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Meeting, mating, and intermediating: How incubators can overcome weak network problems in entrepreneurial ecosystems

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ABSTRACT

To promote economic growth and overcome societal challenges, policy-makers often try to shape an entrepreneurial ecosystem (EE) that will facilitate technological entrepreneurship. An EE consists of a knowledge subsystem and a business subsystem, which are often unconnected. A financial support network (FSN) consisting of startups and private venture capitalists can bridge two subsystems and thus enable critical technology transfer in EEs. These FSNs remain underdeveloped in many European regions, however; the literature on innovation systems refers to this lack of connectivity as a "weak network problem." While incubators can function as intermediaries to overcome such weak network problems, how they do so is poorly understood. This research thus poses the following research question: *What is the effect of incubators' support mechanisms on the occurrence of weak network problems in entrepreneurial ecosystems?* We develop a theoretical model in which network development is a function of two processes: "meeting" and "mating." We argue how different incubator support mechanisms influence these two processes; we then apply these insights in an agent-based model, which allows for estimating how much each support mechanism contributes to overcoming weak network problems in the FSN. Our simulation shows that developing a strong network among startups is key to overcoming weak network problems in FSNs. The most effective way to do so is to introduce incubated startups to non-incubated startups through field-building. Our results provide new theoretical insights into how networks in EEs and innovation systems develop, and what role incubators play as intermediaries in this process. The systemic benefits of incubators also greatly enhance their societal value proposition.

1. Introduction

Technological entrepreneurship is an important means for contributing to economic growth (Ahmad and Ingle, 2013; Wong et al., 2005) and helping to overcome societal challenges (Geels and Schot, 2007). Policy-makers often facilitate this form of entrepreneurship by stimulating the development of an entrepreneurial ecosystem (EE), which consists of all the factors that affect the founding, growth, and survival of startups in a given region (Ács et al., 2014; Autio, 1998; Spigel, 2017; Stam, 2015). A key ingredient for a successful EE is the continued existence of a network between startups and other stakeholders (Feld, 2012; Spigel, 2017; Van Weele et al., 2018a). This network brings actors together and serves as a conduit for funds, information, knowledge, or know-how (Yli-Renko and Autio, 1998). Different subsystems within the EE, each with its own network, may be distinguished (see Clarysse et al., 2014); the knowledge subsystem produces new knowledge and innovations, which are then commercialized as products and services in the business subsystem. Further, a financial support network (FSN) exists that provides funding and, as some authors found, bridges the gap between the knowledge subsystem and the business subsystem (Clarysse et al., 2014; Powell et al., 2012). This makes the FSN critical for successful technology transfer in EEs.

In many European regions, however, the actors in FSNs are often overly disconnected (Van Weele et al., 2018b). The literature on innovation systems refers to this lack of connectivity in a system as a "weak network problem" (Klein Woolthuis et al., 2005; Wieczorek and Hekkert, 2012). Intermediary organizations can help to overcome weak network problems (Howells, 2006). Within the context of the FSN,

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business incubators can take on the role of the intermediary (Van Weele et al., 2018b); such incubators are typically programs and organizations that primarily support new technology-based startups (Bergek and Norrman, 2008; Bruneel et al., 2012; Hackett and Dilts, 2004).[1] In their efforts to help their tenants, incubators connect these startups with other stakeholders (Bruneel et al., 2012; Eveleens et al., 2017). This also strengthens the entrepreneurial ecosystem as a whole (Fernández Fernández et al., 2015), although little research has been conducted on how the latter process actually works (Van Weele et al., 2018b). In particular, two important gaps deserve further academic inquiry.

First, to understand how incubators can help overcome weak network problems, one must understand how FSNs develop in EEs. Although the entrepreneurship literature has considered the role that networks play for individual startups (Davidsson and Honig, 2003; Ter Wal et al., 2016; Witt, 2007), (Alvedalen and Boschma, 2017, p. 894), the EE "literature has not yet produced a comprehensive network approach that could shed light … on the crucial question why some [EEs] are able to make vital connections while other [EEs] fail to do so."

Second, incubators can help alleviate weak network problems in various ways (Van Weele et al., 2018b). For example, they can unburden startups from other tasks, thus giving them time to search for network partners (Amezcua et al., 2013; Bergek and Norrman, 2008; Patton, 2013), or they can introduce potential network partners to each other. But the theoretical mechanisms for how incubators drive network formation are underdeveloped (Eveleens et al., 2017; Theodorakopoulos et al., 2014). Moreover, it is difficult to empirically disentangle separate effects of different support mechanisms, since they are commonly employed simultaneously (Bergek and Norrman, 2008; Bruneel et al., 2012; Schwartz and Hornych, 2008). How the different forms of support help overcome weak network problems thus remains unknown.

These two gaps inhibit us from understanding how incubators can effectively help overcome weak network problems in the FSN. The field thus lacks an understanding of how to build the critical link between knowledge subsystems and business subsystems that will enable technology transfer through entrepreneurship. The present study poses the following research question to address this gap: *What is the effect of incubators' support mechanisms on the occurrence of weak network problems in entrepreneurial ecosystems?* We combine insights from the literature on social networks, entrepreneurial ecosystems, innovation systems, and incubators. We argue that the support mechanisms influence two important factors in the process of network formation: "meeting" and "mating." We apply these insights in an agent-based model (ABM) in which we test the effect of each separate support mechanism on the formation of the FSN. Doing so allows us to estimate how much each support mechanism contributes to overcoming weak network problems.

Theoretically, this paper is the first to systematically consider the effects of separate support mechanisms on the performance of EEs from a network perspective. Our study advances the related literature on entrepreneurial ecosystems and innovation systems by showing how incubators as intermediary organizations can overcome weak network problems in financial support systems. Further, the literature on incubation to date has primarily focused on how these organizations improve the business performance of startups (Eveleens et al., 2017; Theodorakopoulos et al., 2014). Considering the incubator as a part of an EE adds a dimension to assessing the effect of incubators and can significantly add to their societal value proposition. Based on our results, we then make recommendations to policy-makers and incubator managers about strengthening EEs.

2. Theory

2.1. Entrepreneurial ecosystems and innovation systems

The idea of EEs is relatively new but is closely related to the more developed literature on innovation systems (Ács et al., 2014; Alvedalen and Boschma, 2017; Stam, 2015). The main difference between the two is that EEs explain how system conditions influence actors' entrepreneurial agency to create value (Ács et al., 2014; Stam, 2015), while innovation systems look at the development of innovations. The close relationship between the two allows for borrowing concepts and ideas from innovation systems and applying them to entrepreneurial ecosystems.

Following innovation systems thinking (Carlsson and Stankiewicz, 1991; Van Rijnsoever et al., 2015; Wieczorek and Hekkert, 2012), we conceptualize the entrepreneurial ecosystem as a set of *actors* that interact and exchange resources in a *network* under an institutional regime and an infrastructure. Analogous to regional innovation systems, an entrepreneurial ecosystem works on a regional level (Acs et al., 2017a; Feld, 2012; Spigel, 2017; Stam, 2015) that is embedded in a national context (Ács et al., 2014).

By actors, we mean individuals or organizations that play a role in shaping startups' chances of success within EEs. The prime actors in most EEs are entrepreneurs within their startup firms (Stam, 2015). These startup firms need to seek out other actors who can supply them with resources and with whom they can interact (Feld, 2012; Neck et al., 2004; Neumeyer et al., 2018; Stam, 2015; Van Weele et al., 2018b). They require a network to do that, which is the focus of the present study. Networks in an EE can be associated with the knowledge subsystem, the business subsystem, or financial support[2] (Clarysse et al., 2014). Universities, research organizations, R&D departments, and other educational institutes in the knowledge subsystem can supply talent, knowledge, or specialized equipment to develop new innovations (Cooke, 2002; Saxenian, 1996). The business subsystem contains the value network required to commercialize the product and includes various types of enterprises as well as users and clients (Cooke, 2002; Lin et al., 2010). Finally, actors in the FSN include private venture capitalists (VCs), banks, public funders, and business angels as sources of financial capital. Innovative startups must be active in all three networks, as they need to transform science-based prototypes into commercially viable products or services. Analogous to this process, startups must transform themselves from science-based organizations to scalable commercial enterprises (Clarysse and Bruneel, 2007; Freeman and Engel, 2007; Nelson, 2014). This requires a substantial amount of time and funds (Westhead and Storey, 1997), which the FSN can supply. VCs also provide startups with valuable knowledge and advice on how to make such a transformation (Malhotra, 2013; Ter Wal et al., 2016). Finally, VCs can be connected to actors in other subsystems, which allows them to serve as network brokers for the startups they have invested in Çetindamar and Laage-Hellman (2003), Clarysse et al. (2014) and Huggins (2008).

But not all actors in the FSN are equally valuable in this process. Clarysse et al. (2014) have found that public funders do not play a bridging role between the knowledge and business subsystems; in addition, business angels invest relatively early in the venture, are relatively difficult to identify, and are generally not institutionalized

[1] There is great variety among incubators and their practices (Aernoudt, 2004), and many other initiatives partially draw on the same support mechanisms as incubators; examples include co-working spaces focused on startups (Butcher, 2012; Spinuzzi, 2012), accelerators (NESTA et al., 2011; Pauwels et al., 2015), and venture builders (Diallo, 2015). Yet many of these entities can be thought of as manifestations of the pluriform incubation phenomenon (Bosma and Stam, 2012). For clarity, we refer to all such initiatives as "incubators."

[2] We do not treat financial support as a separate subsystem, as no innovation processes take place in the FNS.

(De Clercq et al., 2006; Steier and Greenwood, 2000), all of which makes them less likely to play a bridging role (Huggins, 2008). In contrast, private VCs seem to be sufficiently connected to bridge the barrier between knowledge and business ecosystems (Çetindamar and Laage-Hellman, 2003; Huggins, 2008). Private VCs typically invest in startup portfolios on behalf of a group of institutional investors. The aim of such investments is to grow the company and increase its value (De Clercq et al., 2006; Investopedia, 2017). To protect their investment and to facilitate the growth process, VCs demand an equity stake in the startup (Bjørgum and Sørheim, 2015; Harkness, 2016). This situation often leads to an in-depth, mutually committed relationship between the VC and the startup (Ter Wal et al., 2016). Because private VCs often have multiple VC funds, each with a lifespan of about ten years, they are a continuous and visible presence in the ecosystem, and they support the startup long enough to build meaningful relationships (De Clercq et al., 2006). This makes a well-developed FSN consisting of startups and private VCs critical to the success of new innovations by startups in entrepreneurial ecosystems.

2.2. Network formation processes in the financial support network

In order for a FSN to emerge that will bridge the knowledge and business ecosystems, startups and private VCs (henceforth simply VCs) must form relationships (i.e., network ties) with each other. Analytically, such a FSN has three types of ties, each of which may be thought of as a network of its own: a network of ties (1) among VCs, (2) among startups, and (3) between startups and VCs. In line with the notion that VCs are institutionalized and well embedded in an EE, we can treat the network among VCs as a stable homogenous connected entity. In contrast, the short lifespan of startups ensures that the latter two types of networks will be dynamic over time. We focus on the formation of these two networks in this paper, as well as how incubators facilitate such formation. Finally, intermediary organizations such as incubators can also have ties to startups or VCs, but are not mandatory for a bridging FSN to form.

Network formation involves two primary processes: meeting and mating (Kalmijn and Flap, 2001; Snijders et al., 2010; Van Duijn et al., 2003; Verbrugge, 1977). *Meeting*, which refers to two potential partners encountering each other at a moment in time, can take place via two distinct processes: meeting at random and meeting through brokerage (Jackson and Rogers, 2007). *Mating* refers to actors forming a tie after meeting. Successful partnering ultimately depends on both (Flap and Völker, 2004; Verbrugge, 1977).

2.2.1. Meeting at random

Meeting at random assumes that bounded rational actors need to search a largely unknown environment to meet potential partners. In the case of a FSN, meeting at random is mostly applicable to startups meeting each other, since startups meet VCs almost exclusively through brokerage (Engel et al., 2017; Fritsch and Schilder, 2008; Shane and Cable, 2002). Meetings at random between startups can take place anywhere: on the street, on the bus, or at the pub. Startups' search efforts are inhibited by the fact that they typically have relatively short lifespans, which limits the time available to develop search routines, meet other actors, or arrange introductions (Kaandorp et al., 2019). Startups are also frequently preoccupied with survival and building their organizations, which further constrains their search efforts. Finally, startups are often difficult for others to find, as they are small and lack the connections or reputation to be known or considered as attractive partners (Goldberg et al., 2003).

2.2.2. Meeting though brokerage

Meeting through brokerage means that actors utilize their own networks by meeting "friends of friends" (Jackson and Rogers, 2007). Startups can meet a potential partner via introductions by other startups, incubators, or other intermediaries (Bøllingtoft and Ulhøi, 2005; Dutt et al., 2016). Some form of network must already be in place for meeting through brokerage to occur, but such networks need not be dense. The average path length in a network decreases logarithmically with the number of ties (Albert and Barabási, 2002; Watts and Strogatz, 1998), which means that the chances of meeting a certain actor increase only marginally as the number of ties grows.

Situations where startups meet each other through brokerage commonly occur in EEs that have strong communities in which startups are willing to introduce their ties to one another (Feld, 2012; Van Weele et al., 2018a). These meetings are often informal and can take place during network events such as drinks gatherings or pitch competitions. For meetings between startups and VCs, the literature suggests that such meetings almost exclusively take place via brokerage (Engel et al., 2017; Fritsch and Schilder, 2008; Shane and Cable, 2002). Such brokerage typically takes place either via other startups that are tied to a VC or via another intermediary actor such as an incubator, and they can be either informal or formal.

2.2.3. Dating, mating, and the honeymoon period

For mating to take place, both potential partners must see the benefits of forming a relationship. The relationships among startups are often low risk and informal, and they primarily evolve around referrals, exchanging advice, and friendship (Van Weele et al., 2018a). Hence, they are easily forged. In contrast, relationships between VCs and startups involve the transaction of valuable resources and are often managed through formal mechanisms, such as contracts. The negotiations for these contracts typically lead to a time lag of two to three months (De Clercq et al., 2006) between meeting and mating; this is called the "dating" period during which both potential partners explore the possible opportunities and downsides of a relationship (see De Clercq et al., 2006; Hallen and Eisenhardt, 2012). During the dating period, startups commonly begin negotiations exclusively with one VC about an investment deal (Casamatta and Haritchabalet, 2013). While such exclusive negotiations may not always lead to the best monetary VC deals (ibid), they do contribute to building trust, which is crucial for such long-term relationships (Malhotra, 2013). But this exclusivity also means that the startup will not meet and "date" other VCs. If both partners see the merits of the other partner at the end of the dating period, then they can form a relationship, which is the moment of mating. A "honeymoon" often follows the moment of mating: a period with high perceived opportunism for the new relationship. Startups rarely actively seek additional funding during this period, and the relationship runs a low risk of decay (Burt, 2002) or dissolution (Fichman and Levinthal, 1991; Knoben et al., 2006). After the honeymoon period ends, startups will need to seek additional funds if they wish to expand further.

2.2.4. Weak network problems in financial support networks

Within a given FSN, the network among startups and the network between startups and VCs reinforce each other. A network among startups, and possibly intermediaries, must be in place for meeting through brokerage between startups and VCs to occur. This network forms the social infrastructure across which meetings with VCs can diffuse. In turn, startups that form ties with (i.e., mate with) VCs receive investments, which will then lead to extra funds that will prolong their lifespans. This situation enables these startups to serve for longer periods of time as network brokers for meetings among startups and between startups and VCs. The following processes thus need to take place in a bridging FSN if the network is to be sustained in the long run:

- meetings among startups, either at random or via brokerage
- matings among startups
- meetings between startups and VCs via brokerage
- matings between startups and VCs.

If one of these processes takes place insufficiently, then the "virtuous cycle" will be broken and a weak network problem in the FSN is likely to occur. A weak network problems means that a network is not well developed to fulfill its purpose (Carlsson and Jacobsson, 1997; Klein Woolthuis et al., 2005). The literature on innovation systems primarily views weak network problems as inhibiting interactive learning and innovation (Carlsson and Jacobsson, 1997; Weber and Rohracher, 2012; Wieczorek and Hekkert, 2012). However, weak network problems will also apply to EEs if they inhibit the transfer of resources for startups that want to develop their business and create innovations. This is especially true for a FSN that provides financial resources and advice that then help startups bridge the gap between knowledge subsystems and business subsystems. The support mechanisms incubators use can be used to overcome weak network problems by strengthening the four processes noted above.

2.3. Incubators and support mechanisms

The primary goal of incubators is to support startups (Amezcua et al., 2013). They do so by offering a shared infrastructure, such as office space, facilities, and possibly specialized equipment; by promoting business learning through professional consulting services, coaching, or mentoring; and by offering network services (Bruneel et al., 2012; Hansen et al., 2000; Lalkaka, 2002). Through network services, incubators also help startups to connect to resource providers such as VCs (Bruneel et al., 2012; Eveleens et al., 2017).

The EE literature recognizes that incubators, through their network services, can also function as system builders (Stam, 2015; Van Weele et al., 2018a,b). By orchestrating the building of a network that would have remained underdeveloped or even stillborn without their intervention (Dagnino et al., 2016; Paquin and Howard-Grenville, 2013), they partly fulfill the role that intermediaries play in innovation systems (Howells, 2006). Incubators have several support mechanisms at their disposal to do so. Bruneel et al. have (2012) classified these mechanisms as generations of incubators that focus on business learning, creating economies of scale, and networking. Others have looked at the practices observed in incubators and have categorized the support mechanisms as *direct support* (Amezcua et al., 2013), *networking* (Bergek and Norrman, 2008; Patton, 2013), *community-building* (Bøllingtoft and Ulhøi, 2005; Hughes et al., 2007), and, sometimes, *field-building* (Amezcua et al., 2013).

In this paper, we classify the support mechanisms based on the formation processes of a FSN, and we match these mechanisms with the practices observed in the literature. Table 1 summarizes how each support mechanism influences the network formation process, and which part of the FSN they target. We discuss each support mechanism below.

2.3.1. Community-building

The first mechanism is *community-building*, which occurs when the incubator deliberately connects incubated startups to each other, thus serving as an extra network broker. In doing so, the mechanism primarily increases the meeting chances for incubated startups. Activities associated with community-building include co-working, hosting social events within the incubator, having a critical selection of new members, and actively introducing tenants to each other by the incubator (Van Weele et al., 2018a). These activities lead to the building of a community within the incubator (Bøllingtoft and Ulhøi, 2005; Hansen et al., 2000; Tötterman and Sten, 2005), which then leads to learning from peers and gaining a sense of belonging as a startup (Van Weele et al., 2018a).

Table 1
Support mechanisms that incubators can apply to tenant startups, and that help to overcome weak network problems in the FSN, the processes the mechanisms influence, and the part of the FSN they target.

Support mechanism	Process	Part of the FSN
Community-building	Meeting	Startups (incubated)
Field-building	Meeting	Startups (non-incubated)
Peer-coupling	Mating	Startups
Infrastructure support	Meeting	Startups, Startups-VCs
VC-networking	Meeting	Startups-VCs
Deal-making	Meeting	Startups-VCs
Business learning	Mating	Startups-VCs

2.3.2. Field-building

Field-building, which is closely related to community-building, occurs when the incubator deliberately introduces incubated startups to their peers outside the incubator. Such introductions increase the meeting chances between incubated startups and non-incubated startups and potentially bolster the network among startups. In their description of field-building. Amezcua et al. (2013, p. 1636) state that the way "sponsors increase new organizations' alignment and engagement with critical stakeholders is by connecting those organizations to other similar and new organizations within a field, to improve the opportunity for collaboration, knowledge sharing, and ultimately legitimacy for these emerging organizational communities." Activities associated with field-building include active introductions, network meetings, or social events with startups outside the ecosystem.

2.3.3. Peer-coupling

One theoretically possible support mechanism that has received little explicit empirical attention is what we call *peer-coupling*, which refers to all activities that increase the mating chances between startups. These activities may include workshops, coaching, or other actions that will help the startup acquire the capabilities to engage and manage relationships (Niesten and Jolink, 2015; Schilke and Goerzen, 2010); other activities may help to build a culture in which startups trust each other (Bergh et al., 2009; Van Weele et al., 2018a). Peer-coupling is not mentioned in the literature as an explicit support mechanism because it involves a great deal of learning by doing, such as interacting with other startups. It is also in practice conflated with other support mechanisms, such as community-building, field-building, or business learning. But because peer-coupling is theoretically a separate mechanism, we treat it as such in this work.

2.3.4. Infrastructure support

Infrastructure support, also known as the creation of economies of scale, entails the sharing of tangible resources, such as office space, facilities, and parking (Barrow, 2001; Bruneel et al., 2012; Patton, 2013), as well as supplying limited funding. Sharing resources reduces costs and allows incubated startups to focus their time and effort on developing or searching for resources crucial to the business (Barrow, 2001; Bruneel et al., 2012). Similarly, supplying limited funding can also buy the startup time. Startups can use the time they have gained and by seeking network partners, which effectively increases the meeting chances among startups, or between startups and VCs.

2.3.5. VC-networking

VC-networking means that incubators serve as network brokers between startups and VCs, which will increase the meeting chances between the two groups. VC-networking is thus a specific variation of general networking practices among incubators, which refers to those activities that help startups connect to actors who can provide them with valuable resources (Davidsson and Honig, 2003; Eveleens et al., 2017). VC-networking can be done through encouragement, through organizing events at which both parties are present, through introductions, or through referrals made by coaches, mentors, or the incubator management (Eveleens et al., 2017; Patton et al., 2009; Rice, 2002).

2.3.6. Deal-making

The *deal-making* support mechanism has received relatively little attention, both in the literature and in practice. The term refers to incubator activities that are meant to shorten the dating period, regardless of its outcome. This effectively increases the number of meetings with VCs during the lifespan of a startup and thus the meeting chances between startups and VCs. The rationale is that startups can miss out on deals with other VCs during the exclusive dating period, so it is in the startup's best interest to gain certainty about the outcome of the negotiation process as soon as possible. Incubators can contribute to shortening the dating period by providing startups with knowledge about financial and legal issues, as well as by teaching skills that will allow startups to build trust (Malhotra, 2013). With more complex deals, incubators can further shorten the dating period by facilitating the negotiation process or by contributing in an advisory capacity.

2.3.7. Business learning

Business learning, also known as direct support, entails the acquiring, distributing, interpreting, and structuring of business-related knowledge by the startup (Dodgson, 1993; Huber, 1991). Having sufficient business knowledge and experience is generally thought to be critical to making technology-based startups successful (Bruneel et al., 2012; Schwartz and Hornych, 2010). Incubators promote learning through professional consulting services, coaching, and mentoring, all of which lead to a better use of resources, the gaining of capabilities that will facilitate network building, the existence of improved business models, and a more developed organization (Bergek and Norrman, 2008; Rotger et al., 2012; Van Weele et al., 2017). From a theoretical perspective, business learning makes startups more attractive partners for actors who can provide them with resources, which then invokes trust. The business-learning mechanism thus increases the chances of *mating between* startups and VCs.

3. Methods

We simulated the effects of the support mechanisms noted above on overcoming weak network failures in a FSN using an agent-based model (ABM) (see Bonabeau, 2002; Snijders et al., 2010); such models are becoming increasingly important in the study of innovation (Faber et al., 2010; Huétink et al., 2010; Lopolito et al., 2013; van der Vooren et al., 2012). Using an ABM lets artificial agents at the micro level follow simple behavioral rules over time under different conditions. We programmed our model in NetLogo, and we have followed Rand and Rust's (2011) recommended approach when developing the model.

3.1. Agents, properties, and environment

Our scope in this work is to model how the interaction between a heterogeneous set of 100 startups leads to a FSN in an EE environment, and how this process is influenced by several incubator support mechanisms. We base the number 100 on empirical size estimates of EEs that commonly vary between 50 and 178 startups (Casper, 2007; Clarysse et al., 2014; Cooke, 2002). We simulate a period of about 40 years, which corresponds to the time it can take to build a thriving EE such as Silicon Valley. In our model, each time step represents about one week, and 50 time steps correspond to a year; our model thus iterates for 2000 time steps. In most instances our model reaches a dynamic equilibrium state much sooner than that (fewer than 1000 time steps), but to ensure the reliability of our results, we have used 2000 time steps.

Each startup has the properties listed below.

- **Funds** (between zero and infinite time steps): indicates the number of time steps that the startup can survive. Funds are the source of heterogeneity among startups, as they effectively determine cumulative meeting chances over time.
- **Ties to other startups**: records the other startups with which a focal startup has a tie.
- **Tie to VC** (true/false): indicates if the startup is tied to a VC.
- **Dating period** (between 0 and 10 time steps): indicates the remaining time steps of the dating period with a VC; the length of the dating period is based on the typical duration of negotiating an investment deal with a VC, which is between two and three months (De Clercq et al., 2006).
- **Deal period** (between 0 and 100 time steps): indicates the remaining time steps during which the startup is tied to the VC. Having an investment deal with a VC typically allows a startup to survive for about two extra years (De Clercq et al., 2006; Suster, 2018), which serves as the basis for the length of the deal period in this work.
- **Honeymoon period**: (between 0 and 75 time steps): indicates the remaining time steps during which a startup cannot meet a VC. The length of the honeymoon period is based on the notion that after three-quarters of a VC deal period, startups will need to seek new funds again (De Clercq et al., 2006; Quintero, 2017a).
- **Incubated** (true/false): indicates if a startup is part of an incubator.

3.2. Model initialization and startup behaviors

The initialization phase of each model run starts with the creation of 100 startup agents. All startup properties are set to false or zero, except for funds. The model then allocated funds to startups according to a Poisson distribution, with a mean of 200 time steps (four years). The number 200 is based on previous studies' average empirical survival rates for startups, which commonly vary between 56% and 67% after three years (Boyer and Blazy, 2014; Eurostat, 2017; Hyytinen et al., 2015).[3] Finally, the "tie to VC" is set to true for four randomly selected startups. These four startups serve as initial agents to broker ties between the other startups and VCs.

During each time step, startups can display the behaviors listed below.

- **Update:** one time step is subtracted from each startup's funds, dating period, deal period, and honeymoon period if that property has a value larger than 0.
- **Meeting another startup at random**: each startup is randomly assigned to another startup as a potential partner. Each startup then receives a random number between 0 and 1. If this number is smaller than the chances of meeting at random among startups, then the two potential partners meet. Because the literature has no reliable empirical estimates of the chances of meeting at random, we determine suitable values during model calibration.
- **Meeting another startup through brokerage**: for each startup that is tied to more than one other startup, two of the startups it has a tie with are randomly selected; these two startups then meet.
- **Mating with other startups**: for each pair of startups that meet, the model generates a random number between 0 and 1. If this number is smaller than the mating chances among startups, then the startups in that pair form a tie with each other. Because the literature lacks reliable empirical estimates of the chances of mating among startups, we determine appropriate values during model calibration (Section 3.4).
- **Meeting with a VC**: startups with both a dating period = 0 and a honeymoon period = 0, and that are tied to a startup that is tied to the VC, will meet the VC. The dating period is set to 10 time steps.

[3] This empirical survival rate is quite high but includes that startups may have secured funding from other actors who are not connected to the knowledge and business ecosystems, such as friends, family, and angel investors (De Clercq et al., 2006).

- **Mating with a VC**: If the dating period of a startup becomes 0, then the model generates a random number between 0 and 1. If this number is smaller than the mating chances with a VC, then "tie to VC" is set to true for the startup. The funds of the startup are increased by 100 time steps, the honeymoon period is set to 75 time steps, and the deal period is set to 100 time steps. Empirical data suggests that the mating chance with VCs is about 3% (Becker, 2014; Kerr et al., 2014), which we have also used in our models.
- **Admit startups**: if the number of startups with "incubated = true" is smaller than the incubation capacity, then the model randomly selects one startup with "incubated = false." This startup then sets "incubated = true."
- **Exit and entry**: startups that have "funds = 0" die; a new startup is then created with the same properties and the same values as startups upon model initialization.

3.3. Input and output variables

Our input variable is the implementation of the separate support mechanisms. The model implements the support mechanisms in the following ways:

- **None:** no support mechanisms are implemented; this is the reference model.
- **Shared infrastructure**: upon forming a tie with the incubator, startups receive additional funds.
- **Community-building**: two randomly selected incubated startups that are unconnected to each other form a tie.
- **Field-building**: a randomly selected incubated startup meets a randomly selected non-incubated startup.
- **VC-networking**: a randomly selected incubated startup with dating period = 0 and honeymoon period = 0 meets a VC; the dating period is set to 10 time steps.
- **Peer-coupling**: increases the chances of incubated startups mating with other startups after meeting.
- **Deal-making**: decreases the number of time steps of the dating period.
- **Business learning**: increases the chances of incubated startups to mate with VCs after meeting them.

We determine the exact levels of intensity of each mechanism in Section 3.4. After each model run, we record the following output statistics:

- **Startup meetings at random**: the number of times that startups meet at random during a time step.
- **Startup meetings through brokerage**: the number of times that startups meet through brokerage during a time step.
- **Mechanism induced startup meetings**: the number of times that startups meet as a direct result of a support mechanism during a time step.
- **Total startup meetings**: the number of times that startups meet during a time step; this is the sum of the three variables listed above.
- **Total startup matings**: the number of times that startups mate with another startup during a time step.
- **Startups tied to other startups**: the number of startups that have ties to other startups at the end of a model run; this is an indicator of the size of the network among startups.
- **Ties among startups**: the number of ties among startups; this is another indicator of the size of the network among startups and serves as an aggregate of the mating processes among startups over time. It is also an indicator for the density of the network among startups.
- **Startup-VC meetings**: the number of times that startups meet a VC during a time step.
- **Startup-VC matings**: the number of that startups mate with a VC during a time step.
- **Startups tied to VCs**: the number of startups that are tied to VCs; this indicates the size of the network of startups and VCs.

We run the model 1000 times for each separate support mechanism. In our final results, we present the difference between the median of these variables for each support mechanism and the reference model in each starting condition. We have chosen to present the median because some of the output variables have an overrepresentation of zeros in their distribution. Despite this overrepresentation, no strong differences have been found between presenting the mean or the median, although presenting the latter is more appropriate in this situation.

3.4. Model calibration and validation

A good ABM corresponds to reality (Rand and Rust, 2011). This requires ensuring that the internal mechanisms and input values the model uses are correct (East et al., 2016). Our internal mechanisms are based on the concepts of meeting and mating processes among startups and between startups and VCs that we derived from the literature. These processes have led to an empirically observed FSN at the macro level (see Clarysse et al., 2014). We have also related incubators' support mechanisms to this process of network formation.

As noted in Section 3.1, we have based various factors on empirically observed data to use as input values, including (1) the number of startups in an EE, (2) the survival rate of startups, (3) the length of the dating and honeymoon periods, and (4) the mating chances between startups and VCs. Because no empirical data is available for the meeting and mating chances among startups, we have determined their appropriate value by conducting parameter sweeps and assessing how sensitive our results were to changes in these values. We did not need to determine the chances of meeting through brokerage, as such meetings are a function of the other two processes, as noted in Section 2.2.2. The results of these simulations (see Appendix A.1) show that above certain values of meeting at random and mating chances among startups, the network among startups reaches a maximum size; this maximum in turn caps the development of the FSN. Empirical studies have demonstrated major differences between EEs (Acs et al., 2017b; Autio et al., 2014; Global Entrepreneurship Monitor, 2017; Startup Genome Project, 2017) and have shown that those conditions that influence networks among startups often lie at the root of these differences (Feld, 2012; Van Weele et al., 2018a). To take these effects into account, we have identified four starting conditions by varying the mating chances among startups (see Appendix A.1). The starting conditions represent different developmental states of the network among startups:

- **Undeveloped:** In the undeveloped condition the mating chances among startups are set to 10%. Almost half of the startups is connected to at least one other startup (median: 44), but the low number of ties among startups (median: 109, about 1.1% of all possible ties) indicates that the network is very sparse. This gives little opportunity for meeting startups of VCs trough brokerage. Hence, there are hardly any startups that are tied to VCs (median: 0). Thus, large weak network failures exist in the FSN if no support mechanisms are in place.
- **Emerging:** In the emerging condition, the mating chances among startups are set to 20%. About two-thirds of the startups is tied to at least one other startup (median: 68), but the number of ties among these startups is still relatively low (median: 464, about 4.7%). Also, there is little opportunity for meeting trough brokerage, and there are hardly any startups tied to VCs (median: 0). Even though the network among startups is a bit more developed in the emerging condition than in the undeveloped condition, large weak network failures remain in the FSN when it comes to the number of startups tied to VCs.

- **Maturing:** In the maturing condition, the mating chances among startups are set to 40%. A median of 85 startups is tied to at least one other startup, and the number of ties among these startups is substantial (median: 1375, about 13.9%). This provides opportunities for meeting trough brokerage, which leads to a median of 14.5 startups being tied to VCs. For reference, the largest median number of startups tied to VCs that we found in our calibrations is 21. This only happened if the meeting chances among startups were larger than 14%, and the mating chances among startups were larger than 70%. Hence, in the maturing condition the FSN is already relatively well-developed without any support mechanisms.
- **Developed:** In the developed condition, the mating chances among startups are set to 80%. A median of 93 startups is tied to at least one other startup, and the number of ties among startups is substantial (median: 2708, about 27.3%). The doubling of mating chances and the consequential number of ties among startups translates only to a modest increase in startups tied to VCs (median: 17). The developed condition thus has a well-developed FSN but is not much better than the maturing condition.

For each starting condition, we test the effect of each support mechanism.

Second, to model the effect of incubation on the FSN, we need to determine the number of startups that can receive support from the incubator: this is called the incubator capacity. Our analysis (Appendix A.2) shows that an effective percentage of incubated startups in the EE is 20%, and empirical data confirms this percentage to be realistic (Van Rijnsoever et al., 2017). Larger percentages have little additional effects on the networks between startups and VCs.

As final input validation, we tested the effects of several levels of intensity of each support mechanism on the FSN. These analyses (Appendix A.3) showed that applying community-building, field-building, and VC-networking more than once each time step had little effect on the FSN; the same applies to adding more than 50 time steps via shared infrastructure or more than 20% to the mating chances among startups via peer-coupling. We thus apply each support mechanism only once during each time step and fix the values of shared infrastructure to 50 time steps, and 20% for peer-coupling. Shortening the number of time steps during the dating period through deal-making, and increasing the mating chances between startups and VCs through business learning, has an approximate positive linear relationship with the number of ties between startups and VCs in the range of values that we explored. Taking these factors into account, we report the effect of reducing the length of the dating period by four time steps (i.e., one month) for deal-making, which is a substantial but not unrealistic decrease. We also report the effect of doubling the mating chances between startups and VCs through business learning, and we discuss the implications of the linear relationship of this mechanism with having ties to VCs.

Finally, we have validated our output by comparing the results from our model with a combination of different empirical data sources (CBinsights, 2018; Quintero, 2017b; Van Rijnsoever et al., 2017). Appendix A.4 shows that the range of output values our model produces corresponds to empirical estimates, which likely makes our model valid. We also conclude that the emerging and maturing starting conditions are in practice the most realistic starting conditions to observe[4].

4. Results

Table 2 shows the median of how much each support mechanism influences the different steps in the network formation process. When no support mechanisms are in place (the “none” column), the meeting at random process mainly functions as the ignitor of an initial network among startups. The brokerage process, however, is responsible in all starting conditions for creating the bulk of the ties in this network. In turn, the network among startups serves as the infrastructure through which the ties to VCs diffuse. In the emerging, maturing, and developed starting conditions, this situation translates to a larger number of startups meeting and mating with VCs, while the undeveloped condition stays in a permanent state of weak network failure. As such, a lack of meeting and mating among startups is indeed a cause of weak network problems in the FSN.

We now consider the effects of the support mechanisms. Community-building and field-building both increase the number of meetings among startups; some of these meetings are translated into mating. This increases the size of the network among startups, which in turn provides a basis for meetings through brokerage with other startups and with VCs. In all starting conditions, field-building is a more effective mechanism than community-building in developing both types of ties. The difference between community-building and field-building can be explained by the fact that the former targets incubated startups, which are already likely connected to each other, while field-building brings new non-incubated startups to the network. The effectiveness of field-building is largest in the undeveloped (+11) and emerging (+14) starting conditions. In those starting conditions, field-building is the most effective of all support mechanisms in overcoming weak network failure. In the starting conditions with maturing or developed networks, the effect of field-building dwindles. Community-building only has an effect in the emerging starting condition.

We see a similar, but smaller, effect for peer-coupling. The extra ties created by peer-coupling facilitate additional meetings through brokerage, which translates into a marginal increase in ties in the FSN in the emerging starting condition; the other starting conditions show no effects of peer-coupling.

In none of the starting conditions does having a shared infrastructure have a strong impact on any indicator of the network formation process. Letting startups remain available as network partners for half a year beyond their initial average lifespan is thus not beneficial from a systemic perspective.

VC-networking increases the number of meetings with VCs directly, which leads to a moderate increase in the number of ties with VCs in the undeveloped starting condition (+4) as well as a substantial increase in the emerging starting condition (+9). In the other two conditions, startups already meet VCs regularly, and most are engaged in a dating or honeymoon period. VC-networking adds little in these conditions. VC-networking also bypasses the network among startups, which means that such networks do not develop and that the extra ties with VCs hardly diffuse.

Deal-making does not have a strong influence on the ties among startups or the ties between startups and VCs in any of the starting conditions. Shortening the dating period for incubated startups is thus not an effective way to overcome weak network problems in a FSN.

Increasing the mating chances between startups and VCs through business learning has a small effect on the number of ties between startups and VCs in all starting conditions but does not strengthen the network among startups. However, this business learning becomes more effective as the network among startups becomes stronger in the different starting conditions. Still, doubling the mating chances with VCs only leads to three extra ties with VCs in the developed starting condition. A separate analysis (not shown in the table) shows that a tripling of the mating chances only leads to two extra ties with VCs.

5. Conclusions and implications

We posed the following research question in this paper: *What is the effect of incubators’ support mechanisms on the occurrence of weak network problems in entrepreneurial ecosystems?* We have discussed and modeled how networks among startups and between startups and VCs form, and

[4] The complete NetLogo and analysis codes (in R) are available upon request from the lead author.

Table 2
The effect of different incubator support mechanisms on different processes in the formation of the FSN. The columns with the support mechanisms indicate differences compared to the "none" column.

	Undeveloped	None	Community-building	Deal- making	Peer- coupling	Business learning	Field-building	VC-networking	Shared infrastructure
Startup network indicators	Startup meetings at random	4	0	0	0	0	0	0	0
	Startup meetings through brokerage	14	+6	0	+6	0	+21	+1	-1
	Mechanism induced startup meetings	*NA*	+1	0	0	0	+17	-1	0
	Total startup meetings	18	+7	0	+6	0	+38	0	-1
	Total startup matings	2	+3	0	+3	0	+6	0	0
	Startups tied to other startups	44	+9	0	+8	+1	+40	+2	+1
	Ties among startups	104	+150	-2	+92	+1	+510	+8	-4
Startup-VC network indicators	Startup-VC meetings	0	0	0	0	0	+3	+1	0
	Startup-VC matings	0	0	0	0	0	0	0	0
	Startups tied to VCs	0	0	0	0	0	+11	+4	0
	Emerging	**None**	**Community-building**	**Deal- making**	**Peer-coupling**	**Business learning**	**Field-building**	**VC-networking**	**Shared infrastructure**
Startup network indicators	Startup meetings at random	4	0	0	0	0	0	0	0
	Startup meetings through brokerage	30	+3	0	+2	+1	+12	+1	+1
	Mechanism induced startup meetings	*NA*	+3	0	0	0	+18	0	0
	Total startup meetings	34	+6	0	+2	+1	+30	+1	+1
	Total startup matings	9	+5	0	+4	0	+9	0	0
	Startups tied to other startups	67	+6	+1	+5	+1	+26	+3	+3
	Ties among startups	458	+224	+12	+160	+31	+884	+52	+18
Startup-VC network indicators	Startup-VC meetings	0	+2	0	0	0	+5	+3	0
	Startup-VC matings	0	0	0	0	0	0	0	0
	Startups tied to VCs	0	+5	0	+2	0	+14	+9	0
	Maturing	**None**	**Community-building**	**Deal- making**	**Peer-coupling**	**Business learning**	**Field-building**	**VC-networking**	**Shared infrastructure**
Startup network indicators	Startup meetings at random	4	0	0	0	0	0	0	0
	Startup meetings through brokerage	42	+1	0	+1	0	+6	0	+1
	Mechanism induced startup meetings	*NA*	+8	0	-1	0	+18	+1	0
	Total startup meetings	46	+9	0	0	0	+24	+1	+1
	Total startup matings	24	+9	0	+3	+1	+12	0	+1
	Startups tied to other startups	85	+1	0	+1	0	+11	0	+1
	Ties among startups	1398	+198	+14	+124	+88	+1086	+20	+103
Startup-VC network indicators	Startup-VC meetings	5	0	+1	0	0	+2	+1	0
	Startup-VC matings	0	0	0	0	0	0	0	0
	Startups tied to VCs	14	+1	+1	0	+3	+5	+2	+1
	Developed	**None**	**Community-building**	**Deal- making**	**Peer-coupling**	**Business learning**	**Field-building**	**VC-networking**	**Shared infrastructure**
Startup network indicators	Startup meetings at random	4	0	0	0	0	0	0	0
	Startup meetings through brokerage	50	0	0	0	0	+4	0	0
	Mechanism induced startup meetings	*NA*	+16	0	0	0	+17	0	0
	Total startup meetings	54	+16	0	0	0	+21	0	0
	Total startup matings	47	+16	0	+2	0	+19	0	0
	Startups tied to other startups	93	0	0	0	0	+5	0	+1
	Ties among startups	2782	+139	+29	+30	+114	+1213	+10	+148
Startup-VC network indicators	Startup-VC meetings	6	0	0	0	0	+1	0	0
	Startup-VC matings	0	0	0	0	0	0	0	0
	Startups tied to VCs	18	0	+1	0	+3	+2	0	0

how various incubator support mechanisms influence these processes.

Our model has shown that a sufficiently strong network among startups is key to overcoming weak network failure in a FSN. By only supporting 20% of all startups, incubators can effectively further this goal, especially when the network among startups is emerging. Field-building is the most effective support mechanism. Deliberately introducing startups to their peers outside the incubator greatly expands the network among startups and benefits all startups in the ecosystem by facilitating the diffusion of extra ties with VCs. When the network among startups is sufficiently developed, the most effective way to increase the number of ties between startups and VCs is by increasing the mating chances between these two actor types through business learning. Shared infrastructure, peer-coupling, and deal-making turned out to be the least effective support mechanisms.

5.1. Theoretical implications

Theoretically, this paper adds to the related fields on EEs and innovation systems. First, by introducing the concepts of meeting and mating to systems thinking, we have identified theoretical causes for the occurrence of weak network problems (Klein Woolthuis et al., 2005; Wieczorek and Hekkert, 2012); if insufficient meetings (either at random or through brokerage) and mating take place among startups, or between startups and VCs, a weak network problem in the FSN occurs (see Section 2.2.4). Especially, the meeting process among startups proved to be critical in EEs with an undeveloped or emerging startup network. Our analysis contributes to a much-needed comprehensive network approach to explain why certain entrepreneurial ecosystems develop crucial connections, while others do not (Alvedalen and Boschma, 2017). Moreover, the process of meeting and mating that we have described is generic and can theoretically also be applied to other types of networks in EEs or innovation systems in general, such as networks between researchers and entrepreneurs, between startups and potential customers, or between established corporate firms and researchers. Doing so, however, requires adapting the conceptualization of the meeting and mating processes to the empirical cases at hand and finding the most plausible values for each parameter, which is a challenge for future research.

Second, we have also found that brokerage among startups is a key process that catalyzes (see Hallen and Eisenhardt, 2012) the development of the FSN. The process drives the formation of the network among startups, which serves as a social infrastructure for the ties to VCs to diffuse across. This finding supports claims about the importance of building a culture of trust, cooperation (Feld, 2012; van Stijn et al., 2018; Van Weele et al., 2018a), and “intelligent altruism” among startups (Engel et al., 2017) in an EE. When such a facilitating culture arises, startups are also more likely to broker relationships between other startups and different actors. Startups that benefitted from this brokering are further more likely to reproduce the facilitating cultural norms, values and actions (van Stijn et al., 2018). However, starting such a facilitating culture is difficult. Future researchers should study how and when actors such as incubators and startups, as institutional entrepreneurs (Battilana et al., 2009; DiMaggio, 1988), contribute to building of the cultural conditions for a strong network among startups, and if doing so indeed leads to long-term FSNs. Another question to ask is if the role of the network intermediary to overcome weak network problems must be fulfilled by an incubator, or if other actors, such as chambers of commerce, regional development agencies or technology transfer offices, can also take on this role? This is an avenue for future research.

Third, we have shown how to overcome weak network problems in FSNs in order to facilitate technology transfer through startups in EEs. In EEs with an undeveloped or emerging network among startups, field-building is the most effective support mechanism, while in EEs with a developed network among startups, business learning is most effective, but this effect is limited. Thereby, we contributed to solving Clarysse et al.’s (2014) empirically identified problem of the underdevelopment of ties in these networks between private VCs and startups.

We have also contributed to the literature on incubation. First, this paper places incubators in a systemic context. Our model shows that incubators can have a clear influence on network development in EEs, from which all actors can benefit, but that the support mechanisms’ effectiveness depends on the starting conditions. The systemic benefits of incubators, especially as network intermediaries, have received little empirical attention to date, which is a task for future research. An important question to look into is what the consequences would be to a FSN if incubators stopped supporting startups (Van Weele et al., 2018b).

Second, by linking the different support mechanisms to the network formation processes in a FSN, we have strengthened the theoretical basis of research on networked incubation and startup support (Bruneel et al., 2012; Eveleens et al., 2017; Theodorakopoulos et al., 2014). The insights in how different support mechanisms facilitate tie formation complements the theoretical approaches that are mostly used in networked incubation, such as Organization Learning, the Resource Based View, and Social Capital Theory (Eveleens et al., 2017). In contrast, our approach focuses largely on the process of how ties are formed, rather than on what the ties entail.

5.2. Practical implications

The systemic benefits of incubators make their value larger than previously assumed and provide a rationale to policy-makers to support incubators that employ these support measures, even if these incubators are private. Ultimately, incubators must foster a culture in which the sharing of knowledge and network contacts is the norm (Feld, 2012; van Stijn et al., 2018; Van Weele et al., 2018a). Policy-makers should consider that an incubation capacity of about 20% of all startups in a region is sufficient for overcoming weak network problems. Moreover, other actors in an EE can also employ certain support mechanisms, which makes it necessary to coordinate support actions.

Incubators themselves also have a good reason to engage in system building. The fostering of a network among startups is beneficial to incubated and non-incubated startup alike, which shows that the concept of the networked incubator (Bruneel et al., 2012; Eveleens et al., 2017; Hansen et al., 2000) does indeed add to the incubators’ value proposition. Field-building is the most effective support mechanism for building a network among startups. It is also a relatively cheap support mechanism, as it only requires facilitating meetings between incubated and non-incubated startups. Holding regular events (such as drinks or gatherings) for outsiders can be an effective way to attract startups from outside incubators. The Silicon Beach events in Australia (siliconbeachaustralia.org), which seem to have been designed for this purpose (Van Weele et al., 2018a), are a good example. These events (for example drinks or pitching challenges) helped sparking the ecosystem. They were well-known in the community, accessible and open to everyone. Moreover, they had a good supporting online forum. This brought people together, strengthened the network among startups, and facilitated meeting though brokering.

Other ways to attract startups from outside the incubator to the network among startups include using social media or actively scouting startups at universities, through chambers of commerce, or online. From a systemic perspective, VC-networking can be beneficial, but such networking does not promote the development of networks among startups. Moreover, VC-networking also requires that incubators actively build ties with VCs, which can be a time-consuming process. While business learning is the most effective support mechanism in those EEs with maturing or developed starting conditions, business learning within undeveloped and emerging starting conditions has no systemic benefits in the form of ties to VCs or among startups. Incubators should only heavily invest in this relatively expensive support mechanism if startups have sufficient opportunities to meet VCs. Commonly described support mechanisms such as community-building and having a shared infrastructure hardly contribute to overcoming weak network problems. However, these mechanisms can still be useful for the primary purpose of the incubator, which is to help tenant startups. Community-building contributes to a sense of belonging among startups (Van Weele et al., 2018a), while having a shared infrastructure often attracts new startups to an incubator (McAdam and McAdam, 2008; Soetanto and Jack, 2016; Van Weele et al., 2017). Finally, it is not surprising that deal-making and peer-coupling have received scant attention in the literature. According to our model, neither mechanism is very fruitful for startups or EEs.

The main practical implication for entrepreneurs, incubated or not, is that it is beneficial to remain connected in a network with other startups, and even contribute to building such a network. This enhances their chances of meeting VCs via brokerage. This can be done by actively participating in startup communities and by participating in startup events, such as the aforementioned Silicon Beach events. Even if these activities do not directly lead to meetings with VCs, they can do so on the longer term via brokerage processes.

5.3. Limitations

This paper has three main limitations. First, although some parameters are based on empirical data, ABMs are impossible to completely validate (Rand and Rust, 2011). Our elaborate theoretical and empirical validation efforts have led us to conclude that our model is plausible. We use arguments and data based on Western Europe and North America; future researchers should further verify our results and explore the extent to which the findings can be extrapolated to EEs elsewhere in the world.

Second, because we aimed to keep the model parsimonious (Bonabeau, 2002; Lave and March, 1993), we omitted factors that were not required to answer our research question but that could have provided further nuances to our results; examples are the inclusion of a dating or honeymoon period for ties among startups. We also assumed in our model that the meeting and mating chances would remain stable over time. Future researchers should explore the effects of such changes on the development of the FSN. In addition, we only allowed for connecting to VCs via brokerage. During an initial analysis, we also experimented with simulations that did allow for meeting at random, but doing so led to a negligible number of additional ties to VCs. For the sake of parsimony, we decided not to include this mechanism. A last parameter that deserves further exploration is the starting conditions that we identified. In this paper, we only explored a variation in meeting and mating chances among startups. However, the starting conditions in an EE can also be influenced from the side of VCs. For example, we now modeled only one VC with sufficient funds to invest in any startup. In reality, private VCs prefer to invest in local startups, but are not always sufficiently present in an EE (Clarysse et al., 2014; Van Weele et al., 2018b), which leads to different starting conditions in different regions (Chen et al., 2010). Moreover, we modeled all VCs as one agent, while in reality multiple VCs are often present in an EE operating in a syndication network (Alexy et al., 2012). Their position in this network creates heterogeneity in the meeting chances between startups and VCs. An avenue for further research is thus to explore the effects of the presence of VCs and the network structure amongst them on the development of the FSN.

Finally, incubators can also employ other methods that will not directly contribute to system building but will add to their value proposition. Examples include encouraging startups to engage with clients or to develop their business in a lean fashion (Blank, 2013; Ries, 2011). One could also argue, however, that these measures would be covered by an increase in mating chances through business learning.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Model calibration

A.1. Calibration of meeting and mating chances among startups

To calibrate the meeting and mating chances among startups, we explored the effects of a range of values on the development of FSNs. For meeting chances, we modeled the effects of values to vary between 0% and 20% of two startups that meet each other at random per time step. We let the mating chances among startups vary between 0% and 100%, with increments of 10%. We fixed meeting through brokerage at one time per time step. We modeled each combination 100 times. Table A.1 presents for each combination the median number of (a) startups tied with other startups, (b) ties among startups, and (c) startups tied to VCs.

The table shows that increasing the meeting and mating chances leads to better-developed FSNs but that, with each increment of either meeting or mating chances, the rate of development declines. This situation occurs because the network among startups reaches its maximum size relatively soon. Given the variety in outcomes and differences in starting conditions in real life (Acs et al., 2017b; Autio et al., 2014; Global Entrepreneurship Monitor, 2017; Startup Genome Project, 2017), we selected four starting conditions for the EEs in our models. To this end, we fixed the meeting chances among startups at 4% and varied the mating chances among startups by starting with 10% and doubling the percentage three times. Our simulation thus covers the full range of values shown in Table A.1.[5] We refer to the starting conditions as *undeveloped* (10% mating chance), *emerging* (20% mating chance), *maturing* (40% mating chance), and *developed* (80%).

[5] We conducted a similar exercise by fixing the mating chances at 20% and doubling the meeting chances three times, starting at 2%, which yielded very similar results. Because the support mechanisms are dependent on the state of the existing network, we present our results for each starting condition.

Table A.1
The median number of (a) startups tied with other startups, (b) ties among startups, and (c) startups tied to VCs for each combination of meeting and mating chances among startups.

Mating chances

(a) Startups with ties to other startups — Meeting chances	0	10	20	30	40	50	60	70	80	90	100
0	0	0	0	0	0	0	0	0	0	0	0
2	0	26	44.5	58.5	69	76.5	81	84	85	87	89
4	0	44	68	79	85	89	91	92	93	94	95
6	0	57	78	87	91	92	94	95	95	96	96
8	0	65	85	90	93	94	95	96	97	97	98
10	0	70.5	88	92	94	96	96	97	97.5	98	98
12	0	76	90	94	95	96	97	98	97	98	98
14	0	80	92	95	96	97	97	97	98	98	99
16	0	84	93	96	96	97	97.5	98	98	99	98
18	0	85.5	94	96	97	97	98	98	98	99	99
20	0	88	95	96	97	98	99	98	98	99	99

(b) Ties among startups — Meeting chances	0	10	20	30	40	50	60	70	80	90	100
0	0	0	0	0	0	0	0	0	0	0	0
2	0	40	144	400	758	1113	1509	1775	2012	2276	2509
4	0	109	464	984	1375	1809	2163	2514	2708	3076	3217
6	0	196	712	1312	1783	2137	2548	2931	3189	3506	3825
8	0	284	932	1548	2023	2519	2833	3266	3522	3818	4112
10	0	346	1097	1735	2219	2716	3114	3487	3772	4122	4350
12	0	430	1223	1914	2420	3014	3337	3711	3948	4395	4570
14	0	534	1341	2062	2617	3105	3465	3907	4244	4475	4736
16	0	585	1439	2202	2720	3283	3629	4078	4343	4766	4881
18	0	652	1553	2284	2926	3394	3853	4126	4562	4834	4968
20	0	734	1652	2401	3015	3599	3934	4290	4662	4827	5162

(c) Startups tied to VCs — Meeting chances	0	10	20	30	40	50	60	70	80	90	100
0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	6.5	11	14	15	15	17	16.5
4	0	0	0	13	14.5	16	18	17	17	18	19
6	0	0	10	15	17	17	18.5	18	19	19	19
8	0	0	13	16	18	18	19	18.5	19	19	20
10	0	0	14.5	17	18	18	19	19	19	20	20
12	0	0	16	17	18	19	20	20	19	20	20
14	0	7	16	18	17.5	20	19	20	20	20	21
16	0	9	16	18	18	19	20	20	20	21	20
18	0	12	16	18	19	20	20	20.5	20	20.5	20
20	0	12	18	18	19.5	20	19.5	21	20	21	20

A.2. Calibration of incubator capacity

Next, we assessed the effect of an incubator's capacity on the development of a FSN. For each starting condition, we explored the effect of a range of values that varied between 0% and 100% of startups that had been incubated (Table A.2), across all support mechanisms. We modeled each value of capacity 100 times for each support mechanism. In all starting conditions, the increase in the number of startups tied to VCs became smaller with each increment of incubation capacity. In all conditions, increasing the incubator capacity above 20% yielded few extra ties to VCs. Because an incubator capacity of 20% of all startups is a number that is attainable in real life (see Van Rijnsoever et al., 2017), we have used this number in our analyses.

Table A.2
Median number of ties to VCs in all starting conditions for different percentages of incubator capacity.

Incubator capacity (%)	Undeveloped	Emerging	Maturing	Developed
0	0	0	14	18
10	0	8	17	19
20	0	9	16	19
30	0	10	17	19
40	0	10	17	20
50	0	11	17	19
60	0	12	17	19
70	0	11	18	19
80	0	12	18	20
90	0	12	18	20
100	0	12	18	19

A.3. Calibrating the intensity of support mechanisms

As the final calibration step, we explored the intensity of the different support mechanisms for each condition. For community-building, field-building, and networking, we let the incubator perform the mechanism between one and four times. In almost all instances, having more than one execution of the support mechanism per time step did not yield an additional increase of more than 1.5 startups tied to VCs; this number also declined with each extra execution of the support mechanism. Given these limited effects, we only present the results of one execution per time step.

For shared infrastructure, we explored giving startups a range of between 25 and 100 extra time steps, which corresponds to funding between one-half and two years. For all values, we only found small effects. We fixed the value for this shared infrastructure to 50 extra time steps, as this was the value where the largest effect was reached. We also explored a range of values for peer-networking and business learning, but we did not find a strong decline in increased startups tied to VCs. For peer networking we thus present the results of adding 20% to the mating chances between startups. For deal-making, we shortened the number of time steps by increments of two until reaching zero. Each increment had a similar effect on the number of startups tied to VCs. In this paper, we present the results of reducing the dating period with four time steps, which is an ambitious but attainable target. For business learning, we present the results of doubling the mating chances with VCs from 3% to 6%; we found that extra increments also had an equal effect on the number of startups tied to VCs.

A.4. Output validation

To validate our model, we benchmarked our output against empirical data. This is not an easy task, as reliable data is difficult to obtain. Many data sources suffer from survival bias, and the starting conditions or the share of incubated startups are not always documented. We found that the best-documented variable to validate our findings against was the percentage of startups that receive VC funding, which serves as a proxy for startups tied to VCs. We combined numbers from different data sources and studies. The first source is a representative data set of 935 nascent innovative startups from North America and Western Europe used by Van Rijnsoever et al. (2017). This data set contains information about (1) which startups have received funding from investors, (2) whether or not they were incubated, and (3) the starting conditions in different EEs. The downside of this data set is that the startups are nascent and are no more than two years old, so the number of VC deals is likely underrepresented. This database shows that 23.6% of all nascent startups in Western Europe and North America received seed funding from private investors; in the United States alone this percentage is slightly higher (26.5%). Of all startups, 24.3% were incubated; the percentage for the United States is 25.3%.

The second data source is Quintero's (2017b) analysis of VC funding. That study is based on data from 35,568 startups (no countries are provided) listed in CrunchBase, which is the leading database on startup investments. The study, which makes no distinction between starting conditions and does not consider incubation, shows that 20.6% of all startups receive seed funding, which is close to Van Rijnsoever et al.'s (2017) findings. The percentage of startups that receive seed investments is thus slightly over 20%. Quintero (2017b) also shows that, of the startups that received seed funding, 50% also obtained VC funding. This number is complemented by CBinsights (2018), which estimates this percentage at 48% based on 1119 US startups.

If we multiply Quintero's (2017b) percentages, the share of startups that receive VC funding is about 10.3%. If we multiply the share of 25.3% seed-funded US startups (Van Rijnsoever et al., 2017) with the conversion rate to VC funding of 48% (CBinsights, 2018), we find that about 13.5% of US startups receive a first round of VC funding and thus have a tie to a VC. Both the 10.3% and 25.3% values lie between the median output values of the emerging and maturing starting conditions of our model with an incubation capacity of either 20% or 30% (Table A.2) and thus are realistic.

We also validated the output for different starting conditions. Van Rijnsoever et al. (2017) asked each startup which region they came from; based on this information, the authors calculated the approximate distance of these startups to EEs in North America and Western Europe that ranked highly on the Startup Genome index (Marmer et al., 2012) and thus are generally considered to have favorable starting conditions. They calculated distances to Amsterdam, Berlin, Boston, London, New York, Paris, Silicon Valley (focused on Palo Alto, California), Toronto, and Vancouver. In the database we identified 97 startups that were located within 10 kilometers of the center of these EEs and that likely had favorable starting conditions. Of these 97 startups, 28.4% had received seed funding, and 29.9% were or had been in an incubator. Assuming a conversion rate of 50% (Quintero, 2017b), 14.2% of these startups would have received VC funding. This figure is close to the median percentage of 17% of the maturing condition with an incubator capacity of 30% from our simulation (Table A.2). The 14.2% estimate may also be conservative, as Quintero (2017b) does not take into account that startups in EEs with favorable starting conditions will likely have a better chance of attaining an investment deal with a VC.

Startups that are not close to any of these EEs (i.e., they are more than 100 kilometers distant) likely operate in less favorable conditions. From the same calculations, these 710 startups have a 11.7% chance of obtaining a VC deal, while 22.5% are or have been incubated. This number is close to the median percentage of 9% startups tied to VCs in the emerging starting condition with an incubator capacity of 20% from our simulation. The 11.7% estimate may even be slightly too high, as the conversion rate to VC funding is likely lower in EEs with less favorable starting conditions. We also do not know exactly which support mechanisms the incubated startups in the EEs with favorable and less favorable conditions were exposed to, or how their benefits spilled over to the rest of the ecosystem. While these limitations make it impossible to exactly validate the number of ties to VCs, the range of output values our model produces corresponds to empirical estimates, which likely makes our model valid. We also conclude that the emerging and maturing starting conditions are in practice the most realistic starting conditions to observe.

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