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An agent-based model approach to innovation niche creation in socio-technical transition pathways

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Abstract

The creation of an innovation niche depends on the interaction of three mechanisms involving: converging expectations, adequate level of individual and network power and efficient knowledge creation and diffusion (Lopolito and Morone, 2010). Such mechanisms define the key characteristics of a network of firms (i.e. the innovation niche), and the interaction among them guides the creation and development of a new technology. In this paper, we propose an agent-based model to investigate the dynamics characterising such interactions and the role that policy intervention can have in governing the niche development process. Specifically, we consider and assess the impact of two policy actions: (1) increasing actors' expectations towards the new technology by means of information spreading, and (2) providing subsidies aimed at stimulating technological switch. Our preliminary results confirm the importance of policy intervention and show the complementarity of the two policy measures considered. Hence, a mixed policy action could serve the purpose of a rapid and stable creation of an innovation-niche.

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1. Introduction

Innovation niches are small networks of dedicated actors interacting for the development and use of promising technologies by means of experimentation. The development of such niches is crucial in order to allow possible socio-technical transition to occur. In fact, while variation in the technological scenario could open opportunities for a transition, if there are not sufficiently developed niches, then there is no clear substitute for the incumbent technology (see, for instance, Geels and Schot 2007).

In this paper we propose a model, grounded on the agent-based approach, to investigate the fundamental social processes involved in the rise of a stable innovation niche and the role that policy intervention can have in governing such processes.

First, we shall briefly review the essential literature about what an innovation niche is, and how such a reticular structure can spontaneously emerge. In doing so we will refer to what have been labelled niche mechanisms (see, among many others, Lopolito *et al*. 2011) – i.e. the key requirements for a set of connections to stabilise into an innovation niche. Subsequently, we specify an agent-based model (ABM) developed to capture such niche mechanisms and investigate the role of policy actions in stimulating/facilitating the emergence of such niche. Specifically, we will consider and assess the impact of two policy actions: (1) increasing actors' expectations towards the new technology by means of information spreading, and (2) the provision of subsidies aimed at stimulating technological switch.

The remainder of the paper is organised as follows: in section 2 the niche mechanisms are briefly presented;[1] in section 3 the simulation model is described in detail; section 4 presents our preliminary findings; and section 5 concludes and provides a discussion for further developments.

2. The niche mechanisms

The niche formation process can be modelled as the emergence of a stable network of agents who directly form a sufficient "critical mass" able to support the development of the niche technology. Following the discussion developed in Lopolito and Morone (2010), we shall define in our theoretical model three key mechanisms for the emergence of niche-innovations:

1. The *expectation mechanism*. The convergence of actors' expectations towards a common view is crucial for the emergence of an innovation niche. One of the main barriers to the adoption of a new technology is that its advantages are not clearly understood by all possible adopters (Kemp *et al.* 1998). Indeed, actors take part in risky projects on the basis of their expectations (Van der Laak *et al.* 2007); at the same time, diverging expectations can negatively affect the way goals are defined and prioritised (Smith *et al.* 2005). This initial obstacle can be overcome only through the development of a robust and shared vision among the actors potentially involved. Such convergence provides the willingness to act that legitimates actors to invest time and effort in a new technology, although it does not yet have a clearly defined market value (Raven 2005). Thus, as noted by Smith *et al.* (2005: 1503), "the challenge […] is to analyse how contrasting visions and expectations enrol actors into coalitions of support, come to define their interests, and shape the way that they seek to respond to selection pressures". This process occurs more easily when promises of the new technology are credible (supported by facts and tests), specific (referred to clearly identified problems), and coupled with shared problems not yet addressed by existing technology (Kemp *et al.* 2001).

[1] For a detailed description of such mechanisms see Lopolito and Morone 2010 and Lopolito *et al*. 2011.

2. The *power mechanism*. Considering the niche as a "small network of dedicated actors" (Geels and Shot 2007: 400), powerful actors joining the network is a fundamental condition for its formation. Their support is crucial to gather and mobilize the resources required to guide the technical change in a desirable way (e.g. costs reduction implemented via substantial investments in process innovations). Indeed, no single actor has sufficient resources on her/his own to coordinate the innovation process (Smith *et al.* 2005). As a result, niche members are dependent upon each other for important resources, and power is to be understood as a network feature, as well as an individual one.
3. The *knowledge mechanism*. An adequate level of knowledge on the niche technology is required in order for the niche to emerge as a stable network of dedicated actors. Once a group of actors has established an innovation niche, they start producing using the new technology; this activates a learning-by-doing process, which augments the available stock of knowledge. Moreover, firms belonging to the emerging innovation niche will typically share their knowledge for the further development of the new technology (learning-by-interacting). A large part of this process is deeply informal as tacit and uncodified knowledge can only be acquired and shared by means of intensive and direct interactions. Both these learning processes will, in turn, reduce the uncertainty typically associated with a new technology. Hence, as an innovation niche emerges, the knowledge content relevant to the technology grows, making the network itself more stable. This mechanism, therefore, is the final step of a process aiming at generating a stable and strong new technological niche able, eventually, to replace the incumbent technological regime.

3. Model description

The niche mechanisms described above define a rather composite social environment within which complex dynamics take place. Such dynamics can hardly be described through traditional mathematical methods; hence, we decided to resort to simulation in order to disentangle such complexity, using an agent-based modeling approach. Agent-based modeling is a powerful simulation technique in which a system is modeled as a set of autonomous decision-making entities called agents. Basically, an ABM is formed by a set of agents and the relationships among them. Agents are capable to assess their situation at each point in time and making decisions on the basis of a set of behavioural rules. This allows investigating specific features of the overall system emerging from the interaction of the agents and their behaviour. The programmable modeling environment used for building the niche creation ABM is NetLogo 4.1. NetLogo was authored by Uri Wilensky (1999), and is periodically up-graded by the Center for Connected Learning and Computer-Based Modeling. NetLogo proved to be particularly useful for modeling complex systems evolving over time.[2]

The aim of the model is to capture the major network dynamics which characterise the emergence of a stable innovation niche and simulate the effects of various policy actions. It encompasses all the main internal dynamics of the niche influencing the process of technological innovations discussed in section 2. As we believe, this model contributes to answer several 'open questions' relative to the use of the innovation niche framework as a policy tool, an area of enquiry which has been - so far – largely under-investigated. Specifically, we shall attempt to provide an answer to the following questions: (1) how do external elements (e.g. information provided by local institutions) and foreseen opportunities associated with the adoption of the new technology shape actors' expectations? (2) how do agents' expectations affect the emerging network structure, and how does such structure

[2] The source code of the agent-based model presented hereafter is available upon request.

influence the learning process? (3) how, in turn, do agents' expectations change as they learn more on the new technology? (4) and finally, how do patterns of agents' interaction influence the development and diffusion of the niche technology?

The model depicts a socio-technical system in which agents (firms) widely use an incumbent technology (i.e. the regime option) in their economic activity (a productive activity). Periodically, agents compare the incumbent technology with the niche option (i.e. an alternative production technology) and decide whether to keep using the regime option[3] or switch to the new one. In order to grasp the mechanisms governing the technical transition, the model conceives all agents as profit maximisers, bounded in their rationality and operating in a complex and risky situation – i.e. firms behaviour is *intendedly* rational but only *limitedly* so (Simon 1957). As we will clarify in the following paragraphs, the compared profitability of the nice option depends both on its technological development (i.e. the degree of maturity of the niche technology) as well as on the individual expectations towards such option (which, in turn, depends upon social interaction in terms of information and knowledge).

3.1 The profit structure and the space of interactions

The model depicts a finite set of productive agents (i.e. firms) $I = \{1, 2, 3, \ldots, N\},\quad N << \infty$.

Initially, all firms produce a generic good, using the regime option (i.e. the incumbent technology) under the conditions of perfect competition,[4] in which every firm has extra profits equal to zero:

$$\Pi_{i,t} = R_{i,t} - C_{i,t} = 0 \tag{1}$$

where $R_{i,t}$ and $C_{i,t}$ are respectively firm *i* revenues and costs associated with production at time *t*.[5] Time is discrete and the generic time-step is denoted by t = 0, 1, 2, …. With time, firms have to decide whether to keep producing using the incumbent technology or switch to the innovation niche option. Profits might rise as firms switch to the niche option (we shall discuss how profits change for switching firms later in this section). Let us define the profits of firms producing with the niche technology as follows:

$$\Pi^n_{i,t} = \begin{cases} R^n - C^n_{i,t} \ \ with \ \ probability \ \ p \\ 0.5R^n - C^n_{i,t} + \ with \ \ probability \ 1-p \end{cases} \tag{2}$$

where R^n is the niche technology revenue (and is invariant across firms and over time), $C^n_{i,t}$ is the niche technology cost for firm *i* at time *t*, and *p* is the probability (set, at the initialisation phase, equal to 0.5) that firm *i* will obtain at time *t* the highest profit. This probability

[3] Note that firms which produce using an incumbent technology may be operating in various markets, this crucially depends on the type of niche technology under investigation as it defines the set of firms potentially keen on joining the innovation niche.

[4] The assumption of perfect competition is based on the Product Life Cycle theory (Klepper 1997), according to which as products mature and become commoditized, price competition intensifies. Hence, we assume that a regime technology is a mature and standardised technology characterised by perfect competition, as opposed to the niche technology which, being in the earlier 'introduction' stage of the cycle, is characterised by a lower level of competition. Note that this is not a necessary assumption for the model. In fact, discarding this assumption and assuming the presence of extra profits also in the regime technology would require a stronger supporting policy in order to stimulate the transition to the new niche technology. However, as we believe, this should not have an impact on the overall transition process.

[5] Note that under the assumption of perfect competition, we set $R_{i,t}$ and $C_{i,t}$ constant overtime and identical for each producer.

captures the risk associated with production under the niche option, which stems from the lack of knowledge on the new technology.
Firms are located in an economic and social space (i.e. not a geographic space) represented as a 2-dimentional, finite, regular grid of cells.
The spatially explicit feature of the model serves to structure the spatial proximity on which the agents' interaction is based (i.e. each agent can interact with other agents within a certain radius). Specifically, we shall assume that two firms can interact any time their social proximity is at a maximum (i.e. their social distance is equal to zero as they are on the same cell). The social proximity of any pair of agents changes over time as firms are initially assigned a random position in the social space and they move randomly within the social space (moving only among adjacent cells). Moreover, not all the cells of the grid are occupied by agents, and those occupied may contain more than one agent. In order to model deeper interactions, ties can be established among firms which share similar high expectations towards the niche technology. The stability of ties and their intensity depends on some characteristics of the vertexes which will be described in detail in sub-section 3.2. Hence, over time a network of relations among supporting firms can emerge. Such a network, which is the emerging innovation niche, can be seen as the socio-economic space within which firms develop the new technology "by doing" as well as by sharing their knowledge.

3.2 The niche's mechanisms

3.2.1 Expectations mechanism

Those firms who switch to the niche option are called active ones. For this to happen, firms must find it convenient to produce with the niche technology; this occurs any time their expected profit is greater than zero (and therefore higher than the profit obtained producing with the incumbent technology). The expected profit is calculated as follows:

$$E\left(\Pi_{i,t}^{n}\right)=E\left(R^{n}\right)-E\left(C_{i,t}^{n}\right) \tag{3}$$

where $E\left(R^{n}\right)$ is the expected niche revenue and $E\left(C_{i,t}^{n}\right)$ is the expected niche cost of firm *i* at time *t*.
Each firm is characterised by a level of expectation $ex_{i,t}$ that is the preference of firm *i* at time *t* towards the new technology. The value of expectation will vary from 0 (if the agent does not have preferences for the new technology) to 1 (if the agent has a complete preference for the new technology). At initialisation phase all firms have an expectation set to a specified starting value (see table 1 below). The higher is the expectation, the more likely it is that the firm will switch to the new technology. In fact, the level of expectation influences positively the expected cost (reducing it) and the expected revenue (increasing it) of the new technology, as showed in equations [4] and [5]:

$$E\left(C_{i,t}^{n}\right)=\frac{1}{ex_{i,t}}C_{i,t}^{n} \tag{4}$$

$$E\left(R^{n}\right)=ex_{i,t}R^{n} \tag{5}$$

where $C_{i,t}^{n}$ and R^{n} are respectively the actual cost of firm *i* at time *t* and the actual revenue associated with the niche technology (initial values of niche's cost and revenue are set equal to 1 and 1.3 respectively).[6] Hence, in this model we assume that firms tend, in general (i.e. unless their expectations are equal to 1) to underestimate niche revenues and overestimate niche costs.

Once a firm reaches a high level of expectation (set at 0.75), it becomes a supporter of the niche option. Whenever two supporting firms interact (i.e. their social proximity is at a maximum) they establish a tie. The tie is instable in the sense that every time that one of the two vertexes is no longer a supporter (i.e. its expectation drops below 0.75) it disappears. Thus, a dynamic niche network can emerge based on firms' interactions.

Expectations of active agents can increase or decrease overtime. Specifically, *ex* will increase any time the actual profit obtained producing with the new technology exceeds the expected profit and *vice versa*.

Hence, firms' expectation will increase if $\Pi_{i,t}^{n} \geq E\left(\Pi_{i,t}^{n}\right)$; if the contrary is true (i.e. the actual profit is smaller than the expected profit), then the expectation of the niche technology will decrease. It increases/decreases according to the following rule: $ex_{i,t+1} = ex_{i,t} + \Pi_{i,t}^{n}$.

Note that in this model we are, therefore, assuming that firms producing under the new technology do not possess perfect information (i.e. their expectations are bounded) and adapt their expectations on past experience.

3.2.2Power mechanism

Another crucial attribute of the firms is individual power. It describes the firms' endowment of strategic resources.[7] At initialisation phase all firms are assigned an individual power value (see table 1 below). Any time an active firm (i.e. one producing under the niche option) obtains an extra profit, it increases its individual power (I^{power}) as this extra profit is added to its pool of resources; likewise, individual power will decrease if the profit turns to be negative ($I_{i,t+1}^{power} = I_{i,t}^{power} + \Pi_{i,t}$).[8] It is assumed that each time two supporting firms (*i*, *j*) establish a tie, the total amount of their respective resources flows through this tie. Thus, each tie has a feature called energy (*En*), which is the sum of the resources of the agents on either end of the tie:

$$\forall\, i,j \in N,\ \ \exists En_{i,j} \geq 0:\ \ En_{i,j} = \begin{cases} I_{i,t}^{power} + I_{j,t}^{power} & if\ i\ and\ j\ are\ linked \\ 0 \quad if\ i\ and\ j\ are\ not\ linked \end{cases} \tag{6}$$

The total sum of links' energy represents, in turn, the overall network power $\left(N^{power}\right)$. Hence, we can write:

$$N_{t}^{power} = \sum_{i,j} En_{i,j} \quad with \quad i \neq j \tag{7}$$

Both individual and network power have an impact on the cost structure faced by active firms operating under the niche option. On the one hand, we assume that increasing individual power will allow active firms to engage in costs reduction activities (e.g. by investing extra profits in R&D, firms could introduce process innovations). On the other hand, as the

[6] Note that actual niche cost varies across firms and overtime. In fact, as we will see later on in this section, we allow costs to decrease whenever firms accumulate extra profits. This is not the case for costs associated with production under regime technology, which are invariant across firms and overtime since no extra profits are allowed.

[7] Intuitively, a strategic resource is a resource which can be used in order to develop and promote a new technology. For instance, an R&D laboratory is a resource which could serve the purpose of developing a new technology. A wide-ranging proxy of such resources could be firms' turnover as, in general, larger firms would also be the most powerful.

[8] Note that the individual power is subject to an upper bound set equal to100.

network power increases, active firms will have access to a growing amount of external resources. In other words, we maintain that resources accumulated by other firms can be exploited by means of spillovers within the emerging social network. Hence we have:

$$\begin{aligned} &if \quad \Pi^n_{i,t} > 0 \quad \rightarrow \quad C^n_{i,t+1} = C^n_{i,t} - cI^{power}_{i,t} - nN^{power}_t \\ &with \quad c \in [0,1]; \quad n \in [0,1] \quad and \quad c >> n \end{aligned} \tag{8}$$

where $cI^{power}_{i,t}$ and nN^{power}_t represent respectively the cost reduction derived from the accumulation of individual and network power.

3.2.3 Knowledge mechanism

Each firm is initially assigned a specific level of knowledge with respect to the new technology (see table 1). Each time the firm produces using the new technology, its knowledge of it increases. This captures the learning-by-doing activity. Knowledge will increase/decrease in a linear fashion according to the exogenous parameter θ.

Moreover, any supporting firm can learn from those firms with whom it has established a link. Every time-step a (randomly determined) proportion of knowledge flows among each pair of firms connected by an active link. Such a knowledge mechanism represents the idea of developing expertise; a link will provide an opportunity to refine the technology by means of learning-by-interacting.

It is quite important to observe that as the overall level of firms' knowledge on the niche technology increases, the probability p of obtaining the high profit $\Pi^n_{i,t} = R_{i,t}{}^n - C^n_{i,t}$ increases. This is because, overall, as agents become more knowledgeable on the niche technology, the risk associated with the production involving such new technology decreases. This is a system feature which affects also firms currently not involved in the niche option; in fact, if they will switch to the niche option they will get $R^n_{i,t}$ with a higher probability. Specifically, we assume that the probability p increases in a linear fashion: $p_{t+1} = p_t + \varepsilon \sum_{i=1}^{S} K_{i,t}$; where S is the size of the niche, $K_{i,t}$ is the relevant knowledge accumulated by firm i at time t, and ε is an exogenous parameter.

3.3 Modelling policy actions

The model described above can be used to investigate complex niche mechanisms in order to draw insight on the spontaneous emergence of technological transition patterns. However, policy makers are also interested in how they can change the emerging patterns in a desirable way. In what follows we introduce two other model elements that can be used to depict the policy intervention in the process of niche creation.

The first is represented by a particular set of agents called 'spreaders' $S = \{1,2,3,\ldots,M\}$, with $M < N << \infty$. Spreaders are institutional agents whose only purpose in the model is to promote the new technology, enhancing firms' expectations towards it. Their number (M) is an exogenous parameter, which could be varied in order to fine-tune the policy action. These agents interact only with firms who are not already supporters (as spreaders have no interest in interacting with firms which are already supporting the new technology), warping on the nearest one to influence its expectations. Specifically, every time a firm interacts with a spreader, its expectation increases in a linear fashion according to exogenous parameter η.

The second policy tool is represented by subsidies. Subsidies modify the equations of actual and expected profit (equation 2 and 3) as follows:

$$\Pi_{i,t}^{n} = \begin{cases} R^{n} - C_{i,t}^{n} + sub & \text{with probability } p \\ 0.5R^{n} - C_{i,t}^{n} + sub & \text{with probability } 1-p \end{cases} \tag{2 bis}$$

$$E\left(\Pi_{i,t}^{n}\right) = E\left(R_{i,t}^{n}\right) - E\left(C_{i,t}^{n}\right) + sub \tag{3 bis}$$

where *sub* is an exogenous parameter which refers to the presence of a subsidy (it will be greater than zero if the policy maker decides to encourage the adoption of the niche technology).

4. Preliminary findings

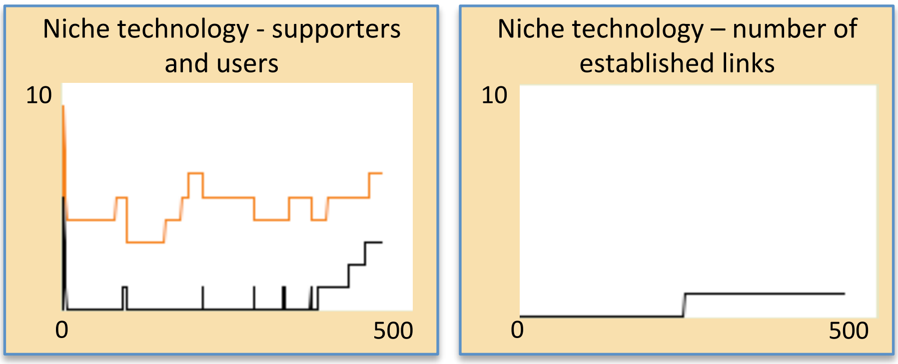
The preliminary results presented in this section are based on the parameterisation summarised in table 1. We will first present the results obtained with zero subsidies and only one spreader (i.e. the minimum amount of policy intervention, since with zero spreaders there would be no activity at all in the model). Subsequently we shall investigate the impact of the two policy actions described in section 3.3. The timeframe we will investigate is 500 time-steps; as we believe, such timeframe represents a reasonable length of time for an innovation niche to emerge as a stable network.[9]

Table 1: Experimental parameters' summary table

Parameter	Value	Description
Expectation	0.5	Initial level of expectations assigned to each firm
η	0.005	Rate at which expectation increases as firms interact with spreaders
Power	Rand. [0-0.3]	Initial power endowment assigned to each firm
n	0.01	Rate at which production cost is reduced as network power increases
c	0.01	Rate at which production cost is reduced as individual power increases
Knowledge	Rand.[0-0.01]	Initial knowledge endowment assigned to each firm
θ	0.025	Rate at which knowledge increases as firms learn by doing
ε	0.01	Rate at which the risk associated to niche production decreases as the knowledge in the system increases
Subsidy	Various	Amount of subsidies provided to firms operating within the niche
Spreaders	Various	Number of spreaders present in the system
R^{n}	1.3	Actual revenue under the niche technology option
$C_{i,t=0}^{n}$	1	Initial actual cost under the niche technology option

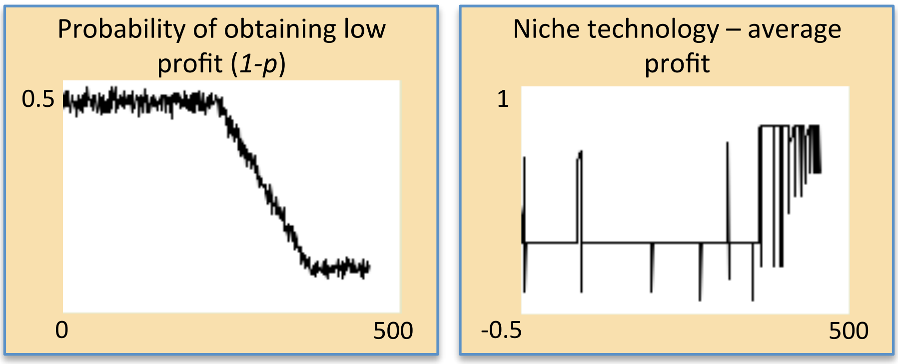
[9] If we consider a time-step equal to a week, 500 steps would represent around 10 years. Generally speaking, a week seems a good time proxy for a step: in the real world, a week is, in fact, a reasonable time for an entrepreneur to evaluate whether it would be convenient to switch technology or not. This has been confirmed by a group of organic food producers interviewed while conducting a case study in the province of Foggia (Morone *et al*. 2010). We will also refer to a much longer time span (5000 time-steps) which will be our long run framework. Indeed, changes occurring beyond such a time horizon would be quite irrelevant for policy action.

Figure 1: Innovation niche emerging dynamic – medium run
(zero subsidies and one spreader)



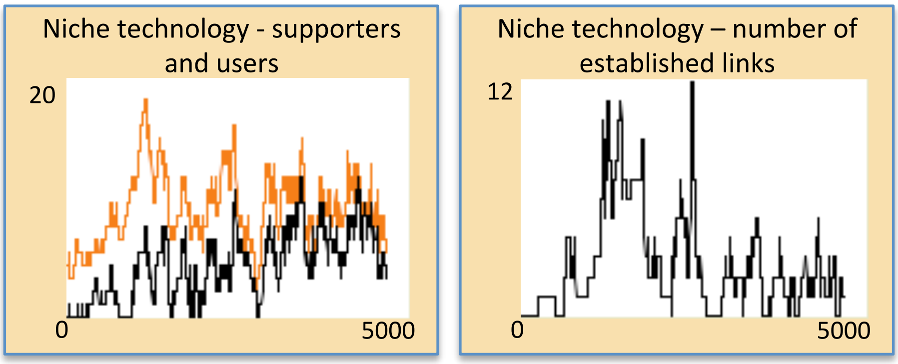
As it clearly emerges from figure 1 (left panel), the system is highly unstable as far as the number of supporters and users (respectively, orange and black lines) of the niche technology is concerned. Moreover, the network configuration (figure 1 – right panel) is rather loose with just a small number of agents establishing links. Interestingly, towards the end of the time-step considered, the system starts gaining momentum as the number of firms switching to the niche option grows slightly. This is matched by a substantial reduction in the uncertainty surrounding the niche option – ascribable to the knowledge mechanism which is driven by learning-by-doing (see the significant drop in the probability of obtaining a low profit in figure 2 – left panel) and a sharp increase in the average profit (ascribable to both the reduced uncertainty and the power mechanism which allows firms to reduce production costs; figure 2 – right panel). Both of these dynamics might suggest that in a longer timeframe the niche could emerge as a stable configuration in the system.

Figure 2: Risk and profit for niche technology – medium run
(zero subsidies and one spreader)



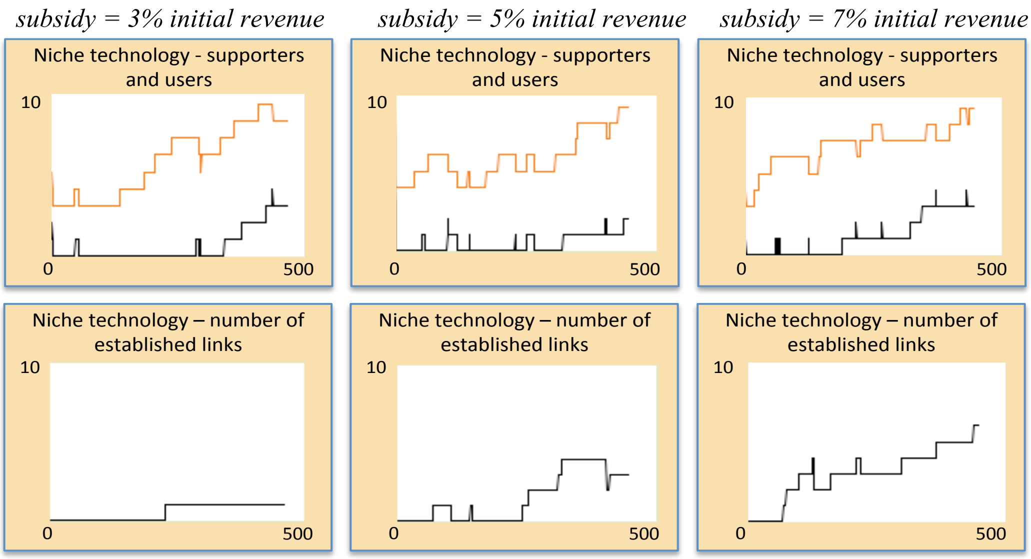
If we look at a tenfold time span (5000 steps), we can observe that, although the number of supporters and – to a lesser extent – of users take up after around 1000 steps, they drop sharply in the following 1000 steps and keep fluctuating around an average value of seven supporters/users for the successive 3000 steps (figure 3). In fact, the system does not converge towards any stable equilibrium, not even in the very long run. Hence, instability emerges as a persistent feature of such system.

Figure 3: Innovation niche emerging dynamic – long run
(zero subsidies and one spreader)



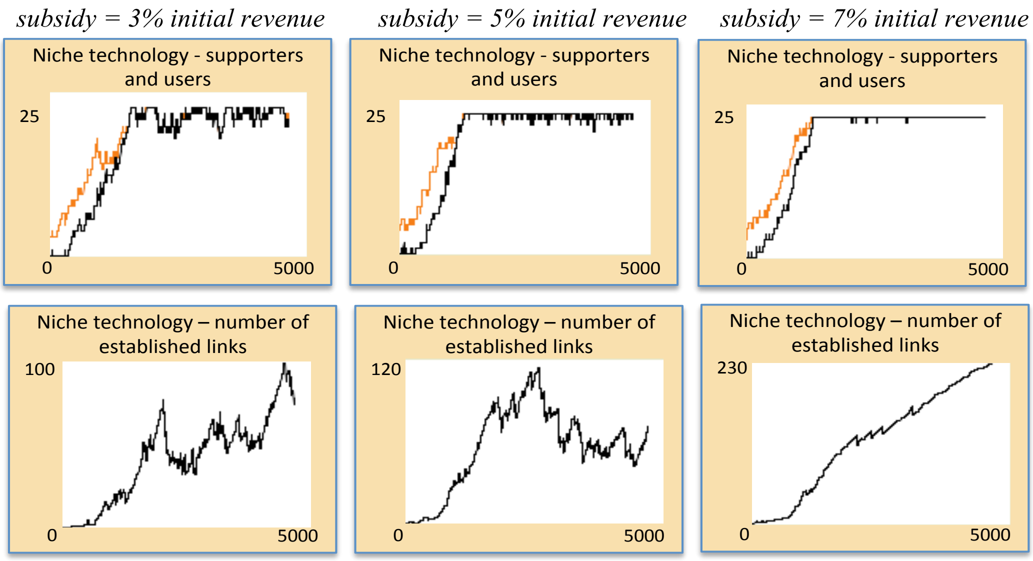
We will now investigate the impact of two alternative policy actions on the emergence of a stable innovation niche. Namely we will consider: (1) the impact of subsidies, and (2) the impact of an information campaign. First, we look at the impact of introducing a subsidy. As we raise the subsidy to 3, 5 and 7 percent of the initial revenue,[10] we can observe that the innovation niche becomes increasingly denser (figure 4 – three bottom panels). However, convergence does not occur within the medium run (500 time-steps); in fact, just a rather small number of firms switch technology (see the black line in the three top panels of figure 4). More insights can be gathered from the long run results.
As it emerges clearly from figure 5 (top right corner panel), with the highest subsidy it takes, on average, 1500 time-steps for a stable convergence to occur – i.e. all firms switch to the niche option and persistently keep producing with it. For lower levels of subsidy, convergence occurs within a slightly longer time span and is indeed less stable (see the fluctuation around the steady state in the left and central top panels of figure 5). Hence, as we increase the amount of subsidies we significantly increase the stability of the system in the long run. We can conclude that providing an adequate subsidy will enhance the long run system stability, but will have a minor impact on the speed of convergence – i.e. the minimum time required for a stable niche to emerge.

Figure 4: Innovation niche emerging dynamic – medium run
(various levels of subsidies and one spreader)



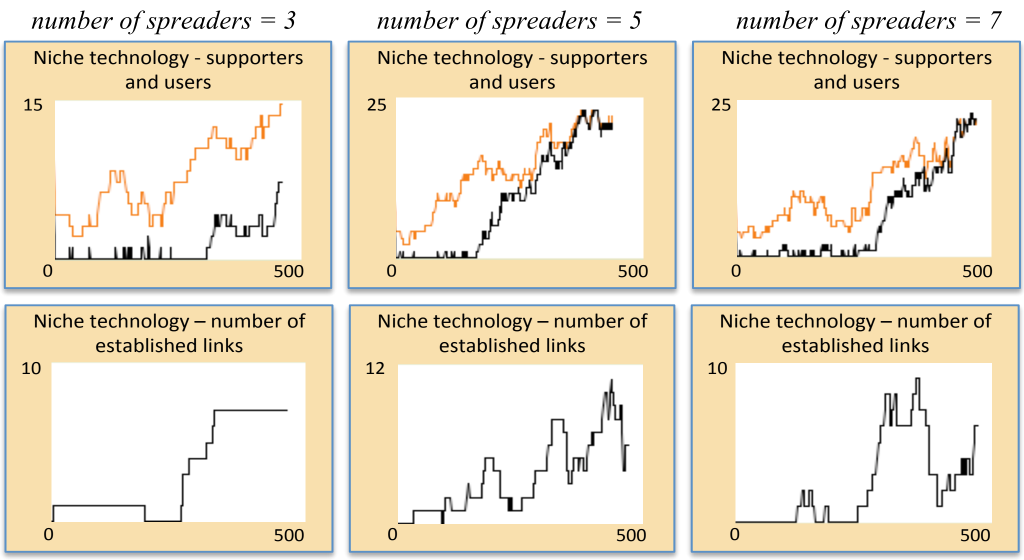
[10] By initial revenue we refer to the revenue obtained by those firms operating in perfect competing markets.

Figure 5: Innovation niche emerging dynamic – long run
(various levels of subsidies and one spreader)



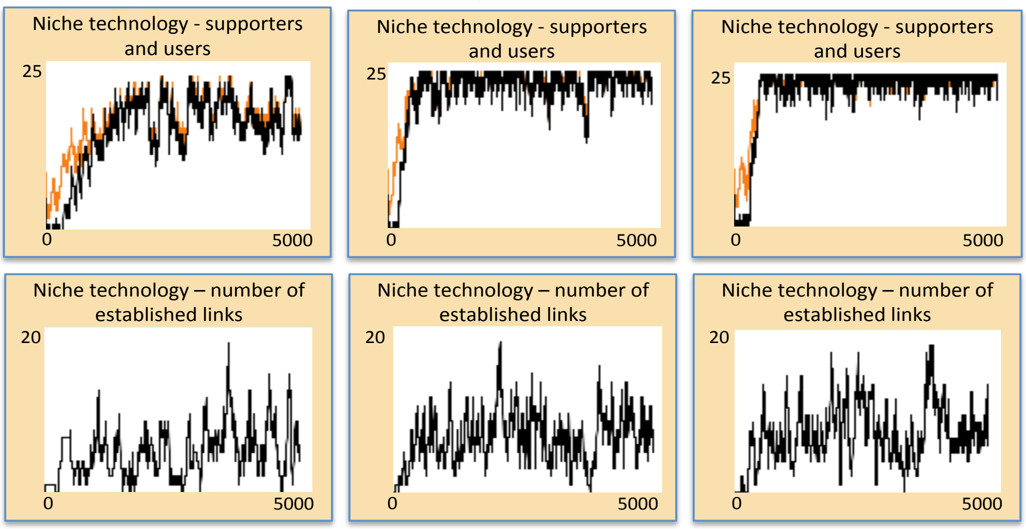
A rather different picture emerges if we consider a different policy tool: with the introduction of an information campaign on the use of the niche technology (i.e. increasing the number of spreaders) the speed of convergence rises sharply, even with a small effort.
We report in figure 6 findings of three batches of simulation where the number of spreaders was set equal to 3, 5 and 7. As it clearly emerges from figure 6, the full niche convergence trend is present in the medium run any time five or more spreaders are involved in the diffusion process. Even with just three spreaders a clear rising trend, both in terms of supporters and adopters, is observable. However, the convergence is quite unstable as the number of supporters/users fluctuates quite substantially around the positively-sloped trend line.

Figure 6: Innovation niche emerging dynamic – medium run
(zero subsidies and various levels of spreaders)



Hence, we may conclude that this second policy action generates a much faster converging trend, but the system preserves a high degree of instability. This finding is confirmed when we look at the long run results (figure 7): as we increase the number of spreaders, the system converges quickly towards the full niche emergence, but preserves a certain degree of instability as the number of supporters/adopters fluctuates below the steady-state value (i.e. 24, the total number of firms involved in the simulation).

Figure 7: Innovation niche emerging dynamic – long run
(zero subsidies and various levels of spreaders)



5. Conclusions and future extensions

In this study we developed an ABM aimed at investigating the emergence of an innovation niche in a stable form. Generally speaking, we found that agent-based modelling is a well-suited analytical tool for a long-term policy analysis, especially when investigating systems characterised by rather complex behaviours (e.g. novelty, indeterminacy, self-adapting behaviour).

The simulation carried out using this model showed the importance of policy intervention aimed at governing the creation niche process in a desirable way. In the absence of any policy intervention, the system did not converge towards any stable equilibrium and instability emerged as a persistent feature of the model. On the contrary, both policy actions modeled (i.e. subsidy and information spreading) showed some valuable consequences. On the one hand, subsidy resulted useful to enhance the long run system stability but it poorly affected the speed of convergence. On the other hand, the speed of convergence increased in the case of the information campaign, even if the emerging equilibrium resulted quite unstable as the number of supporters/users oscillated quite substantially around a positively-sloped trend line. On this ground, we can conclude that the two policy measures have different and, to some extent, complementary effects. Hence, a mixed policy action could serve the purpose of speeding up convergence while at the same time ensuring the stability of the system.

Although promising, the results presented in this paper are rather preliminary. We suggest the following lines of research for future work (some of which have already been undertaken):

1. A calibration of the model grounded on a case study. The objective of model calibration is to improve the relevance of the model in terms of some previously defined numerical inputs or parametric variables. An 'applied' model has a specified real-world system as its target of investigation where empirical data and/or stylized facts are gathered. Empirical data are then used to limit the parameters' space as well as to redefine the

initial conditions. At present, we are working on a case study on the development of bio-refineries (as a possible innovation-niche) in a specific territory (the province of Foggia), by using documental and interview data via questionnaire and focus-groups.

2. A robustness analysis that can account for the stability of results and the sensitivity of findings to the model parameterisation. This can be done by: a) carrying out repeated simulation experiments (e.g. batches of a hundred runs each), to dispose of artefacts introduced by the random aspect of model initialisation, and b) assessing the results' robustness to alternative initial parameterisation.
3. The identification of the optimal policy mix. This can be done combining the results of the ABM with benchmark analysis tools as the use of efficiency frontier methodology, to highlight the most efficient policy-mix.

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