Why Novelty Is Essential for Economic Evolution – and Why It Is so Hard to Analyze

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abstract

The emergence of novelty is a driving agent in evolution. In the context of (evolutionary) economics, the introduction of new technologies, the implementation of new institutions, the spreading of new products and services, to mention just the most visible cases, are the backbone of development and growth. Despite its central importance, the emergence of novelty is largely a blind spot in economic theory – an indication of the notorious problems it poses. This paper tries to shed some light on both the difficulties that theorizing about novelty faces and some positive insights that seem nonetheless feasible.

I. Introduction

Novelty, in the sense of something not previously thought or experienced, is a pervasive feature in science, technology, and cultural and economic life. New ideas of acting challenge our ambitions and desires, inventions result in new artefacts, innovations trigger waves of new commercial opportunities and actions. Man-made novelty of this kind fuels competition, structural change, and economic growth. These developments, in turn, can generate (often unintended) collective historical outcomes not previously experienced – a kind of novelty of its own. The latter is often the motive for innovative political responses inducing regulatory and institutional change. As a matter of everyday life experience these phenomena are so obvious that they do not need to be documented here.

What can be said about novelty, this ubiquitous agent of change? Where does it come from? In which way is it created? How can the fact be dealt with that, by its very nature, novelty is something unpredictable? These rarely addressed questions seem to touch on the epistemological bounds of our thinking. They challenge theorizing about novelty as much as not yet known novelty challenges decision making in science, technology, politics, and the economy. Given the enormous impact novelty has, it seems warranted to take a closer look at the nature of novelty.

Man-made novelty occurs in many forms and guises. If it is not the result of accident or arbitrary coincidence, its ultimate source is the creative activity of the human mind. As would therefore be expected, many insights relating to how novelty emerges have been provided in the vast literature on human creativity (cf., e.g., Sternberg 1999). Many relevant aspects have also been investigated in cognitive science and linguistics, e.g. in the rich work on the formation of cognitive concepts (cf., Hofstadter e.a. 1995, Fauconnier and Turner 2002). Furthermore, there is the long tradition of research in history into how inventive thought has revolutionized science, technology, and the economy and still does so (Usher 1954, Vincenti 1990, Mokyr 2002 to mention just a few). Yet, all these different strands of thought have not directly focused on, and did not result in, a systematic account of novelty and its abstract properties. One of the reasons for this neglect may be the problems implied by the very nature of novelty.

With respect to the point in time at which novelty emerges and reveals its meaning, theorizing about novelty can be done from two alternative perspectives: from an *ex ante* and an *ex post* point of view. The epistemological difference is that, in the first case, novelty is synonymous with something "unknowable" while, in the latter case, it is synonymous with something "not previously known". Distinctions similar to these have often been suggested (Machlup 1980, Chap. 8, Witt 1993, Boden 1999). Yet, their epistemological implications, that complicate the scientific analysis of novelty in a characteristic way, have rarely been addressed. As far as novelty created in the human mind is concerned, there is an additional problem. The explanation of how it emerges hinges critically on what happens in our mind when we think, experience, or do something new. Despite considerable progress in the past, these mental processes are still far from being known. The act by which new meaning, or semantic content, is created is neither well understood (not to speak of the underlying neuronal processes in the brain, cf. Koch and Crick 2000, Edelman and Toroni 2000), nor can its outcome be predicted.

The emergence of novelty is thus hard to analyze. In the present paper an attempt will be made to better understand the underlying problems, to explore possibilities for dealing positively with novelty, and to figure out some methodological consequences that follow for economic theorizing from the fact that novelty emerges within the economic domain. Section II suggests a procedural approach to novelty that distinguishes between different operations involved in the creation of novelty. The distinction helps to understand what happens in the human mind when novelty emerges and what limits there are to emulating the activities outside the human brain. Section III discusses on this basis where precisely the novelty-induced conceptual and epistemological problems reside and proposes to distinguish between pre-revelation and post-revelation analysis to account for the problems in economic theorizing. Section IV turns to the two-way relationships between novelty and dynamic modeling. In the one direction the question is how the emergence of novelty can be accounted for in modeling economic processes. In the opposite direction one can ask what role dynamic models can play for explaining the emergence of novelty. Section V addresses the problem of causality that has sometimes been considered unsolvable with regard to novelty. It is argued that causes exist, but that there is a difference between causes for the emergence of novelty and causes for the specific content of the emerging novelty . Section VI offers the conclusions.

II. How Novelty Is Being Created

The imagining and the discovery of novelty is the result of an inductive mental act in the human brain (Knight 1996). If it informs and motivates new action, this is an input to the transformation of economic reality that comes from within the economy and, hence, is an endogenous source of change. What can be said more specifically about that creative, mental act? It has often been argued to be some form of recombinatory, inductive logic. In his treatise on the act of creation, Arthur Koestler (1964, Part II) refers to a large number of proponents of such a combinatory principle and provides several compelling examples. By a more or less accidental displacement of attention to something not previously noted, he claims, new elements are entered into a given context with which they have not been associated before. Although they come from a different frame of reference, the new elements are in some way similar to the familiar elements, so that a cross-over or recombination becomes feasible. Identifying a previously hidden analogy – an act which Koestler calls "bisociation" – gives rise to the discovery of novelty.

It is indeed important to note that recombining some elements is not sufficient to arrive at novel insights. An element that is drawn, perhaps accidentally, from a different context and therefore represents something foreign to the given context does not induce a new meaning unless the difference is alignable with the given context (Gentner and Markman 1997). Only if the conceptual inputs to be blended have some kind of similarity, some common element, their non-common elements can be integrated in an associative act into a new, meaningful concept (Fauconnier and Turner 2002, chap.3). Whether or not there is some kind of similarity is, of course, a matter of conceptual judgement that needs to be exerted independent of the actual recombination. Often the similarity criterion is implicitly ensured by admitting only sufficiently similar input sets or input spaces to the recombination. [1]

As long as the similarity requirement is satisfied, the recombination – or, more generally, the generative operation – can, in principle, be done by any arbitrary device. The integration of what is newly recombined into a newly emerging, meaningful concept requires an interpretative operation. In the human mind, generating recombinations and interpreting them may factually coincide. From an analytical point of view, however, these are two logically distinct operations: a generative and an interpretative operation. The logical difference between them can best be demonstrated by a semantic representation. At the semantic level we can take advantage of our capacity to spontaneously recognize similarity and difference and to intuitively grasp the induced new meaning.

Consider cognitive concepts which are so simple that they can be represented by sentences with just a subject, a predicate, and an object, for instance, the two factual statements: "hair grows in tufts" and "hair can be cut by clippers". The two statements have the subject "hair" in common. In cognitive psychology, such statements, sharing a concept indicated by the same subject, are taken as representations of what is called "propositional networks" (Anderson 2000, chap. 5). The structure of the propositional network can be denoted more formally by

grows in tufts

(i) *hair*

can be cut *by clippers*.

Propositional networks like (i) are used to encode conceptual knowledge that people associate with a cognitive concept like "hair". If people are given such a concept, they start associating several things connected in their memory with the concept. If people are given another concept, say "grain", and are asked to come up with what they associate with this concept, it may happen that the result are the factual statements "grain grows in tufts" and "grain can be cut by scythes". The corresponding propositional network would be

[1] Because of the conceptual judgement that discriminates between cognitive inputs, the recombination device, despite its arbitrariness, does not produce "blind variation" as is sometimes assumed (see, e.g., Campbell 1960)

grows in tufts

(ii) *grain*

can be cut *by scythes*.

The propositional networks (i) and (ii) have a certain similarity. More specifically, the syntactic structure is identical, and they share the elements in italics. The recombinant, generative operation then means to use the common elements as the basis to recombine the non-common ones (put in italics). Thus, exchanging the subjects "hair" and "grain" for each other in (i) and (ii) results in two new combinations: "*grain* can be cut *by clippers*", and "*hair* can be cut *by scythes*". As mentioned before, the interpretative operation has to be left to our intuition that, in this case, tells us that the latter statement appears rather nonsensical. Not so, however, the former. Here the common element seem to allow a conceptual integration. As a matter of fact, this association is said to have inspired McCormack's invention of the mechanical reaper (Martindale 1999).

For logical completeness it should be mentioned that the original statement "*grain* can be cut *by scythes*" is not invalidated. The newly created statement can therefore be combined into what will be called here a combinatory extension of the form

(iii) "*grain* can be cut *by scythes and clippers*".

The fact that meaningful recombinations often result in combinatory extensions is important for understanding the relationships between novelty and the extension of knowledge.

Independent of their meaning, any two different propositional networks like (i) and (ii) satisfying a formal similarity requirement can be recombined in a similar way. Hence, the generative operation itself requires no semantic knowledge. It is an arbitrary procedure and can easily be imagined to be carried out mechanically or by alpha-numerical algorithm laid down in a computer program. However, carrying out the generative procedure -- whether mechanically or electronically -- is but one and, in fact, the easier part of the problem. What is lacking is a way of discriminating between combinatory extensions that do make sense and those that do not. This is the interpretative operation by which conceptual similarity is identified and semantic meaning or sense is attributed. What can be said more precisely about the interpretative operation that in the above example has been left to be carried out by our intuitive comprehension?

As mentioned, both cognitive science and creativity research are not yet able to provide a detailed explanation of how the human brain's spontaneous associative activity works. In cognitive science it has been speculated that the associative act is a search process in an extremely high-dimensional memory space (cf. Kohonen 1987). In that space connections are traced to concepts which have been laid out by earlier experience. The stored concepts, it is argued further, are sampled with a probability derived from ranking how closely earlier stored concepts appear connected to the new concept under consideration. This would mean that the new combinations are exposed to a test of coherence with already existing cognitive concepts in the sense of determining how close to each other they are in the relevant dimensions. However, a notion like that critically hinges on a metric of closeness in a semantic space which, it seems, could not yet be established.

Because of these problems, there is no way to carry out the intuitive attribution of meaning by some artificial device outside the brain. To do so in the form of a computer algorithm, say, would require being able to handle the complexity of a myriad of selectively activated neural nets – something which is presently out of reach (cf. Edelman and Toroni 2000, chap. 10). For this reason, unlike in the case of the generative operation, the interpretative operation cannot presently be transferred to non-human intelligence, not to speak of any device by which its outcome could be predicted. Instead, what is needed for the interpretative operation to be applied to some, probably artificially generated, combinatory extension is the *in vivo* carrying out of associative act by a human observer.

III. Novelty-induced Bounds of Unknowledge and the Methodological Consequences

Speculative imaginings that have emerged from recombinations as discussed in the previous section often precede inventions and discoveries. More or less vague, or even erroneous, new ideas may inspire and motivate people to search for turning their visions into reality – McCormack's invention of the mechanical reaper being a case in point. However, the induced search processes often transcend the sphere of the individual and become an object of collective efforts. Unlike the very conceiving of novelty, its further use and practical application may employ a whole population of agents who have somehow learned about a new idea. In logical terms, when the information about novelty spreads out, this is, of course, no longer the emergence, but rather the dissemination of novelty. For each single agent encountering the artefact or idea for the first time, it may then feel like a discovery or experience of novelty. This fact connects to the already mentioned asymmetry in viewing novelty *ex ante* and *ex post*. The asymmetry implies that there are actually two epistemologically different kinds of novelty.

An agent exposed to something for the first time that has been known to other people before, encounters novelty only relative to her current state of knowledge. This kind of novelty can be classified as subjective or psychological. If, in contrast, an agent encounters novelty which no one else has ever experienced before, then this is novelty in an objective or historical sense. From an epistemological point of view there are significantly different constraints to theorizing about subjective novelty on the one hand and objective novelty on the other. In the case of subjective novelty, other people, including, perhaps, a scientific observer, already hold some knowledge about the properties and implications of that particular novelty. On that basis, it may be possible to formulate hypotheses about, e.g., the reaction patterns of the agents to be exposed to that novelty.

Indeed, this is common practice in diffusion research (cf. Rogers 1995). In the case of objective novelty, in contrast, there is nobody – not even a scientific observer – having any experience on which theorizing about future objective novelty could be based.

What implications do the epistemological constraints – the "bounds of unknowledge" as Shackle (1983) put it – have? One consequence is that in all scientific domains in which novelty can emerge all predictions and projections are contingent on the possible intervention of the yet unknown, newly generated novelty. Obviously, this contingency hampers the predictive power in scientific disciplines in whose domains novelty is a generically occurring feature. These are, in particular, the evolutionary sciences facing endogenously generated novelty. (Evolution can in abstract terms be characterized generically as a self-transformation process driven by the emergence and selective dissemination of novelty within a certain domain, see Witt 2003). For example, the potential emergence of genetic novelty makes it impossible to predict the future course of evolution in evolutionary biology. Likewise, the potential creation of mental novelty constrains the ambition to predict cultural, scientific, or economic developments.

However, regarding the scientific practice, the contingency on non-predictable novelty may not always be equally relevant. In dealing with the explanation of phenomena and conditions involved in, or relating to, the creation of novelty, the fact that the meaning of novelty cannot be anticipated is a crucial constraint. When it comes to explaining the consequences and effects caused by a particular novelty that has emerged it may, in contrast, often seem justified to assume that the information content or meaning of that novelty has already fully been revealed. The difference, again relating to the *ex ante* vs. *ex post* asymmetry, suggests to distinguish between two forms of analysis: *pre*-revelation and *post*-revelation analysis. At the methodological level, the difference between the two is significant.

In post-revelation analysis it is usually assumed that te scientific observer knows all relevant properties the novelty under consideration. If, in addition, it is assumed that no further novelty will intervene in the post-revelation analysis, the epistemological constraint is factually eliminated. (The occurrence and revelation of the particular novelty considered is shifted to the antecedent conditions.) Most diffusion theories dealing, with the adoption of subjective novelty make these assumptions – often tacitly. These are, of course, simplifying assumptions that may be counter-factual. Very often important implications of some particular novelty are discovered only with significant delay. Harmful side effect of scientific and technological innovations that become evident only years or even decades after their large-scale introduction are cases in point. Similarly, the no-further-novelty-intervening assumption is often illusionary, particularly in the domain of evolutionary theories where the generation of novelty is endemic and often even triggered by novelty that has occurred before. Thus, the predictive strengths of post-revelation analysis is a contingent one. Pre-revelation analysis does not hinge on such provisos, but its power obviously suffers from the lack of predictability.

IV. Novelty and Dynamics

The methodological consequences of novelty discussed so far seem obvious. Nonetheless, they are often not recognized and accounted for when dynamic models are used in disciplines like economics in which the generation of novelty is a ubiquitous feature. The notion of dynamics is originally an outgrow of the Newtonian physics of celestial bodies where novelty has no role to play. With its selective interest in patterns of convergence to unique equilibria, i.e. states of rest, of gravitating systems this approach focuses on difference or differential equations that allow to derive all implications analytically once the specification and the initial conditions are known. This "closed" version of dynamics is extended to the economic domain in the theory of general economic equilibrium. The fact that novelty frequently occurs in economic context is neutralized, first, by treating the emergence of novelty as an "exogenous shock", i.e. an unexplained effect disrupting the equilibrium state from outside. Second, it is claimed that this kind of economic theorizing is concerned only with the price system's capacity to return to the state of general equilibrium after exogenous shocks of whatever origin (Fisher 1983).

Taking such a restricted view on theorizing in economics has often been criticized, particularly by authors who focus on economic change and consider innovations central to its understanding (e.g. Nelson and Winter 1982, Chap. 2). When it comes to modeling economic change, the critics also make use of dynamic models (differential or difference equations), of course. The goal is not to analyze the stability conditions of unique equilibria but the out-of-equilibrium features of the processes of change. On a closer inspection it turns out, however, that the nature of the models used in the two cases and the kind of dynamics they represent are not really much different. Some examples may support this assessment.

A first example is the analysis of diffusion or adoption processes of innovations (see Metcalfe 1988). The basic idea here can be put as follows. The utility that can be derived from adopting an innovation, and hence the agents' probability to adopt, systematically change with the number of adopters. The quality or versatility of an innovation may, for example, decline with a rising relative frequency of adopters. Or the individual competitive advantage accruing from an innovation may fade away as more competitors in the market adopt the innovation too. In more abstract terms, this is the logic of a frequency-dependency effect (Witt 1997). It can be captured by the simple function $q(t) = f(F(t))$ that maps the relative frequency of adopters $F(t)$ at time t (via the implicit utility assessment) into the probability $q(t)$ that an agent who decides in t will adopt the innovation. As long as $q(t) > F(t)$ the expected relative share of adopters grows and vice versa.

Obviously, the shape of function f determines what happens during the diffusion process. For example, in the case of a quadratic specification $q(t) = aF(t) - aF(t)^2$, with $a > 0$, $F(t)$ grows to an upper bound F_a, $0 < F_a \leq 1$, that depends on the size of a. The expected change of F over time can be approximated by $[F(t + \Delta t) - F(t)] / \Delta t = q(t)/m$. Let the number m of potential adopters be very large. Inserting the quadratic specification above and taking the limit then results in

(1) $dF(t)/dt = \alpha F(t) - \alpha F(t)^2$,

with $\alpha = a/m$. By integration of eq. (1) the diffusion path can be shown to follow an S-shaped logistic trend as it has been associated with the diffusion of innovations since the seminal study by Griliches (1957).

A second example for modeling out-of-equilibrium dynamics are selection processes. Selection can be assumed to operate, e.g., on cost differentials between competing firms that result if some of the competitors innovate (see Metcalfe 1994). Consider a competitive market with a uniform price p(t). Let $s_i(t)$ denote the market share of firm i = 1, ..., n at time t measured in terms of output. The average level of unit cost in the industry is given by $c(t) = \sum_i s_i(t) \cdot c_i$, where c_i is the constant unit cost of firm i. Because in a competitive market p(t) = c(t), the average profit (per unit) in the industry, $\pi(t) = 0$. For at least one firm i, however, the individual profit $\pi_i = p(t) - c_i > 0$ unless the entire market is served by the firm with the lowest level of unit cost. Now let the change of the size of firm i over time be expressed by the increment of its market share $ds_i(t)/dt$. Assume furthermore that the latter is a monotonic function ϕ of the firms' profit per unit – the very core of the selection analogy – weighed by its market share. After trivial transformations one then obtains

(2) $ds_i(t)/dt = \phi\,(c(t) - c_i)\, s_i(t) = \phi\,(\pi_i(t) - \pi(t))\, s_i(t)$.

Eq. (2) is a "replicator equation" (Hofbauer and Sigmund 1988, Chap. 16). Analogously to the natural selection argument it states that the performance differences between firms (fitness differences between reproducing organisms) translate into a corresponding differential growth rates across the firms (differential growth rates of the corresponding gene frequencies in the population).

From a purely formal point of view the diffusion model (1) and the selection model (2) have basically the same structure as the Walrasian auctioneer model in general equilibrium economics (for a discussion see Joosten 2006). The latter represents the out-of-equilibrium price adjustment dynamics by

(3) $dp_j(t)/dt = g\,(x_{dj}(\mathbf{p}(t)) - x_{sj})$,

where p_j denotes the price of commodity j = 1, ... k, $\mathbf{p}(t)$ the price vector for all k commodities, x_{dj} the demand for, and x_{sj} the (fixed) supply of, commodity j. (The excess demand function g is assumed to be a sign preserving function with $g(0) = 0$).

In the equations (1) - (3), the time increment of the dependent variable (the adopter frequency, the firms' market share, the price of a commodity) is made dependent on a measure for the distance from a state of rest which is characterized by the right-hand side of the equations taking the value 0. This means that all three models are based on the same "closed" version of dynamics that is good for analyzing the convergence to equilibria. Since they cannot deal with the emergence of novelty or, for that matter, innovations, they have to take them as given. Hence, even though they do not declare the generation of novelty/innovations an exogenous shocks, diffusion and selection models factually relegate the emergence and revelation of novelty to the antecedence conditions.

Moreover, they assume that no further novelty emerges during the convergence process. These are all the assumptions of post-revelation analysis, and it is this what the diffusion and selection models do – all mentioned contingencies included

Something similar also holds for more sophisticated stochastic, dynamic models with multiple equilibria that are used to model the diffusion of competing innovations. The question here is which of the multiple equilibria will eventually be reached. The new feature is that the answer depends not only on the specification and the initial conditions, but also on the random influences the actually realized trajectory is subject to. This condition has been called the "path-dependence" of such processes (Arthur 1994). Suppose that, unlike in the former diffusion model, there are two variants or standards of an innovation that serve the same user needs and therefore compete in their diffusion. Assume further that for each of the variants, the users' utility rises with the number of adopters. Such "increasing returns to adoption" have been found for, e.g., electric current transmission, video recorder systems, or the layout of typewriter keyboards (David 1985). In more abstract terms this is but the frequency dependency effect $q(t) = f(F(t))$, except that it now affects the rivaling innovations inversely: q(t) now denotes the probability of adopting the first variant, F(t) its share of adopters, and 1-q(t) and (1-F(t)) the respective values for the second variant. [2]

The simplest way of expressing a frequency dependency effect with this features is a cubic specification of the function *f*, i.e. $q(t) = 3F(t)^2 - 2F(t)^3$. With the same approximation for the change of F(t) over time as before, this results in

$$(4) \qquad dF(t)/dt = \beta F(t)^2 - \gamma F(t)^3,$$

where F(t) in eq. (4) is now the mean value and $\beta, \gamma > 0$, $\gamma/\beta = 2/3$. Suppose both variants become available simultaneously and offer the same inherent benefits. Hence, $q(0) = ½$ and $F(0) = ½$. Once $F(t) \neq ½$, increasing returns to adoption raise the individual adoption probability more than proportionately for one of the variants. The realization of the stochastic diffusion process *F*(t) initially fluctuates around ½, but small historical events and cumulative random fluctuations drive the process in the direction of either F = 0 or F = 1 where the first or the second variant are gradually disappearing respectively. In fact, for $t \to \infty$ the process will be "locked in" to either the one or the other attractor with probability 1 (Arthur, Ermoliev, and Kaniovski 1984). This means a more complex convergence process but still a version of the "closed" dynamics. Not surprisingly, the typical assumptions of post-revelation analysis can be found: the emergence of novelty – in this case the two competing innovations – is relegated to the antecedence conditions; no further novelty is assumed to emerge during the convergence process.

While so far the consequences of the emergence of novelty for modeling economic processes have been discussed, non-linear dynamical models can conversely also be used to generate novelty

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[2] Thus, the tail probability/tail frequency do not, as in the diffusion model before, denote the probability of not adopting / the relative frequency of non-adopters. Agents who refrain from adopting any of the rivaling variants are not considered. For a discussion see Witt (1997).

– provided they are sufficiently complex. The most simple example is the Verhulst equation

$$(5) \qquad F_{t+1} = 4\,\lambda\,(1 - F_t)\,F_t\,,$$

with $0 \leq F \leq 1$, $0 < \lambda \leq 1$. Formally, this is the discrete analogue to eq. (1) with, however, much more complicated dynamics: for parameter values $0.8924864 < \lambda < 1$, the trajectories generated by eq. (5) result in "deterministic chaos". [3] This means that the time series resulting from initial conditions in the critical parameter range show no regular features any more. Put differently, the precise coordinates of the dependent variable in the phase space after a certain number of iterations can only be determined by carrying out the iterations. Indeed, the particular coordinates after the n-th iteration is the novel information content that can be claimed to emerge here. [4] Obviously, in comparison to the case of novelty emerging in the recombination of semantic content in Section II, novelty emerging from eq. (5) has a different quality.

This becomes clear also by considering the generative and the interpretative operation that are at work in this case. The numerical iteration of eq. (5) can be seen as a generative operation, albeit one with a much simpler structure than the recombinant extensions discussed in Section II. Since an equation like (5) implies a binding interpretative context for the outcome of the generative operation, the interpretative operation does not have to be left to the associative act of the human mind. It can even be carried out before the generative operation and results in constraints for what the emerging novelty can mean. (For example, it can trivially be anticipated that whatever path the dependent variable will take, the phase space will be constrained to the unit box.) Hence, in this case, constraints can be specified in the pre-revelation analysis by which a significant extent of the information content of the emerging novelty can be anticipated.

However, by slightly changing the question, the constraints that can be imposed in the pre-revelation analysis may lose their relevance, and a situation returns in which the outcome of the interpretative operation can no longer be anticipated. In the case of higher-dimensional, chaotic dynamical systems, for instance, it may still be possible to pre-specify the constraints on the phase space. Yet, it is not possible to anticipate whether the iterated generative operation will produce recurrent patterns– called "strange attractors" (Ruelle 1989) – in the trajectory and, if so, how they look like. These are questions that still require an interpretative operation to be carried out *in vivo* in the mind of the researcher who tries to identify patterns in the trajectories after the generative

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[3] Variants of eq. (5) have been applied in economics, among others, to business cycle theory and the theory of economic growth (e.g. in Day 1982, Baumol and Behabib 1989). However, these economic applications do not focus on the capacity of a dynamic systems like this to generate novelty, but on their behavior over time as a possible explanation for the out-of-equilibrium dynamics of economic time series.

[4] Since the novel features of deterministic chaos were discovery of the 1960s (see May 1976), to speak about "novelty" in this context means to take an *ex post* perspective on what was then historical novelty.

operation has been carried out.

In principle, thus, the analysis in the previous sections of how novelty is being created also applies to simulation-based methods of producing novelty. Indeed, as already mentioned, even the recombinant, generative operation can be based on such methods, e.g. the inductive cross-overs numerically executed by genetic algorithms or, more generally, evolutionary algorithms (Bäck 1996). These algorithms also include a pre-specified interpretative operation that usually mimics numerically a selection environment, i.e. picks those generated variants for further recombination that meet a certain fitness criterion. The criterion may be pre-specified in which case a convergence process to a local fitness optimum results. (This feature is exploited when evolution algorithms are applied to complex optimization problems.) Yet, the selection environment and its criteria may also be allowed to change endogenously. In that case, an artificial co-evolution of the generative and interpretative operations is possible that does generate novelty (Markose 2005), though the result may not necessarily be meaningful by the standards of the human mind.

V. The Causality Problem: Novelty Emergence vs. Novelty Content

The discussion of the nature and role of novelty in this paper has been based on three hypotheses: first, that novelty emerges endogenously in the economy; second, that economic novelty is to a significant extent the result of human creative acts; third, that the emergence of novelty is, thus, a caused event. All three hypotheses have been contested by Hodgson (1995; 1999, Chap. 6). He raises objections to the idea of endogeneity of novelty, to the possibility of tracing its origins back to the activity of the human mind, and to the underlying notion of a cause for the emergence of novelty. It seems appropriate, therefore, to discuss the hypotheses and their counter arguments in more detail now.

Endogeneity vs. exogeneity of the cause of an event like the emergence of novelty are concepts defined relative to an explanatory domain, for example that of the economy. Usually, the state of the economy is explained by (or causally attributed to) the constraints it faces and the individual choices responding in the past and present to those constraints. In the sense in which man-made novelty – originating from the creative activity of the human mind – is a facet of the agents' behavior just as their choices are, its cause is endogenous to the explanatory domain of economics. Hodgson (1999, Chap. 6) finds this notion of endogeneity problematic (probably because he rejects the attribution of the cause to the individual level) and suggests instead a distinction between open and closed systems. However, whether or not a system is an open one is not independent of the endogeneity or exogeneity of the emergence of novelty. Let the economy be interpreted as a system. It is then precisely the capacity to endogenously generate novelty that is sufficient for the economy to qualify as an open, more specifically an evolving, system. In this point it differs from, say, the system of celestial bodies, on which Newtonian physics focuses, that lacks such a capacity.

The second point raised by Hodgson (ibid.) relates to historical novelty like the clash of institutions or wars – events that result from collective action as an often individually unintended outcome. Hodgson doubts that such kind of novelty can indeed be traced back to creative mental acts of individuals. It is true that such historically unique events, not been experienced by someone before, indeed fit the above given definition of objective novelty. It is also true that objective novelty can emerge in different ways. There may be truly exogenous causes like weather fluctuations, natural disasters, etc. As far as the endogenous causes are concerned, however, they can indeed be assumed to have their origin in earlier introduced novel behavior. Even if, say, the sudden collapse of an institution (e.g. a bank) can be attributed to the formation of a critical mass of agents openly distrusting the persistence of the institution, the very formation of this critical mass may ultimately result from innovative moves and strategies of some agent(s) involved. [5] The causation discussion connects here to the problem of unintended collective outcomes of individual activities and that can be decided in a similar way as that problem. The beginning of the complex causal chain eventually resulting in a novel collective outcome may indeed be assumed to be a creative act of some agent(s) involved that leads to new forms of behavior.

Hodgson's third point relates to the question of whether the creative activities of the individual minds have themselves causes and, if so, what causes. Hodgson (1995; 1999, Chap. 6) claims that the emergence of novelty is a case of an "uncaused cause". While it may not be compelling to assume that novelty is uncaused, [6] it does seem useful to introduce another distinction. Consider a particular novelty, for example the invention of a punch card based mechanism for electro-mechanically tabulating and sorting information by Herman Hollerith in the 1880s. [7] One may ask what the causes are for this particular new combination of elements: punch cards, coding numbers by a specifically placed hole on the card, and a mechanical reading device using spring-mounted needles that, while passing through the holes, make an electrical connection. This is the question of what causes the novelty's specific information content. A different question one may ask is what caused Hollerith's invention, i.e. what the causes for the emergence of that novelty are. As far as the first question is concerned, it has been mentioned in Section II that the associative act underlying the interpretative operation in the human brain is still little understood. What causes the specific information content of some particular novelty is therefore difficult to say even *ex post*. There is no indication, however, that there are no causes in the complex neural activities for their outcome.

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[5] See, e.g., Kuran (1989). The underlying hypothesis is that of a frequency-dependency effect in opinion or belief formation. Once sufficiently many people express their distrust, this is assumed to induce a rising number of former supporters to loose their faith in the persistence of the institution (Witt 1989).

[6] Hodgson (2004, Chap. 3) himself does no longer uphold this claim – without acknowledging, however, the systematic relevance of the causes at the individual level and the endogeneity of novelty that follows from these causes.

[7] For details see Kistermann (1991). Hollerith's invention was commercially exploited by his Tabulating Machine Company, later sold the Computer Tabulating Recoding Company renamed in 1924 into IBM.

In contrast, there are causes for why novelty emerges that are not affected by the limited insight into the neural activities. These causes relate to the fact that, as in the case of Hollerith's invention, man-made novelty is very often the result of active search and experimentation. Where novelty emerges as a result of such activities, the causal question refers to the motivation with which these activities are undertaken in the first place. These causes can be explained in terms of a behavioral theory that is economically relevant but not itself a theory of economizing (optimizing) behavior. Because the binding bounds of unknowledge, people are prevented from knowing in advance what time and effort will produce what result. Hence, they cannot determine an optimal amount of time and effort going into search and experimentation. The optimization hypothesis, as any other hypothesis in which individual motivation is explained by an expected outcome, is unsuitable – except it is assumed that people have illusions regarding the possibility of anticipating the necessary information. Hypotheses avoiding such an assumption can refer to the individuals' past or situation as motivating search into the unknown. Such hypotheses are well known in economics.

One of them is associated with the long established concept of "satisficing" (Siegel 1957, March and Simon 1958, Chap. 2). According to this hypothesis, it is dissatisfaction with the status quo, relative to an agent's aspiration level, that provides the motivation for, and determines the amount of time and effort going to, search and experimentation. The current aspiration level is subject to adjustments that reflect earlier successes and failures in the attempt to reach previously valid aspiration levels. Consider an event - perhaps a competitor's innovative activity - that negatively affects the alternatives feasible for the agent. Assume that the best choice available to the agent after the event is inferior to the best one before. Such a situation usually violates the current aspiration level. Accordingly, the satisficing hypothesis would predict that a motivation to search for new, not yet known, choices is generated even though it is not known whether the search will be successful. The motivation to search declines the longer the search is continued without a successful novelty has been found, because the aspiration level declines. The latter may eventually converge to the best option presently feasible and the motivation to search thus fades away. If, on the other hand, search turns out to be successful, in the sense that an option better than the best one presently feasible is discovered, then the aspiration level will increase to this new level.

The other hypothesis offering an explanation for the motivation to search for yet unknown outcomes suggests that experiencing novelty as such is a rewarding experience (see Scitovsky 1976). This motivational force is related to the disposition of curiosity. It means to assume a preference for novel mental or sensory stimuli that again hinges on the present situation of the agents. More specifically it varies with the degree of relative deprivation: the more boring a life otherwise is, the more the novel stimuli are appreciated and, hence, longed and searched for. Where the environment does not offer such stimuli (or not enough of them) the agents may be motivated, with the usual inter-individual variance, to create them by inventing and/or trying something new.

The two motivation hypotheses are complementary. However, the causes for searching and coming up with novelty are different. In some cases they may coincide (as can be speculated for the case of Hollerith whose family background may have induced a high aspiration level and a strong technological curiosity in him, see Austrian 1982). In other cases, the conditions under which they become relevant differ. The satisficing model suggests that search for novelty is typically triggered in situations of challenge or crisis (these may be anticipated crises). The preference-for-experiencing-novelty hypothesis predicts a short-term fluctuation of this preference between deprivation and satiation so that novelty is sought with a, perhaps rather low but constant, basic rate. Taken together, individual novelty creation can be expected to take place at a basic rate independently of the specific time and place, but to increase significantly beyond this rate in situations of challenge and crisis. At a social or organizational level, selective reinforcement in the one or other direction channels innovativeness and may foster, or impede, the individuals' creation of novelty.

V. Conclusions

The emergence of novelty is a major driving agent in economic development, but it is difficult to analyze. In this paper an attempt has been made to identify where the problems are, what basis there is for a positive theory of novelty, and what methodological consequences follow from the emergence of novelty for economic theorizing. Novelty has been defined as thinking or experiencing something not previously known. The discussion focused on objective (as opposed to subjective) novelty. In the emergence of novelty two logically distinct operations, a generative and an interpretative one, were distinguished. In the generative operation, it was argued, conceptual input (the epistemic base of novelty) are recombined. More specifically, these input sets were expressed by propositional networks that have to satisfy certain similarity criteria. It was shown that, if the recombined elements can be integrated, meaningful combinatory extensions of the original propositional networks emerge. The integration itself is done by the interpretative operation that, at present, is not well understood. However, the insights that are possible suffice already to better understand the generic features of novelty and the epistemological and methodological consequences that follow from its emergence.

The fact that the inductive logic of interpretative operation is not accessible results in an epistemological constraint on theorizing about the emergence of novelty. The practical implication is a constrained predictive power of all scientific disciplines in whose domains novelty is a generic feature. In the case of universal laws of nature (which are supposed to be invariable and independent of whatever novelty will occur), laws of motion may exist whose features can be captured by dynamic systems with uniquely a priori determined solutions. Something similar cannot be expected where the emergence of novelty is a constitutive part of the course of events as in disciplines dealing with evolution. The potential emergence of genetic novelty makes it impossible, for example, to predict the future course of evolution in evolutionary biology. Because of the human inventive capacity and the strong incentives to use it, the creation of mental novelty similarly constrains predictions of the economic development.

Obvious as this constraint may appear, it is often tried to evade. A frequently used way to do so is to logically partition theorizing into pre-revelation and post-revelation analysis and to eliminate the epistemological problems in post-revelation analysis by idealizing assumptions. The information content or meaning of novelty that has emerged is assumed to be completely revealed and no further novelty is assumed to emerge in the post-revelation period of analysis. As has been shown, these are the typical assumption made when dynamical models are used in economics.

Finally, the problem of causation of the emergence of novelty has been addressed. Three different aspects of the problem were discussed. The first is whether the causes of the emergence of novelty are endogenous or exogenous to the explanatory domain of economics. It was argued that, if the explanatory domain of economics is defined as including the level of individual behavior, then man-made novelty – originating from creative activities – is as much endogenous as any other forms of the agents' economically relevant behavior. The second, related, aspect is whether all economically relevant novelty can indeed be traced back to creative human activities. This question connects, it was submitted, to the problem of unintended collective outcomes of individual activities and can be answered similarly. If not the result of truly exogenous forces (weather, natural disasters etc.), the beginning of the complex causal chain eventually resulting in a novel collective outcome can indeed be assumed to be the creative activity of some agent(s) involved. The third aspect is the question of whether the creative activities of the individual mind are themselves caused. It was suggested to distinguish between the causes that determine the particular information content of some novelty and the causes for the emergence of novelty. While the former do not seem uncaused, the causes are not clear, because of the epistemological constraint. With respect to the causes relevant for the emergence of novelty as a result of human creative acts, the situation was shown to be different. Here hypotheses on the causes of search for, and experimentation with, novelty have been established in economics since long.

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