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ABSTRACT

Drawing upon the science of complexity we propose a network-centric, complex-systems internationalization (NCCSI) perspective of firm internationalization that can help us understand observed patterns of internationalization that are difficult to explain using traditional theories. While individual firm internationalization behavior is impossible to predict, aggregate patterns are to some extent. We review existing research on the role of networks in the internationalization process and explain how theories of complexity apply. We also describe three ways in which we can build NCCSI models using social physics and agent based simulation models, the associated research opportunities, and their value for managers and policymakers.

1. Introduction

Most theories of internationalization are firm-centric, they seek to explain internationalization behavior and performance in terms of various characteristics and behavior of firms. Here we argue that this focus is misplaced and propose instead a network-centric, complex-systems internationalization (NCCSI) perspective, which can explain internationalization behavior that is difficult using firm-centric theories.

Existing theories explain the process of internationalization from four overlapping perspectives. First are the theories based on *international economics*, which are integrated in the eclectic or *Ownership, Location and Internalization* (OLI) theory developed by Dunning (1980). This theory focuses on the economic drivers of ownership (e.g., a firm's specific technical knowhow), location (e.g., low-cost labor in a foreign country) and internalization (e.g., the benefits of owning the production mechanisms rather than contracting through partnerships). A second theory, or set of theories, the *Internationalization Process Model* (IPM) explains firm internationalization in terms of an incremental process by which firms learn about and engage in international markets over time and the various types of mechanisms involved, such as incremental commitment, learning, and relationship building (e.g., Coviello & Munro, 1997; Johanson & Vahlne, 1977, 2009). A third theory, the *Opportunity-Based View of Internationalization* (OBV), explains internationalization as an entrepreneurial, innovation process in which firms discover, develop and exploit international market opportunities gradually, over time (Chandra, Styles, & Wilkinson, 2009;

Chandra, Styles, & Wilkinson, 2012; Chandra, Styles, & Wilkinson, 2015; Chandra, 2017; Jones & Coviello, 2005; Knight & Liesch, 2016). A fourth theory, emphasizes the role and impact of the *relationships and networks* in which a firm operates and how this enables and/or constrains what the firm can learn and do (e.g., Coviello & Munro, 1997; Coviello, 2006; Johanson & Mattsson, 1988; Johanson & Vahlne 2009).

All these theories are based on *methodological individualism*, which seeks to explain social phenomena based on the characteristics of the individual agents, in this case a firm (Hodgson, 2007). "We want to believe that X succeeded because it had just the right attributes, but the only attributes we know are the attributes that X possesses; thus we conclude that these attributes must have been responsible for X's success" (Watts, 2011, p. 27). An example Watts uses concerns Leonardo da Vinci's Mona Lisa. We want to believe it is among the best-known paintings worldwide because of the painter's technical and painterly skills, and the painting's innovative style – the mysterious smile and three-quarter length pose against a landscape of trees and water. But, as Sassoon (2001) shows, the painting's fame is not necessarily due to its intrinsic characteristics nor da Vinci's genius. For centuries, the Mona Lisa was overlooked until, in August 1911, it was stolen from the Louvre. The resulting story of the theft and who stole it (a museum worker) catapulted this painting into the public consciousness, and it rose to prominence when the thief attempted to sell it to an Italian museum and it was recognized.

"The result is that what appear to us to be causal explanations are in fact just stories – descriptions of what happened that tell little, if anything, about the mechanisms at work" (Watts, 2011, p. 27). Such

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theories lack predictive power. They cannot say what will happen because the future depends on a complex set of factors and events taking place over time (Sewell, 2005; Watts, 2011). "History never flows in a predictable way. It is always a result of seemingly random currents and incidents, the significance of which can be determined – or, more often, disputed – only in hindsight" (Anderson, 2016, p. 2).

This kind of explanation is common in social science and business. In business, we try to explain highly successful firms in terms of a firm's key characteristics (e.g., technical knowhow, product portfolios, ambidexterity or market and learning orientation) and those of its leaders, such as Peters and Waterman's book In Search of Excellence (1982), only to find out later that these same firms with their key characteristics floundered (Chapman, 2006). Wiggins and Ruefli (2002) show that very few firms remain leaders in their industry over extended periods of time regardless of their intrinsic qualities. Business life is complex and attributing outcomes to firm specific characteristics and behavior is doomed. As James March characterizes the situation "An organization reacts to the actions of others that are reacting to it. Much of what happens is attributable to these interactions and thus not easily explicable as the consequences of autonomous action" (March, 1996, p. 283).

More generally, scholars have tried to explain firm performance based on correlations with managers' retrospective perceptions of their firms, such as its market orientation and its leaders' decisions, or its engineers' skills, or its learning orientation. The direction of causation here is problematic, because, as theories of sense making, selective perception, and causal attribution bias suggest, performance may drive managers' perceptions rather than the other way around (March & Sutton, 1997; Rong & Wilkinson, 2011). When managers know their firm is performing well (or poorly), this knowledge affects their perceptions of the firm. Their thinking goes like this: If my firm is performing well, it must produce superior products, have brilliant managers and engineers, cutting-edge marketing tactics and it must be market oriented and sensitive to the environment. If it is not performing well, then these attributes must be weaker or else the environment must be very challenging.

Theories of internationalization fall into the same trap. Retrospectively, we can trace the course of events affecting how a firm's internationalization behavior (e.g., timing or speed of international market entry) unfolded, and interpret it in terms of the firm's characteristics and the environment. These can include employees with the right international skills and experience, relevant resources and orientations; links to influential firms, a strong network position that enables it to identify and respond to opportunities, plus a degree of luck. And even this may be problematic, as a firm's path to internationalization can appear confusing, follow zig-zag directions, and lack apparent rhyme or reason (Ellis & Pecotich, 2001).

Here, we view the firm from the perspective of the network rather than the network from the perspective of the firm. Instead of focusing on explaining the internationalization behavior and performance of the individual firm over time, we focus on explaining the internationalization behavior and performance of the network as a whole. We argue that business networks are *complex adaptive systems*. The internationalization behavior and performance of the network over time are not a simple sum of the individual firm behavior and performance of the firms comprising the network; they emerge in a self-organizing way from the complex network of actions and interactions taking place over time across the network in an environment. The network structure is the primary driver of behavior and is itself shaped by the behavior taking place over time. Network structure shapes the flow of information, the nature of international market opportunities to be discovered and exploited. While individual firm internationalization behavior and performance over time is impossible to predict, aggregate patterns are to some extent.

Drawing upon the science of complexity we propose a network-centric, complex-systems internationalization (NCCSI) perspective of

firm internationalization that can help us understand observed patterns of internationalization that are difficult to explain using traditional theories. The NCCSI perspective can shed light on why firms go international early or fast, or enter various countries in no apparent order (Knight & Cavusgil, 2004; McDougall, Shane, & Oviatt, 1994), pull out from international markets (Benito & Welch, 1994a; Chandra, 2017), re-internationalize (Welch & Welch, 2009), change entry modes (Chandra, 2017), or use multiple entry modes simultaneously (Benito & Welch, 1994b). The NCCSI approach also offers new lines of enquiry, new theories, alternative research methods, and unique management and policy implications.

The relevance of the theories and methods of complexity for advancing our understanding of business and economic systems is being increasingly recognized (e.g. Allen, Maguire, & McKelvey, 2011; Arthur, Durlauf, & Lane, 1997; Choi, Dooley, & Rungtusanatham, 2001; McKelvey, 2004; Surana, Kumara, Greaves, & Raghavan, 2005; Wilkinson & Young, 2013). But this perspective has not been applied to the study of firm internationalization. Therefore, the basic research question addressed here is: *How can a complex adaptive systems perspective advance our understanding of firm internationalization?*

The rest of the article is organized as follows. First, we review existing theories of firm internationalization and the role of networks. Second, we describe the nature complex adaptive systems and how they apply to firm internationalization. Third, we describe ways in which NCSSI models can be developed based on theories of social physics and agent based computer simulation models and their implications for research and practice. The concluding section summarizes the key contributions and their implications.

2. Internationalization theories and the role of relationships and networks

Firms operate in markets and industries comprised of networks of interconnected and interacting firms, which enable and constrain their behavior and performance (Anderson, Håkansson, & Johanson, 1994; Håkansson & Snehota, 2000; Johanson & Vahlne, 2010; Johansson & Mattsson, 1994; Ritter, Wilkinson, & Johnston, 2004; White, 2002; Wilkinson, 2008). The role of relationships and networks in firm internationalization has been emphasized by many (e.g., Coviello & Munro, 1995, 1997; Hånell & Ghauri, 2015; Hertenstein, 2015; Johanson & Vahlne, 2009; Wilkinson, Mattsson, & Easton, 2000). Relationships and networks affect firm internationalization in two main ways: they affect *international opportunity recognition* (discovery, creation, and actualization) and a firm's ability to *develop and exploit international market opportunities*. We summarize these processes in Fig. 1.

The internationalization process model (IPM) proposed by Johanson and Vahlne (1977, 2009) provides a starting point for understanding the ways in which relationships and networks impact firm internationalization. Change processes within the firm result in changes in a firm's position in an industry and/or in global networks, and the international opportunities it can discover or create and actualize (Chandra, 2017; Ramoglou & Tsang, 2016). This has feedback effects on a firm's decisions to commit effort and resources to these relationships and its subsequent learning, co-creation of knowledge and development of trust with other firms. To gain access to a network's benefits, the firm must first become an "insider", an established participant in the relevant industry network. The firm gains entry into networks through direct and indirect interactions with established network members. Otherwise, the firm suffers from the liability of outsidership (Johanson & Vahlne, 2009), or the disadvantage of network exclusion. This highlights network interactions as an important characteristic or driver of firm internationalization.

Firms gain market-specific and general knowledge via their network relationships and this allow them to discover, create, actualize, and develop international market opportunities. Over time, firms develop and *revise* their opportunities and change how they create or discover
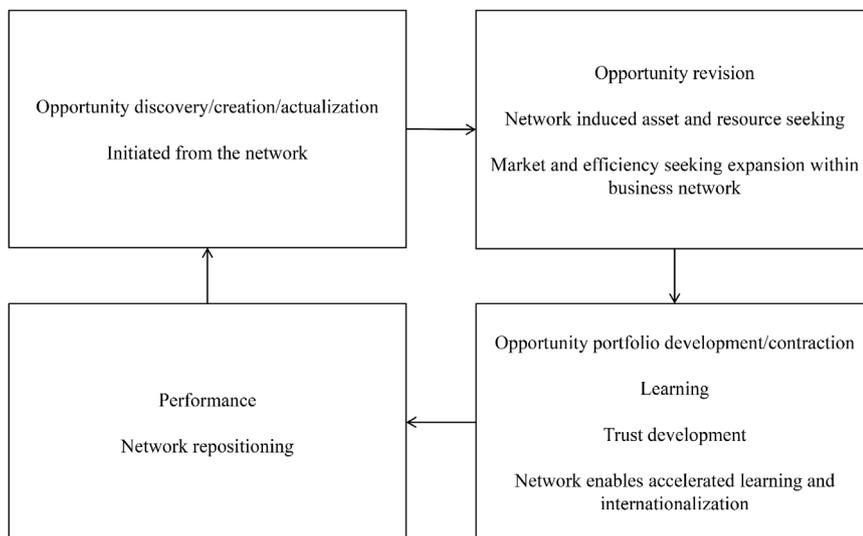
and actualize international opportunities (Chandra, 2017; Gielnik, Frese, Graf, & Kampschulte, 2012; Muthukrishnan, Pham, & Mungale, 1999). Through internationalization behavior, such as searching for new raw materials, foreign suppliers or business partners, firms build positions in international networks. Internationalization requires the development of mutual trust and the commitment of resources to international relations and markets. This increases interdependence, which further facilitates the co-development and sharing of knowledge and opportunities (Johanson & Vahlne, 2006). Ties (weak and strong) and links (formal and informal) between network members contribute to firms' knowledge development and sharing (Fernharber & Li, 2013; Kontinen & Ojala, 2011; Nowinski & Rialp, 2015). Weak ties play an important role as they are a potential source of new information because they can bridge structural holes (i.e., unconnected groups of firms) in networks, and link otherwise disconnected knowledge domains (e.g., unconnected expertise possessed by unconnected groups of firms) (Burt, 2004; Granovetter, 1973; Johanson & Vahlne, 2009). Strong, trustworthy relations can also provide new knowledge and resources to network firms because they help firms co-create new knowledge and share ideas (Chandra et al., 2012; Child & Hsieh, 2014; Johanson & Vahlne, 2009).

Firm relationships and networks also affect a firm's ability to *exploit* international market opportunities. They provide the means by which firms gain access to additional skills and resources that enable them to move successfully into international markets (Hertenstein, Sutherland, & Anderson, 2015). Firms build relations and trust with other firms to leverage the resources of other network firms, to overcome constraints such as size, newness and trepidation in entering new international markets (Gabrielsson & Gabrielsson, 2013).

The mix of internationalized and non-internationalized firms in a network affects the kinds of problems and challenges a firm faces in internationalizing (Johanson & Mattsson, 1988). Some firms – lonely internationals – try to internationalize in a network that is minimally internationalized. This presents the most difficult situation for the firm, as information, experience and support is limited. Its chances of successfully internationalizing are limited.

But when a firm operates in a network in which there are internationally focused and competitive firms, information, experience, support and access to international markets is readily available. A firm can benefit from both the local and foreign based networks of internationalized firms, which open up opportunities for them to form relationships to learn about paths to international markets and gain support for moves into these markets (Wilkinson et al., 2000). One way this can happen is through the link between the firm's inward and outward connections (Welch & Luostarinen, 1993). Through its

international sourcing operations, a firm can learn about and gain support in entering international markets (Hertenstein et al., 2015; Mathews, 2006). Another way is through firms becoming local suppliers of internationalized firm. Hertenstein et al. (2015) use the international process model to explain how a number of Chinese automotive component suppliers began by supplying parts to multinational corporations (MNCs) in China. They show how these small Chinese firms were able to leverage this base in various ways to identify and exploit international market opportunities, and eventually to become highly internationalized. Serving MNCs locally could also constrain a supplier's internationalization because an MNC can resist moves by a supplier to enter international markets to serve its competitors and restrict access to key technologies of local partners and contractors to prevent the partners and contractors from exploiting international market opportunities (Wilkinson et al., 2000).

Having reviewed the various ways that relationships and networks help explain firm internationalization, we now describe business networks from a complex adaptive systems perspective and how this applies to firm internationalization and advances our understanding.

3. A complex systems perspective of firm internationalization in networks

We argue that business networks are complex adaptive systems of interacting firms and other types of organizations (Holland, 2014; Miller & Page, 2007). Through the interactions taking place over time knowledge, skills, resources and customer value are co-created and co-developed. Such systems have also been described as business or service eco-systems (Baldwin, 2011; Iansiti & Levien, 2004; Moore, 1996; Wieland, Polese, Vargo, & Lusch, 2012) but here we will use the language of complexity theory. We argue that using a complex systems perspective can advance our understanding of firm internationalization and the role of business networks and explain patterns of behavior that are otherwise difficult to explain. The application of complexity science to management and organization studies is a fast-growing area of research and is being taken up by practitioners in business, government and non-government organizations (e.g. Allen et al., 2011; Blume & Durlach, 2006; Choi et al., 2001; Earnest & Wilkinson, 2017; McKelvey, 2004; Parrott et al., 2011; Pathak et al., 2007; Surana et al., 2005; Wilkinson & Young, 2013). But it has not been applied to firm internationalization.

In this section we describe the main features of complex adaptive systems and how they apply to the internationalization of firms in business networks. In the following section we describe ways of developing network centric complex system models of firm

internationalization of use to researchers, managers and policymakers.

A complex system is not the same as a complicated system (Holland, 2014). Cars and computers are complicated systems that are designed for a purpose and have predictable behavior. If one part is removed or damaged, the system fails. Also, complicated systems are centrally managed; for the car, the driver is the central manager, for the computer, the user is. Complex systems differ in that they exhibit new and evolving behaviors that are *self-organizing* (i.e., a process where overall coordination results from interactions between smaller component parts); the behavior of individual elements is *unpredictable*, they comprise *autonomous interacting actors*, members can be removed from the system without disrupting its functions, and they are *not centrally managed*. Examples of complex systems include social insects (Bonabeau, 1998), ecological systems (Anand, Gonzalez, Guichard, Kolasa, & Parrott, 2010), cities (Batty, 2007), societies (Sawyer, 2005), education systems (Jacobson, Kapur, & Reimann, 2016), firms and organizations (Allen et al., 2011); industries (Baldwin, 2011); markets and economies (Arthur et al., 1997; Axtell, 2005; Holland, 2014), and financial systems (Battiston et al., 2016).

Various ways have been used to summarize the main characteristics of complex adaptive systems and there is no agreed list. Here we describe them in terms of seven key features, that have been identified in the literature drawing on Holland (2014); Jacobson et al. (2016); and Mitchell (2009) and explain how each can be applied to firm internationalization in networks. They are *networks of interacting actors, self-organization and emergence, sensitivity to small perturbations, parallelisms, conditional action, top-down effects*, and *adaptation and evolution*. They are summarized in Table 1.

3.1. Network of interacting actors

A complex system contains networks of interacting elements, entities, agents or actors such as birds in a flock, ants in a colony, people in an organization, and firms in a network. In complex physical systems, such as planetary systems and weather systems, the entities follow fixed physical laws. "Neither the laws nor the elements change over time; only the positions of the elements change" (Holland, 2014, p. 13). But in complex adaptive systems the rules governing behavior and the members of the system can change over time "Complex adaptive systems … are composed of elements called *agents*, that learn and adapt in response to interactions with other agents" (Holland, 2014, p. 24). Business networks are complex adaptive systems because they comprise networks of interacting firms, such as producers, suppliers, distributors, intermediaries, customers, as well as other types of organizations, such as government agencies, involved in creating and delivering value to domestic and international customers in the form of products and services. They learn and adapt their behavior over time to the experience and outcomes of the various types of interactions taking place, such as selling, buying, communicating, observing, competing, co-operating, complementing and controlling.

3.2. Self-Organization and emergence

The second characteristic of complex systems is *self-organization and emergence* (Goldstein, 2011; Holland, 2014). Complex adaptive systems are not centrally directed and controlled, there is no leader. Large scale order emerges in a self-organizing bottom up manner from the local interactions taking place over time. There is no wing commander bird organizing a flock of birds into its classic flying V formation, the lead bird rotates. The queen in a beehive or ants' nest is not in charge and no one has a blueprint of the structure of the hive or nest to work to, it emerges out of local rules of interaction and adaption (Camazine, 1991). No one decides there will be a traffic jam, herding behavior or group think.

The large-scale patterns that emerge can be quite counterintuitive. A classic example is the work of Thomas Schelling, the Nobel Prize winner, to explain the emergence of segregated neighborhoods in cities (Schelling, 1971, 2006). This was commonly attributed to racial prejudice but he showed, using simple simulations on a chequerboard, that this can occur over time even if people are not prejudiced. All it required was a preference to live in a neighborhood with at least some people of the same race, otherwise people moved. Another example is Conway's Game of Life, (www.conwaylife.com) where simple rules about whether individual cells on a two-dimensional array of square cells is "alive" (black) or dead (white) produces very complex and unexpected patterns of behavior on the array over time (Poundstone, 1985). Research on the behavior of these kinds of complex systems, known as cellular automata, has revealed many examples of how complexity can arise from simple underlying rules of behavior (e.g., Weunsch, 2016; Wolfram, 2002).

Business networks are self-organizing systems, even though some firms may have more power and influence than others. Two emergent properties of a business networks that play and key role in driving firm internationalization in networks. The first is what has been termed its "collective intelligence" (Pentland, 2014; Woolley, Chabris, Pentland, Hashmi, & Malone, 2010), "collective mind" (Mattsson, Corsaro, & Ramos, 2015), or "schema configuration" (Welch & Wilkinson, 2002). This property enables and constrains the discovery and creation of international market opportunities – what a network can think. Pentland's research shows that what matters here is not the characteristics of the individual members of a system but the structure of the network of interactions (Pentland, 2012). The second

Table 1
Features of Complex Adaptive Systems and Their Application to Firm Internationalisation.

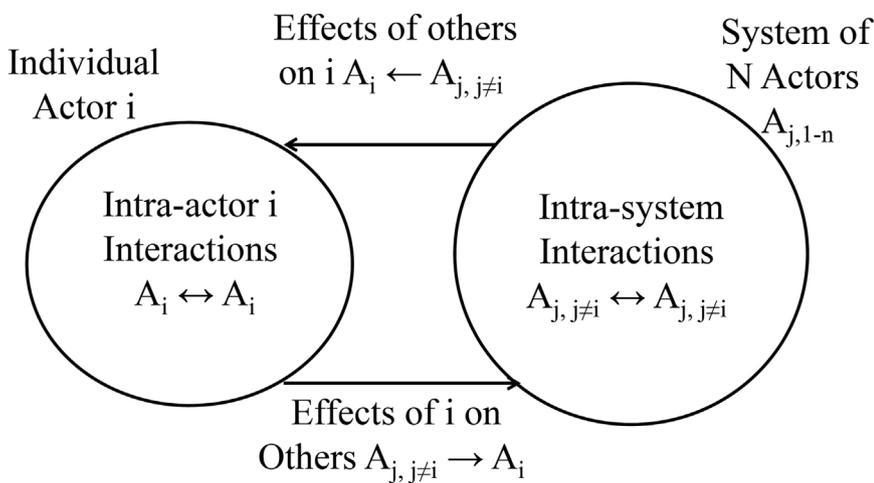|	Feature	Examples	Application to firm internationalization
1	Networks of actors	Birds in a flock, neurons in the brain, social insects, social groups, cars on roads,	Networks of Interacting firms and other types of organizations
2a	Self Organization	Birds Flocking, social behavior of insects, herding behavior, markets	Formation of international markets and business networks from individual actions and interactions
2b	Emergence	V formation of bird flocks, termite nests, traffic jams, central place hierarchies	The collective intelligence and collective ability of the network and associated aggregate patterns of firm internationalization
3	Sensitivity to minor perturbations	Butterfly effects, tipping points	Unsolicited orders, chance encounters, environmental shocks
4	Parallelism: simultaneous interactions among actors across the network	Local interactions amongst ants in a nest; interactions among people in a crowd; cars reacting to each other along a road	Simultaneous interactions among firms across a business network
5	Conditional action: if condition X exists an actor will do Y	Ants responding to other ants, and pheromone trails; cars responding to the behavior of other cars around them	Firms respond to communication and observations of other firms and environment in an if-then fashion − if condition X exists an actor will do Y.
6	Top down effects	Ants responding to the emergent physical structure of the nest; cars responding to a traffic jam	Firms respond to known emergent aggregate patterns of internationalization across the network
7	Adaptation and evolution	Evolution of ant species to different environments; people adapting to driverless cars.	Firms learn and adapt their behavior and responses to changing environments, technologies and ideologies.

emergent property is its "collective ability", which constrains and enables the development and exploitation of international market opportunities (Dagnino, 2004; Wilkinson et al., 2000) – what a network can do. These properties emerge over time as a result of the knowledge and ideas, learning, skills and resources that are co-developed and co-created via the interactions taking place. There will be differences in the diversity of information individual firms have access to from this collective intelligence, which will affect their creativity and recognition of international opportunities (Gielnik et al., 2012; Hargadon, 2003; Hills & Birkinshaw, 2010; Nowiński & Rialp, 2016; Shane, 2000). This will depend on their position in the network, how this changes over time and the particular sequence of interactions taking place. Hence, which firms in the network discover and exploit which opportunities cannot be predicted. Firms with similar characteristics to begin with may end up following quite different patterns of internationalization over time. Only retrospectively may we be able to make some sense of why things developed as they did.

3.3. Sensitivity to small perturbations

The third feature of complex systems is their *sensitivity to small perturbations,* such as minor events and changes in starting conditions, that can cause disproportionate effects, acting as *tipping points* driving the system in very different directions. This occurs because complex systems are highly nonlinear (i.e. where X is action and Y is outcome, X is not linearly related to Y) due to the interdependencies among the system's actors and their responses. This extreme sensitivity, also known as the *butterfly effect* (Omerod, 2011), named after the meteorological models of Lorenz (1963), who used nonlinear equations to demonstrate that tiny wind fluctuations, such as the flapping of a butterfly's wing, could potentially affect weather conditions in distant places. Other examples are how small gaps in a child's kindergarten academic performance increase over the years to high school and how the effects of early learning experiences influence subsequent learning (Jacobson et al., 2016).

This feature of complex systems is consistent with previous research showing how nonlinearities (Åkerman, 2015), chance events and serendipity (Crick & Spence, 2005) impact firm internationalization. An unsolicited order, chance encounter, a search for a new supplier, a job relocation to a different city or country, or other minor event can affect a firm's path of internationalization, both directly and indirectly (Chetty & Agndal, 2007; Crick & Spence, 2005; Styles & Harcourt, 2001). Firms may move into foreign markets due to unsolicited orders or chance encounters that can occur early or late in its development and create path-dependent effects (Sydow, Schreyögg, & Koch, 2009). Firms often stumble into unforeseen events or quagmires and withdraw from international markets. Firms may fail, new ones may form, people move

between firms, innovations unexpectedly change market opportunities, network firms may enter or exit a market making room for new opportunities or leaving a vacuum, regulations may change, natural and human-made disasters (e.g., earthquakes, 9/11, respectively) happen, each buffeting firms and networks in different ways.

A good example of a chance event with a major impact is the Biovite Australia, Ltd. case (Chandra et al., 2015), in which a chance encounter between an entrepreneur and a biotech scientist led to the establishment of a successful international biotech venture. Both men were attending a board meeting of a New Zealand school that their children attended and talked about their lines of work and interests. They did not meet again for two years, at another chance encounter shortly after the entrepreneur moved to Queensland, Australia's biotech haven, just as the government introduced a policy encouraging investment in the biotech industry. This reinforced the entrepreneur's and scientist's interest in the opportunity, leading to further actions (i.e., proactive search for international opportunities) and interactions. The 9–11 disaster disrupted their plans, and a series of chance encounter with other individuals including a German firm that had access to the European market, among others, completely changed their path to internationalization and financing model.

3.4. Parallelism

The fourth feature of complex systems is *parallelism,* which refers to the relevance and importance of the simultaneous interactions across the whole network of actors (Holland, 2014; Jacobson et al., 2016). There are multiple interactions taking place all the time in parallel across the birds in a flock, ants in a nest, cars on the road. Individual firms engage in interactions with others in their part of the network, while other interactions are simultaneously taking place in other parts. As these interactions occur in parallel across the network they have both direct and indirect effects on other parts of the network.

The basic logic here is summarized in Fig. 2, which depicts the different types of interactions that occur in parallel in a complex system with N actors (based on Emery & Trist, 1965). First are the *internal interactions* of an individual actor or firm i ($A_i \leftrightarrow A_i$), the internal processes of interaction and planning among a firm's managers, workers, and departments, and the impacts of past experience and outcomes. These are the focus of many existing firm-centric theories of internationalization, such as the effects of management characteristics and planning and response tendencies. Next are interactions between firm A_i and *others in the network* ($A_i \rightarrow A_{j,j \neq i}$) and ($A_i \longleftarrow A_{j,j \neq i}$), where j varies from 1 to N, the size of the network. These effects are reflected in existing theories of the role of other firms as sources of information, ideas, resources and skills. The final type of interactions, are those occurring in parallel among other firms and organizations in the

network ($A_{j,j \neq i} \leftrightarrow A_{j,j \neq i}$). The latter type of interactions is ignored in firms-centric theories but play a central role in understanding and modelling firm internationalization from a network-centric complex systems perspective.

3.5. Conditional action

The fifth feature of complex systems is *conditional action* (Holland, 2006, 2014). Actors respond to local signals in an if-then fashion – if condition X exists, an actor will do Y. For example, each bird responds to the behavior of other birds flying near, to the general direction of the flock, as well as to its local environment such as the weather, presence of predators and location of trees and buildings. In ant colonies, each ant behaves according to its interactions with other ants and local environmental conditions, including the results of other ants' previous behavior such as scent trails and nest-building efforts.

A similar type of scenario plays out in a business network. The actions of firms are based on managers' memory of past actions and their outcomes, the current behavior of other firms and organizations in their network, as well as more general environmental conditions such as industry or economic stability, geography and the political climate. It is important to emphasize that conditional action is not about correlations between the behavior of different firms but about the results of the operation of various types of causal mechanisms including, social, psychological and economic mechanisms and processes that drive action and response (Hedstrom & Bearman, 2009; Hedstrom & Swedberg, 1998). For example, the response to another firm's behavior will be affected by prior learning and relationship building, perceptions and interpretations, economic calculation, planning and decision-making processes and goal seeking behavior.

3.6. Top-down effects

The sixth characteristic of complex systems is *top-down effects,* whereby the emergent system properties have feedback effects on local actions and interactions. For instance, the overall direction of a flock of birds emerges from the interactions taking place in the flock within an environment, which in turn has feedback effects on individual bird behavior and their local interactions. For ants, the physical structure of the nest is an emergent property of ant interactions over time and this affects the local conditions of individual ants and their behavior. A traffic jams changes the behavior of the cars involved.

In business networks, top-down effects occur from the aggregate properties of the network that emerge over time including, the structure of the network, its collective intelligence and collective ability, and the patterns of internationalization in the network. These in turn affect the local network positions of firms in the network, such as the presence in their part of the network of internationally competitive firms and the international opportunities they can discover and exploit. These in turn reshape the emergent properties.

3.7. Adaptation and evolution

Finally, the seventh feature of complex systems is *adaptation and evolution*. The top down and bottom effects occurring in the system over time in an environment will shape its pattern of evolution and adaptation. The system's composition, structure, and rules of interaction change over time in response to the changes within the system and its ever-changing environment (Holland, 2006; Morel & Ramanujam, 1999). Biological systems adapt and evolve through natural selection processes. Social systems adapt and evolve due to changes in the environment and the emergence of new technologies and ideologies. A complex adaptive system never stands still; it is in a constant process of being and becoming.

The same processes occur over time in business networks. Firms learn and adapt their behavior based on their experience and

performance and to changing environmental conditions. The emergence of new resources and technologies, such as the internet and new means of production and distribution, alter the flow of information, change industry structures and the links between them and the interaction patterns among firms, creating new types of international opportunities and adaptations. The entry of new types of firms in the network affects its collective intelligence and collective ability and the opportunities for firms to form new types with international consequences. New political realities and industrial policies shape patterns of action and interactions closing some international opportunities opening up others.

A pioneer of complexity economics, Arthur, 1999W. Brian Arthur, summarizes the overall process this way: "the elements adapt to the world – the aggregate pattern – they co-create. Time enters naturally here via adjustment and change: As the elements react, the aggregate changes; as the aggregate changes, elements react anew" (1999, p. 107).

4. Toward network-centric, complex-systems internationalization models

Here we describe three ways of building on our complexity perspective to develop NCCSI models. The first is based on social physics and the influence models developed by Pentland and his colleagues at MIT to study the dynamics of social networks (Pentland, 2014). The other two are based on computational methods and the development of stylized and realistic agent based computer simulation models of the international behavior of firms' networks.

4.1. A social physics influence model of firm internationalization in networks

"Social Physics is a quantitative science that describes reliable, mathematical connections between information and idea flow on the one hand and people's behavior on the other. Social Physics helps us understand how ideas flow from person to person through the mechanism of social learning and how these ideas end up shaping the norms, productivity, and creative output of our companies, cities and societies" (Pentland, 2014, p. 4).

Social physics uses observations of the behavior of actors in complex networks over time to develop an *influence model* of the network that can reproduce its behavior and predict how interventions and changes in the network affect behavior and performance. This approach has been used successfully to reproduce the behavior of many types of complex social and business networks, including: power station network dynamics, work group interactions and performance, purchasing behavior, financial decision making, traffic patterns and flu outbreaks. As Pentland notes, this model is quite general and may be applied to other types of networks including firms but it has not been used to model the internationalization behavior of business networks. In this section we describe the main features of the influence model and how it can be applied to develop a NSSCI.

Formally, the influence model is a type of Hidden Markov Model (HMM) estimated from data about the behavior of a network of actors over time. The technical details of the estimation methods involved need not concern us here, instead we focus on the main logic of the model.

In terms of firm internationalization, the influence model is a model of a complex adaptive system adaptive comprising a network of interacting firms, who directly and indirectly influence each other's internationalization behavior. Each firm has a *latent state of internationalization*, which refers to its potential to engage in international behavior. A firm's internationalization potential is not directly observable by other firms, only its international behavior or stage of internationalization. Different stages of internationalization can be represented in the model in various ways such as no international

behavior, pre-internationalization behavior such as moves interstate, a firm's first move into international markets and increasing levels of investment in international markets.

A firm's international behavior each period depends, in a probabilistic way, on its internationalization potential in the previous period and the influence of the international behavior of other firms in the network in the previous period. The model begins with a network of firms who differ in terms of their potential to internationalize and their international behavior due to some unspecified history of past behavior and other firm influences. The influence network reflects the creation and flow of knowledge and ideas across the network, which can be described as its collective intelligence. This collective intelligence affects the emergence of aggregate patterns of international behavior over time, which is an emergent property of the network. As firms adapt and re-adapt their internationalization potential and actual behavior to each other aggregate patterns of internationalization emerge. The internationalization behavior over time of individual firms cannot be predicted as it depends on influence interactions taking place across the network, only aggregate patterns can be predicted. Over time an individual firm's international potential and stage of internationalization varies and may increase or decrease depending on what is going on in other parts of the network. As other firms in the network increase their investment in international markets they influence other firms to do so but if they reduce their levels of internationalization they will influence others to do so.

In mathematical terms the influence model may be described as follows. Let the latent (hidden) variable of firm c at time t, its international potential, be $h_t^{(c)}$ and the observed behavior, its stage of internationalization, be $O_t^{(c)}$. Let the number of observed states be S. The observed behavior is conditional on the latent variable, i.e., Prob ($O_t^{(c)}$ | $h_{t-1}^{(c)}$), which means the higher firm c's internationalization potential, the greater its level of the internationalization is likely to be. The latent variable of firm c is also conditionally dependent on the latent variable in the previous period of all other firms in the network, their international potentials. It is conditionally dependent as it depends on the observed behavior in the previous period, $O_{t-1}^{(c)}$, of all the other firms and the influence matrix $R_{c',c}$ which indicates the tie strength, or degree of influence, between each firm.

The conditional probability becomes:

$$\text{Prob}(h_t^{(c')}|h_{t-1}^{(1)}, ..., h_{t-1}^{(C)}) = \sum_{c \in \{1, ..., C\}} \underbrace{R_{c',c}}_{\text{tie strength}} \times \underbrace{\text{Infl}(h_t^{(c')}|h_{t-1}^{(c)})}_{\text{influence } c \rightarrow c'},$$

This influence model is very complex. With a network of size C with S possible states of internationalization, the number of unique states is C^S. Working with an HMM of these dimensions is not practical due to the numerous parameters involved. To make the model practical the influence network is simplified. What this means in terms of firm internationalization is that the pattern of influence of other firms in the network on each individual firm is assumed to be the same. The technical methods by which the parameters of the model are estimated need not concern us here, for details see Pan et al. (2012).

To estimate this NCCSI influence model requires data on the internationalization behavior of firms in a network over time. To our knowledge such data does not yet exist and represents a future research opportunity. One possibility is to recast the model at a national or regional level and use data on international trade flows to estimate the model. Having estimated an influence model, we can use it to analyze how it behaves when various types of changes of interest are made. These can include network focused trade policy interventions to encourage greater levels of internationalization such as those described in Wilkinson et al. (2000). For example, influence patterns can be changed by altering the flow of information within the network and by introducing new ideas from outside to boost the collective intelligence of the network. The influence of more internationalized firms could be strengthened by facilitating more interactions with them, by

incentivizing internationalized firms to cooperate more with less internationalized firms and introduce them to international markets.

4.2. Developing agent based models of firm internationalization in networks

A second way to model complex adaptive systems is the use of computational methods to develop agent based computer simulation models. Agent based models are used to model the behavior of complex systems because they cannot be reduced to the sum of the behavior of their parts. As described already, they are highly non-linear system due to the complex interdependencies involved, which makes it not amenable to analysis using traditional algebraic methods (Leombruni & Richiardi, 2005). Instead, we must use agent based computer simulation models (ABM) to model their behavior. ABMs are conceptual and methodological tools to help understand the behavior of complex systems by simulating their behavior (Epstein, 2006; Gilbert, 2008; Miller & Page, 2007). They are used by researchers to produce pseudo-data about the behavior of the system under different conditions of interest that can then be analyzed using traditional statistical methods to tease out key features of a system's behavior.

Simulation methods have been described as a third way of doing science, in contrast to deduction and induction (Axelrod, 2006) and are fast gaining traction in various disciplines. This is reflected in developments such as agent-based computational economics (Tesfatsion, 2006), computational social science (Epstein, 2006; Gilbert, 2010; Miller & Page 2007; Yang & Chandra, 2013) and computational biology (Kitano, 2002). Most recently its value is reflected in the "Ground Truth" initiative of the USA's Defense Advanced Research Projects Agency (DARPA). The aim is to develop simulated social systems of varying complexity to test the accuracy of social science modeling methods in order to distinguish between mere correlations versus causation (www.darpa.mil/news-events/2017-04-07).

Building ABM requires new types of skills and ways of thinking. It is more about synthesis than analysis. ABM are not about developing correlational models of variables measuring different aspects of behavior but about modelling actors acting and interacting, the causal mechanisms underlying this and the events taking place (Hedstrom & Bearman, 2009; Hedstrom & Swedberg, 1998; Van de Ven & Engleman, 2004). Noble Laureate Herbert Simon (1968) describes the type of explanation we seek: "To 'explain' an empirical regularity is to discover a set of simple mechanisms that would produce the former in any system governed by the latter" (p. 44).

To build ABM requires programming skills and algorithmic thinking that are different to the more commonly used statistical and mathematical methods, which has slowed down the appreciation of their potential contributions and their widespread use. But programming languages and software platforms are becoming increasingly accessible and user friendly, such as the *AnyLogic*, *Mason*, *Mathematica*, *NetLogo* and *Repast* program development platforms (Nikolai & Madey, 2009), and better introductory and advanced textbooks exist to help researchers develop and improve their skills (e.g. Gilbert, 2008; Miller & Page, 2007; Railsback & Grimm, 2011; Wilensky & Rand, 2015). We recommend the NetLogo platform developed and maintained by Uri Wilensky at Northwestern University as a good place to start. It is freely available, a relatively simple language to learn (it has its origins in primary schools), and is full of examples of ABM in different contexts (ccl.northwestern.edu/netlogo/).

The relevance and value of ABM for the study of social, business and economic systems and networks is now being increasingly recognized (e.g., Altiparmak, Gen, Lin, & Paksoy, 2006; Baldwin, 2011; Chen, Ong, Tan, Zhang, & Li, 2013; Earnest & Wilkinson, 2017; Farmer & Foley, 2009; Garcia & Jager, 2010; Held, Wilkinson, Marks, & Young, 2014; Labarthe, Espinasse, Ferrarini, & Montreuil, 2007; Rand & Rust, 2011; Seibel & Kellam, 2003; Yang & Chandra, 2013), there are special issues of business journals devoted to the topic (e.g. D'Alessandro & Winzar, 2014; Garcia & Jager, 2010Garcia and Jager, 2010D'Alessandro &

Winzar, 2014; Garcia & Jager, 2010; Gilbert, Jager, Deffuant, & Adjali, 2007) and a specialized journal *Journal of Artificial Societies and Social Systems*. We believe they can profitable be used to develop NCCSI models.

ABM can be used in two ways. The first is to develop stylized models of internationalization in business networks that include some of the key features of interest. The second is to build more realist models of the internationalization behavior of actual business networks, which is now possible given advances in computing power and programming methods. In the following we describe how each approach may be developed and used.

4.2.1. Building stylized models of network internationalization using NK models

Stylized simulation models are simplified models of a complex system used to focus attention on key features in order to better understand them. One type of stylized model of complex systems that could be used to model and provide insights into network internationalisation is the NK models developed Stuart Kauffman (1993, 1995). While originally developed to study the dynamics of genetic networks they have been used to model business and social systems, including: management strategies (McKelvey, 1999; Rivkin & Siggelkow, 2007), the evolution of the microcomputer industry (Vidgen & Bull, 2011), trading networks (Easton, Brooks, Wilkinson, & Georgieva, 2008), and supply chains (Behdani, van Dam and Lukszo, 2010; Earnest & Wilkinson, 2017; Labarthe et al., 2007).

A detailed description of the way these models work is beyond the scope of this paper but their essential characteristics and how they relate to the internationalisation context are as follows. N refers to the number of entities comprising a network, which, in our case, is the number of firms in a business network. K refers to how interconnected the entities in the network are in terms of the number of other entities that affect an individual entities behaviour. In our case this refers to the number of other firms that influence an individual firm's internationalisation behaviour and performance. Rules of interaction govern how the mix of behavior of the K influencers affects an individual entities behavior. In our case this refers to the way the international behavior and performance of the K influencing firms enable and constrain the internationalisation behavior of an individual firm. The rules of interaction can be varied to reflect different types of real world influence on a firm internationalisation such as via communication systems and the behaviour of customers, suppliers, distributors, complementors and competitors. Research on NK models show that, even with simple rules of interaction, complex patterns of behaviour emerge as entities (firms) adapt and re-adapt their behaviour to each other over time. But different types of network patterns emerge, with varying degrees of stability, depending on model conditions that have real world counterparts, such as how interconnected the network is, how sensitive individual behaviour is to that of others, starting conditions and environmental impacts.

We believe that NK models can be used to better understand some of the factors driving aggregate patterns of network internationalization because they capture many of the key features of complex business networks described above. They can be used to (1) investigate the effects of various types of network structures on network behavior and aggregate performance, (2) provide insights into and demonstrate the behavior and outcomes of complex internationalization networks, (3) identify the impacts of various network characteristics such as centrality, connectivity and size, and (4) test the impact of key interventions and model assumptions.

4.2.2. Building realistic models of network internationalization

While stylized models can help advance our understanding it is also possible to develop more realistic, fine grained ABM of complex adaptive systems. Some examples indicate their potential value and scope. The first is an ABM model of the wholesale electricity market in

the USA designed to assist regulators (Sun & Tesfatsion, 2007). The second is the development of an ABM of the Proctor and Gamble supply chain to assist managers in improving its performance (Seibel & Kellam, 2003). The third is the multi-agent model built to assist the integrated management of human activities in the Saguenay-St. Lawrence Marine Park and the proposed St. Lawrence Estuary Marine Protected Area in Quebec (Parrott et al., 2011). The 3MTSim simulator includes numerous individual agents representing people, whales, krill, fisherman, tourist whale watching boats, ferry and cargo boats, pleasure craft, as well as the its topography, location of tourist attractions, tides, and visibility. The simulator was based on detailed observations, understanding and modeling of the behavior of each system agent and was tested and validated against actual data and behavior at the micro and macro levels.

To develop and test realistic ABM of network internationalization we need detailed maps of business networks and how they develop over time and a better understanding the causal mechanisms involved driving the way members of the network behave and respond, including firms and other organizations involved. These are not mere correlations among variables describing behavior but models of the causal processes involved, the cogs and wheels driving behavior (Elster, 1989; Hedstrom & Bearman, 2009; Hedstrom & Swedberg, 1998). Existing theories of firm internationalization and the role of networks described in an earlier section provide the basis for developing such models. Additional research is required to identify the actual mechanisms operating in particular business networks over time (e.g. Buttriss & Wilkinson 2006; Wilkinson & Young, 2013) and to develop, test and validate models of them. The type of research involved is similar to that required to develop the 3MTSim model described above. In this way research in the real world and simulated world are not competing ways of studying firm internationalization in networks but complement and reinforce each other.

Once we have built and validated an ABM for a focal international business network, we can use them to generate pseudo data about the behavior of the network over time under different conditions of interest. Computer experiments can be used to investigate the effects of different kinds of changes, interventions or environmental shocks, which would be impossible and not ethical to do in the real world. The results can help guide real world research on firm internationalization and networks by directing attention to key factors and conditions to be investigated. They can also be used by managers and policymakers to identify and test network based strategies, as has been done using the models described above. They could be used to identify and test types of network-based trade and industry policies to stimulate or enhance the internationalization of an industry, such as by targeting the hub or keystone firms (e.g., Iansiti & Levien, 2004; Wilkinson et al., 2000). We can also test the viability of different firm-based adaptive strategies (e.g., North & Macal, 2007). For this reason, ABMs have been referred to as "flight simulators" for managers and policy makers (Lempert, 2002, p. 7195).

5. Summary and conclusions

We have described how firm internationalization can be re-seen from a network-centric, complex adaptive systems perspective and we have proposed ways in which we can develop models of this of use to researchers, managers and policymakers to better understand and cope with such systems. We conceptualize business networks as complex adaptive systems exhibiting seven key characteristics: *networks of interacting actors, self-organization and emergence, sensitivity to minor perturbations, parallelisms, conditional action, top-down effects,* and *adaptation and evolution.* Aggregate patterns of firm internationalization in the network emerge in a bottom-up, self-organizing from the pattern of micro interactions that occur over time across the network. These aggregate patterns cannot be traced to the autonomous actions of an individual firm; rather, they emerge from two emergence properties of

such systems underlying its behavior. The first is its collective intelligence, which enables and constrains what a network can see – its ability of firms to identify international market opportunities. The second its collective capability, which enables and constrains what the network can do – the international market opportunities it can exploit. These two emergent properties arise from the co-creation and co-development of ideas, knowledge, skills and resources over time in the network.

While the internationalization behavior of the network as a whole is predictable to some extent, that of the individual firm is not. We cannot predict which firms will identify and exploit which opportunities or the path of internationalization of an individual firm because it depends on such a complex and unpredictable series of direct and indirect interactions with other firms and organizations over time. Small, seemingly insignificant events and differences can have disproportionate effects on an individual firm's path of internationalization, such as a chance encounter between two strangers, an unsolicited order, a search for a new supplier or manager, a customer's sudden success in international markets or an international market blunder.

This helps explain hitherto elusive aspects of individual firm internationalization behavior. A firm's actions may appear irrational or insignificant at times because they are not driven by the logic or the needs of one firm but by the interactions and needs of their collective "hive" or network. The most efficient international market-entry modes may not be effective for a focal firm because markets keep changing in unanticipated ways and depend on what others are doing, are expected to do, and will do. What may have seemed efficient and reasonable at one point in the past may not remain so at another point in time. Firms' individual histories matter. At any given time, we encounter echoes of past experiences and outcomes that have wave effects, creating path-dependent interconnected patterns of firm internationalization (Chandra et al., 2012; Sydow et al., 2009). A firm's earlier moves lead to commitments to international markets that create market knowledge leading to further commitments and the discovery of new international market opportunities that impact other members of the network, who in turn influence others. Together these firms co-create and adapt to the network in which they operate. From this can emerge false starts and retreats based on bad experiences and poor results or vice versa. Some firms become market leaders who open the doors for others or they block the entry of others through first-mover advantages and trade barriers. Market-following and market-leading strategies can emerge and produce positive results but for a limited period of time.

This means that an individual firm's internationalization and subsequent performance cannot be explained simply by firm-centric theories of internationalization, which are the dominant mode of explanation and theorizing about internationalization. But it should be noted that our complex systems perspective does not undermine the value of existing firm-centric theories and research. Far from it. Firm-centric theories are relevant because they help identify some of the core causal mechanisms, processes and events that underlie firm behavior and responses in the system and empirical data that can be used to test and validate NCCSI models. They are the foundation for developing complex adaptive system models of firm internationalization in business networks.

Our research opens up exciting research opportunities that build on existing internationalization theories and research. We draw attention to three main ways of developing NCSSI models of firm internationalization. The first is based on using social physics and applying the influence model developed by Pentland (2014) to firm internationalization. The second is to build stylized agent-based computer simulation models of key aspects of firm internationalization in networks, such as the NK models developed by Kauffman (1993, 1995). The third is to develop more realistic agent-based models of actual business networks that can be used to guide real world research and act as "flight simulators" to help managers and policymakers to identify and test strategies to cope with the behavior of these complex adaptive systems.

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