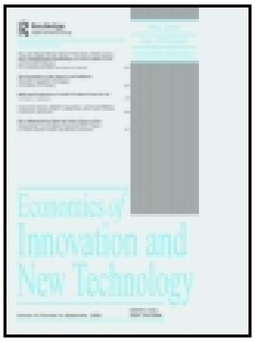

Economics of Innovation and New Technology

ISSN: 1043-8599 (Print) 1476-8364 (Online) Journal homepage: https://www.tandfonline.com/loi/gein20

Innovation in online higher-education services: building complex systems

David A. Harper, Félix-Fernando Muñoz & Francisco J. Vázquez

ECONOMICS OF INNOVATION AND NEW TECHNOLOGY
https://doi.org/10.1080/10438599.2020.1716508

Routledge
Taylor & Francis Group

Check for updates

Innovation in online higher-education services: building complex systems

David A. Harper [a], Félix-Fernando Muñoz [b] and Francisco J. Vázquez [c]

[a]Department of Economics, Faculty of Arts and Science, New York University, New York, NY, USA; [b]Departamento de Análisis Económico: Teoría Económica e Historia Económica, Universidad Autónoma de Madrid, Madrid, Spain; [c]Departamento de Análisis Económico: Economía Cuantitativa, Universidad Autónoma de Madrid, Madrid, Spain

ABSTRACT

Digitization is increasing the complexity and variety of educational services supplied and demanded. However, there is a lack of a systematic treatment of this phenomenon from the perspective of innovation and entrepreneurship. This paper employs the complex adaptive systems approach to explore how digitization changes the characteristics, generativity (combinatorial possibilities) and architecture of online educational services. Our main claims are that: (a) online courses (OCs) are modular complex hierarchical systems; (b) the development of new OCs is a significant type of innovation (not limited merely to technological change) brought about by entrepreneurial reconfiguration of modules that create new combinations in the design space of new educational services; (c) these new combinations generate new OC systems; and (d) OCs are embedded in broader institutional and social structures (e.g. universities) that co-evolve with technological change. By means of a formal combinatorial model, we examine the computational mechanism and the principles of connection-making that govern how new OCs are created and adapted.

ARTICLE HISTORY
Received 8 January 2019
Accepted 7 January 2020

KEYWORDS
MOOCs; digitization; online education; recombinant innovation; complexity; institutional change

JEL Codes:
A29; B52; I21; O30

> [I]t is the biggest innovation to happen in education for 200 years … It's going to reinvent education … transform universities [and] democratize education on a global scale. (Anant Agarwal, cited in Rifkin 2014, 116)

1. Introduction

Digitization is a disruptive technology that is deeply transforming the production and distribution of myriad goods and services; it is changing the way participants generate, access and share knowledge, and altering how they interact with one another. The digitization of information and the digital infrastructures that process and distribute this information facilitate radically new (re)combinations of digital and physical components that yield novel services (Barrett et al. 2015, 141). By combining technological advances in computing, telecommunications and networking, digital ICT infrastructure creates a space of possibilities that serves as a 'melting pot for innovation' (Henfridsson and Bygstad 2013, 918). It generates a multidimensional design space that entrepreneurs explore through creating new combinations whose introduction and diffusion constitutes real economic change (Schumpeter 1934).

CONTACT Félix-Fernando Muñoz felix.munoz@uam.es Departamento de Análisis Económico: Teoría Económica e Historia Económica, Universidad Autónoma de Madrid, C/ Francisco Tomás y Valiente 5, 28049 Madrid, Spain

Educational services, in particular, are being transformed by the digitization of content of all kinds – text, images, audio and video content, and artifacts. Educational entrepreneurs, their agents, student-consumers and other users can store, process, manipulate and transmit digital content using digital devices and networks at negligible cost. In addition, users can combine digital content emanating from multiple kinds of sources (Yoo, Henfridsson, and Lyytinen 2010, 720, 726).[1] Generativity is enhanced as users enjoy many more combinatorial opportunities for mixing and matching education-related components (i.e. modules) from diverse sources.

The case of online courses (OCs), such as massive open online courses (MOOCs) and small private online courses (SPOCs), provides a prominent example of how digitization is giving rise to radically new combinations in the supply of higher-education services. This new form of education has emerged as an evolutionary complex system, initiated by educational entrepreneurs and innovative institutions. OCs can make educational services stand in a more proximate causal relation to students' needs and thereby increase their usefulness to student-consumers. For example, MOOCs dramatically expand the spatial location and temporal availability of educational services, bringing these services directly into our homes and workplaces twenty-four hours a day. In addition, as digital technologies and networks, OCs enable teachers to act upon existing capital goods (i.e. conventional in-class courses) with new digital tools and apply their creative energies to alter their internal composition and shape through connecting and combining modules with other elements and digital objects. Of course, such increases in generativity require the maintenance of major indivisible capital-goods combinations (e.g. broadband architecture, data centers) as well as widespread access to desktop computers, tablets and smartphones, and the development of new skills and capabilities by scholars, administrative staff and students. As digitization continues its advance, the implications of OCs for revenues, profits, and opportunities will be increasingly significant (Bughin, LaBerge, and Mellbye 2017, 1).[2]

In the midst of this innovative activity, Cousera, edX and Udacity have emerged as important platforms for integrating and distributing different kinds of digital content created by users.[3] They have become meso-level platforms for providing educational services and corporate training.[4] These platforms enable users to perform a wide range of activities: to construct and present their social identity in a personal profile; to connect and communicate with other users about their learning experiences; to create, share and exchange user-generated content; to build on others' contributions through collaborative projects, such as wikis; and to find out about the reputations of particular providers of online educational services among their reference groups (Barrett et al. 2015; Singaraju et al. 2016).

Digitization and digital ICT infrastructure have also facilitated the formation of generative networks in higher education. These networks are learning communities that solve problems and engage in co-creative processes, so that the development of online educational services has become a highly distributed and socially embedded process. These generative networks bring about innovative changes in the structure of systems at organizational, industrial and macro-levels (Harper and Endres 2012). These changes occur because digitization enhances the generative potential of multiple types of participants to mix and match heterogeneous resources into new combinations (Rifkin 2014; Shapiro and Varian 1999). In particular, the provision of educational services can become a joint production (Kuchar and Dekker 2019) of education providers and student-consumers, in which student-consumers are co-builders of the 'service space' (Aubert-Gamet 1997). Students supply various resources (such as skills, capabilities and imagination) which they combine with the resources of the university or other provider in order to co-create new educational services (Chalcraft and Lynch 2011). In this manner, online courses can become open-source objects, with each participant adding input. However, the development of online higher-education services is not just driven by the quest for open and participatory structures in the knowledge commons. Higher-education institutions can also develop and use OCs as a means of capturing profit (value) from their innovative activities and brand-name capital. In other words, OCs can also be appropriability mechanisms that education entrepreneurs construct to try to capture a greater share of the value they have created through innovation in both related and dissimilar activities, including brand building.

From a general systems-theoretic perspective, what we are witnessing in online education is increasing complexity – not only of the capital structure of the education sector, but also in the variety of educational services supplied and demanded.[5] In this paper, we develop a conceptual framework based on the complex adaptive systems approach in order to explore this emergent complexity and investigate how digitization enables changes in the architecture and affordances (i.e. the use-related characteristics) of online courses and how it increases the generativity (i.e. combinatorial possibilities) of educational services. In particular, we show how: (a) the development of OCs and OC variants is a significant type of innovation and not merely an instance of technological change; (b) innovation in OCs results from educational entrepreneurs reconfiguring modules to create new combinations (i.e. new OCs); (c) these new combinations generate novel OC systems and even new ecosystems; and (d) OCs are embedded in broader institutional and social structures (e.g. universities) that co-evolve with technological change. We are interested in the principles of connection-making that govern how OCs are created and adapted and how recombinant entrepreneurs reconfigure modules to create new OCs that incorporate different kinds of complementarities.

The structure of the paper is as follows. In section 2, we introduce the analytical framework that portrays OCs and OC variants as complex modular hierarchical systems that possess important adaptive properties. Section 3 presents a heuristic model that shows how different configurations of OCs result from different settings of key 'choice variables' (design parameters) that bear upon system architecture. Section 4 then develops this model more formally by introducing a combinatorial model to show how recombinant innovation in OCs is giving rise to increasing complexity in the provision of online higher-education services and to the emergence of new (unexpected) patterns in the evolution of OCs at the industry or meso level. This formal combinatorial model employs the binary representation of combinatorial possibilities in discrete space (as developed in our heuristic approach) and adds a computational mechanism for how this economic evolution might occur. The paper finishes with some concluding remarks.

2. Building evolutionary complex systems

From an evolutionary point of view, an online higher-education course can be thought of as a complex system. The performance of such a system depends both on the particular elements of which it is composed and on the particular pattern of connections between them. Recombination (defined widely to include combining existing elements as well as adding novel components brought in from outside) is the main method for building complex systems, such as OCs.[6] The recombinant method is particularly appropriate for processes that must proceed by trial and error and that cannot be reversed. Trial and error is typically guided by conjectures that are intended to produce particular results, although most conjectures are refuted and unintended consequences are rather common (Popper 1972). People in different circumstances develop different categories (goals, means and actions) that lead them to think and act differently. The boundaries of these categories and interpretative systems are typically not well defined and categories may be modified in various ways – knowledge and its application are always context-limited. The evolving system generates new knowledge, which undermines some established knowledge but also supplies the elements for further innovation in a creatively destructive process. Organizations and institutions frame the growth of knowledge as well as the potential connections between new enhanced capabilities and the services that they might provide, and between new services and productive opportunities.

A major source of knowledge is specialization. Although specialization is usually associated with substitution, different 'pieces of knowledge' are complementary. Complementarity, a reconfiguration of what is connected to what, plays a key role in evolutionary processes. As Dopfer, Potts, and Pyka (2016, 753) show, the concept of complementarity can take two distinct forms in evolutionary economic systems: (a) *downward complementarity* that implies increasing specialization and the division of labor; and (b) *upward complementarity*, which involves the discovery of emergent complementarity between existing components and products as well as their complementarity (hitherto unimagined) with novel components introduced from outside the current system. Downward complementarity proceeds by division, differentiation and reorganization, whereas upward complementarity proceeds by making new combinations or cross-fertilization among seemingly different inputs (Dopfer, Potts, and Pyka 2016, 755). Downward complementarity emerges from a process of ongoing modularization that breaks an already existing whole into parts. It is a source of economizing gains, due to specialization at the level of the parts, that results in greater efficiency at the level of the whole. Increasing variety at the modular level also drives increasing economic complexity at the level of substitute inputs. In contrast, upward complementarity is the open-ended generation of new wholes from lower-level parts – it involves recombining existing factors of production and bringing in new resources and ideas from outside in order to create new technologies, goods and services that can lead to new markets and industries. The emergence of internet-based platforms – and of OCs – is an example of this interplay between up- and downward complementarity.[7]

How does recombination relate to the emergence of order and evolution? For Kauffman (2000, 4) there are two sources of order in complex systems: self-organization and evolution. However, discussions about evolution within economics usually focus on variation, selection and retention, at the expense of the self-organization of complex systems (Schubert 2014). Beinhocker (2011) argues that information theory offers the potential to integrate evolution and self-organization as computational processes that can be applied to human social phenomena. According to this view, evolution is a process of algorithmic search through a *combinatorial design space*: '[e]volution depends on the existence of self-organizing forces, and evolution acts on designs for self-organizing structures' (Beinhocker 2011, 393). Two questions arise here: (a) how that space is formed; and (b) how the evolutionary process explores such a huge combinatorial design space.[8] Recombination would explain the first question. Kauffman (1993) provides an answer to the second question: he conceptualizes evolution as a process of search over fitness landscapes.[9] In economic processes, landscapes are formed by technological and institutional design spaces. Agents seek higher positions – that represent superior levels of fitness – on these landscapes. Fitness depends on purposes that in the economic sphere are integrated into business plans.

For Beinhocker, the size of a design space depends on the number of modules or dimensions that the design can be varied on, and the number of possible variants for each of those modules or dimensions. Although finite, the number of alternative design settings and potential combinations may be enormous. However, for most design spaces, only a very small subset of possible designs will ever be rendered and brought into existence during the process of economic evolution (see Basalla 1988). Thus, evolution can be characterized as a kind of search algorithm – the familiar mechanism of variation, selection and retention – that explores a combinatorial design space. The algorithm of evolution is particularly good at searching within such almost-infinite spaces of possible designs for designs that are fit for their purpose (Beinhocker 2011, 400–404).

Adapting Beinhocker's approach for our own purposes, the multistage development of OCs involves combining (1) *physical technologies* (PTs) – methods and designs for transforming matter, energy and information from one state into another in pursuit of one or more goals; and (2) *social technologies* (STs) – institutional methods and designs for organizing people in pursuit of a set of goals (Nelson and Sampat 2001). In addition, *business plans* (BPs) implement potential new combinations of PTs and STs, binding them together in enterprises or projects that pursue economic goals. As new PTs and STs are discovered and rendered by means of experimental tinkering, they are combined and recombined into new business plans which are rendered into organizations, whose activities then change the PT and ST fitness function, leading to changes in the business plan fitness function and so on, creating a co-evolutionary dynamic.

3. A heuristic model of the evolution of higher-education online courses

3.1. Innovation and the creation of new OCs

Innovation in higher education is a process, a sequence of events that consists of serial, qualitative changes in the state of the system. Educational innovation entails continual flux, change and qualitative transformation of restless structures that produce and use educational services. New digital ICTs focused on the Internet enable not only professional teachers but also many other participants to participate in the production and innovation of new online educational services, including instructional videos, video-hosting on YouTube, video-recording, self-publishing of e-books, and blogging (Harwood and Garry 2014; Herman, Coombe, and Kaye 2006; Watkins, Denegri-Knott, and Molesworth 2016). As educational entrepreneurs and other participants create new combinations of inputs, outputs, activities and skills, old combinations are disrupted and disappear. Innovation in higher education thus involves things coming into and going out of being, systems acquiring and losing properties, and the making and breaking of connections. The piecemeal reshuffling of new combinations that dispersed educational entrepreneurs and co-creative users (including students) carry out day by day, within and between micro and meso levels, is the real source of innovation and economic development. The outcomes of this process are path-dependent: they depend critically upon the particular trajectory along which knowledge grows and learning occurs – that is, they depend vitally upon what has already been discovered and produced in the past in the education sector and related industries (David 2001).

Online educational services development can be defined as an entrepreneurial problem-solving process, taking place under conditions of structural uncertainty, which seeks to create and capture value through creating new capital-goods combinations. From an institutional (e.g. university) perspective, educational online platforms are instruments of production that help universities to build and distribute differentiated educational service offerings at negligible marginal cost.[10] The development of online educational services is a kind of recombinant innovation that is carried out by educational entrepreneurs and co-creative users. Applying the concepts elaborated in the previous section, we can say that the multistage production of OCs incorporates combinatorial processes of physical (PT) and social (ST) technologies and the formation of business plans (BP).

As modular complex hierarchical systems, all OCs have distinct component parts or subsystems within themselves, and interaction rates within individual subsystems are greater than those between subsystems. As such a system, an OC is the emergent result of its constituent elements and their connections (Holland 1997): its capabilities and functionality cannot be reduced to its individual subsystems, which include digital platforms, sets of rules (e.g. how to grade, etc.), trade names and brand capital (i.e. the reputations of higher-education institutions used to develop and certify online courses) (Harper and Endres 2012; Kay, Leih, and Teece 2018). At the institutional (e.g. university) level, developing OC architecture is how entrepreneurs create order in educational and ICT capital structures. An OC architecture is not a jumbled collection of videos, assignments, digital platforms, a staff of instructors and other resources. As with all capital goods, all OCs form part of a whole and have to fit into a pattern or structure to provide a service (i.e. to perform a function). The construction of OC architecture is a kind of entrepreneurial specification of the concrete form of capital combinations that are jointly employed in the production of online educational services (Endres and Harper 2012). To the extent that entrepreneurial intentions – molded in business plans – are realized, OC architecture reflects 'designed complementarity' (Lachmann 1956, 53) resulting from purposeful and deliberate coordination by the entrepreneur.

In order to develop a particular OC architecture, educational entrepreneurs apply different principles for decomposing and organizing the online course portfolio into different modules. Each of the patterns organizes existing learning rules and materials into new bundles and makes new connections among them. As circumstances change and as they engage in exploring new technological opportunities (for example, 5G technology), educational entrepreneurs adapt their OC architectures over time. These changes in OC architecture are themselves remodularization processes that constitute a form of capital regrouping and recombinant innovation. They also alter the division and organization of knowledge within the higher-education institutions and repartition *de facto* control rights over OC-combinations among decision-makers in the institution.

3.2. Major parametric settings of online courses, and connecting principles

From a complex adaptive systems perspective, the production of an OC refers to a system formed of elements (subsystems) of different kinds: digital content (image and sound); hardware (electronic devices such as tablets, PCs, servers, etc.); software platforms; and pedagogical methodologies (quality control, grading) that connect those contents on a platform. The development of any OC is an exercise in recombinant innovation and can be represented by a combinatorial model.

Ideally, we would like to identify and represent the major 'parametric settings' of the design characteristics involved in the creation of new higher-education services. In the case of MOOCs, the four main characteristics are Social connectivity, Openness, Diversity of agents and Massiveness – or {*S*,*O*,*D*,*M*} for short. For example, any MOOC can be defined in terms of its degree of massiveness (number of people that have access to the course), its degree of openness (degree of accessibility), its degree of connectivity (degree of interaction among participants) and its degree of diversity (i.e. the heterogeneity of students). More specifically,

– **[*S*]**ocial conectivity: this parameter relates to the degree of social interaction and has at least three possible positions: NO / S-S / S-P. The first setting means that there is NO interaction among participants. The second indicates that there is interaction among students (S-S), and the third setting means that there is interaction among students and professors (S-P). For ease of exposition, we reduce the range of options to only two alternatives by assuming that there is always some kind of S-P interaction. Thus, by focusing on just S-S, we have an ON/OFF binary setting. For instance, if there is a blog, the position is ON.
– **[*O*]**penness: this parameter is a binary (ON/OFF) dimension that refers to actual accessibility to the educational services in question. ON means that the course or platform is open to the entire population. Although technological limitations (e.g. lack of broadband access to the Internet) can preclude access, the degree of accessibility is mainly an *institutional* limitation selected and imposed by the university itself (or other kinds of suppliers) – as is the case with small private online courses (SPOCs).
– **[*D*]**iversity of agents: this parameter relates to whether students differ in terms of skills, capabilities and knowledge. This parameter has two alternatives: ON allows for heterogeneity of agents, and OFF excludes and prohibits such heterogeneity (that is, it imposes homogeneity). Heterogeneity is reduced by imposing selective filters on who can use the platform, for example, by requiring evidence of graduation, proof of passing an entrance exam, certification of language competence, the possession of an '.edu' email address and so on. Limits on *D* reduce agents' heterogeneity.
– **[*M*]**assiveness: this parameter refers to the number of participants. The upper limit on the number of participants is the entire population, whereas the effective limit of an OC is the population with access to the Internet, platforms, and requisite language capabilities. Conditions that limit access constitute a kind of excludability criterion or measure. For example, a MOOC is massive to the extent that it can potentially reach an entire population defined by a particular language or a specific set of capabilities.

These design characteristics or dimensions can be considered as 'choice variables' for the educational entrepreneur. We can imagine a switch for each characteristic that can be either ON or OFF: a social-connectivity switch, an openness switch, a diversity switch and a massiveness switch. We are interested in identifying the observable patterns (so-called 'parametric clusters') that result from different parameter settings. Of course, changes in the settings change the type (kind) of online course that will emerge or be created. For this purpose, let us define a column vector x in which each cell may be thought of as a switch with two positions: ON and OFF. Given the four dimensions $\{S,O,D,M\}$, we have the resulting template as shown in Figure 1 below.

From this basic setting, we can think of different combinations.[11] To simplify the argument, let us consider a minimum default setting X_{DEF}, consistent with online personalized tutoring,[12] and a MOOC setting labeled X_{MOOC}. These configurations may be written in terms of a vector of connections:

$$X_{DEF} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}; X_{MOOC} = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

Each element represents a setting of the switch ON or OFF, and each row represents the four dimensions $\{S,O,D,M\}$, where 1 means that that position is ON, while 0 means it is OFF. Of course, there are many other possible combinations. Given the basic setting of our previous example, there are 2^4 different possible configurations. As we shall see in section 4.1, the basic setting may be amplified by means of introducing new dimensions or varying existing ones. Consider, for example, the case of a SPOC (Small Private Online Course). The configuration of the corresponding matrix must reflect the fact that the course is closed (not open) and 'small' (not massive) by setting the O and M parameters to zero as follows:

$$X_{SPOC} = \begin{pmatrix} \cdot \\ 0 \\ \cdot \\ 0 \end{pmatrix}$$

where the dots refer to the values of the first and third parameters (i.e. S and D), which may be set to either OFF or ON. Obviously, at each instant t, ON/OFF positions depend on the entrepreneurial selection of parameter settings within the current technical and institutional constraints at t (Figure 2).

The coevolution of technology and institutions gives rise to new settings. Digitization, for example, has not only provided scope for X_{MOOC} to emerge but it has also introduced changes at the legal and institutional level and in the scope of entrepreneurs' business plans. During the last decade, different clusters have emerged over time in the multidimensional design space of online higher-education services. The best known clusters are Coursera, edX and Udinet platforms, as well as other quite similar configurations, such as the Kahn Academy. All of them have produced a rather similar combination and arrangement of design characteristics, and in this sense a recurrent pattern has emerged based on available physical and social technologies (PTs and STs) and business models. For example, edX videos are uploaded in YouTube.

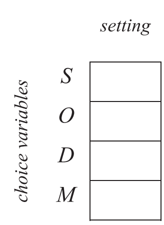

Figure 1. The basic template of OC parameter settings. Each cell takes a value of 0 (OFF) or 1 (ON).

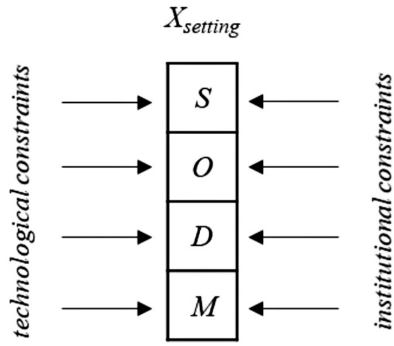

Figure 2. The impact of technological and institutional constraints on choice of OC parameter settings.

4. Further developments of the heuristic model

Markets for online higher-educational services are dynamic, creative and evolving. Conventional mechanistic economic models, which treat the phase space (the 'configuration space') as fixed, cannot capture the emergent properties of such adaptive markets that generate ever-changing kinds of services (Koppl et al. 2015, 6–8). Change wrought by innovation in higher-education services cannot be stated ex ante or computed in advance; the process of creating new OCs is not the inevitable unfolding of predetermined dynamics. New combinations are not already out there, just waiting to be discovered. The design space is truly open-ended – new dimensions come into being and genuinely novel OCs emerge. (The computational mechanism underpinning this open-endedness will be examined further in our formal combinatorial model in section 4.2.)

4.1. Increasing variety of OCs and the emergence of new meso-trajectories

The emergence of new dimensions allows increasing complexity in markets for educational services. Each new dimension adds an increasing number of combinations. The most recent dimension to emerge due to digitization in higher education has no doubt been massiveness [*M*] and the potential for large-scale operation. This dimension increases the number of combinations of OCs from 8 to 16. Figure 3 shows how the space of combinations – the design space – of OCs evolves at four successive stages, taking into account only the above mentioned four dimensions {*S*, *O*, *D*, *M*}.[13]

As the OC design space expands, two related phenomena appear. On the one hand, there is an increase in scalability – and thus in economies of scope and scale – as a consequence of digitization and modularity. However, an even more interesting phenomenon is *bifurcation*, that is, the emergence of two main 'meso-trajectories' in online higher-education services, one centered around SPOCs and the other constituted by MOOCs.[14] This bifurcation at the meso-level is portrayed in the matrix of Figure 4. By the term 'meso', we are here referring to the level of economic organization that pertains to the population of all carriers of a particular rule – it is the rule (or rule-system) and the population of all its actualizations (Dopfer, Foster, and Potts 2004). Thus, the parametric settings for SPOCs listed in columns *b* to *d* pertain to a cluster of rules, which is instantiated by each and every SPOC that adopts these rules, thereby generating the population of SPOCs at the meso-level. A meso-trajectory is thus akin to a technological trajectory and relates to how that population comes into being, grows and declines over time. To show how the bifurcation in OCs emerges, it is useful to write the combinatorial space as a matrix of zeroes and ones, as shown in Figure 4.

Above the matrix of combinations, we have designated each column with a letter from *a* to *p* in order to identify the different combinations within the OC design space. At the far left, in column *a*,

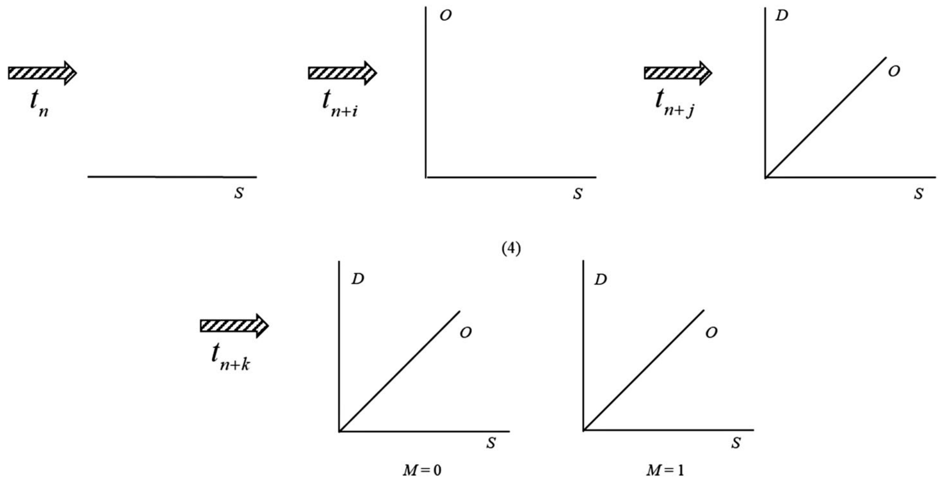

Figure 3. The open-ended emergence of new dimensions and increasing complexity in the OC design space. The four dimensions are as follows: S = social connectivity; O = openness; D = diversity; M = massiveness. Time periods are arranged in temporal sequences, such that $n > 0$ and $k > j > i$.

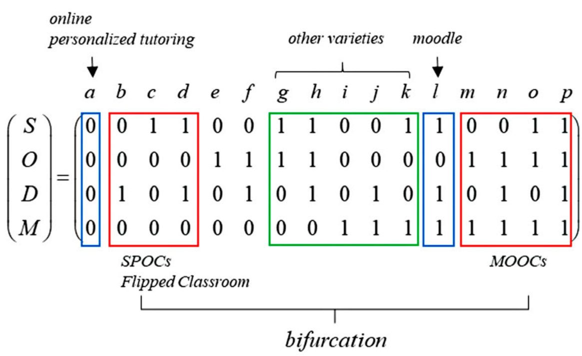

Figure 4. Varieties in the OC design space. A zero (0) means that the specific design characteristic is OFF (i.e. it has not been selected or activated), and a one (1) means that this characteristic is ON (i.e. it has been selected).

we would locate online personalized tutoring since all parameters are set to zero: *S* is OFF because there is no student-to-student interaction; *O* is OFF because the class is closed to other students; *D* is also OFF because having one student prohibits heterogeneity; and finally, *M* is OFF since it has the smallest possible class, there being only one student. In columns *b* to *d* we have different varieties of SPOCs. Columns *c* to *d* also include 'flipped classrooms' in bricks-and-mortar universities that provide online videos of lecture material that students watch prior to attending interactive classes in person. Column *f* corresponds to the streaming of a semi-public lecture online that is targeted to a small audience. Columns *g* to *k* depict a heterogeneous mix of less frequent kinds of OC courses and will not be examined further here. Column *l* includes online open-source learning platforms, such as Moodle. Finally, columns *m* to *p* relate to different configurations of MOOCs. Column *p* corresponds to the pure type of MOOC and consequently, all parameters are set to one: these OCs are massive and open so both *M* and *O* are ON; and they facilitate student-to-student interaction and a diverse student body, so both *S* and *D* are also ON. Column *n* captures the parameter settings of MIT OpenCourseWare, which differs from the pure MOOC in that student-to-student interaction is not available, so *S* is OFF.

According to Figure 4, it seems that two main configurations of OCs are emerging as alternative paradigms. First, we have SPOCs and SPOC variants, such as flipped classrooms and in-house online education in corporations. These varieties are being integrated, even captured, by incumbent higher-education organizations (e.g. traditional universities) as complements to their bricks-and-mortar services model. Second, MOOCs are converging towards the classical distance education paradigm and emerge as an alternative to the SPOC model. In between these two poles, we can find different and far less common varieties of online higher-education services.

To explain this polarization requires us to examine the different role that digitization plays in educational entrepreneurs' business plans. As far as the new technology is retained within a particular and closed population – a captive market – digitization is being employed as a means to generate upward and downward complementarities, giving rise to more complex combinations of educational services. On the other hand, if digitization is employed to 'democratize' higher-education services, the resulting OCs – in particular, MOOCs – are the outcome of pursuing massive scalability and opening up access to courses (e.g. through the elimination of institutional entry restrictions), thereby giving rise to the emergence of a rival business model that serves as a substitute for the traditional paradigm of higher-education organizations.

The development of OCs has generated an explosion of novelty in the provision of educational services. It has dramatically increased the complexity of markets for educational services. It seems that innovative combinations of physical and social technologies have led to two distinct new meso-trajectories in higher-education services. The emergence of these two trajectories originally led to disruption at the meso-level as new online services impinged upon the business plans of existing bricks-and-mortar educational institutions, especially universities. At first, OCs were seen to stand in a relationship of substitutability with traditional educational services. Digitization was seen as a disruptive technology. However, in recent years, there has been a significant recoordination of business plans at the meso-level that emphasizes the upward complementarity relationships between OCs and traditional educational services. This recoordination is also partly the result of coevolution among physical and social technologies in the education sector.

We conjecture that the initial phase of this meso-trajectory was essentially Schumpeterian in that it highlighted substitutability between new online courses and existing educational services (Schumpeter 1934). This phase has now been superseded by a Lachmannian phase in which complementarity relationships are paramount (Lachmann 1986). In particular, a plausible conjecture is that established players (mainstream universities) have appropriated OCs as a means to leverage their brand-name capital.[15] In other words, OCs offer traditional universities an opportunity to create and capture value (make and seize profits) in virtual digital spaces by exploiting the significant economies of scope from using their existing brand capital as a joint input. Universities can also voluntarily 'give away' online educational services (e.g. Yale's open courses) as a means to generate new information and client networks that they can use up- or downstream to improve their marketing activities, to enhance their reputation capital and to generate extra revenues from other educational services.

4.2. A combinatorial model of the emergence and diffusion of OC characteristics

The following combinatorial model possesses many of the features that we have discussed above as well as some interesting extensions.[16] Of course, as with all models, formalization introduces its own limitations, including restrictions on the agents and their mode of interaction, and the number of iterations. Nevertheless, as we shall see, the insights yielded are sufficiently general and fruitful to justify using the model to explain the emergence and diffusion of new combinations (i.e. new varieties) of online courses (OCs).

The combinatorial model considers a given number of agents ($N = 500$) – educational entrepreneurs. Each agent i offers in each period t a particular type of OC, represented as a vector $\bar{v}_i^t \in R^n$ of zeros and ones (as in the case of the heuristic model {S,O,D,M} depicted in Figure 4). The starting point is an initial random distribution of courses $\bar{v}_i^0 \in R\,(i = 1, \ldots 500)$ which evolves over a total of $T = 100$ periods (iterations) in accordance with the mechanisms described below.

The occurrence of innovations is modeled by means of a stochastic process of Poisson type, with an occurrence rate $\lambda = 0.05$ (that is, on average, an innovation occurs every 20 periods). Each innovation consists in the introduction of a new variety (a new type) of OC, thereby giving rise to a new dimension in the vector space. The innovation is initially introduced by a randomly selected agent. Hence, if an innovation occurs in period $t + 1$, then $\bar{v}_i^{t+1} \in R^{n+1}$, such that $\bar{v}_{i_0}^{t+1} = (\bar{v}_{i_0}^t, 1)$ for a particular $i_0 \in [1, 500]$ and $\bar{v}_j^{t+1} = (\bar{v}_j^t, 0)$ for each $j \neq i_0$.

If an innovation does not occur in a particular period t, the agents interact locally in different ways, imitating the most innovative combination or the combination most frequently supplied by their neighbors, thereby generating a particular diffusion process, whether it be diffusion of the latest innovation or of the most frequent combination. Of course, we allow for the possibility that an agent does not want to interact, so that the agent does not change the particular OC combination it currently offers. In particular, if no innovation occurs in period t, then the agents (who were previously ordered randomly) will go on deciding iteratively over time whether to imitate the most innovative vector, or to imitate the 'median' vector (which indicates the central tendency of courses offered in the online high-education sector), or whether to simply continue offering the same courses that they themselves have offered previously. An important feature of our model is that an agent's observation of innovation or of the behavior of other agents is restricted to a specific 'locality', i.e. agents in the model do not observe the actions of all other agents in the model but instead only observe the behavior of those agents in their particular neighborhood. This modeling approach has two implications. First, it involves positing that each agent occupies a certain position on a linear continuum (in the manner of a Hotelling model).[17] Second, it introduces the degree of locality as a parameter of the simulation, thereby determining the size of each agent's neighborhood. Accordingly, in order to make a decision, the agent which occupies the ith position only observes the actual OC combinations offered by the k agents on its left and by the k agents on its right.[18] In these circumstances, agent i has three mutually exclusive options in each period: with a particular probability p, agent i decides to copy the most innovative vector in its environment; with probability q, to copy the most frequent vector; or with probability $1 - p - q$ to not change its behavior (i.e. to continue offering its current course).

Even in spite of its simplicity, the proposed combinatorial model enables us to generate different scenarios by varying the values of the parameters λ and k. The overall behavior of the agents is captured by measuring how many *representative courses*[19] there are of each variant of courses as a result of the iterative decisions of agents.

The results obtained yield some interesting insights. First, the maximum variety of online courses is produced when the agents focus upon a small-to-medium environment (Figure 5). In the battery of simulations we ran, the greatest degrees of course variety were always obtained for values of $k \in [3, 7]$, that is, neither for values of k that are very small nor for values of k greater than 7. It is

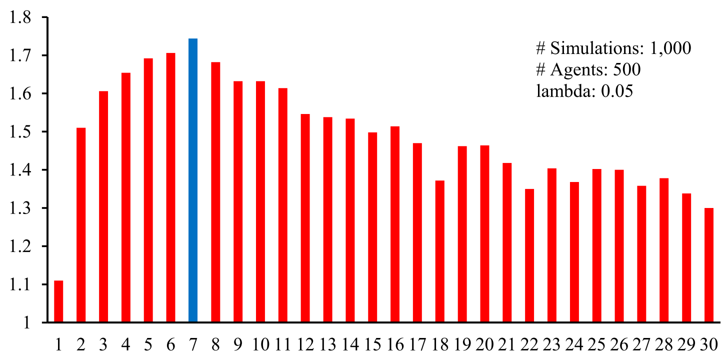

Figure 5. Mean number of courses for distinct radii of neighborhood (values of k between 1 and 30).

noteworthy that if we increase the size of each agent's neighborhood and raise it to values greater than 250 agents (up to a maximum of 499 agents), behavior remains basically the same: agents focus upon a relatively close environment. A higher (lower) value of λ accelerates (slows down) the introduction of innovations, producing the same pattern of behavior.

Finally, in Figures 6(a,b), we show different diffusion patterns for online courses which are obtained in two different particular simulations (labeled I and II). Each time that an innovation occurs, it can either be diffused or not diffused. In the first case, its diffusion can reach all agents (i.e. 100% saturation of the market with this type of course) or a lower degree of market penetration. It can even happen that once new varieties of courses emerge, some past courses will end up disappearing as they are displaced from the market by new varieties of courses.

Although the heuristic model discussed in section 3 was limited to four dimensions, this combinatorial model can generate a greater number of potential dimensions. The model explains how patterns of imitation, emergence and diffusion of new OC courses can be generated through randomly occurring innovations.

5. Educational entrepreneurship and business plans

The evolution of online courses depends on the experiments that entrepreneurs undertake with different adjacent states in the ever-expanding OC design space – which include modifications to existing structures, new modules and new links. These experiments give rise to a change of state

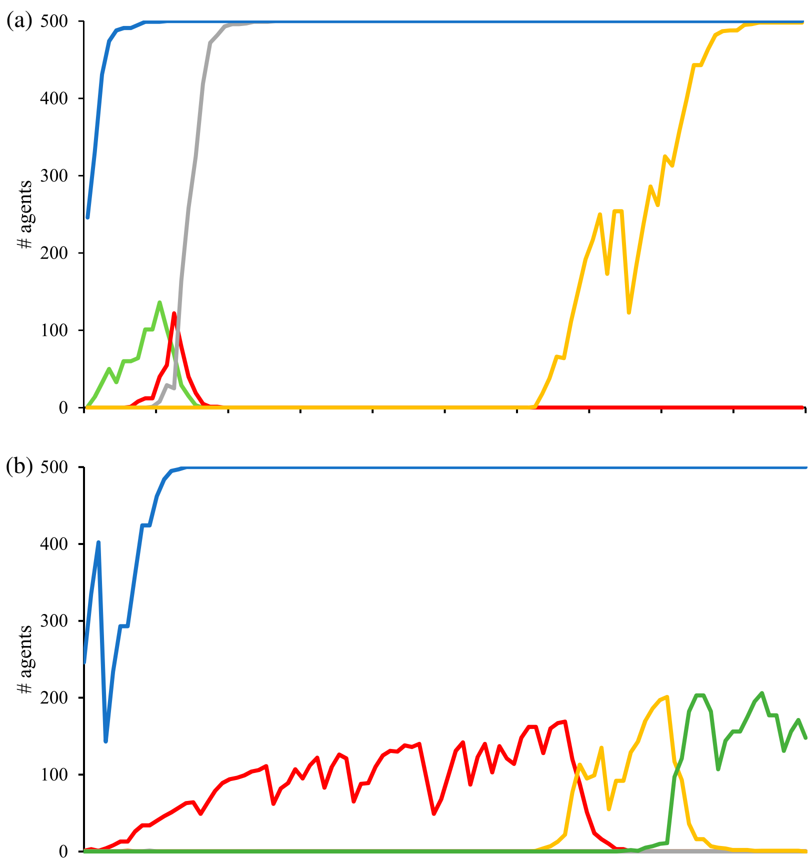

Figure 6. (a) Patterns of diffusion of OC characteristics in simulation I, after 100 simulations. (b) Patterns of diffusion of OC characteristics in simulation II, after 100 iterations.

in the corresponding choice variable, which will turn an OC design parameter from ON to OFF, or vice versa. As a capital structure, an OC only becomes productive once it is connected to, and combined with, other structures (including other OCs) in a business plan (Harper and Endres 2010, 32, 40). And as with any other capital structure, OCs are not silos that can exist independently of human action; they always have to fit into a larger pattern and are institutional and socially embedded. OCs can both crystallize into relatively stable institutions while at the same time fostering institutional change over time through ongoing recombinant activity that is occasioned by new business opportunities.

Whenever educational entrepreneurs or co-creative users discover (or 'create') a new opportunity in the OC landscape and turn existing online educational services to novel uses in order to fill a perceived gap in current service offerings, they influence the success of the production plans (BPs) of those with whom they interact. Hence, because of linkages at the meso-level, novel uses of OCs by one higher-education institution (e.g. a university) will require the regrouping of OC-rule combinations in other institutions as well as in the original organization that initiates the innovative OC use. Consequently, new combinations of this kind of capital, which are designed to fill in existing gaps in the OC structure, always disturb existing rule combinations and may unintentionally open up new gaps elsewhere. An example is edX, which emerged as educational service providers forged alliances with other higher-education institutions so as to create a meso-level platform (the edX standard).[20] The place of edX and other meso-level platforms in the historical evolution of MOOCs is depicted in Figure 7. This figure provides a historical overview of how new OC varieties and platforms have emerged to fill gaps in the capital structure, tracing the steps from open access arrangements (e.g. as in open-source software) to open educational resources (OERs) to early connectivist MOOCs, which were then followed by the emergence of multiple OC platforms (edX, Cousera, Udacity) as well as a wide range of differentiated MOOC variants.

A panoply of complementary assets is available when experimenting with new combinations in the field of educational services. Complementary assets include:

- publishing companies' facilities, such as those of Springer, CUP, OUP, MIT Press, which make available e-books, e-journals and electronic access and offer open access to academic content;
- scientific databases, such as WoS, Scopus, Mendeley, Kudos, Google Academics;
- providers of software 'platforms' (Saltzman 2014, 20);

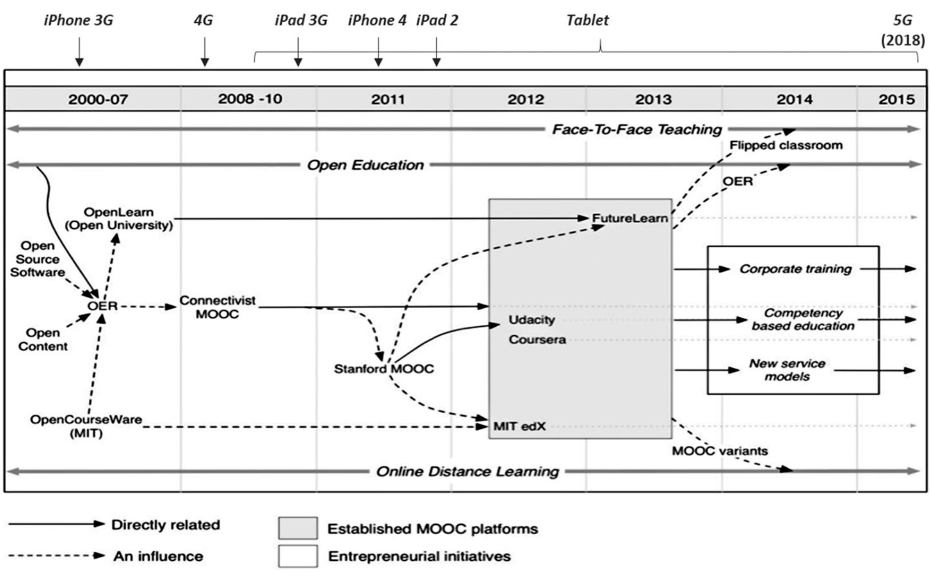

Figure 7. Evolution of MOOCs. Source: Yuan and Powell (2015, 2) and own elaboration.

- fast and relatively inexpensive Internet access (4G, 5G);
- repositories of knowledge, such as ResearchGate, Academia, RePec, SSNR;
- web technologies, such as Skype, YouTube, and Facebook.

Online courses evolve as the evolutionary economic process searches for fit designs in the design space of online educational services. As agents of change, entrepreneurs initiate innovation and carry out new business plans, actively exercising their creative abilities to experiment with new combinations that combine existing and new resources in creative ways and inject novelty into the system. Intentionality is at the basis of entrepreneurship and is expressed in the action plans that make up particular strategies (Muñoz, Encinar, and Cañibano 2011; Muñoz and Encinar 2014). Entrepreneurial intentionality directs the strategies that sample the design space for combining physical and social technologies and for forming business plans. Business plans play a critical role in that they meld PT and ST under a single *strategy* (Beinhocker 2006, 238). The above distinction between downward and upward complementarity suggests two kinds of strategies. In the case of downward complementarity, educational entrepreneurs are alert to opportunities for personal gain that can be tapped by arbitraging hidden inefficiencies in the provision of educational services. In the case of upward complementarity, visionary entrepreneurs create novelty through forming new combinations. In this case, entrepreneurs assemble existing parts into new wholes and can generate a new 'meso trajectory' by originating and actualizing a new set of rule-combinations. These new rule-combinations also have a disruptive effect at the meso-macro level as existing structures of rules are being re-coordinated (Dopfer, Foster, and Potts 2004; Dopfer and Potts 2008). As we have seen, both types of entrepreneurship are present in online educational services.

All beliefs and expectations about new forms of online courses are fallible and subject to refutation by the market mechanism at any time. A new online course is based upon a set of entrepreneurial conjectures about the most urgent of the as yet unsolved problems of student-consumers and about the new bundles of OC characteristics that will satisfy these latent demands. Through a process of trial and error elimination, entrepreneurial higher-education institutions and large firms, such as Google and Pearson, try to discover the constellation of demand for particular kinds of educational services. If their plans fail, higher-education entrepreneurs have to revise their conjectures and reshuffle their OC portfolio. OCs are perpetually incomplete structures: they are always half-completed projects from the forward-looking planning perspective of prospective OC users. This experimentation has yielded a huge increase in the variety of OCs: MOOCs, SPOCs, x-MOOCs, c-MOOCs, SPOOCs, NOOCs and so on. (See Pilli and Admiraal (2016) for an extensive catalog of different types of OC.) The explosion of variety resembles the markets for personal computers in the 1980s. However, an industry-wide standard has not yet emerged.

Finally, OCs always entails divergent interpretations and expectations about the nature and economic significance of online education, the kinds of users and uses it will attract, and its connections with other kinds of educational services. Actors can reach different judgments about the relationships of complementarity and substitutability that hold among traditional and online educational services, giving rise to hybrid forms, such as 'flipped classrooms'. Divergent interpretations and expectations motivate and channel diverse experiments in OC development. The very nature of OCs provides opportunities for expanding access to higher education and creates a space for experimentation with online teaching and learning. OCs not only expand access to education for those who seek it, they can also extend an institution's (e.g. a university's) geographic reach and increase its visibility and reputation internationally. The 'digital footprint' of learners using the technology can be captured in large data sets that can potentially provide useful insights into online teaching and learning with very large numbers of students at low or minimal cost. For example, edX institutions such as MIT and Harvard use MOOCs to understand how students learn and to improve innovation in teaching and learning on campus (Yuan and Powell 2013, 8–9).

6. Concluding remarks

ICTs are playing a transformative role in the creation of new online higher-education services. Digitization helps transmit educational services faster, more efficiently and at a lower cost. By fostering increased connectivity, network ubiquity and higher degrees of economic specialization, digital technological platforms provide educational entrepreneurs (e.g. universities) and co-creative users with greater scope for integrating heterogeneous hardware and software elements into novel combinations that render new and more complex kinds of services.

This paper has argued that the development of online higher-education services (OCs) is a type of innovation that entails more than just technological change in that it also includes the development of novel social technologies and business models (including voluntary giveaways). Educational entrepreneurs can inject novel ideas and reconfigure physical and social technologies to create new combinations – new OCs. Educational entrepreneurs discover gaps in the education sector and make new markets for new kinds of online educational services. Hence, OCs are always the result of entrepreneurial agency. Moreover, OC development is a social growth-of-knowledge process: every OC is an experiment with particular design parameters, subject to ongoing 'market testing' in the network of student-consumers.

We outline an approach that systematically deals with these experiments in design parameters while still being open to the emergence of genuine novelty in the design space for services. Our approach shows that innovation both requires and generates continual change in the design space within which economic dynamics occur.

The explosion of grassroots innovation is generating increasing variety and complexity in markets for online higher-education services. There is a proliferation of different types of online services and a great deal of entrepreneurial experimentation with new configurations and design formats. However, amidst all this change and increasing complexity, we discern two main design configurations of OCs that seem to be emerging as two new meso-trajectories in higher education: namely, MOOCs and SPOCs.

This approach also helps us to interpret industrial dynamics and strategic changes at a deeper level. In particular, at first glance, digitization and the 'democratization' of education through MOOCs seem to be severely disrupting the operations of incumbent suppliers of higher-education services, such as traditional bricks-and-mortar universities. This initial phase emphasized substitutability of online courses for traditional educational services and the displacement of existing business models by new ones. However, we also find that there are significant complementarity relationships among online and traditional educational services. Incumbent higher-education institutions, such as established universities, have been able to employ OCs in general and SPOCs in particular as a vehicle to create and capture value. This model enhances the ability of universities to appropriate the returns from their investments in brand-name capital. They can increase their geographic reach without major new investments in physical infrastructure, such as real estate.

Notes

1. In addition to standardizing data ('data homogenization'), digital technology is distinguished by its multilevel modular architecture and the communicability and reprogrammability of digital devices (e.g. the installation of new apps on a smartphone gives it greater functionality) (Yoo, Henfridsson, and Lyytinen 2010).
2. However, although their presence is likely to increase over time, MOOCs are still a relatively small part of the online higher-education scene: in 2012, they constituted only five percent of all US bachelor's degrees awarded (Goodman, Melkers, and Pallais 2016).
3. For a classification of the types of social media platforms and activities related to education, see Kaplan and Haenlein (2010) and Kietzmann et al. (2011).
4. The distinction between micro-, meso- and macro-levels is elaborated in Dopfer, Foster, and Potts (2004).
5. By 'capital structure' of the education sector, we mean here the network of combinations of complementary resources that are used to generate educational services at micro-, meso- and macro-levels.

6. See Langlois (2018) for additional mechanisms of innovation and how they relate to recombination processes for building complex systems.
7. In fact, all cases of new combinations that re-use existing parts that are already being employed in established combinations involve, in different degrees, both downwards and upwards complementarity that decompose existing combinations, rearrange parts and create new wholes. Consider, for example, the 'flipped classroom': it breaks down the regular in-house model of teaching a course, then swaps out an old component and replaces it with a new component (e.g. video of lecture instead of in-class lecture), and it also reverses the order of the regular production/education process (i.e. with a flipped class, students first watch videos of lectures online and then afterwards they do interactive exercises in class with the professor).
8. As a first approximation, it is possible to model economic evolution in a limited way by providing a partial characterization of evolution as algorithmic search in a combinatorial design space, provided that explicit assumptions are made upfront that rule out the injection of novelty into the system in question. This is indeed the implication of the paper by Koppl et al. (2019).
9. However, Kauffman's thinking has progressed to emphasize much more openness and to include the addition of novel components into the system (see Felin et al. 2014). The combinatorial model in section 4.2 below also includes this feature.
10. Perhaps predictions of near-zero marginal cost for OCs are exaggerated. Consequently, OCs may not undermine traditional suppliers of higher-education services to the same extent that the Internet has devastated newspapers, CD music, and travel agents. But hybrid forms of OCs are likely to have a growing role in higher education. See Saltzman (2014, 27).
11. Implicitly, and for the sake of simplicity, we are missing a fifth dimension ('digitization' – ON or OFF) in order to separate out the digital (online) from the analogue (traditional) teaching approaches. Thus, apprenticeship and bricks-and-mortar institutions are not considered here.
12. Examples of online personalized tutoring include online private language classes via Skype (e.g. as provided by EasyEspañol).
13. We could speculate over what has been the historical sequence of the emergence of these dimensions. In the case of online higher education, a likely conjecture – based on the historical evolution of MOOCs shown in Figure 7 – would be $S \to O \to D$. Nevertheless other sequences, such as $S \to D \to O$, are possible, but they do not affect the main argument advanced here.
14. For a formal treatment of bifurcation in complex systems, see Strogatz (2000).
15. Goodman, Melkers, and Pallais (2016) provide indirect support of this proposition. Analyzing the case of Georgia Tech's Online Master of Science in Computer Science, they find evidence that online (high quality) education improves access to education but does not necessarily displace in-person (traditional) education.
16. This combinatorial model bears some resemblance to that in Koppl et al. (2015).
17. We could construct the model using other 'topologies', such as a circular model instead of a linear one, but this does not alter the basic characteristics of the results obtained. More generally, we could extend the number of dimensions for characterizing neighborhood effects by using a network topology that captures how agents acquire information about new innovations within a social network, which constitutes an item on the agenda for future research.
18. This holds provided that, in the case of the linear model, there are indeed that number of agents on each side of the agent; i.e. in the vectors $\bar{v}_j^t$ for $j \in [\max(i-k, 0), \ \min(i+k, N)]$.
19. In order to obtain 'smoother' and less erratic results from the model, we define the variable *representative courses* to include only those varieties of courses adopted by at least 10% of the population of agents.
20. As with most platforms, edX courses consist of weekly learning sequences, each composed of short videos and interactive learning exercises. Courses usually include tutorial videos, online textbooks, discussion fora, and wikis. EdX offers a variety of ways to take courses: auditing (no cost), studying for an edX Verified Certificate (fees vary by course) or working toward XSeries Certificates for packages of verified courses in a single subject (fees vary by package). It can also be utilized in 'blended classrooms'.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

David A. Harper http://orcid.org/0000-0002-4716-3638
Félix-Fernando Muñoz http://orcid.org/0000-0002-5460-9108
Francisco J. Vázquez http://orcid.org/0000-0002-0250-1517

References

Aubert-Gamet, Véronique. 1997. "Twisting Servicescapes: Diversion of the Physical Environment in a Re-Appropriation Process." *International Journal of Service Industry Management* 8 (1): 26–41. doi:10.1108/09564239710161060.

Barrett, Michael, Elizabeth Davidson, Jaideep Prabhu, and Stephen L. Vargo. 2015. "Service Innovation in the Digital Age: Key Contributions and Future Directions." *MIS Quarterly* 39: 135–154.

Basalla, George. 1988. *The Evolution of Technology*. Cambridge: Cambridge University Press.

Beinhocker, Eric D. 2006. *The Origin of Wealth: Evolution, Complexity and the Radical Remaking of Economics*. Boston, MA: Harvard Business School Press.

Beinhocker, Eric D. 2011. "Evolution as Computation: Integrating Self-Organization with Generalized Darwinism." *Journal of Institutional Economics* 7 (3): 393–423. doi:10.1017/S1744137411000257.

Bughin, Jacques, Laura LaBerge, and Anette Mellbye. 2017. "The Case for Digital Reinvention." *McKinsey Quarterly* (February): 1–15.

Chalcraft, D., and J. Lynch. 2011. "Value Propositions in Higher Education: An S-D Logic View." *Proceedings of the Academy of Marketing Conference*, Liverpool, 5–7 July.

David, Paul. 2001. "Path Dependence, Its Critics and the Quest for 'Historical Economics'." In *Evolution and Path Dependence in Economic Ideas: Past and Present*, edited by P. Garrouste and S. Ioannides, 15–40. Cheltenham: Edward Elgar.

Dopfer, Kurt, John Foster, and Jason Potts. 2004. "Micro-Meso-Macro." *Journal of Evolutionary Economics* 14 (3): 263–279. doi:10.1007/s00191-004-0193-0.

Dopfer, Kurt, and Jason Potts. 2008. *The General Theory of Economic Evolution*. New York: Routledge.

Dopfer, Kurt, Jason Potts, and Andreas Pyka. 2016. "Upward and Downward Complementarity: The Meso Core of Evolutionary Growth Theory." *Journal of Evolutionary Economics* 26 (4): 1–11. doi:10.1007/s00191-015-0434-4.

Endres, Anthony M., and David A. Harper. 2012. "The Kinetics of Capital Formation and Economic Organisation." *Cambridge Journal of Economics* 36: 963–980. doi:10.1093/cje/bes002.

Felin, Teppo, Stuart Kauffman, Roger Koppl, and Giuseppe Longo. 2014. "Economic Opportunity and Evolution: Beyond Landscapes and Bounded Rationality." *Strategic Entrepreneurship Journal* 8 (4): 269–282. doi:10.1002/sej.1184.

Goodman, Joshua, Julia Melkers, and Amanda Pallais. 2016. "Can Online Delivery Increase Access to Education?" *National Bureau of Economic Research Working Paper Series* No. 22754. doi:10.3386/w22754.

Harper, David A., and Anthony M. Endres. 2010. "Capital as a Layer Cake: A Systems Approach to Capital and Its Multi-Level Structure." *Journal of Economic Behavior & Organization* 74 (1-2): 30–41. doi:10.1016/j.jebo.2010.01.006.

Harper, David A., and Anthony M. Endres. 2012. "The Anatomy of Emergence, with a Focus Upon Capital Formation." *Journal of Economic Behavior & Organization* 82 (2-3): 352–367. doi:10.1016/j.jebo.2011.03.013.

Harwood, Tracy, and Tony Garry. 2014. "Co-Creation and Ambiguous Ownership Within Virtual Communities: The Case of the Machinima Community." *Journal of Consumer Behaviour* 13 (2): 148–156. doi:10.1002/cb.1437.

Henfridsson, Ola, and Bendik Bygstad. 2013. "The Generative Mechanisms of Digital Infrastructure Evolution." *MIS Quarterly* 37 (3): 907–931.

Herman, Andrew, Rosemary J. Coombe, and Lewis Kaye. 2006. "Your Second Life? Goodwill and the Performativity of Intellectual Property in Online Digital Gaming." *Cultural Studies* 20 (2-3): 184–210. doi:10.1080/09502380500495684.

Holland, John H. 1997. "Emergence." *Philosophica* 59 (1): 11–40.

Kaplan, Andreas M., and Michael Haenlein. 2010. "Users of the World, Unite! The Challenges and Opportunities of Social Media." *Business Horizons* 53 (1): 59–68. doi:10.1016/j.bushor.2009.09.003.

Kauffman, Stuart A. 1993. *The Origins of Order: Self-Organization and Selection in Evolution*. Oxford: Oxford University Press.

Kauffman, Stuart A. 2000. *Investigations*. Oxford: Oxford University Press.

Kay, Neil M., Sohvi Leih, and David J. Teece. 2018. "The Role of Emergence in Dynamic Capabilities: A Restatement of the Framework and Some Possibilities for Future Research." *Industrial and Corporate Change* 27 (4): 623–638. doi:10.1093/icc/dty015.

Kietzmann, Jan H., Kristopher Hermkens, Ian P. McCarthy, and Bruno S. Silvestre. 2011. "Social Media? Get Serious! Understanding the Functional Building Blocks of Social Media." *Business Horizons* 54 (3): 241–251. doi:10.1016/j.bushor.2011.01.005.

Koppl, Roger, Abigail Devereaux, Jim Herriot, and Stuart Kauffman. 2019. "A Simple Combinatorial Model of World Economic History." https://arxiv.org/abs/1811.04502.

Koppl, Roger, Stuart Kauffman, Teppo Felin, and Giuseppe Longo. 2015. "Economics for a Creative World." *Journal of Institutional Economics* 11 (1): 1–31. doi:10.1017/S1744137414000150.

Kuchar, Pavel, and Erwin Dekker. 2019. "Lachmann and Shackle: On the Joint Production of Interpretation Instruments." *Research in the History of Economic Thought and Methodology* 37B: 25–42. doi:10.1108/S0743-41542019000037B005.

Lachmann, Ludwig M. 1956. *Capital and Its Structure*. London: Bell & Sons, Ltd.

Lachmann, Ludwig M. 1986. *The Market as an Economic Process*. Oxford: Basil Blackwell.

Langlois, Richard N. 2018. "Fission, Forking and Fine Tuning." *Journal of Institutional Economics* 14 (6): 1049–1070. doi:10.1017/S1744137417000455.

Muñoz, Félix Fernando, and María Isabel Encinar. 2014. “Intentionality and the Emergence of Complexity: An Analytical Approach.” *Journal of Evolutionary Economics* 24 (2): 317–334. doi:10.1007/s00191-014-0342-z.
Muñoz, Félix Fernando, María Isabel Encinar, and Carolina Cañibano. 2011. “On the Role of Intentionality in Evolutionary Economic Change.” *Structural Change and Economic Dynamics* 22 (3): 193–203. doi:10.1016/j.strueco.2011.04.002.
Nelson, Richard R., and Bhaven N. Sampat. 2001. “Making Sense of Institutions as a Factor Shaping Economic Performance.” *Journal of Economic Behavior & Organization* 44 (1): 31–54. doi:10.1016/S0167-2681(00)00152-9.
Pilli, Olga, and Wilfried Admiraal. 2016. “A Taxonomy of Massive Open Online Courses.” *Contemporary Educational Technology* 7 (3): 223–240.
Popper, Karl. 1972. *Conjectures and Refutations. The Growth of Scientific Knowledge*. 4th ed. London: Routledge & Kegan Paul.
Rifkin, Jeremy. 2014. *The Zero Marginal Cost Society*. New York: Palgrave MacMillan.
Saltzman, Gregory M. 2014. “The Economics of MOOCs.” In *The NEA 2014 Almanac of Higher Education*, edited by Harold S. Wechsler, 19–29. Washington: National Education Association.
Schubert, Christian. 2014. ““Generalized Darwinism” and the Quest for an Evolutionary Theory of Policy-Making.” *Journal of Evolutionary Economics* 24 (3): 479–513. doi:10.1007/s00191-013-0304-x.
Schumpeter, Joseph Allois. 1934 [1983]. *The Theory of Economic Development. An Inquiry Into Profits, Capital, Credit, Interest, and the Business Cycle*. Cambridge, MA: Transaction Publishers.
Shapiro, Carl, and Hal R. Varian. 1999. *Information Rules. A Strategic Guide to the Network Economy*. Boston, MA: Harvard Business School Press.
Singaraju, Stephen P., Quan Anh Nguyen, Outi Niininen, and Gillian Sullivan-Mort. 2016. “Social Media and Value Co-Creation in Multi-Stakeholder Systems: A Resource Integration Approach.” *Industrial Marketing Management* 54: 44–55. doi:10.1016/j.indmarman.2015.12.009.
Strogatz, Steven H. 2000. *Non-Linear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry and Engineering*. Reading: Perseus Books.
Watkins, Rebecca D., Janice Denegri-Knott, and Mike Molesworth. 2016. “The Relationship Between Ownership and Possession: Observations from the Context of Digital Virtual Goods.” *Journal of Marketing Management* 32 (1-2): 44–70. doi:10.1080/0267257X.2015.1089308.
Yoo, Youngjin, Ola Henfridsson, and Kalle Lyytinen. 2010. “Research Commentary—The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research.” *Information Systems Research* 21 (4): 724–735. doi:10.1287/isre.1100.0322.
Yuan, Li, and Stephen Powell. 2013. *MOOCs and Open Education: Implications for Higher Education*. In White Paper: Cetis.
Yuan, Li, and Stephen Powell. 2015. “Partnership Model for Entrepreneurial Innovation in Open Online Learning.” *eLearning Papers* 41: 1–9.

Appendix: Combinatorial model Matlab code

```
clear all

% PARAMETERS

N = 500;                               % Number of agents (institutions offering courses)
T = 100;                               % Number of iterations
lambda = 0.05;                         % Poisson arrival rate of innovations
k = 5;                                 % Degree of locality
rep = 0.1;                             % Significance threshold for courses

%INITIAL DATASET

tend_ = rand(3,N);                     % Trend (random 3d vector) for each agent
tend_norm = tend_ ./ sum(tend_);       % Normalized trends
tend_innovacion = tend_norm(1,:);      % Probability of copying the most innovative agent
tend_mayoria = tend_norm(2,:);         % Probability of copying the "mode" agent
tend_nocambio = tend_norm(3,:);        % Probability of not changing
cursos_ini = randi([0,1],[1,N]);       % Initial distribution of courses
suma_cursos = nan(2*ceil(lambda*T),T); % Number of agents offering each characteristic in
                                       each t

% MAIN PROGRAM

cursos = cursos_ini;

for t = 1 : T
  dim = size(cursos,1);
  salto = rand(1);

  if dim == 1 || salto < lambda
    cursos = [cursos;zeros(1,N)];
    indice = randi([1,N],[1,1]);
    cursos(dim+1,indice) = 1;
  else
    pot = 2.^[0:dim-1];
    cursos_base10 = sum(cursos.*pot');
    orden = randperm(N);               % Random rearrangement of agents

    for agente = 1 : N
      ag = orden(agente);

      if ag <= k
        modacursos = find(cursos_base10 ==mode(cursos_base10(1:ag+k)),1);
        cursoinnovador = find(cursos_base10 ==max(cursos_base10(1:ag+k)),1);
        eleccion = rand(1);

        if eleccion < tend_innovacion(ag)
          cursos(:,ag) = cursos(:,cursoinnovador);
        elseif eleccion < tend_innovacion(ag) + tend_mayoria(ag)
          cursos(:,ag) = cursos(:,modacursos);
        else
          cursos(:,ag) = cursos(:,ag);
        end

      elseif ag >k & ag<= N-k
```

```
                modacursos = find(cursos_base10 ==mode(cursos_base10(ag-k:ag+k)),1);
                cursoinnovador = find(cursos_base10 ==max(cursos_base10(ag-k:ag+k)),1);
                eleccion = rand(1);

                if eleccion < tend_innovacion(ag)
                    cursos(:,ag) = cursos(:,cursoinnovador);
                elseif eleccion < tend_innovacion(ag) + tend_mayoria(ag)
                    cursos(:,ag) = cursos(:,modacursos);
                else
                    cursos(:,ag) = cursos(:,ag);
                end

            else
                modacursos = find(cursos_base10 ==mode(cursos_base10(ag-k:N)),1);
                cursoinnovador = find(cursos_base10 ==max(cursos_base10(ag-k:N)),1);
                eleccion = rand(1);

                if eleccion < tend_innovacion(ag)
                    cursos(:,ag) = cursos(:,cursoinnovador);
                elseif eleccion < tend_innovacion(ag) + tend_mayoria(ag)
                    cursos(:,ag) = cursos(:,modacursos);
                else
                    cursos(:,ag) = cursos(:,ag);
                end

            end

        end

    end

    suma_cursos(1:size(cursos,1),t)= sum(cursos,2);

end

% OUTPUT

[Cont_cursos,ia,ic] = unique(cursos','rows');
variedad_car = size(cursos,1);                      % Number of characteristics
variedad_cur = size(unique(ic),1);                  % Number of variants of OCs
porcentaje_cursos = [];
for jj = 1 : variedad_cur
    porcentaje_cursos = [porcentaje_cursos ; sum(ic==jj)/N];
end
var_cursos_repres = sum(porcentaje_cursos>rep)      % Number of representative variants
                                                    of OCs
```

Note: This simulation model has been programmed using Matlab R2019a.