures a firm's propensity for strategic exploration, could serve as a starting point for such an investigation.

Fourth, this paper focuses on strategic complexity as a primary characteristic of sustainability strategies. Future research could explore content-specific dimensions that determine strategy superiority in different contingencies. For example, are strategies focused on innovation superior to those focused on operational changes in fast-moving environments? When are symbolic, advocacy-focused strategies more valuable than substantive, structural ones? Moving beyond *how complex* a strategy is to *what kind* of strategy is optimal *when* is a natural next step.

Finally, we focus on firm value (Tobin's Q) as our primary outcome. While this is a critical metric, sustainability strategies may generate value along other important dimensions. A related question is how strategic complexity impacts organizational resilience. It is plausible that more complex strategies, by preparing a firm for a broader range of systemic contingencies, enhance its ability to withstand crises. Examining this link would further deepen our understanding of the long-term benefits of strategically engaging with grand challenges.

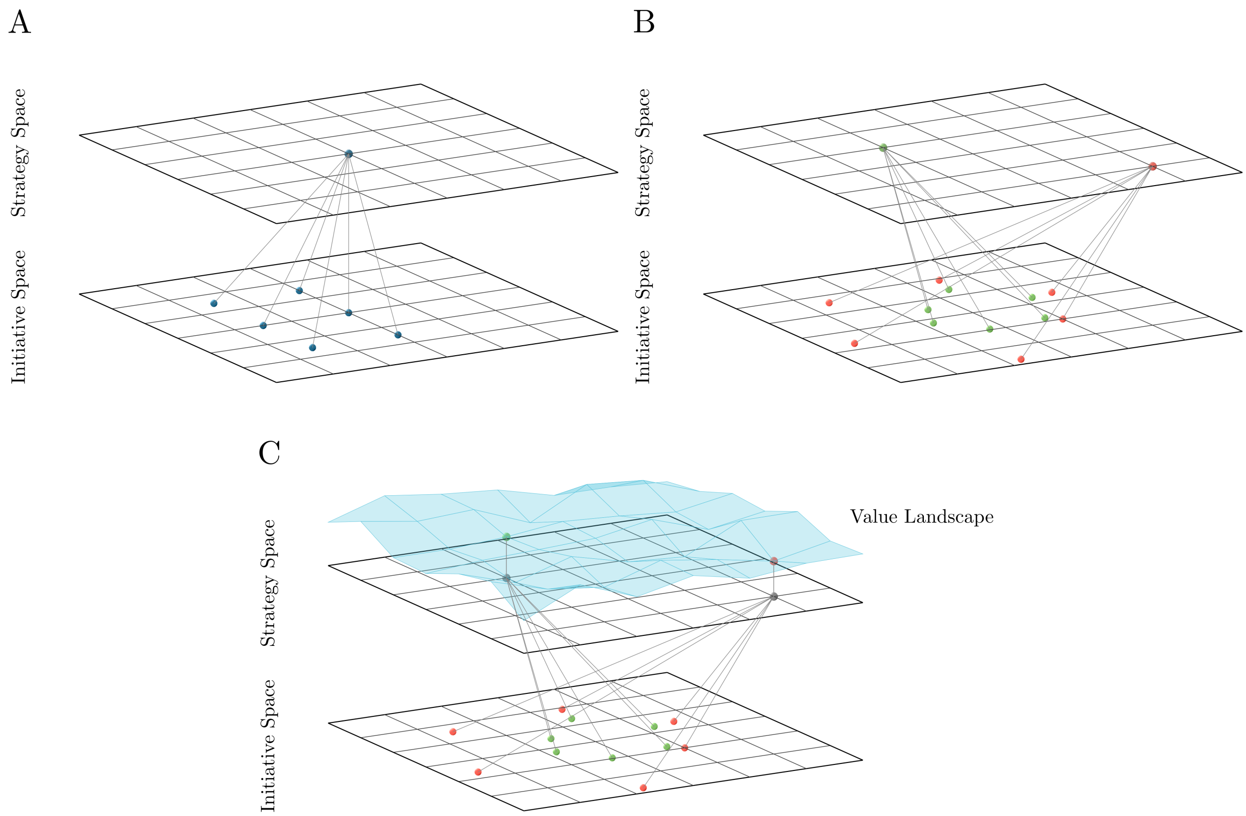

Figure 1: **Initiatives and strategies**. The Figure illustrates that observed initiatives can be mapped into a lower-dimensional strategic space (Panel **A**). Panel **B** shows that heterogeneity in strategies results in heterogeneity in the "footprint" of observed initiatives. Finally, we show in Panel **C** how firm-level value considerations are tied to the strategic domain, rather than to the initiative space.

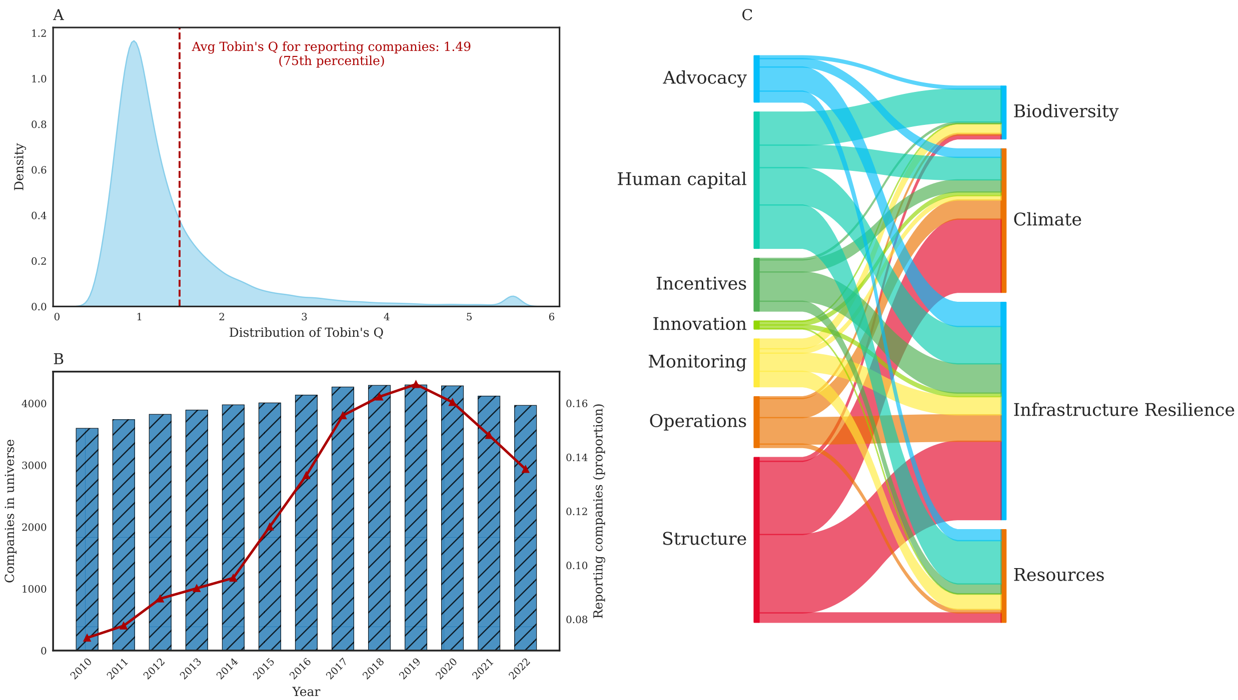

Figure 2: **Descriptives**. The figure reports coverage and descriptives of the sample of companies that disclose sustainability information with respect to the Compustat population. In Panel **A** we report the distribution of firm value (Tobin's Q) across our universe, and compare it with the average of companies in our sample (red vertical line). Panel **B** focuses on the evolution of reporting prevalence over time. On the main axis, we break down the number of firms in the Compustat universe by year (blue hatched bars), while in the secondary axis we include the proportion of firms that issued a sustainability report we could find (red line). Finally, Panel **C** shows the joint occurrences of goals and actions in sustainability initiatives across all recorded sustainability reports.

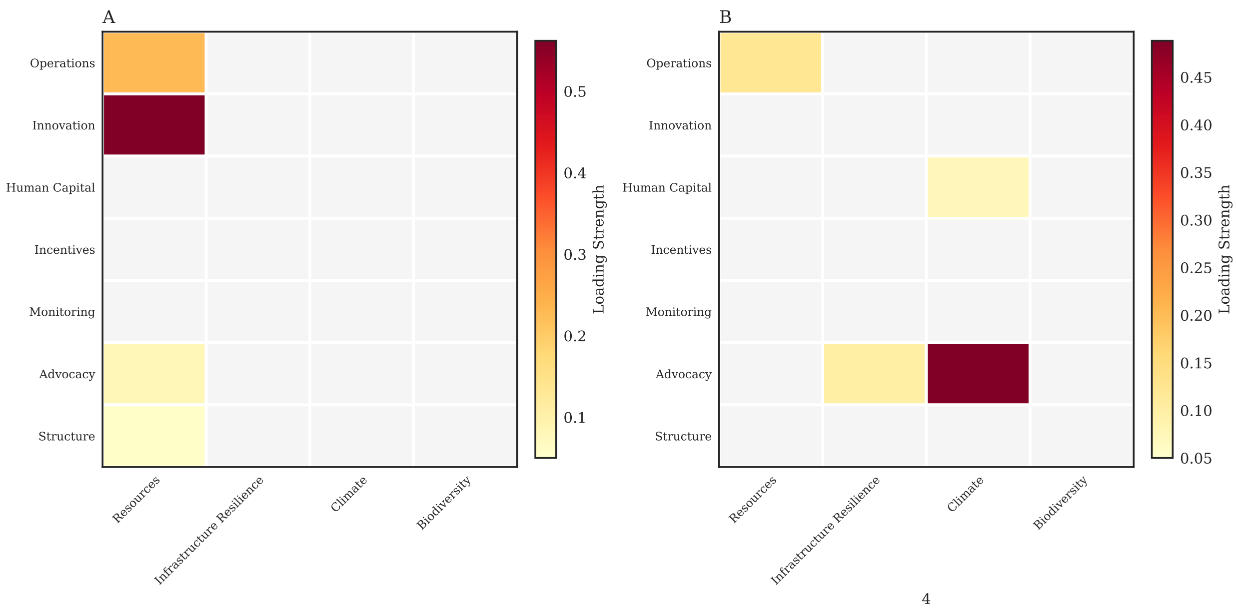

Figure 3: **Strategies and implied behavior**. The Figure reports examples of strategies that companies pursued in the sample period, broken down according to their implied behavioral profile. In each Panel, each cell's color correspond to the degree is which the associated initiative type in terms of goals (columns) and actions (rows) is prevalent for the strategy described by the Panel. In Panel **A**, we show a strategic archetype focused on resource management, but that implies a broad array of substantive activities that need to be performed in this domain (with safety public relations management via some investment in advocacy). Conversely, Panel **B** describes a more horizontal strategic archetype, with a larger focus on symbolic activities. For a full breakdown of all recorded strategies, see Complete description of identified strategies.

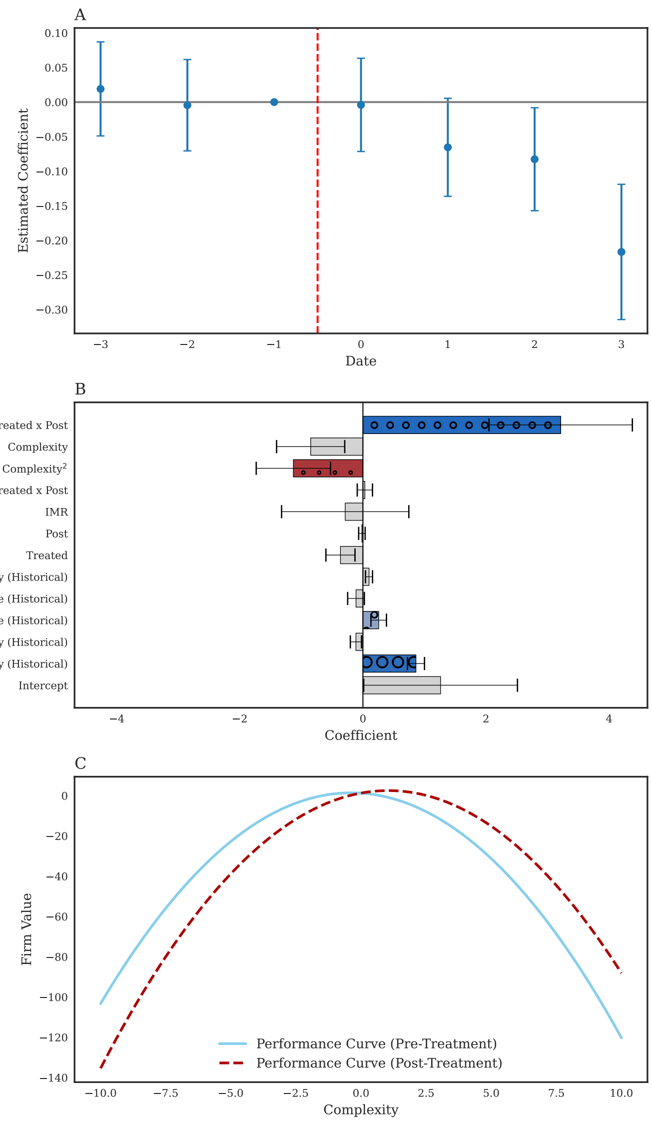

Figure 4: **Main Analysis**. The Figure reports the major steps of the main analysis. Panel **A** shows the lead-lag coefficients to verify that parallel trends hold in the pre-treatment period. In Panel **B** we include the normalized coefficients for our main specification. The level reached by each bar corresponds to the value of the associated coefficients (colored red or blue for negative or positive, respectively), with error bars at the 95% confidence intervals. Coefficients associated to bars with bubble, dot, or dash hatches are significant at the 99%, 95%, or 90% confidence interval, respectively. Panel **C** models the inverted u-shaped relationships between complexity and value implied by the estimated coefficients for control (blue) and treatment (red). Finally, in Panel **D** we break down the heterogeneity of the treatment effect across complexity bins.

Variables	Treated	
	WLS (1)	**OLS** (2)
Profitability	0.01	-0.0
	(0.01)	(0.01)
Tangibility	-0.0	-0.05^{***}
	(0.01)	(0.01)
Leverage	-0.01	0.04^{***}
	(0.01)	(0.01)
Size	0.0	0.01
	(0.01)	(0.01)
R^2	0.001	0.016
Covariance	cluster	cluster
F	0.915	16.572
$P(F)$	0.454	0.0
N	4327	4327

Table 1: **Propensity Score Balance.** The Table shows how treatment and control groups can be made comparable on observables through non-parametric propensity score matching. In model (1) the regression with propensity weights shows the lack of predictive power of observables in discriminating between treatment and control. A general indicator for the success of the procedure is if the F statistic is below 5. Model (2) shows the unweighted version for comparison.

	Tobin's Q
Variables	**WLS** (1)
Intercept	-0.21 (0.19)
Lead/Lag (-3)	0.02 (0.03)
Lead/Lag (-2)	-0.0 (0.03)
Lead/Lag (0)	-0.0 (0.03)
Lead/Lag (1)	-0.07 (0.04)
Lead/Lag (2)	-0.08^{*} (0.04)
Lead/Lag (3)	-0.22^{***} (0.05)
R^2	0.854
F	39.461
$P(F)$	0.00
N	6589
Firm FE	True
Year FE	True

Table 2: **Parallel Trend Regression.** The Table reports the results of a lead-lag regression with firm-year fixed effects to confirm that the parallel trend assumption holds in the pre-sample period (negative lags). To avoid perfect collinearity, the -1 lag has been omitted and used as reference period.

Variables	Selection Indicator
	Probit
	(1)
Intercept	-2.66^{***}
	(0.16)
Peer Disclosure	8.24^{***}
	(1.54)
Profitability	0.02
	(0.06)
Tangibility	0.22^{*}
	(0.09)
Leverage	0.02
	(0.06)
Size	0.45^{***}
	(0.11)
Profitability (Historical)	0.08
	(0.06)
Tangibility (Historical)	-0.1
	(0.09)
Leverage (Historical)	-0.01
	(0.06)
Size (Historical)	0.04
	(0.1)
Treated	0.67^{***}
	(0.08)
R^2	0.098
N	3508

Table 3: **Heckman Regression.** The table reports the results for the probit regression used to control for selection bias in the main specification. The exclusion restriction (Peer Disclosure) is highly significant, confirming the validity of the procedure.

Variables	Complexity WLS (1)	$Complexity^2$ WLS (2)	Complexity:Treated:Post WLS (3)
Intercept	0.59	0.8	0.56^{*}
	(0.64)	(0.99)	(0.26)
Profitability (Historical)	0.09^{**}	−0.06	-0.01^{*}
	(0.03)	(0.05)	(0.01)
Tangibility (Historical)	-0.14^{***}	0.22^{***}	−0.0
	(0.02)	(0.04)	(0.0)
Leverage (Historical)	-0.07^{*}	0.21^{**}	0.01
	(0.03)	(0.07)	(0.01)
Size (Historical)	−0.04	−0.04	-0.07^{*}
	(0.08)	(0.12)	(0.03)
Intensity (Historical)	0.0	0.1^{*}	0.01
	(0.02)	(0.05)	(0.01)
Treated	-0.2^{*}	−0.11	-0.06^{*}
	(0.09)	(0.12)	(0.03)
Post	0.11^{*}	−0.09	−0.01
	(0.05)	(0.1)	(0.01)
IMR	−0.48	0.01	−0.56
	(0.7)	(1.07)	(0.29)
Treated x Post	−0.07	0.25	−0.03
	(0.11)	(0.16)	(0.08)
Peer Disclosure	−0.85	1.21	-0.75^{*}
	(0.76)	(1.24)	(0.29)
Peer Verbosity	-0.14^{***}	0.13^{*}	−0.0
	(0.03)	(0.05)	(0.0)
Verbosity (P) x Treated x Post	0.11	-0.16^{*}	−0.02
	(0.06)	(0.08)	(0.06)
Profitability (H) x Treated x Post	-0.19^{*}	0.02	−0.1
	(0.1)	(0.1)	(0.09)
Tangibility (H) x Treated x Post	0.03	−0.17	−0.1
	(0.06)	(0.09)	(0.06)
Leverage (H) x Treated x Post	−0.12	-0.42^{***}	-0.2^{*}
	(0.1)	(0.13)	(0.09)
Size (H) x Treated x Post	0.03	−0.06	0.04
	(0.06)	(0.08)	(0.05)
R^2	0.04	0.033	0.022
F	120.121	66.492	17.37
$P(F)$	0	0.0	0.362
N	3408	3408	3408

Table 4: **Endogeneity Regressions.** The Table reports the results of confirmatory regressions to inspect the validity of the instrument set provided to the IV-GMM procedure on all three instrumented sites (complexity, complexity squared, and complexity interacted with the did coefficient).

Variables	Tobin's Q
	IV-GMM
	(1)
Intercept	1.26
	(1.25)
Profitability (Historical)	0.86***
	(0.14)
Tangibility (Historical)	−0.11
	(0.09)
Leverage (Historical)	0.26*
	(0.13)
Size (Historical)	−0.11
	(0.14)
Intensity (Historical)	0.1
	(0.06)
Treated	−0.37
	(0.24)
Post	−0.02
	(0.05)
IMR	−0.29
	(1.03)
Treated x Post	0.03
	(0.12)
Complexity^2	−1.13*
	(0.6)
Complexity	−0.85
	(0.55)
Complexity x Treated x Post	3.21**
	(1.16)
R^2	0.02867
Covariance	cluster
F	184.65
$P(F)$	0
N	3408

Table 5: **Main Regression.** The Table reports the result of the main specification. The coefficients of complexity and its squared term confirm the u-shaped relationship hypothesized

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Appendix

A1 First-difference value model

We start from (5) for t and $t-1$ and substitute Strategic separability and Diminishing returns:

$$\Pi_{i,t} = \ln S_{i,t} + V_Z(Z_i) + V_H(H_t) \tag{33}$$

$$\Pi_{i,t-1} = \ln S_{i,t-1} + V_Z(Z_i) + V_H(H_{t-1}) \tag{34}$$

Taking the difference and calling it $\pi_{i,t}$:

$$\Pi_{i,t} - \Pi_{i,t-1} = \ln S_{i,t} - \ln S_{i,t-1} + V_Z(Z_i) - V_Z(Z_i) + V_H(H_t) - V_H(H_{t-1}) \tag{35}$$

$$\pi_{i,t} = \ln \frac{S_{i,t}}{S_{i,t-1}} + (V_H(H_t) - V_H(H_{t-1})) \tag{36}$$

And using Path dependence to substitute $S_{i,t}$:

$$\pi_{i,t} = \ln \frac{g_1(x_{1,i,t}, S_{i,t-1})g_2(x_{2,i,t}, S_{i,t-1})g_3(Z_i)g_4(H_t)S_{i,t-1}}{S_{i,t-1}} + (V_H(H_t) - V_H(H_{t-1})) \tag{37}$$

$$\pi_{i,t} = \ln g_1(x_{1,i,t}, S_{i,t-1})g_2(x_{2,i,t}, S_{i,t-1})g_3(Z_i)g_4(H_t) + (V_H(H_t) - V_H(H_{t-1})) \tag{38}$$

$$\pi_{i,t} = \ln g_1(x_{1,i,t}, S_{i,t-1}) + \ln g_2(x_{2,i,t}, S_{i,t-1}) + \ln g_3(Z_i) + \ln g_4(H_t) + (V_H(H_t) - V_H(H_{t-1})) \tag{39}$$

Now we can take the conditional expectation on both sides and use the linearity of the expectation operator to get:

$$\begin{aligned}\mathrm{E}\left(\pi_{i,t}|X_{i,t},\bar{x}_{i,t},Z_i,H_t\right) = \mathrm{E}\Big(&\ln g_1(x_{1,i,t},S_{i,t-1}) + \ln g_2(x_{2,i,t},S_{i,t-1})\\ &+\ln g_3(Z_i) + \ln g_4(H_t) + (V_H(H_t) - V_H(H_{t-1}))\Big|X_{i,t},\bar{x}_{i,t},Z_i,H_t\Big)\end{aligned} \tag{40}$$

$$\begin{aligned}\mathrm{E}\left(\pi_{i,t}|X_{i,t},\bar{x}_{i,t},Z_i,H_t\right) &= \mathrm{E}\left(\ln g_1(x_{1,i,t},S_{i,t-1})\Big|X_{i,t},\bar{x}_{i,t},Z_i,H_t\right)\\ &+\mathrm{E}\left(\ln g_2(x_{2,i,t},S_{i,t-1})\Big|X_{i,t},\bar{x}_{i,t},Z_i,H_t\right)\\ &+\ln g_3(Z_i) + \ln g_4(H_t) + (V_H(H_t) - V_H(H_{t-1}))\end{aligned} \tag{41}$$

Where we can substitute Observables and define $\delta_t := \ln g_4(H_t) + V_H(H_t) - V_H(H_{t-1})$, which depends only on t and not on i, and $\gamma_i := \ln g_3(Z_i)$ which depends on i and not on t, so that:

$$\mathrm{E}\left(\pi_{i,t}|X_{i,t},\bar{x}_{i,t},Z_i,H_t\right) = f_1(\bar{x}_{1,i,t},X_{i,t-1};\beta_1) + f_2(\bar{\theta}_{i,t},X_{i,t-1};\beta_2) + \delta_t + \gamma_i \tag{42}$$

Finally, we can define the error term $u_{i,t} := \pi_{i,t} - \mathrm{E}\left(\pi_{i,t}|X_{i,t},\bar{x}_{i,t},Z_i,H_t\right)$:

$$\pi_{i,t} - u_{i,t} = f_1(\bar{x}_{1,i,t},X_{i,t-1};\beta_1) + f_2(\bar{\theta}_{i,t},X_{i,t-1};\beta_2) + \delta_t + \gamma_i \tag{43}$$

$$\pi_{i,t} = f_1(\bar{x}_{1,i,t},X_{i,t-1};\beta_1) + f_2(\bar{\theta}_{i,t},X_{i,t-1};\beta_2) + \delta_t + \gamma_i + u_{i,t} \tag{44}$$

Where (44) is expression (6), which is what we wanted to show. Importantly, by definition $u_{i,t}$ satisfies $\mathrm{E}\left(u_{i,t}|X_{i,t},\bar{x}_{i,t},Z_i,H_t\right) = \mathrm{E}\left(u_{i,t}|X_{i,t},\bar{x}_{i,t},\gamma_i,\delta_t\right) = 0$, which is a key condition for regression estimation.

A2 GOLDEN categories

Type of action

Communication
donation & funding
association
pricing
adoption of standards and rules
assessment and measurement
organizational structuring
modification of procedures
asset modification
training
incentives
r&d investments
new products
volunteerism

SDG

No Poverty (1)
Zero Hunger (2)
Health (3)
Quality of education (4)
Gender Equality (5)
Water (6)
Energy (7)
Work and Economic growth (8)
Innovation and Infrastructure (9)
Reduced Inequalities (10)
Sust. cities (11)
Resp. cons. and prod. (12)
Climate action (13)
Life below water (14)
Life on Land (15)
Peace and justice (16)
Partnerships (17)

Figure A1: **Actions and SDGS.** The figure reports the full 14 action types and the 17 SDGs present in the GOLDEN dataset

Type of action	Action description
Donations and Funding	Philanthropic activities through which companies donate money, goods or services as gifts.
Communications	Activities that bring specific information or knowledge from the firm to a certain interlocutor, to generate awareness, engage stakeholders, communicate policies.
Volunteerism	Activities that stimulate and promote volunteerism, fundraising and personal donations from individuals within or outside the firm (i.e. employees, costumers, community volunteerism).
Incentives and Disincentives	Activities that typically involve the devolvement of benefits, privileges, or rewards toward a particular stakeholder in order to gratify or stimulate an action.
Pricing	Marketplace activities by which the firm temporarily sets up or modifies pricing structures and tariffs.
Organizational Structuring	Activities that involve a structural change in the organizational structure of the firm.
Modification of Procedures	Activities that modify the procedures adopted by the firm in order to perform a specific activity.
Assets Modification	Activities that build, expand or modify the physical assets owned and used by the Company to run their activities.
Training	Teaching activities aimed at improving knowledge, skills, and competencies.
R&D Investments	Activities that encompass an investment aimed at introducing a technological novelty in a product, service or process.
Association	Activities through which companies join, collaborate or promote cooperation with other firms, organizations, institutions or communities, including multilateral agreements and collaboration initiatives.
Assessment and measurement	Activities with which the firm collect and analyse information from inside or outside.
Adoption of Standards Rules	Activities involving the underwriting, adoption or compliance with externally sourced policies, guidelines, procedures, or standards.
New products	Launch of a new product or service (made available to the market). It includes new product's technical specification, the inclusion of new components or features into an existing product or service, as well as packaging.

Table A1: Type of actions classification and associated description in the GOLDEN dataset.

A3 Complete description of identified strategies

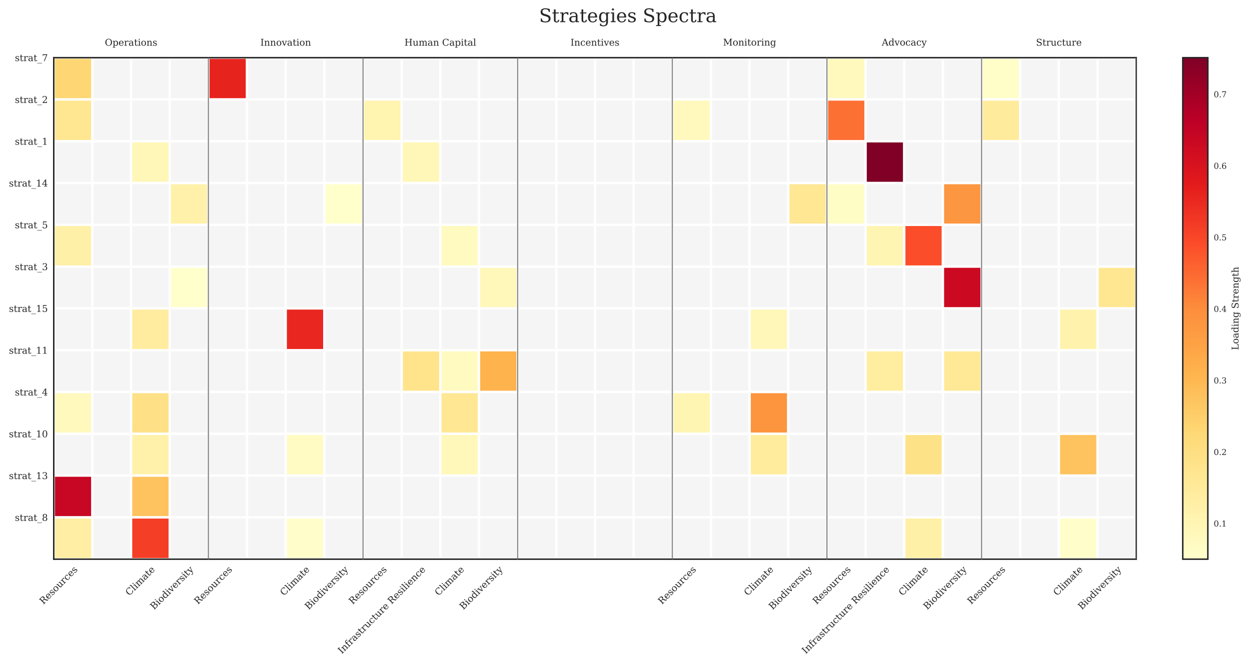

Figure A2: **Behavioral footprint of all emergent strategies**. The Figure reports the implied combinations of goals (bottom) and actions (top) for each emergent strategy (left). The color of each cell is determined by the relative prevalence of that the associated combination of goal and action the associated strategy implies.

A4 Strategic groups

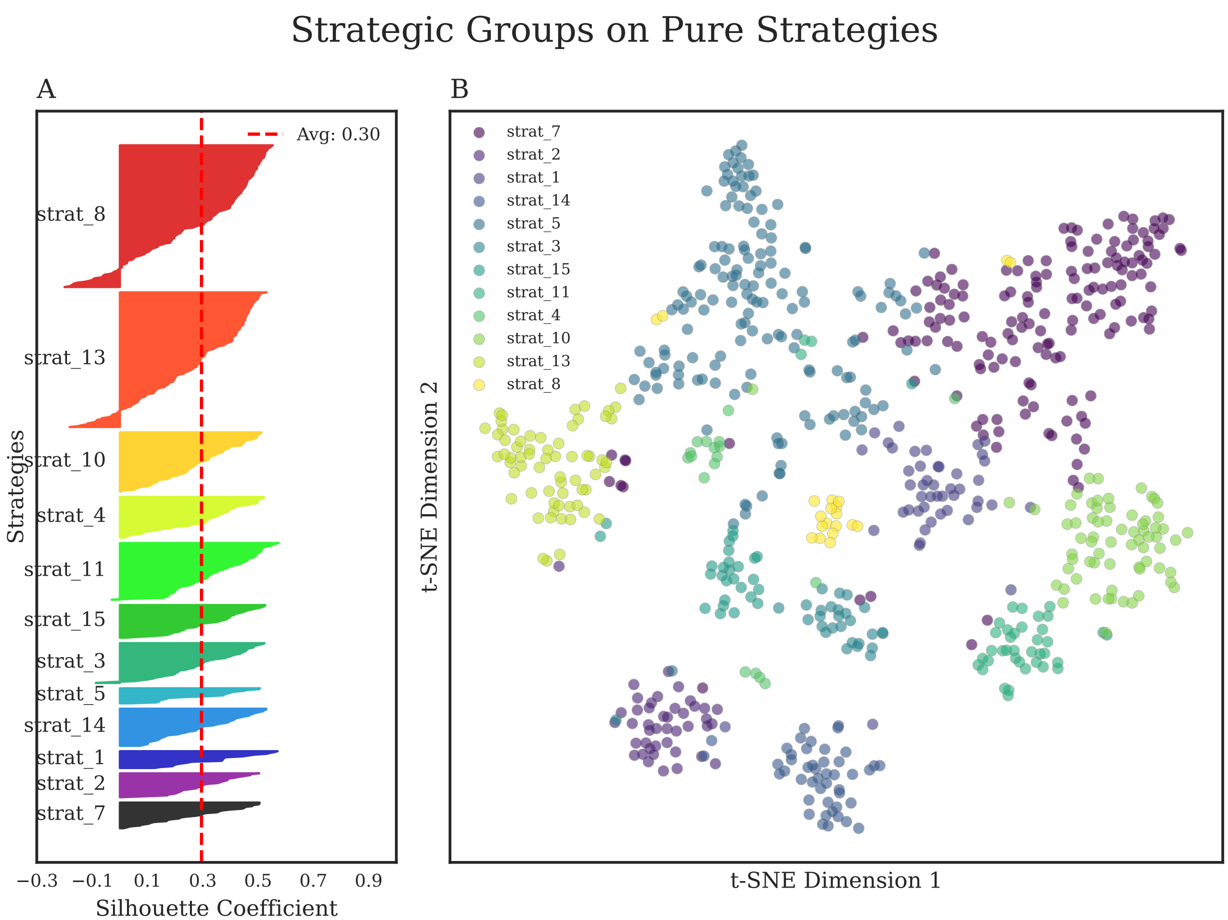

Figure A3: **Strategies and strategic groups**. The Figure reports the prevalence of the strategies effectively present in the sample, numbered from 1 to 8, and their silhouette plots (Panel **A**). In Panel **B**, we show the similarity and distinctiveness of the strategic groups emerging from the concrete strategic positioning observed, using a TSNE projection.