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Innovation through exaptation and its determinants: The role of technological complexity, analogy making & patent scope

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ABSTRACT

The concept of *exaptation* has been recently introduced in innovation studies. Previous empirical studies have only focused on the organization-level conditions of exaptation. This paper fills the gaps by focusing on invention and inventor-level conditions such as *technological complexity*, *inventors' analogical ability*, and *patent scope*. To test our hypotheses, we analyse a large sample of U.S. patents obtained from the USPTO and NBER databases. Based on our findings, we discuss a number of implications of exaptation for the management of innovation as well as for policy makers.

1. Introduction

Originally, Schumpeter coined the term of 'recombination' as the creation process that leads to new combinations and, in turn, to creative destructions in the economy (Schumpeter, 1939). Until now, the dominant view on recombination has considered recombination as the creation of new linkages between unlinked (technological) components or creating new linkages between already linked components (i.e. linking them in new ways), aimed at a specific application (Hargadon and Sutton, 1997; Nelson and Winter, 1982). In line with evolutionary theorizing, this process has been also referred to as 'adaptation', formed by technological search activities that are progressively adapted and improved through a selection environment made up, among others, of user needs. However, in Schumpeter's view, the application of a given set of (technological) components in a *new* domain of use can also be considered as a new combination that qualifies as an innovation (Schumpeter, 1939). Whereas the dominant focus in the literature has mainly been on the launch of new products through adaptations to existing products or the application of new methods of production, much less emphasis has been placed on Schumpeter's third type of innovation, formed by the opening of a new domain of use and new market, through a new application of an existing technology.

This phenomenon of the emergence of a new domain of use and market for an existing technology refers to the idea of exaptation. Recently, the concept of *exaptation* has made its appearance in innovation studies (Andriani and Cattani, 2016; Andriani and Cohen, 2013; Andriani and Carignani, 2014; Cattani, 2005, 2006; Dew et al., 2004; Furnari, 2011; Lane et al., 2007; Felin et al., 2014, 2016). Gould and Vrba (1982: 6) originally introduced the concept of exaptation in evolutionary biology to contrast it with that of adaptation and refer to 'biological characters evolved for other usages (or for no function at all) and later "coopted" for their current role'. In innovation studies, an exaptation refers to a technology that is fit for its current function thanks to technological features that were selected for old functions – or that had none at all – and were later 'co-opted' for their current function. Gutenberg's invention of the printing press, for example, was based on technological components of the wine press co-opted for the new function of printing (Johnson, 2010).

Innovation through exaptation forms a pervasive phenomenon in many industries and the examples abound. For instance, the birth of the entire modern pharmaceutical and chemical industries was triggered by multiple exaptations of coal tar. Another example is the microwave oven, which resulted from the discovery of a new function of the radar magnetron. Or the tractor engine, a

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power generator then exapted as a chassis in order to provide structural rigidity to the tractor (see more examples on Ref. Andriani and Carignani, 2014). Despite its importance as a key mechanism underlying the emergence of new technologies and the 'genesis of new markets' (Dew et al., 2004: 70), the literature on exaptation is still limited in size and it has focused on the theoretical aspects, or it has been conducted though case studies and simulations. The few empirical studies have mainly focused on the organization-level conditions of exaptation (see Ref. Cattani, 2005). As noticed by Stuart Kauffman, 'one of the most striking facts about current economic theory' is the lack of an account of the persistent explosion of technologies, goods, and markets into their 'adjacent possible' through exaptation events (Kauffmann, 2000: 212). Whereas these events imply the ífunctional shift' of technological features that was not 'anticipated' ex ante, the literature offers a limited understanding of this alternative mechanism of innovation that, therefore, has been often attributed to 'serendipitous' processes that imply high levels of randomness. In this paper, we analyze the likelihood of functional shift events and its determinants. Hence we attribute this alternative mechanism of innovation to processes that have an underlying structure and can be, therefore, possibly controlled by managers and policymakers.

In order to address this, this paper digs deeper into exaptation by adopting a micro approach and by focusing on invention and inventor-level conditions rather than organization-level conditions. This focus on invention and inventor-level conditions is consistent with a recent call for research on exaptation: Cattani argued that inventors play a 'key role in facilitating the diffusion and recombination of skills and knowledge accumulated in otherwise distinct technological domains [and] future research should explore this issue more deeply' (Cattani, 2005: 577). Our focus on invention-level conditions is also consistent with a very recent contribution by Andriani and Carignani (2014) who analyzed the relationship between technological modularity – an invention-level condition – and exaptation, and argued that modularity plays a positive role for exaptation. However, their contribution is mostly theoretical and no empirical test exists on the impact of these conditions on exaptation. Our paper is a first attempt in that direction. Based on the empirics of Fleming and Sorenson (2001), we explore those conditions that foster 'exaptive innovations' (rather than 'adaptive innovations') and in this way offer a more comprehensive understanding of the origins of new innovations.

To accomplish this aim, we will examine: (1) invention-level conditions related to the underlying technology, and in particular *technological complexity*, (2) inventor-level conditions formed by inventors' ability to draw *analogies* between different technological domains; (3) we will also examine institutional conditions formed by *patent scope*. The comprehensive treatment of these conditions allows us to focus both on the invention and the agents acting on the invention, and to avoid focusing solely on one while reducing the other to a secondary role (Lane et al., 2007). In this way, our study contributes by developing and in-depth understanding of the extent to which innovation through exaptation follows systematically from these conditions. In order to test our hypotheses, we analyse a large sample of patents obtained from the U.S. Patent and Trademark Office (USPTO) and the National Bureau of Economic Research (NBER) databases. As our objective is to examine the conditions of exaptation at the invention and inventor level, we assume that a generic invention is identified by a patent and introduce a novel measure of exaptation. The measure relies on using cross-class forward citation patterns in order to capture two central aspects of exaptation: (1) a functional shift aspect and (2) a non-anticipation aspect that arises when the emergence of a new functionality has not been originally envisioned.

The paper is organized as follows. In Section 2 we formulate testable hypotheses, in Section 3 we describe the data and the empirical setting, and in Section 4 we present the results. Section 5 presents our discussion and conclusions, and also formulates a number of important implications for managers and policy makers with an interest and ambition in stimulating innovation through exaptation.

2. Theory

2.1. Innovation and the economy: a missing link

As argued by Beinhocker (2007), the modern global economy is characterized by a multitude of technologies and goods, as demonstrated by the fact that there may be more or less 10 billion distinct goods for sale in a city such as New York City. As noted by Koppl et al. (2014), the importance of the phenomenon has justified the introduction of a name for it – 'cambio-diversity' – which is the analogous of bio-diversity and refers to the diversity and variety of exchanged technologies and goods. The importance of the phenomenon lies in the fact that a positive relationship has been observed between the diversity of goods and technologies and economic growth (Hidalgo et al., 2007).[1] Some scholars have recently disentangled the relationship and analyzed how the key driver of diversity – new combinations – positively affects economic growth (Weitzman, 1998). Where do new combinations – and, as a consequence, diversity – come from? As recently argued by Felin et al. (2014: 7), 'radical and emergent heterogeneity in nature is not explainable by appealing to the mechanisms of [adaptive] selection alone' but also to exaptation. In a similar way, it has been recently noted that new combinations are enabled by exaptation and not only adaptive. This points to the far-reaching economic implications of exaptation, which have been recently emphasized and discussed by Felin et al. (2016).

Despite this emphasis, an analysis of the micro-determinants of exaptation and of how exaptation enables new combinations is still missing. As a consequence, this alternative mechanism of innovation has been often linked to under-explained serendipitous processes, rather than to a set of systematic conditions that affect the likelihood of exaptation. We do not attribute to managers the power to 'predict' the occurrence of 'specific' exaptation events because, as recently argued by Kauffman (2008: 171), 'there appears to be no "mechanical effective procedure" [. . .] to find novel uses of existing goods [. . .]'. However, 'it may still be possible to extract statistical organizational laws (p. 171)'.[2]

2.2. Exaptation

Example: *the Radar Magnetron.* Andriani and Carignani (2014) provide several examples of exaptation. An example of the breakthrough-generating nature of exaptation is the invention of the microwave oven, which resulted from the sudden discovery of a new function of a component of the radar called 'magnetron'. The discovery happened serendipitously when Mr. Spencer – an engineer working for a U.S military contractor – discovered that the magnetron was responsible for the melting of a candy bar in his pocket. Now the magnetron is a key component of the microwave.

Despite the pervasiveness of similar examples in several industries, the research on exaptation is still limited in size. Research has been mainly conducted through case studies (Cattani, 2006; Furnari 2011), computer simulations (Lane et al., 2007), or it has focused on theoretical aspects (Andriani and Carignani, 2014; Dew

[1] These studies fall under the field of 'complexity economics' (Beinhocker, 2007).
[2] Although managers cannot 'predict' the phenomenon, they can 'control' it. See Ref. Wiltbank et al. (2006) for a distinction between prediction and control in exaptive settings.

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