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Collaborative Innovation Blocs and Antifragility

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Abstract: We present the theory of the collaborative innovation bloc (CIB), an evolving system of innovation within which activity takes place over time. We show how the application of the CIB perspective can help make institutional and evolutionary economics more concrete, relevant, and persuasive, especially regarding policy prescriptions. Such policy actions should strive to improve the *antifragility* of CIBs and the economic system as a whole, thus enabling individual CIBs and the broader economic system to thrive when faced with macroeconomic shocks. With this in mind, we develop heuristics to evaluate antifragility at the micro, meso, and macro levels before identifying a set of institutional areas where reform can be undertaken to improve antifragility.

Keywords: Evolutionary economics; Institutional economics; Entrepreneurship; Innovation; Institutions

JEL *Codes*: D20; G32; L23; L26; O33.

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1. Introduction

Evolutionary economics and institutional economics need one another (Nelson 2005; Hodgson and Stoelhorst 2014). Combining these perspectives makes it possible to study the realm of mesoeconomics, which posits the existence of an intermediate level between microeconomics and the fully aggregated level of macroeconomics (Dopfer et al. 2004), while taking into account the interactions between actors and technological as well as institutional change (Ménard 2014). In presenting the theory of the collaborative innovation bloc (CIB), an emergent system of innovation within which activity takes place over time, we try to do just that. We show how the application of the CIB perspective can help make institutional and evolutionary economics more concrete and relevant, especially regarding policy prescriptions, which, we contend, should strive for antifragility (Taleb 2012).

The CIB perspective offers a concrete way of thinking about coordination and economic change, treating economic evolution as a knowledge process. The perspective places innovative entrepreneurship at the core of new business development and long-term wealth creation (Kirchhoff 1992). When entrepreneurship and innovation are conceived through the CIB perspective, it becomes possible to trace the evolution of economic processes from micro (firms) to meso (CIBs) to macro (economic performance) levels and back again.

We motivate the CIB perspective's focus on entrepreneurship and innovation by the fact that "the independent innovator and the independent entrepreneur have tended to account for most of the true, fundamentally novel innovations" (Baumol 2005). To some extent, however, the adjective independent is misleading; at every turn, these entrepreneurs and innovators were dependent on gathering and mobilizing crucial skills that others possessed. The CIB perspective acknowledges this by treating the entrepreneur as a collaborator. Schumpeter (1989 [1949], p. 261) argued that the entrepreneurial function "may be and is often filled cooperatively," and several perspectives on entrepreneurship and innovation (explicitly or implicitly) acknowledge the same fact (e.g., McCloskey and Klamer 1995; Garud and Karnøe 2003; Sarasvathy 2008).

The crucial question is how entrepreneurs find and engage with their collaborators, and this is where the CIB comes in: such a bloc consists of several (stylized) pools of economic skills, encompassing entrepreneurs, inventors, key personnel, early-stage financiers, later-stage financiers, and customers. People are recruited from these pools to form part of an entrepreneur's collaborative team, which is necessary if innovation-based venturing is to flourish.

The CIB perspective offers a path to concerted and logically consistent policy action. Preferably, such action should strive to improve the *antifragility* of CIBs and the economic

system as a whole. Since Taleb (2012) coined this term, antifragility has been studied within such varied realms as physics (Naji et al. 2014) and computer science (Lichtman 2016). The core distinction between antifragility and seemingly similar terms such as robustness or resilience is that an antifragile object, firm or economy not only endures a shock (robustness) or bounces back from it (resilience) but is *strengthened* by and thrives from the shock. This is a desirable property of an economic system.[1]

Macroeconomic stability (antifragility) implies microeconomic instability or turbulence in the sense that many firms are born, compete, and die or, at least, that many economic ideas and economic experiments are tested, developed, and phased out if they do not prove valuable (e.g., Brown et al. 2008). So, what about the mesoeconomic level? A desirable property here is for CIBs to be less fragile than the individual firms and organizations that operate within them, but all healthy economies will see a blend of fragile, robust, and antifragile CIBs and a continuous movement across these three categories.

A newly formed CIB will be fragile before developing a sufficient depth and width, i.e., before it has attracted enough competent actors. Conversely, a CIB that was once antifragile may become increasingly less so, e.g., due to the gradual loss of essential actors who are drawn to another CIB, until it is merely robust/resilient or even fragile—examples are the U.S. railroad industry (Boissoneault 2015) or the Swedish shipping industry (Olsson 1995). Such changes are the mesoeconomic equivalent to microeconomic churning. In a well-functioning institutional setting, the process by which the population of CIBs renews itself should be less volatile and smoother than micro-level processes.

However, no one can be in charge of a CIB in any meaningful sense. As a complex system, "its executive, its intelligence, its central nervous system, is distributed throughout the entire system. It is the system that is complex and smart and adaptive, not some omniscient governor that can be dealt with in isolation" (Dekker 2012, p. 147). Relatedly, no one can design the core properties of a complex system—emergence, creative evolution, and self-organization—meaning that policymakers should refrain from top-down command and control approaches or attempts to pick winners (whether individual firms or CIBs). Instead, economic policy should aim to remove institutional hurdles and bottlenecks that impede the self-organizing ability of CIBs to become antifragile. Not even in countries with high-quality

[1] Antifragility has similarities to Ostrom's (2005; 2010) theory of resilient governance. As conceived by Salter and Tarko (2018), such resilience entails more than the mere ability to bounce back from chocks. Instead, resilience encompasses robustness and adaptability.

institutions is this a modest undertaking. In this paper, we identify six reform areas that are key to protecting or enabling an institutional system that promotes well-functioning CIBs.

We organize the remainder of this article as follows. First, we sketch out the theoretical foundations of the CIB perspective, drawing on complexity science and Taleb's antifragility perspective. We then describe the CIB in detail, highlighting the relevant actor categories and relationships and arguing what is needed for a CIB to achieve its antifragile potential. We then identify feedbacks running between the micro, meso, and macro levels before undertaking an institutional analysis in which we discuss six institutional areas that can enable CIBs to achieve antifragility. The last section discusses core takeaways and limitations of the perspective before highlighting fruitful avenues for future research.

2. Complexity and antifragility

A common perspective of how innovation comes about in modern economies is the R&D-centered story, which sees innovative activities as the result of systematic and purposeful efforts to create new knowledge by investing in R&D, followed by commercialization (Schot and Steinmueller 2018). The CIB perspective has little to do with such a linear, mechanical view. It takes note of a core distinction of Schumpeter's, namely, that between invention and the *implementation* of that invention in the economy. While basic science may be crucial for arriving at an invention—a new synthesis of existing or new technological components or a refinement of a previous combination of technologies (Fleming 2001)—the later innovative stage is what ultimately produces economic value to consumers. That stage has as much to do with R&D as with other innovative practices, such as learning by doing, networking, branding, and combinatorial insights (Bhidé 2008).

A CIB is a complex system. While it may be necessary to simplify this complexity for analytical purposes, one must not lose sight of the ambiguity, uncertainty, and instability that characterizes such systems. Complex systems are adaptive, resilient, and even antifragile *because* of their complexity (cf. Dekker 2012). Moreover, while all systems consist of nodes and connections, the nodes in a human population system can imagine and create new patterns of action, a fact that makes the system even more unpredictable (Shackle 1976).

In a CIB, both success and failure are emergent phenomena, and a thin line often separates these outcomes.[2] The myriad of interactions by which new firms and innovations come to life

[2] According to Lichtenstein et al. (2007), emergence involves "qualitative novelty"—an emergent level enacts system-wide characteristics that are somehow distinct from the components of that system.

are usually non-linear: The same action will have multiple effects in different parts of the network at different times. Some of those causal chains will close in on themselves, feeding back into the conditions that started the chain (Heylighen et al. 2006). Hence, small events may very well yield large effects (cf. McKelvey 2004b). Successful innovation is one example of such superadditivity, while spectacular failure is another.

Moreover, the knowledge of each actor in a complex system is limited and local: Actors respond to information and knowledge presented to them then and there, and they interact only with the small number of agents forming their local neighborhood (Heylighen et al. 2006). Some may have more of a bird's-eye view of things, but physical and social distance interferes with all efforts to know what is going on and where (Vaughan 1996). Specialized knowledge further inhibits any pretense of omniscience. Each actor is thus largely ignorant of the extent to which his or her local actions have global consequences and affect the overall system (Heylighen et al. 2006). This is why system behavior cannot be reduced to the behavior of the constituent actors "but only characterized on the basis of the multitude of ever-changing relationships between them" (Dekker 2012, p. 138).

The term fragility describes how a system suffers when it encounters disorder (Taleb and Douady 2013; Ansar et al. 2016). The outcome is typically an irreversible loss of functionality. Taleb (2012) argues that antifragility should be considered fragility's exact antonym. Robustness and resilience are merely intermediate states on a continuum between fragility and antifragility, implying an ability to withstand harm. Antifragility entails the capacity to gain from harm. A common way to explain this capacity is by the concept of hormesis, which is a favorable biological response to low exposure to toxins and other stressors. Living organisms are generally (to a certain extent and within their life cycle) antifragile, as are many objects, technologies, institutions, social practices, and systems that last for a long time (Blečić and Cecchini 2017).

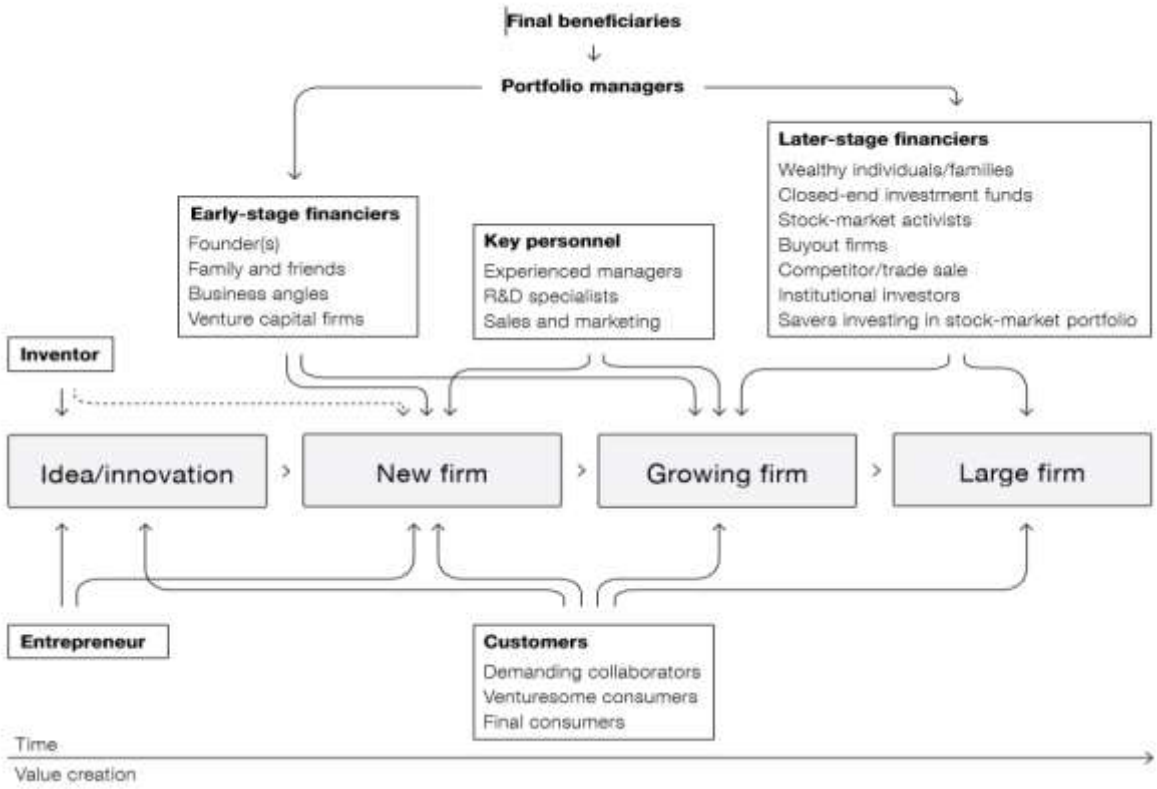
As applied to an organization, hormesis describes its adaptation to the challenges brought about by a changing environment, making it fitter and better able to survive (Derbyshire and Wright 2014; Pech and Oakley 2005). In such contexts, small-scale experimentation and the *optionality* such experimentation entails are key (Barnett and Dunbar 2008). For something to qualify as an option, it must have a convex payoff structure, i.e., large, open-ended upside and limited, known downside. With this payoff structure, it is possible to thrive despite not being right very often.

3. The collaborative innovation bloc

All actors, organizations, and teams in a CIB struggle to survive in an environment characterized by real constraints, such as the amount of capital available, the number of customers they can reach, and the qualifications of available employees. Other organizations try to do similar things and vie for the same skills and resources (cf. Elert and Henrekson 2019; Elert et al. 2019).

Figure 1 provides a schematic overview of the structure of skills that, according to the CIB perspective, are required for a new idea to transform into a growing firm that eventually reaches maturity (as described by, e.g., Fenn et al. 1995 and Gompers and Lerner 2001). The schema is not intended to be causal in any strict sense of the term, as the many simultaneous, non-linear interactions make it impossible to keep track of causal relationships. The purpose is to get a sense of the system's structure, embodied in the patterns of interactions between the actors; however, because complex systems are incompressible, we cannot avoid framing our description of them in some way or another (Cilliers 2000).

Figure 1 The collaborative innovation bloc—an overview.



Note: Financing by founders (using their assets or retained earnings) and by passive individual and institutional investors (in either phase) is not included in the diagram.

The skills and resources required to take an idea from inception to commercial use must be mobilized by drawing upon several skill pools. There are several ways to delineate these pools, and for analytical purposes, we focus on six sufficiently distinct skills: entrepreneurs, inventors, key personnel, early-stage financiers, later-stage financiers, and customers. The actors are themselves less important than the interactions between them (Cilliers 2000), and, in practice, there are more relationships and changes in relationships in a CIB than anyone can predict or keep track of.

Some phenomena are nevertheless sufficiently common to qualify as regularities. Entrepreneurs are regularly the prime movers in a CIB: most ideas and inventions originate with them or with inventors (Baumol 2005).[3] To commercialize the ideas, they usually create new collaborative teams, searching for and attracting the skills they perceive to be necessary to realize their projects. In this role, entrepreneurs benefit from the skill pools in existing CIBs but also create new blocs and help existing CIBs evolve when necessary. However, if their innovations are sufficiently disruptive, they can also help cause the demise of existing CIBs (Beltagui et al. 2020).

The innovative process frequently begins when an entrepreneur identifies a potential opportunity through interactions with demanding *customers*, which he or she then strives to develop, together with an *inventor*, into a successfully commercialized innovation. Generally, the early commercialization phase mainly involves entrepreneurs and, to a lesser extent, *key personnel*. Financing is critical in this uncertain, experimental stage. *Early-stage financiers* usually propel the project into a scale-up phase, during which the conjectured entrepreneurial profits can be realized (assuming the project reaches this point). The entrepreneur also requires more key personnel, often with highly specialized skills. *Later-stage financiers* assume responsibility for financing, which may be substantial. At this point, the innovation may have resulted in adaptive tensions (creative destruction) that drive the emergence of new firms (McKelvey 2004a) as perceptive competitors begin to imitate the innovation (Im and Shon 2019). The market grows through the operational scaling-up of activities resulting from differential growth and selection (Metcalfe 1998). Ultimately, this may result in the emergence of a new industry (Chiles et al. 2004).

[3] Potts (2019) argues that such ideas often originate in the so-called innovation commons, a knowledge commons born of fundamental uncertainty about the prospect of a technical opportunity. The valuable resource that is being shared is information about the entrepreneurial opportunity, and once the pooling of information is realized, the functional rationale for the commons disappears.

Most ideas do not get this far—most business ideas and businesses fail (Hall and Woodward 2010). Moreover, the ideas that are eventually commercialized may be substantially different from the idea that provided the entrepreneur with the igniting spark. Because innovations drift, one needs flaneur-like abilities to keep capturing the opportunities that arise (Taleb 2012). Errors are ubiquitous in this process, but so are plan and error corrections, as actors find ways to cross technological, economic, social, and institutional hurdles through trial and error and learning by doing, guided throughout this search by markets and prices. Nonlinearity and superadditivity also mean that a tiny bit more (or a tiny bit less)—a new marketing phrase, a new permit, or a new button on a display—can yield something qualitatively different and spell the difference between success and failure.

The competition among collaborative teams is part of how CIBs generate economic growth. Paradoxically, the competition-driven success of a firm or collaborative team in one period may spell its demise in future periods. Success can lead to a blindness to errors and risks and an unwillingness to consider dissenting viewpoints, which can cause a gradual, virtually unnoticed deterioration of performance (Dekker 2012). Optimizations that give an edge in the short term may also prove fatal in the long term because they create too tight a coupling among factors; this absence of slack may prove a liability when conditions change, especially if they change quickly and unexpectedly.

Moreover, complex systems are open systems. They are influenced by their environment (say, the broader economic system) and influence that environment in return. The boundaries of any individual CIB are inherently fuzzy: Horizontally, there is usually overlap with other CIBs in that participants in a particular skill pool—say, venture capitalists or key employees—can be available to several blocs. Vertically, the boundary to the political sphere is fuzzy—in some instances, political appointees and state-owned firms may even be big players in a CIB (though they exert influence rather than control) (Wagner 2016).

The boundary is also fuzzy against institutions, which provide the framework conditions within which CIB activity occurs. Surely, the institutional framework determines the incentives for people to acquire and utilize their skills, but it can be difficult to distinguish between choosing the rules of the game and playing the game according to those rules (Wagner 2016; Burfield and Harrison 2018). Differences in what has been labeled meso-institutions (public bureaus, regulatory agencies, and other subsidiaries in charge of implementing the general rules of the game and of framing and delineating the domain of activities that actors can engage in) may also explain why conditions for innovating venturing differ across sectors, countries, and regions (Ménard 2014).

Complex systems such as CIBs are path dependent and sensitive to initial conditions. While we have described the entrepreneur as a prime mover who may contribute to the emergence of new CIBs, this role is not wholly intentional. Entrepreneurs operate with localized knowledge and bounded rationality, facts that make them unable to foresee the full consequences of their actions. As a case in point: When William Shockley located his factory in Palo Alto rather than close to his former employer Bell Labs in New Jersey, he did so not because he aimed to create something like Silicon Valley but because he was nostalgic about his boyhood and wanted to move closer to his mother. Furthermore, his being a terrible boss was not intended to usher in a host of spinouts by "the treacherous eight" and the founding of the broader web of CIBs that we know today as Silicon Valley (Klepper 2016, p. 114–120).

Even so, Silicon Valley's success was far from immediate. In large part, this was because the development of the VC industry in the U.S. before the 1980s was hindered by high capital gains taxes, whereas pension funds were barred from investing in securities issued by small firms, new firms, or VC funds. CIBs remained fragile until a set of reforms removed these obstacles, paving the way for the evolution of a more beneficial CIB structure. Absent these reforms, it is difficult to imagine the American VC industry's impressive growth or the emergence of the kind of contractual forms that are a fundamental part of how Silicon Valley operates today (cf. Fenn et al. 1995; Gompers and Lerner 1998; Gilson and Schizer 2003).

That said, politicians are not omniscient. Granted, the basic motive behind these reforms was to transform unacceptably high risk to manageable levels and minimize the risk of insider trading and moral hazard. However, the reforms were in no way intended to directly promote Silicon Valley, and no one could fully foresee their repercussions for CIBs across the country.

4. Micro-level fragility and antifragility

Micro-level fragility is not necessarily harmful for a system, but individuals and firms in a CIB can behave in more or less antifragile ways. Markey-Towler (2018) develops the idea of antifragile knowledge and the psychological attributes necessary to benefit from radical uncertainty. In sum, a person's knowledge of the world is antifragile if it grows when Black Swan events occur. People with antifragile personalities thus use their imagination to adapt to changing environments and to be agents of change. Other researchers have developed an antifragile approach for firms, described as "a step-by-step, non-deterministic methodology that can be used as a replacement for, or as a complement to, the causally focused approach of scenario planning" (Derbyshire and Wright 2014; cf. Barnett and Dunbar 2008; Sarashvathy 2008). Arguably, the likelihood that a collaborative team will be antifragile depends to some

extent on the antifragility of the skill pools from which actors are drawn. Let us consider the six actor categories in more detail and discuss how they relate to antifragility.

4.1 Entrepreneurs

While much has been made of the difference between Kirzner's (1997) emphasis on entrepreneurial alertness and Schumpeter's view of the entrepreneur as an innovator (Shane and Venkatamaran 2000; Klein 2008), actual entrepreneurs often possess both Kirznerian and Schumpeterian qualities—Markey-Towler's (2018) concept of antifragile personality explicitly contains both elements, as well. While Taleb (2012) views innovation as inherently antifragile, he also sees (p. 79) the vulnerability of every startup as necessary for the economy to be antifragile. The system may even benefit if actors exhibit overconfidence, overestimating their chances of success and underestimating the risks of business failure, provided that their failure is local (p. 88–89).

An antifragile entrepreneurial approach follows an optionality strategy, with a host of small-scale experiments that are continuously assessed and modified. Flexibility is crucial here since it allows entrepreneurs to capitalize on contingencies presented by an evolving environment to adapt their venture as opportunities present themselves (Chandler et al. 2011). This is not to say that entrepreneurs and startups should not take risks, but they should take the most significant risks early on. A CIB will likely remain antifragile as long as the majority of failures occur early.

4.2 Early-stage financiers

The importance of failing early has ramifications for what type of financing is required. As Mougayar (2015) puts it, "[t]hat's the whole *raison d'être* of the steps behind a venture-backed company that goes from seed, to angel, to Series A, B, C, D, etc. There is de-risking at every subsequent stage." More generally, Taleb (2012, p. 235) views debt as fragile and equity as robust and VC as antifragile because it spreads "attempts in as large a number of trials as possible" (cf. Polzin et al. 2018). Firms also have reasons to be wary of excessive debt, since small variations in performance can be enough to make them go bankrupt (Derbyshire and Wright 2014, p. 221)

That said, early financiers do more than contribute financial resources. For example, business angels often provide tight screening and close monitoring of a startup's progress, markedly reducing moral hazard problems (Landström and Mason 2016). Likewise, individuals who perform the VC function often have extensive experience in the industry in which they invest (Busenitz et al. 2014). They are, therefore, able to contribute critical skills, such as

management expertise and market knowledge, as well as access to their business networks. Evidence even suggests that such non-financial value added provided by VC firms is the main driver of the better performance of VC-backed firms (Croce et al. 2013). If need be, VC firms can also enforce change and appoint new management better equipped to lead the company. In sum, these skill transfers help make an innovative project more antifragile.

4.3 Inventors

Schumpeter (1934) distinguished between inventors and entrepreneurs, but the nuance was lost when modern growth models (e.g., Aghion and Howitt 1992) collapsed invention, innovation, and commercialization into one decision (Acs and Sanders 2012). The CIB perspective's chief focus is on implementation, but this does not imply that inventions are unimportant or that research cannot have antifragile properties; according to Taleb (2012, p. 234), payoffs from research have "big, near-unlimited upside but, because of optionality, limited downside. Consequently, payoff from research should necessarily be linear to number of trials, not total funds involved in the trials." A breadth of inventors with different skillsets and ideas thus increases the likelihood that a CIB is antifragile.

To be sure, the act of creating new combinations is no small feat. Although research suggests that technological opportunities increase as interdependence increases, engineers often "spend their time trying to predict, avoid, and debug the subtle interactions between components, rather than exploring new combinations" (Fleming and Sorensen 2001, p. 1024). Here, there is a trade-off between overwhelming complexity and fruitful uncertainty (Baldwin and Clark 2000, p. 32). Decoupling, i.e., making different components of an invention less dependent on one another, "increases the probability that the invention will function, because it truncates the downside risk, however, decoupling also decreases the likelihood of a wildly successful breakthrough because it abbreviates the upside potential as well" (Fleming and Sorensen 2001, p. 1024).

4.4 Key employees

A necessary condition for a new venture's long-term success is that the entrepreneur can recruit key personnel at the opportune time to scale up the business to a full-grown firm (Eliasson 1996; Elert and Henrekson 2019). However, merely locating these individuals is not enough; to survive, firms must successfully coordinate their internally dispersed knowledge (Stoelhorst 2014). When entrepreneurs allow the most informed employees to act upon the knowledge only they possess to promote intra-firm discoveries (Foss 1997), the firm will be better equipped to adapt in a hormesis-like manner, react quickly to change, and encourage innovation.

Firm decentralization is one feasible way to achieve this utilization of local knowledge. To be sure, it risks yielding poorer incentives and efficiency compared to hierarchy, but its benefits are greater flexibility and innovativeness, which may be too costly to ignore in times of rapid market change. In fact, the antifragility approach sees efficiency as synonymous with fragility. Driving out inefficiencies in organizations creates a tight coupling between individuals on a team or stages in a production process. If they become too tight, an error somewhere can have cascade effects (Taleb 2012; Dekker 2012).

Furthermore, the challenges that a firm faces will differ over time. As an entrepreneurial venture grows, professional managers with the expertise of taking the business into a mature stage characterized by large-scale production and distribution become essential. Arguably, managers are cut from a different mold than entrepreneurs; in big firms, managers often overprotect their organizations, essentially shielding them from volatility, thereby risking both longer-term development and adaptation for the sake of short-term tranquility (Pech and Oakley 2005). This fact may explain why many big firms struggle and eventually fail (Gans 2016); resisting such impulses would be beneficial to antifragility.

4.5 Customers

Despite being the ultimate arbiters of an innovation's success, consumers seldom appear in the cast in most accounts of innovation (Bhidé 2008; Harper and Endres 2018). Nonetheless, a nation's (or a CIB's) "venturesome consumption"—the willingness and ability of intermediate producers and individual consumers to take a chance on and effectively use new know-how and products—may be as crucial to prosperity as its capacity to undertake high-level research. When optionality characterizes such consumption, it forms another side of the antifragility coin.

It is also well known that customers can offer critical inputs and feedback that shape emerging innovations (von Hippel 1986; Tripsas 2001). Persistent feedback and demands from early, demanding customers can help a firm innovate in an antifragile manner based on trial and error. The user role is prevalent in industries that produce technical appliances and scientific instruments (von Hippel et al. 2011). Especially in the early stages, demanding collaborators are essential sources of information regarding consumer needs and preferences, provided that they are representative of a large group of customers. Sometimes, they even act as strategic partners who take an active part in the development and commercialization of products, thus having a decisive influence on the development and design of new products (Bhidé 2008).

4.6 Later-stage financiers

Actors in secondary (exit) markets carry out similar functions as venture capitalists in terms of financing and the transmission of knowledge and skills, but this selection usually occurs when entrepreneurs and venture capitalists wish to exit from their investments. Hence, these new actors evaluate firm performance by assessing whether there are potential profits in assuming control and replace the entrepreneur and top management if they lack the ability or the financial muscle to take the firm to the next level.

Buyout firms fill a similar function of knowledge transmission in later funding stages as VCs do earlier on: Evidence suggests that buyouts lead to a reallocation of resources to more productive uses (Tåg 2012), partly by bringing in better knowledge of management practices (Bloom et al. 2009). Generally, buyout firms but also stock-market activists and closed-end investment funds avoid putting all eggs in the same basket—this antifragile policy is accentuated by the fact that they usually have plenty of skin in the game.

5. Meso-level and macro-level fragility and antifragility

At the meso level, it is possible to describe a number of heuristics that, when taken together, make it possible to assess whether a CIB is antifragile. First, a core diagnostic to determine whether a CIB or a sector is fragile is the way it is financed. Acknowledging Taleb's (2012) point that VC is antifragile, equity is robust and debt is fragile, Mougayar (2015) claims that while the "New York-based Banking System is in the 'Fragile' bucket, and at the opposite end, typifying the Antifragile, you will see the Silicon Valley 'Fail fast, be foolish' model." More generally, skin in the game is necessary if a CIB is to have the potential of being antifragile—actors who benefit from the upside of success and suffer the downside of failure have sound incentives.

Moreover, collaboration can, in and of itself, become an antifragile phenomenon, as pointed out by Taleb (2012, p. 238–239) by way of Ridley (2010): "Collaboration has explosive upside, what is mathematically called a superadditive function […] That is pure nonlinearity with explosive benefits." Baumol (2005, p. 3) noted something similar when discussing the revolutionary contributions of small, new firms and the incremental contributions of large firms, stating that "the contribution of the two together is superadditive, that is, the combined result is greater than the sum of their individual contributions."

Whether these effects will materialize in a CIB depends on who is collaborating and to what degree. It has been shown theoretically that when the concentration of interaction is too low, a system will not generate novelty (McKelvey 1999). Conversely, too much

interdependency pushes a system into a "complexity catastrophe" characterized by little adaptation. Instead, truly novel behavior occurs on the verge of order and disorder, that is, on "the edge of chaos" (McKelvey 1999; Lewin et al. 1999).

Diversity is also a necessary (though by no means sufficient) condition for antifragility in both organizations and CIBs. Diversity increases the likelihood that each skill pool contains enough competent actors with different experiences, backgrounds, and points of view. This increases the likelihood that entrepreneurs can find the skills they are looking for or replace a skill that turned out to be erroneous (Dekker 2012).

The organization of a CIB is not fixed but flexible and adaptive since it lacks a blueprint. This is a feature CIBs share with all complex systems, and it makes a naturally evolved organization more robust than one that was consciously designed: "The intrinsic uncertainty, which appeared like a weakness, actually turns out to be a strength, since it forces the system to have sufficient reserves or redundancy and to constantly try out new things so as to be prepared for any eventuality" (Heylighen et al. 2006). Another aspect of this is that the constitution of actors involved with any innovation is not necessarily stable—some may leave, whereas others become more involved or change roles.

Closely tied to a CIB's flexibility is its degree of centralization. A CIB with sufficient depth and breadth and a skill pool that encompasses a host of competent players will be decentralized by necessity. It may even be described as a polycentric governance system with many decision centers (Ostrom 2005, 2010; Salter and Tarko 2018). This adds antifragility because individual failures become less likely to propagate through the system. Instead, errors that spell disaster for the individual entrepreneur or collaborative team may convey valuable lessons to other actors that survive—volatility may thus provide answers regarding the viability of ideas and plans.

Put differently, while an antifragile CIB permits plenty of trial and error and constant bottom-up tinkering, its aggregate result involves the joint mitigation of two errors (Eliasson 2000; Harford 2011): allowing failed projects to survive for too long and rejecting winners. The two errors are linked and omnipresent. For example, accepting a project that one should reject ties up resources that could go into alternative endeavors. Collaborations in the innovation bloc are essential for identifying and correcting such errors early and at the lowest cost possible.

Another vital characteristic for the antifragility of a CIB is its scalability, i.e., the ability "to *effortlessly* transition back *and* forth from the very micro to the very macro *spatial*, *temporal*, and *relational* scales" (Ansar et al. 2016, p. 70). Faced with increasing demand, a

CIB (and all its skill pools) must be able to scale up; conversely, the CIB must be able to scale down if demand falls so that critical skills and resources can be used elsewhere.

Whereas a robust economy would simply be able to endure macroeconomic shocks, an antifragile economy should become stronger when exposed to macroeconomic fluctuations. If the economy is home to a multitude of CIBs, many of which are robust or antifragile, this supersystem will likely be antifragile. Some CIBs will inevitably suffer or fail when an economic shock occurs, but the overall system of CIBs should emerge chastened and stronger. Conversely, macroeconomic developments and regimes can impact an economy's overall antifragility indirectly through their effects at the meso level. Collaborations within a CIB can be more or less antifragile, and there is an inherent unpredictability to them. This is why top-down steering of a CIB is likely to be doomed from the start.

6. Institutions for antifragility

Policymakers' top priority should be to create an institutional environment that facilitates beneficial collaborations, thereby laying the foundation for antifragility. Institutions are commonly seen as society's rules of the game (North 1990). In this capacity, institutions regulate human interaction, reduce uncertainty, and prevent free-riding and conflict. This is crucial from an antifragility perspective because the effective functioning of any society requires the reasonable protection of certain expectations of its members (Hayek 1973–1979). It is noteworthy, therefore, that Taleb (2012) considers many institutions to be inherently fragile. The fact that institutions constrain behavior to an accepted set of norms may be beneficial in 99 out of 100 instances, but the removal of free-thinkers and non-conformers may ultimately be what causes their undoing in the face of that rare shock.

Here, it is essential to distinguish between designed and evolving institutional systems; top-down designs are inherently fragile, whereas bottom-up processes thrive under the right amount of stress and disorder. Moreover, whether institutions evolve and become flexible depends to a large extent on entrepreneurs and the presence of entrepreneurially minded rule-breakers. Such individuals are less constrained by the institutional status quo than others and affect this status quo in a host of ways (Elert and Henrekson 2017)—in Taleb's parlance, such persons are stressors that can help purge the system of obsolete rules and enable the evolution of more appropriate rules. As such, they are likely critical to overcoming institutional lock-in—the stifling of new ideas beyond the realm of current institutional constructions (Liebowitz and Margolis 1995).

6.1 Rule of law and protection of private property

Achieving a balance between protecting expectations and allowing adaptation to new conditions can be seen as a core property of an antifragile institutional system capable of coping with radical uncertainty—a system that safeguards the accomplishments of the past (limited downside) while keeping the door open for beneficial change (unlimited upside). The rule of law and property rights protection are fundamental institutions to achieve this balance. Conversely, deficient rule of law and weak property rights protection within a country cause more uncertainty than necessary, discouraging entrepreneurs and jeopardizing the very collaborations that compose a CIB. Private property rights together with open competition create scalability in economic relationships (Wagner 2016). Flaws in these fundamental institutions explain why many countries lack all but the most fragile of CIBs.

On the one hand, private property must be protected to incentivize productive investment through the accumulation of private wealth. On the other hand, it is necessary to maintain open and contestable markets for new entrants to keep at bay unproductive rent seeking (e.g., lobbying for closed and complex standards) and destructive entrepreneurship (e.g., ventures that disregard public health, exploit natural resources, or appropriate other non-market goods). This balancing act is particularly important when applied to intellectual property rights (IPR), where one must weigh the interests of inventors against the positive spillover effects of knowledge diffusion.

Economic history shows that private property is far from a fixed concept; it is in many ways a function of technology and norms (Christiansen and Gothberg 2001; Yandle and Morriss 2001; Pagano 2011). As Wagner (2016, p. 48) puts it, property rights are just settled quarrels, "settled for now anyway." There may even be a value to property rights continually being challenged and renegotiated—such stressors can improve the property system as a whole.

6.2 Taxation

An antifragile tax system would accept and even benefit from the fact that the future is radically uncertain. Hence, it should promote a level playing field that does not steer the flow of labor, capital, and knowledge away from innovative ventures. However, tax structures almost invariably favor debt over equity financing (Davis and Henrekson 1999), a fact that (unintentionally) biases the flow of financial resources away from innovative entrepreneurial firms and impedes the workings of CIBs.

Artificially Skewing resources in a particular direction will create systemic fragilities and make CIBs more fragile. An antifragile tax system does not unnecessarily cap the upside of

innovative activities; it is thus characterized by neutrality vis-à-vis owner categories, sources of finance, and types of economic activities. The system should be simple, transparent, and characterized by as few exceptions and loopholes as possible, since such complexities will give rise to unproductive or even destructive activities (Baumol 1990). Complex rules in an area of such importance for entrepreneurial venturing as taxes will limit the scope of productive entrepreneurial activity and the workings of CIBs.

The concepts of options and optionality are quintessential to any antifragile strategy, which is why the fiscal treatment of stock options deserves special mention. As a promise of a future ownership stake, employee stock options can be used to give key personnel a convex payoff structure, encouraging them to supply key competencies to a young firm that is short on cash. However, the value of options—and their effectiveness as an incentive mechanism—greatly depends on the option tax code, notably on whether employees can defer the tax liability until they sell the stocks and whether they are taxed at a low capital gains tax rate at this point (Gilson and Schizer 2003).

6.3 Savings and financing

Neutrality is also a core aspect of an antifragile savings policy. Here, the volume is generally not the problem. Europe, for example, has no shortage of savings (OECD 2019)—the allocation rather than the volume of savings is what matters for entrepreneurial activity. In fact, the tax system's tendency to bias financing towards debt is exacerbated by strong legal creditor protection that reduces risks for creditors, as such risks would otherwise justify a higher risk premium on debt financing. The problem is that entrepreneurs are at a disadvantage when competing for debt relative to homeowners, large multinationals, governments, and real-estate investors.

In addition to reducing the fiscal advantages enjoyed by debt financing over equity (e.g., de Mooij and Devereux 2016), many countries must address the fact that financial resources are mainly intermediated through universal banks and institutional investors. These actors prefer large, low-risk, debt-based assets and blue-chip stock over small, risky equity-based investments (Westerhuis 2016). This systemic problem has considerable ramifications for CIBs; one can only speculate as to the number of fundamentally sound entrepreneurial projects that never got off the ground because the financial playing field was tilted against them**.**

6.4 Contestable markets

CIBs are experimental at their core, which makes frequent failure inevitable and sometimes even desirable. Unsuccessful projects are not necessarily a waste of resources; instead, firm

failure provides economic agents valuable information on a business model's viability. In Hayek's (1976, p. 124) view, this "process of learning by trial and error … must involve a constant disappointment of some expectations." As a stressor enabling improvement, learning by failure is thus of paramount importance for both the entrepreneur and society (Harford 2011). A takeaway is that an antifragile institutional system is one where entry and exit are easy and where "fear of failure" does not prevent new entrants from challenging the status quo.

While environmental, health, safety, and quality regulations and occupational licensing often have a sound rationale, they can be abused by incumbents to hamper entry and competition.[4] Excessive rules and procedures discourage potential entrepreneurs and impede the process of creative destruction, but uncertain and ambiguous regulation can be equally damaging. Such regulation must be clear, transparent, and neutrally formulated to ensure that new ways of doing existing and novel things are permitted.

Business failures can stimulate firm founding by opening new opportunities, enabling knowledge spillovers, and making additional resources available (Hoetker and Agarwal 2007; Hiatt et al. 2009). Moreover, a restructured venture with new management or a different firm can often recycle and improve upon the knowledge and ideas from failed projects, laying the foundation for future success. Indeed, more lenient bankruptcy laws are associated with higher rates of venture formation (Fan and White 2003; Peng et al. 2009). In a longitudinal study of the connectedness of barriers to failure, venture growth, and elite entrepreneurs, Eberhardt et al. (2017, p. 93) even find that "lowering barriers to failure via lenient bankruptcy laws encourages *more capable*—and not just *more*—entrepreneurs to start firms." Of course, failure also implies that people suffer, psychologically and financially, and such damage should be minimized. Thus, it is reasonable to institute relatively generous bankruptcy laws and insolvency regulations with provision for discharge clauses, the postponement of debt service and repayment, and the possibility of restructuring.

6.5 Social security

Faced with radical uncertainty, an antifragile system should not steer the flow of labor, capital, and knowledge away from innovative, entrepreneurial ventures, but this is what social security systems and labor market regulations in many countries do. While new ventures are free to offer jobs and recruit workers as they see fit, they do not compete for the talent they need on a

[4] For example, evidence shows that occupational licensing has a significant impact on prices and labor mobility, while little to no evidence supports the claim that quality is higher (Kleiner 2000; Kleiner and Krueger 2013).

level playing field with large firms. This occurs because employing labor typically comes with responsibilities that go beyond paying a competitive wage—responsibilities that may be particularly hard for new ventures to shoulder. Access to key personnel then becomes more constrained than it needs to be, to the detriment of the workings of CIBs.

The incentives encouraging activation, mobility, and risk-taking are best served by universal insurance systems that disregard labor market status, employment history, or attachment. These institutions should ensure portability of tenure rights and pension plans as well as a full decoupling of health insurance from current employers.[5] Such measures would avoid punishing individuals who leave secure, tenured employment positions and pursue entrepreneurial projects, whether as entrepreneurs or as employees in entrepreneurial startups. This would give these people a limited and calculable downside from leaving their tenured position, and the resulting increase in labor mobility would likely make affected CIBs more antifragile. A role model here is Denmark, whose *flexicurity* system combines generous welfare protection and opportunities for retraining with weak job security mandates (Andersen 2005). Danish employees lose little when they switch employers or labor market status, making Danish talent available on more equal terms for entrepreneurial firms (Bredgaard 2013).

6.6 Entrepreneurial human capital

As measured in internationally comparable tests of pupils' abilities and skills, human capital is of crucial importance for economic growth (Hanushek and Woessmann 2015). Combining a carefully sequenced curriculum organized around subject disciplines with external exit exams (Hirsch 2016; Woessmann 2018) is probably a good way to standardize a body of knowledge that everyone, including the craziest free-thinker, can benefit from without becoming too neutered. Beyond that, however, the radical uncertainty of the future means that we cannot predict what skills and knowledge future generations require to thrive.

As a case in point: while the performance of American pupils on internationally compared tests is inferior to that of many European and Asian countries, the U.S. is universally considered the superior venue for Ph.D. training. This "paradox" may occur because "the educational approaches that are most effective in providing mastery of the already extant body of intellectual materials actually tend to handicap a student's ability to 'think outside the box' and

[5] Company-specific health insurance plans, as are common in the U.S., are an obvious example; another example is accumulated pension assets that are difficult to transfer when switching employers, industries, or countries of residence.

thus discourage unorthodox ideas and breakthrough approaches and results" (Baumol 2005, p. 7).

Can society use education to help individuals create antifragile personal knowledge (Markey-Towler 2018), what we may label entrepreneurial human capital? Fortunato (2017) raises the point that standardized practices at every educational level risk yielding fragility. In his view, value differences and knowledge diversity are desirable in education precisely because they introduce instability; this helps the educational system become increasingly antifragile and able to cope with systemic shocks. While he considers imposing standards to bring up the bottom end "a noble goal," he is wary of isolating and eschewing "those productive rebels who might simply see the world differently, question the current paradigm, and create situations that are, let's face it, very hard to measure indeed" (p. 184). Nonetheless, empirical evidence suggests that it is possible to educate and train successful entrepreneurs when that education and training is practically oriented and centered on experiencing every stage of the entrepreneurial process, from birth to death (see, e.g., Elert et al. 2015).

7. Discussion and conclusions

Something antifragile benefits from shocks. Given the uncertainty of the modern world, this is a desirable property of an economic system. By tracing the outlines of the CIB perspective, we have tried to assess under what micro- and macro-level conditions such meso-level phenomena are antifragile and how a healthy population of CIBs can help create antifragile conditions both at the micro level of the individual and at the macro level.

Optionality, i.e., a payoff structure with large, open-ended upside and limited, known downside, appears crucial to any antifragile strategy. This trait characterizes innovation, which is what drives improvements in human material wellbeing. A great deal of optionality is thus present in any antifragile system of innovation—when it comes to CIBs, this means that they are more likely to be antifragile if many of their constituent actors follow an optionality strategy.

Policies that enable the emergence of such a beneficial situation are generally indirect, targeting the institutional underpinnings of CIBs rather than attempting to create CIBs and clusters from the top down. We outlined six institutional areas, which, under the right conditions, will increase the likelihood that CIBs become antifragile.

First, the rule of law and property rights protection should be stable enough to protect people's expectations but permit innovation and be sufficiently flexible to evolve when challenged by stressors. Second, the tax system should avoid artificially skewing resources in a particular direction and be characterized by neutrality vis-à-vis owner categories, sources of

finance, and types of economic activities. Third, the savings system should not only channel available savings into the reproduction and growth of the existing capital stock but also make funds available to new, innovative ventures. Fourth, markets should be contestable, with low entry and exit barriers making it possible for newcomers to challenge the status quo in a stressor-like manner. Fifth, the social security system should be characterized by flexicurity and avoid punishing individuals who leave secure, tenured employment positions to pursue entrepreneurial projects. Finally, the educational system should provide everyone with a robust and stable knowledge base without isolating or eschewing free-thinkers, rebels, and other people of an entrepreneurial mindset.

To be sure, complete and pervasive antifragility on all societal levels is neither possible nor desirable. At the micro level, most business ideas will in all likelihood continue to fail, but the institutional structure should i) ensure that the costs of such failures are not overly dire for the individual, ii) ensure that the knowledge generated from failures is accessible to others, and iii) help cultivate antifragile personalities and antifragile business strategies. This should help usher in more antifragile CIBs at the meso level. However, there will always be movement along the fragile–antifragile continuum, with new CIBs emerging and failing or emerging and becoming antifragile, whereas others go from being antifragile to becoming robust or fragile. This continuous process is what produces antifragility at the macro level.

Sometimes, the fragility of a phenomenon—say, an egg—is readily apparent. Fragility is even intended in the case of an electric fuse. "In contrast, hidden vulnerability is insidious and entails surprise" (Ansar et al. 2016, p. 66). Moreover, there are several dimensions to antifragility: A CIB can be well-positioned to deal with, say, a financial crisis, but fragile to a political crisis or a cyber-attack (Alderson and Doyle, 2010). That said, determining whether a CIB or an economy is fragile or antifragile to a shock using the diagnostic tools laid out in this paper should be more straightforward and meaningful than trying to predict when or where the next economic shock will occur.

Future studies could move in several directions. Importantly, while it is elucidating to examine thriving CIB ecologies as Silicon Valley, much light can be shed by also identifying CIBs that had the potential to become antifragile but never did so. Why was that? Which actors were missing? What facets of the institutional setup were most important in preventing the emergence of an antifragile CIB? And in instances when a CIB went from being antifragile to fragile, what were the reasons for this development? Such questions are probably best answered by conducting case studies or comparative studies focusing on different industries within a country or similar industries in different countries. As a next step, researchers should ask

whether and to what extent findings related to successful CIBs embedded in a specific context (e.g., Silicon Valley in California) can be used to guide policy in other contexts. Taking institutional arguments seriously means acknowledging that institutional complementarities exist and that more than one institutional constellation can enable entrepreneurship and antifragility (Hall and Soskice 2001).

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