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Heterogeneity vs. externalities in technological competition: A tale of possible technological landscapes*

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Abstract. The article presents a stochastic interaction model based on Gibbs random fields to analyze technological competition in a population of heterogeneous adopters with local or global externalities. The relationships between both heterogeneity and externalities and imperfect and asymmetric information are first emphasized. When local externalities and heterogeneity coexist, the technological landscapes of the industry are then shown to depend on the relative influence of these two parameters, with a phase transition: technologies coexist either in approximately equal market shares when heterogeneity is high enough or with one of the technologies only surviving in technological niches when local externalities dominate. Niches do also spontaneously appear: technological options survive in economic space due to the existence of some amount of heterogeneity among agents. On the contrary, when global externalities are added, pure standardization almost always occurs. We finally argue that different public policies should be designed so as to fit with different technological landscapes.

Key words: Externalities – Heterogeneity – Local interactions – Global interactions – Phase transition – Standardization – Stochastic models – Technological competition – Technological niches – Economic landscapes

JEL-classification: C00; O33; R10

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1 Introduction

The economics of technical change has recently seen a surge of new models, explicitly dealing with the role and the influence of interactions and externalities in a population of agents facing technological choice. As a matter of fact, one could no doubt wonder why it is becoming so fashionable to implement into economics complex stochastic models instead of the classical and well-known mathematical apparatus of general equilibrium theory. There are indeed two main reasons, which deal with contemporary economic issues on the one hand and with the advancement of economic science on the other, but which reduce to one: to deal with crucial economic issues regarding technology, economists have departed from classical models because they were no longer suited to the necessary analyses since they got rid of both externalities and heterogeneity of agents.

Related economic questions indeed belong to the core of modern relevant economic issues: the ultimate technological destiny of an industry is a vital element for strategic – both public and private – investment decisions. Governments and public agencies are nowadays trying to define new rules for public interventions in this field, and it is a major dilemma for today's world economy to decide whether State intervention in real economic affairs should be avoided or not, and if not, how it can be made efficient. It is therefore becoming increasingly important for economists to build models and theories which are able to analyze properly such economic phenomena, and afterwards to provide clues to public and private decision makers. This is specially so because economic theories of technological competition tend to prove that unusual economic notions, like increasing returns, path-dependency and the existence of multiple equilibria, make such analysis difficult. The economics of technical change has made major theoretical advances in this regard during the past two decades: the intertemporal complementarity of production factors was insisted upon (David, 1975), which led to the appearance of evolutionism and of the notions of path-dependency and technological paradigms (Nelson and Winter, 1982; Dosi, 1988); initial decisions were also shown to have a crucial impact in this path-dependent framework on the subsequent development of technologies in the industry (David, 1985, 1987), since they could durably lock an industry into a suboptimal technological state.

Unfortunately, classical economic models are not useful in this framework. Their main hypotheses seem in fact today largely inappropriate: even when they are able to take into account this newly-recognized historicity of economic processes, however difficult it might be, they also mostly rely upon a *unique* kind of agent, a 'representative' agent, forgetting that modern economies are characterized by a set of heterogeneous agents whose histories, means, goals, time horizons, neighborhoods, interests and incentives all vary; and forgetting also that no magic, be it the representative individual or the invisible hand, is at work, but rather sequences of individual and collective decisions which slowly shape the economic landscapes of industries and countries. As Kirman (1992) has shown, the representative individual hypothesis, however once perfectly justified, is now obsolete as it leads to erroneous conclusions. It has to be replaced with models and theories where interactions between heterogeneous agents play a leading role. Interactions, such as network externalities, influence industrial trajectories and agents' economic behaviors. The utility of many technologies has been proven to depend on the number of past adopters, which might be a tentative explanation for suboptimal lock-in states (Arthur, 1989). Classical utility maximization models seem to be unable to handle such situations where utility of technologies vary during the diffusion processes.

In this article, it is argued that economies are driven to multiple dynamic equilibria by two opposing forces: heterogeneity of agents, which produces diversity, and externalities, which tend to coordinate actions. We first discuss network externalities, both local and global, whose relationships with imperfect information have been partly neglected, and heterogeneity, which stems from rational behaviors, namely historical path-dependency of actions. Externalities create a positive feedback force and are counterbalanced by heterogeneity which in a sense gives birth to negative feedbacks. Whereas heterogeneity has sometimes been implemented but never properly recognized in global externality models, it has always been neglected in local externality ones. We thus present a stochastic interaction model based on Gibbs random fields which deals with both local externalities and heterogeneity. As a consequence, different kind of equilibria obtain depending on the relative influence of these two parameters. If externalities are strong enough, standardization almost obtains but the dominated technology still survives in niches. Previous models which often rely upon the "master equation" approach are therefore shown to be partly misleading, since they do not properly deal with local externalities. This is the reason we then adapt our model to situations where both local and global externalities exist. We present simulation results showing that niches generally disappear under the influence of global externalities, even for a very heterogeneous population of adopters. Economic consequences on public policy issues are then derived from each of these results.

2 An economic framework

2.1 Externalities

Up to now, interactions models have mostly been devoted to the analysis of interpersonal technological complementarities: agents take decisions and adopt new technologies but their decisions are not independent from what others have already done and decided to do. References are of course to be made here to the works of Arthur (1989), David (1988), and to Katz and Shapiro (1985)'s notion of "network externalities". The basic idea is that firms have incentives to adopt the same technology as others: there exist "network externalities", i.e. the number of agents having adopted a given technology impinges on its utility. Why is this so economically? Network externalities can first be interpreted as positive feedbacks from the macro-state, as emphasized in Arthur's models. Such an acception appears to be close to the original Marshallian notion of "external economies", i.e.

externalities mainly due to number effects. The more a technology gets adopted, the cheaper and more efficient it becomes. These externalities are dynamic and ultimately depend on the size of the market. Such network externalities due to number effects are global, and apply to the industry as a whole (Arthur, 1989), i.e. each firm in the industry can benefit from such cost reductions or efficiency improvements. Network externalities, however, exist in a wide range of situations, and their applications should not be limited to global positive feedbacks deriving from the adoption of communication technologies, such as phone or facsimile standards: in fact, when communication media are involved, standardization of transfer protocols is obviously necessary for information flows to exist. But network externalities also include the emergence of ancillary technologies and simply the exchange of VCR cassettes between users. All these network externalities are due to technological complementarities that are often *local*. One has then to take into account the relevant technological neighbors of a given firm (David, 1988), for instance for electronic data interchange (EDI) technologies (David and Foray, 1992).

Scholars of technological change have underestimated the influence of another kind of externality, namely local informational network externalities. We believe that imperfect and asymmetric information in a population of interacting agents *implies* the existence of local informational network externalities. As a matter of fact, new and emerging technologies are always suspect, as their quality is not pre-determined and appears only during the diffusion process[1]. As a result, information about technological quality is necessarily imperfect, and often asymmetric. When facing the opportunity of technological choice and technological investment, firms have to solve an Akerlof (1970) dilemma: will emerging technologies prove to be ‘‘peaches’’ or ‘‘lemons’’? As many scholars have shown, the diffusion process gives birth to global informational feedbacks through which firms are able to make quality assessments. But let us ask a very basic and crucial question: what do firms do when they try to evaluate the quality of newly available technologies? The answer seems to be, they sometimes rely upon the evaluation of their own R&D structure, since one of the corporate missions of in-house R&D is to evaluate new technologies, and to provide management with information about its quality. But most of the time they also take into account quality assessments from specialized reviews or commercial partners, subcontractors, and even, of course, from the seller of the technology. As a consequence, technological adoption decisions will be partially interdependent, if only because information on a technology is sometimes to be found in other firms and commercial partners; thus most of these interactions are local and not global[2].

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[1] See Arthur (1989) and David (1985) on this, or Callon (1989) and Latour (1989) for more sociological analysis.

[2] As a consequence, the use of local network externality models should obviously not be restricted to pure network technologies: for most diffusing technologies, quality assessment and adoption decisions from other relevant firms and actors are taken into account in a firm's own decision and belong to a firm's neighborhood (David, 1988).

As a matter of fact, one could finally wonder when global informational network externalities are available. During the first steps of the technological diffusion process, it would be surprising if potential adopters had access to relevant information about the market shares of each competing technology as a proxy for technological quality. The only information to which they have access is their own or that of local partners. Institutions and collective actors provide information, too, but this materializes only later[3]. But Arthur's (1989) model of technological competition precisely shows that relevant events occur at the beginning of the diffusion process; i.e. precisely when its hypotheses are not verified, and we have therefore strong doubts about its conclusions. The existence of local network externalities appears as a necessary consequence of imperfect information and uncertainty. Informational network externalities will sometimes be global, when they come from a scientific or technical review, for instance, which happens to publish a favorable report on a new technology, but they are also often local, since relevant information is to be found from technologically or spatially close partners, and specially during the first times of diffusion processes when crucial events occur, as previous works have clearly shown.

2.2 Heterogeneity

Agents do not necessarily obey majority rules, whatever the interactions with others might be; there are many *rational* reasons why some economic agents might choose idiosyncratic behaviors. As we have just mentioned, internal R&D structures provide firm management with evaluations of the quality of available technologies. According to reliable experiments, some firms might decide to adopt a neglected technology just because they are aware of its superior quality, or because it has been proven particularly well-suited with their own existing production processes. Relatedly, some firms might prefer technological compatibility with their internal resources, acquired through time in a lengthy process, to some eventual productivity gains linked to compatibility with external commercial partners. There are therefore reasons why some rational agents might choose against the choices of others: the otherwise-neglected technology may be well adapted to their particular production technology, or some firms are aware, because they have been testing it for a while, that the dominant technology may encounter serious difficulties when it comes to some specific technological matters.

Many models have underestimated the probability of such behavior, and therefore have also not taken into proper account the consequences of modern theories of economic change that emphasize irreversibilities in trajectories. Previous technological investments and the knowledge base of the firm matter greatly when technological choices are to be made; it is the

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[3] Moreover, if purveyors of technologies have cautiously read Arthur's and David's conclusions, then potential adopters will on the contrary always have access to global but also manipulated and contradictory global informations about technologies!

very idea of intertemporal technological complementarities, as assessed by evolutionary economists and also, more specifically, by the economics of localized technological change (Antonelli, 1995; Atkinson and Stiglitz, 1969; David, 1975; Stiglitz, 1987). It is easier for a firm to adopt a given technology if some of its characteristics are not too far from previous investments, or if the firm has acquired some specific knowledge that allows it to get better clues about the efficiency of competing technologies. Time and learning naturally create informational and technological asymmetries. Different firms will therefore not evaluate the profitability of a technology in the same way. Firms have individual capabilities, acquired though time which sometimes lead them to adopt idiosyncratic behaviors. Yet most of the existing literature has denied firms the right to possess their own history and to act according to it. We must acknowledge the existence of individual preferences, inherited from agents' personal histories or due to idiosyncratic situations and resources. These preferences are distributed among the population of firms or agents and create heterogeneity, so that some firms do not follow majority rules, and escape from "positive feedbacks". Heterogeneity creates natural local – idiosyncratic – negative feedbacks.

2.3 Stochastic models

One should then naturally wonder what happens when both externalities (local or global positive feedbacks) and heterogeneity (local negative feedbacks) coexist. This is the reason why "stochastic"models have been proposed: since agents are numerous, it is much easier to suppose that, for each of them, there is a probability that each will do the same as others. This depends on two opposite parameters, one representing externalities and positive feedbacks, and the other representing heterogeneity. A common law of a very simple kind is assumed – two forces driving actions in opposite directions – and is actualized for each actor in a different way. We thus account for heterogeneity and interaction in a population of potential adopters. Stochastic process are well-adapted because of the existence of a population of potential adopters: if a proper analysis of a given firm's situation were made, then we could perhaps determine whether it is going to adopt technology A or B. Under the hypothesis of the existence of a *population of heterogeneous agents*, stochastic models with probability distributions allow us to derive analytic results without either specifying each firm's situation or relying on a "representative firm" hypothesis. The probability of a firm adopting a given technology then depends on its individual preferences, and on local and global externalities.

It has been argued in Dalle and Foray (1995) that stochastic models are richer than others because they do not oblige economists to specify too strong, rationality notably, hypotheses, but only weaker ones: the set of relevant decision parameters and the existence of a population of adopters whose neighborhoods are interconnected, for instance. A common mistake is to infer ant-like or particle-like rationality from such stochastic dependence: agents in these models would be no more intelligent than are ants or particles. But no such property appears to be necessary; moreover, stochastic population models allow us to deal with more than one kind of rationality. It is still an open question whether one can exhibit a single rational model for firm decisions. Recent economic works have invoked the existence of more than one mode of coordination. Is it always possible to exhibit cost functions and optimization programs whose resolution would provide us with the best rational decision rule? When considering a population of adopters, stochastic structures allow us to derive strong economic conclusions without having to give an exhaustive answer to this issue. Since our only hypothesis is that relevant parameters for firm decisions are heterogeneous individual preferences, together with local and global externalities, our framework could be perfectly applied to rational behaviors, if one were to exhibit a cost function, or to other coordination mechanisms, should more than one mechanism actually prevail among the adopters.

2.4 Previous works

Economists have been using stochastic interaction models to study technical change since Arthur's (1989) seminal works. In his model[4], two kinds of agents with different ex-ante preferences have an equal probability of arriving in the market, and each chooses according to relative market shares of technologies. Choices therefore depend upon previous choices, which creates "endogenous" dynamics. Arthur's conclusion is that standardization obtains under the existence of increasing returns. We have already criticized such an approach as regards the availability and relevance of global information about market shares during the early part of the diffusion process, i.e. precisely when relevant events are shown to occur. Heterogeneity of preferences is also limited to the existence of two different kinds of agents, while the model relies on rather strong hypotheses, as Kirman (1991) has noted, which prevents it from exhibiting cyclic or more complex behaviors; more precisely, *heterogeneity is this way sooner or later wiped out and thus standardization quite straightforwardly obtains*.

Although it opened the way to current developments, Arthur's model is not a perfect example of pure "endogenous dynamics"[5] and, as it will become clear in the following pages, was perhaps partly misleading since it made many economists think that standardization was a rule. If economies were to get stuck in a perfectly stable state, from which they would never escape save from mysterious "exogenous" events or major innovations, then, as David and Greenstein (1990) have rightly noted, these strict lock-in states would prevent actual dynamics which empirical economics commonly observe (Foray and Grübler, 1991). Arthur and Lane (1993), Dosi, Ermoliev and Kaniovski (1994), Dosi and Kaniovski (1994) and Kirman (1993) have therefore implemented various kinds of negative feedbacks in the basic model, so that agents are no longer bound to obey strict majority rules. These authors conclude that coexistence might then sometimes

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[4] This stochastic interaction model with *global* externalities is based on the mathematics of Polya urns (see also Arthur, Ermoliev and Kaniovski, 1987).

[5] See Dalle (1994, 1995) on all this.

obtain. However, except for some clues in the papers by Dosi and others, the role of heterogeneity as a counterbalancing force for externalities has surprisingly enough not been fully emphasized. It is indeed surprising that intertemporal complementarities between production factors, path-dependency or the fact that the history of a firm heavily matters and strongly influences what it is to do today and tomorrow, have been forgotten in the very field of the economics of technical change. In fact, the role of heterogeneity is particularly clear but still not properly recognized in Kirman's model: agents always have an ε probability of not following global externalities. This property is critical: both coexistence and standardization might then obtain, depending notably on ε. This "ε" stands, of course, for heterogeneity and negative feedbacks. Kirman is able to prove that there exists a critical value of ε below which coexistence obtains and above which standardization obtains; in this last case, different standardization types will occur between sporadic switches.

These models, and the Polya urn framework, all study pure global externalities. David (1988, 1992), by contrast, has introduced local externality models[6] where agents all face a limited set of relevant neighbors. He has rather strong results with this model, proving that standardization and strict uniformity obtain with only local externalities. In his "voter model" however, economic agents have no choice but to obey strictly the rule of local majority, i.e. they will never be allowed to choose a BETA VCR if all of their relevant neighbors already possess a VHS one. Once more, without heterogeneity and idiosyncratic behaviors, standardization obtains. David and Foray (1992) attempt to implement a degree of individual freedom in the voter model thanks to an additional percolation structure: agents and connections between agents are sometimes open and sometimes closed, depending on percolation probabilities. But these authors were not able to remove from the voter model existing absorbing states which obtain if the population is finite. In their model, lock-in still obtains. Still, however unsuccessful for the time being, percolation theory certainly appears to be a good way to study properly models where local interactions have a role to play so as to explain related economic phenomena (Antonelli, 1996).

The "standardization or coexistence" issue is therefore still an open question when both local externalities and heterogeneity, i.e. positive and negative local feedbacks, compete. This is the reason we first present, in the following section, results proving that Kirman's results for global externalities hold in this case: a parameter measuring the trade-off between indiosyncratic and locally coordinated behaviors has a critical value which differentiates two alternative kinds of economic landscapes (Krugman, 1994), i.e. diversified or structured *technological landscapes*. But, while doing so, we derive another crucial property; this being the existence and appearance of technological niches for which we provide economic explanations. If one wishes to derive such qualitative results – the probable appearance of niches – then the so-called "master-equation" approach is sometimes misleading and local models actually necessary. This, together

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[6] After Puffert's (1987) seminal work.

with some criticism we have already addressed to Arthur's (1989) global externality model of technological competition, leads us to suggest that such a modeling framework should be granted with a much larger set of applications. We indeed show that even global externalities can be modeled in this framework in a very simple way. We present simulation results showing that with both local and global externalities complete standardization obtains. All these results have important consequences for public policy issues which have to be adapted to different kinds of industrial landscapes.

3 A model and some consequences

3.1 Gibbs random fields[7]

Let A be a finite set of potential technological adopters, described here as sites on a network[8]. Each adopter (site) chooses between technologies (states). We use discrete time. At each step a randomly chosen adopter S reassesses his choice: we therefore introduce a probability distribution $P(S)$ (otherwise also called "local specification") which "determines" his choice. When S is a site (an agent), then $t(S)$ is the technology it has adopted. To elucidate the parameters on which such a probability depends, we introduce and define an agent's 'neighborhood' as the set of relevant economic agents with whom interactions or externalities exist. Then $P(S)$ depends only on S's neighborhood.

Many kinds of agents may belong to other agent's neighborhoods, these being other firms, or specialized magazines, or even a member of a state administration, or television, and so on. A neighborhood can be interpreted as a proximity relationship, but if and only if proximity is given an economic sense and not merely, as it is often done, a geographic one; spatial proximity is of course included in our framework, but together with proximity through other horizontal networks.

Since, by construction, $P(S)$ depends only on S's neighbors, P is a Markov random field. We further assume that P does not depend on S (i.e. it is translation invariant), and that idiosyncratic parameters and resources always matter, though sometimes faintly, in agents' choices, i.e. $P > 0$. This last property makes P a Gibbs field. As a consequence a very simple description is available for P, which is given by Theorem 1 below.

Theorem 1 (*Hammersley-Clifford*). *There exists H such that for any x*

$$P(x) = \frac{e^{-H(x)}}{Z} \text{ where } Z = \sum_{\text{all possible } y} H(y)$$

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[7] See Prum (1986) about the underlying mathematics.

[8] This model has previously been studied in Dalle (1992, 1994, 1995).

where x is a configuration i.e. the set of $t(S)$ for all S (the set of choices of the agents in the economy). Z is of course a normalizing constant.

For simplicity and to get strong results, let us further assume that agents (sites) are arrayed on a toric network: each adopter has 4 relevant neighbors, and neighborhoods are interconnected[9] (see Fig. 1). Agents 1, 2, 3, and 4 together constitute the neighborhood of agent S. Assume also that there are only 2 alternative technologies, represented by "1" and "−1".

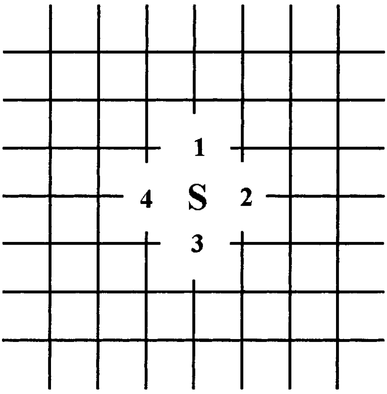

Fig. 1. A potential adopter and its four neighbors

As an immediate consequence of Theorem 1, this very simple model, which happens to be well-known to physicists – as the Ising model –, is characterized by Theorem 2.

Theorem 2 *Let α stand for a technology, there exists b such that for every S*

$$P(t(S) = \alpha) = \frac{1}{1 + \exp\left(-\alpha b \sum_{i=1}^{4} t(i)\right)}.$$

3.2 Local externalities and heterogeneity

From the above, we get the following result, which is also well-known to physicists:

Theorem 3 *There exists a critical value b_c, such that if $b < b_c$, both technologies coexist in on average equal proportions, and if $b > b_c$, there are two possible states where only one technology dominates, i.e. where standardization obtains.*

Below b_c, heterogeneity is strong enough for local externalities not to matter too much. In the limit case, when b goes to 0, externalities disappear

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[9] As David and Foray (1992) have shown, it is a critical property to study such diffusion processes.

and we get independent choices which produce equal market shares. Above b_c, externalities overwhelm heterogeneity effects and standardization obtains. The industry spends a lot of time in the standardization states but endogenous switches between technologies may occur from time to time. This result is of course very close to Kirman's (1993) result for global externalities. We therefore achieve the result we were looking for in section 1 as regards the results of both local externalities and heterogeneity in an aggregate model. The results of David (1988, 1992) and David and Foray (1992) appear as limit cases when b grows to infinity, i.e. when local externalities have such a weight that individual behavior and heterogeneity almost disappear.

The existence of a critical value that differentiates very distinct aggregate behaviors is called a phase-transition in physics. It is not a real surprise, since the critical point appear as the equilibrium point between positive feedbacks due to local externalities and negative feedbacks due to heterogeneity. But what is much more interesting in the "phase-transition" property is the very profound difference between the two regimes. Imagine that there is a way to go from b_- to b_+, such that:

$$b_- < b_c < b_+$$

Then the system goes *very quickly* and *for values of b very close* to b_c from the coexistence to the standardization regime. Another way to put this would be to say that the system is almost non-continuous for $b = b_c$. The existence of such a critical value is, however, still surprising, since economists have not been aware that quasi-discontinuity as a consequence of aggregation phenomena where all functions are continuous might occur.

If such a result was to be confirmed by further studies, it would be high time for economists to warn public decision-makers that uniform public policy instruments might soon become obsolete: standardization policies, for instance, are eligible when an industry experiences coexistence between alternative standards since benefits would be gained from more complete standardization. But in our framework here, the relevant parameter b obviously depends on behavioral and institutional parameters that vary from one industry to the other. For instance, sectors mostly composed of small and medium-sized businesses would certainly have very few internal R&D structures and would therefore correspond to a low b, since quality assessments of technologies would frequently come from neighbors; the probability of idiosyncratic behavior would be low, and the industry would be driven to standardization. On the other hand, large businesses often have internal R&D and the probability that they will decide which technology to adopt according to their own estimates is higher: coexistence will obtain.

As scholars have emphasized, the standardization or coexistence issue is a difficult one as far as public policy is concerned. We do not argue here that either one should be preferred, but only that different industries will have natural economic incentives, due to aggregation phenomena, to converge toward different equilibrium states. Even worse, since the phase transition is sharp, most industries will experience either almost perfect (see below) standardization or almost perfect coexistence. Uniform public policies might then give rise to some rather serious mistakes – and have perhaps already done so – if they continue to believe that, for instance, national decisions can apply in a uniform way to all sectors and industries in a given country. Sectoral, regional, and even district or world-of-production (Salais and Storper, 1993) policies are called for, or decentralized public agencies should at least be granted some freedom in the way they implement national policies. Economists still have to build a renewed theoretical apparatus where relevant parameters accounting for the relative strength of heterogeneity and interactions would be properly identified, so that correct predictions and well-adapted policies could easily be derived and proposed.

3.3 Appearance of technological niches

On the way to such an apparatus, another canonical property of local interaction models has to be emphasized, since it also has strong consequences both for the economic analysis of technological competition phenomena and for public policy decisions:

Conjecture 4 (Simulation): Figures 2 and 3 present typical shapes of the industry when b is below and above b_c, *respectively. In the standardization case, the "other" neglected technology seems to frequently survive in niches. We describe an industry as in Fig. 2 (respectively Fig. 3) as possessing a diversified (resp. structured) technological landscape.*

Economists have long known of the survival of technologies in niches. Such a property should not be restricted to spatial technological districts: as we emphasized above, proximity relationships do not necessarily need to be spatial. It is, for instance, now known that the Betamax standard for VCR has survived among video professionals. To take another more appealing example: contrary to what most people probably believe, vinyl records have not yet entirely been replaced by CDs. If you look carefully in your favorite music store, you will be able to find techno music vinyl records. Why is it so? Notably because DJs in night clubs are used to moving the record with their fingers to produce sound effects. It is obviously very difficult to do so with CDs. Thus a technological niche has appeared, since these people were numerous enough and also very often exchanging records. The proximity here is not spatial but professional, and landscapes, as they have been introduced to economics by Krugman (1994), are not only geographical but also technological; they are, more generally, economic landscapes.

While externalities tend to standardize technological adoptions, potential adopters are frequently heterogeneous enough for some of them to have specific consumption or production habits, which make them prefer the otherwise neglected technology. If they are in neighborhood relationships at the beginning of diffusion processes, then a critical mass (Schelling, 1978) can be reached which allows them to go on using their favorite technology, at least for a while. Our simulation results tend to prove than it often happens to be so, even with a relatively small amount of heterogeneity. To put it briefly, *the existence of a proximity dimension interrupts the pure selection process and allows options to survive*. This should not be a

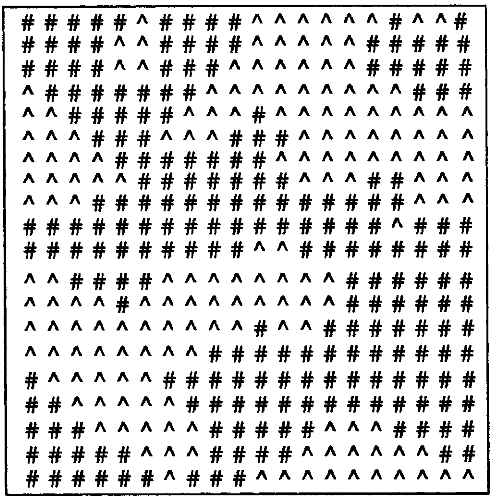

Fig. 2. Diversified technological landscape ($b < b_c$)

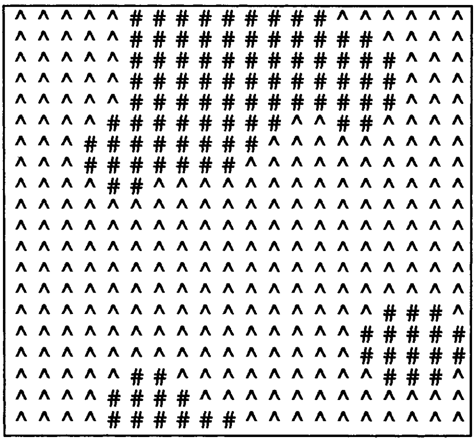

Fig. 3. Structured technological landscape ($b > b_c$)

surprising result for scholars of industrial economics, and specially for evolutionary economists, since the survival of rare and sometimes long disappeared species is widely observed and acknowledged in specific, in this case purely spatial niches.

Public decision-makers also should be aware that niches often appear due to pure market mechanisms; even neglected technologies do this way. Modern economics of technical change is concerned with the possible Pareto inferior outcome of technological competition processes, since suboptimal and less efficient technologies might be selected by market processes and become standards. As David (1987) points out, it is difficult for public decision-makers to correct such market inefficiencies since they are often "blind", i.e. unable to decide whether neglected technologies are better or not, due to an insufficient number of adoptions; it would be unrealistic to suppose that they possess better information than adopters do. If niches appear, then all alternative technologies will experience enough adoptions and if one of them, previously neglected, proves to be better, then market switches will occur[10]. As a consequence, public decision-makers should evaluate all existing information when they come to take decisions, and especially information coming from niches and particular industrial sectors. Policy aimed at promoting uniform standardization might sometimes have adverse effects and prevent superior technologies from re-emerging out of technological niches. To make this point clearer, we have to build a framework wherein both local and global externality would be present at the same time. But before we do so, and so as to justify why we will decide to adopt a rather counterintuitive method, we need to criticize a now almost classical way economists have chosen to deal with global externalities.

3.4 Two alternative methodologies

Only local externality models have been able to show that technological niches sometimes appear, and why they do so (they will perhaps tomorrow be able to explain how and when it is so). As we have emphasized above, Arthur's (1989) urn model proves that suboptimal lock-in states obtain during technological competition, and also that significant events occur during the early phases of diffusion processes. If this be so, and since we believe that the hypotheses are precisely irrelevant at the beginning of diffusion processes, global information about the market shares of competing technologies being not available at that time, then the conclusion is that significant events occur when the hypotheses are not valid. To put it differently, it is obviously too late when Arthur's model becomes adapted, since some very important phenomena occur when only local network externalities are relevant; here, the first adoptions that create local coordination phenomena out of which niches are sometimes born. Global externality models, such as Arthur's, miss this point, because they rely on unrealistic assumptions about the parameters which really matter at the beginning of technological competition processes.

Economists should then be well aware that the so-called master-equation approach (Weidlich and Braun, 1992), whose basic idea is to derive a global equation from a set of local specifications because it is much easier to handle, might sometimes be very misleading. This is an important point since previous work in this field has followed this approach, after Weidlich and Haag (1983) had imported this method from physics. Master-equation approaches tend to be very close to global externality models: the dynamics of particle systems with simplified and very simple master equations tend to be very close to those of Polya urns. The crucial point is that such an equation can mathematically always be derived, but is most of the time far too complicated for analytical resolution; approximations such as the "mean-field" hypothesis are therefore used. Blume (1993) has, for instance, used Gibbs potentials and local interactions in the field of game theory to derive very

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[10] We interpret in this line Foray and Grübler's (1991) empirical study, which shows that a technology for ferrous casting was "unlocked" from a particular niche where it had survived, since an innovation occurred and made it better than the dominant one.

technical conditions for the stationarity of distributions, which only become a little more intuitive to the economist when he happens to refer to the analytic resolution of the Ising model with the so-called "mean field" hypothesis[11]. Although it is well suited to prove the existence of a phase transition, this framework ceases to be adapted when the analysis comes to the derivation of local structural properties, such as the existence of niches. Even if they are more analytically tractable, master-equation and global externality models should not be used as approximations for local dynamics since they might lead to erroneous conclusions. The master-equation approach might often make us neglect some actual and vital economic properties[12]. It is therefore necessary to study properly appropriate local externality models, and it is not surprising that local dynamics might give rise to types of equilibria that global and master equation models fail to discover.

3.5 A local and global externality model

As a consequence, a major issue is to build an analytical framework with both local and global externalities to study, for instance, the influence of global standardization policies on the existence of local structures. We believe the model we have described above to be also relevant in dealing with both local and global externalities. We analyze now another situation where both local and fixed global externalities influence agents' choices[13]. We see no reason why global externalities should be considered as different from local ones, since they are felt locally by each potential adopter: their critical property is only that they influence *every* firm or agent. According to this, we assume that each adopter has the same fifth neighbor (see Fig. 4). The same global externality influences every agent, but is not to be considered by him as different from other local neighbors. We have therefore defined a sort of fictitious "global" agent who belongs to each agent's neighborhood and whose influence on the agent's decisions is not different from local externalities or interactions. Such an agent sometimes actually exists – a specialized review for assessments of the quality of available technologies, public agency choices for technological complementarity issues – and sometimes not – as for externalities which stem from price

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[11] The Ising model was solved using such an approximation, which states that each agent feels the influence of a fictitious mean-field whose value is the averaged sum of the states of all other agents in the population. Orléan (1990, 1992) has results for financial markets similar to Kirman (1993) and therefore similar to the ones we have presented in paragraph 3.2 above, which all make use of theorems proved with the mean-field approximation. See also Föllmer (1974) and Aoki (1996).

[12] To study local externalities, reference should not be made to the "master-equation" approach but rather to the tradition initiated by Shelling (1971) and afterwards followed notably by David (1988), David and Foray (1992) and Durlauf (1993), which focuses on local properties, and with which we feel in line in this article. Simulation studies become useful in this area since analytical results are no more at hand, such as in paragraph 3.3 above.

[13] Cowan and Cowan (1995) have an other model on the same issue.

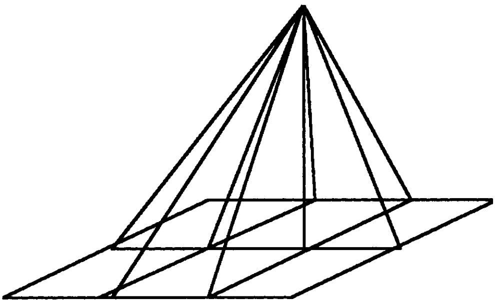

Fig. 4. All adopters have the same fifth neighbor

mechanisms or efficiency improvements –. Mathematically speaking, the probability of an agent choosing a technology is a function of local and global externalities, which is precisely what a "local and global" externality stochastic framework should be; this means only that a global parameter, be it an agent or not, is relevant for agents' choices.

Conjecture 5 (Simulation): In this framework, when global externalities are fixed on a given technology, then standardization always occurs (see Fig. 5). We describe an industry as in Fig. 5 as possessing a homogeneous technological landscape.

Only very small niches hardly appear in this case, thus preventing dynamic evolutions and technological switches. The influence of global externalities is so strong that technological niches cannot survive. Simulations prove that this property seems to hold even when agents are very heterogeneous; global externalities tend to reinforce local ones and drive the system into standardization states.

If this result were to be confirmed, at least two major consequences would derive for public policy. First, the classical distinction between de facto – through market mechanisms – and de jure – through law enforcements – standardization, as suggested by David (1987), would seem less

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Fig. 5. Homogeneous technological landscape

appropriate; public announcement effects, on future laws, for instance, will spontaneously produce de facto standardization, while publicized technological choices by public agencies would have the same effect. Public decision-makers have means to create standardization without any pure regulatory measures. De jure standardization exists, but is probably much rarer than it was thought to be. Second, referring back to paragraph 3.3 above, some public policies will make niches disappear, and renders "unlock-from" phenomena almost impossible. The system is locked-in, even if a very few number of "deviant" firms adopt the neglected technology, and will sometimes not reach its optimal equilibria if regulatory measures have sponsored one of the technologies too early. Diversified technological landscapes are clearly not statically socially optimal, since cost reductions due to standardization are not at all exhausted: public intervention might sometimes be necessary to correct such market inefficiencies. Such interventions are sometimes necessary, sometimes not, depending on the particular "shape" of the economy, i.e. on its particular technological landscape. However, some kinds of public intervention might create homogeneous technological landscapes, which happen to be statically optimal but dynamically not optimal, since the system is strictly locked-in. Early ex ante announcements and anticipatory standards, for instance, should be avoided for the economy to keep some possibility of further market exploration. It might also be a duty for any public agency not to intervene when structured technological landscapes with technological niches spontaneously appear: many empirical studies have proven the importance of regional or sectoral dynamics. It therefore becomes a major challenge to determine how to manage public interventions that would not destroy dynamic efficiency: different technological landscapes deserve different public policies.

4 Conclusion

New economic models are needed to allow economists to deal with the *many interacting and heterogeneous* agents that constitute populations of potential adopters of technologies. As a consequence, and although many more studies are needed to explore correctly the consequences of these models and to study new applications of the Gibbs field class, we have already been able to derive a few interesting properties. Notably, and depending on the existence of local and global externalities, three kinds of landscapes are to be encountered: *diversified* technological landscapes (Fig. 2), *structured* technological landscapes (Fig. 3) and *homogenous* technological landscapes (Fig. 5).

Industries have a landscape, i.e. they are driven by market forces to different kinds of orderly equilibria, with different properties due to characteristic parameters. We have emphasized the role of heterogeneity and externalities as opposing forces. Consequences for public policy issues are overwhelming: public intervention becomes a much more difficult matter than is usually thought. There happen to be many ways to correct market inefficiencies, which are not substitutable and which sometimes crucially depend on industrial landscapes and structures. The shape of particular economies should be taken into account more precisely than through a simple analysis of market shares, or else some policies might lead to mistakes.

More generally, it seems now that strange and non-intuitive properties can be found as a consequence of up-to-date economic models, such as phase transitions or dependence on parameters measuring the relative strength of heterogeneity of agents and externalities. Seemingly odd events – such as the appearance of technological niches – seem to sometimes obey strict mathematical rules. Structures are born seemingly out of nowhere, which durably shape modern economies. These properties, events and structures are now part of the economic landscapes: neither economists nor public decision-makers should ignore them if they wish to set up efficient theories and measures. It might be one of the renewed roles of economic modeling to help all these actors test and simulate the consequences of their tentative actions.

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