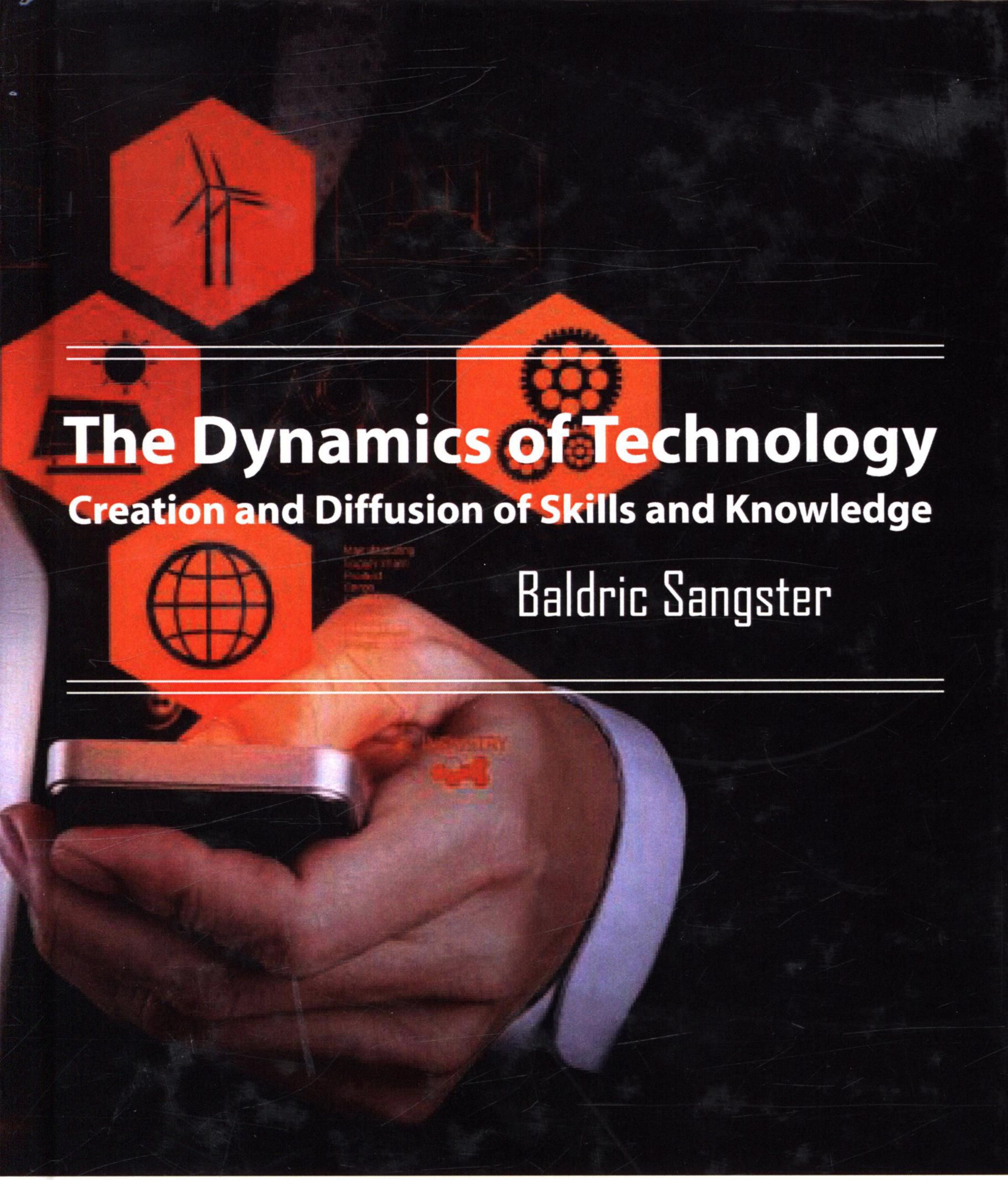

The Dynamics of Technology

Creation and Diffusion of Skills and Knowledge

Baldric Sangster

Socialy Press
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Technology dynamics is broad and relatively new scientific field that has been developed in the framework of the post-war science and technology studies field. It studies the process of technological change. Under the field of Technology Dynamics the process of technological change is explained by taking into account influences from "internal factors" as well as from "external factors". Internal factors relate technological change to unsolved technical problems and the established modes of solving technological problems and external factors relate it to various (changing) characteristics of the social environment, in which a particular technology is embedded.Technology is taking on an increasingly vital and determining role in society, and can provide conflicting results: wealth on the one hand, but also unemployment, environmental imbalances and other social problems on the other. Manufacturing techniques and production organization are chosen in every country based mainly on the specific needs of the companies, while the real needs of each population are often quite different. Already, in order to prevent all forms of technology from becoming increasingly "invasive", towards both the natural supply of resources and the specific - though highly differentiated - needs of humanity, technological paths must be identified and followed which are capable of making the various needs compatible, from the standpoint of sustainable development, the conservation and increase in value of natural resources, and the quality of development.

The Dynamics of Technology: Creation and Diffusion of Skills and Knowledge focuses at the dynamics of technological change. It specifically asks whether technological change occurs in leaps and bounds, or whether it takes place gradually and continuously. It sets up an analogy between technological progress and biological evolution, and tries to apply the concept of punctuated equilibrium to the analysis of technology. It observes that one concept that has been employed in the economics of growth is the steady state, a form of growth which is itself constant and predictable, and thus can be regarded as a dynamic equivalent to the concept of equilibrium. General framework is proposed to relate strategic options and choices to the evolution of technologies, organizations and industry positions following a technological discontinuity. This Book will be of valuable for a general reader to understand the inter-relationship between science, technology and society and particularly the contribution made by engineers towards technology development. It easily explains the underlying dynamics that affect all undertakings in the social sector.

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Editor

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Edited by **Baldric Sangster**

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THE DYNAMICS OF TECHNOLOGY: CREATION AND DIFFUSION OF SKILLS AND KNOWLEDGE

Preface

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CHAPTER 1

The Creative Development of Fields: Learning, Creativity, Paths, Implications

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ABSTRACT

I present a model of the creative development of a field and analysis of the model based on an extensive set of simulations. A field as defined here is a domain for human activity and engagement, including for example standard academic fields as well as practical fields like law, medicine, design, and fields of technology. In the model in this paper, the field is defined in terms of the body of knowledge and elements or products that have been created in the field up to that point. The field begins from an initial state and grows as individuals enter the field and make new contributions; its basic structure resembles a lattice. New elements are created via combining preexisting elements, based on specific rules for combinations; thus I follow much of the creativity literature in defining creativity as creating novel conceptual combinations. The heart of the model is a rational, optimizing model of individual creative development, in which individuals have as their aim maximizing the expected value of their contribution to the field. An individual selects an initial set of elements in the field to learn, then gains intuitive signals about potentially fruitful new combinations based on this learning set, selects additional elements to learn, and finally chooses a potential new element to attempt to make. If the element is viable, it is added to the field, together with any subbundle elements co-created with it. The simulation analysis reveals a rich set of empirical predictions about the development of fields through this process. A first striking find is the diversity of possible paths of development starting from a given initial state. The intuitive signals individuals receive are an important factor in generating this diversity, as signals lead individuals to attempt to make elements they might otherwise not pursue, thus shaping the development of the field in important ways. The results also reveal a high degree of path dependence, generated as individuals build on the work of their predecessors, and interesting temporal patterns for how output in one period is linked with what occurred in the previous period.

Keywords: Creativity • Innovation • Economic growth • Learning

INTRODUCTION

In this paper, I present a model of the creative development of a field. The field is defined as an explicit knowledge structure that starts from a simple initial state, then develops through the series of creative contributions made by successive individuals who enter the field. New elements are added by combining preexisting elements in new combinations. The heart of the model is a rational, optimizing model of individual creative development. Individuals have initial "seed" learning, then gain intuitive signals about potentially fruitful new combinations of elements or subtopics in the field; their signals guide them as they choose further elements to learn and then a new element to attempt to make, basing their choices on expected value calculations. When an individual is successful in his project, the new element he creates is added to the field. The field thus grows over time.

I present an analysis of the model's implications based on extensive simulations. A striking finding is the diversity of possible paths of development starting from a given initial state, in simulations hundreds of paths even for very simple initial conditions. In addition, the results show very substantial path dependence in how a field develops, as individuals build on the work of their predecessors. The results demonstrate the importance of intuitive signals that guide individuals in generating this diversity of paths, for many paths are generated in the full model with signals that are not created in a null "clean" model in which there are no signals. The model predicts distributions for output and the number of elements created over time. I also explore the dynamics of growth, including how expected output in a period depends on the choices and outcome of the preceding period, generating implications about the time series properties of output in the development of a creative field.

The paper fits in the large literature on modeling the innovation process that drives economic growth and cultural development. The importance of innovation has been recognized from the beginnings of the modern literature on growth (Solow 1957) and in the Austrian focus on knowledge and individual initiative (Hayek 1960). Indeed, the central role of innovation in the development of industries was emphasized by Marshall in

Industry and Trade (1919) and the importance of freedom of expression, creativity, and experimentation is the focus of John Stuart Mill's *On Liberty* (1859). In the modern theory of economic growth, the production of new ideas is central to economic development (Aghion and Howitt 1992; for an institutional, historical perspective see Mokyr 2002).

The model in this paper focuses on modeling the creative process in the context of a field of creative activity, which could be a scientific or other intellectual field, a field of technology or design, or a practice. It relates to models of searching for the best new alternative from a distribution of possibilities (Evenson and Kislev 1976; Kortum 1997; Fleming and Sorenson 2004); it also relates to Garicano's model of problem-solving (a form of creativity) in organizations (Garicano 2000). Here, creativity is modeled specifically as combining existing elements in new ways to create new elements. This approach is based on the widely accepted definition of creativity in the field of creativity studies as connecting or relating preexisting elements that have not previously been connected or related (Mednick 1962; Koestler 1964; Poincaré 1908, 1952); I discuss this definition and how it relates to other views of creativity further in "Creating New Elements." My approach is connected to the important contribution of Weitzman on recombinant growth (1998) (Feinstein 2011), although I focus more on the creative process and less on resource limits on the development of new ideas. The model formalizes and builds on the model of creative development developed by Gruber (1974), Feinstein (2006) and Cohen (2009), among others. It is a model of a field so that new ideas are generated in the context of the field (for a recent different formal model of the development of a field see Bramoullé and Saint-Paul 2010). In turn, this allows a representation of how knowledge in a field grows over time, and reveals the structure of the field in terms of how new ideas are generated based on and in relation to older ideas. Interestingly, the structure of the field resembles a lattice, thus also providing a link with the field of economic and social networks (Jackson 2008).

Explicitly modeling the creative process that drives innovation and knowledge creation is important. By formally modeling how this process works, we will be better able to understand and predict the dynamics of how economies and fields develop. This includes how human agents respond creatively to shocks, as well as how they generate new ideas endogenously within a field. The aim is not to predict the exact next idea or innovation, but rather to build models that enable us to calibrate and appreciate the range and distribution of outcomes that may arise given the current state of a field. As I show with the results of this paper, the range is in fact large, and in fact is itself highly variable for different historical paths starting from the same initial condition, with a high amount of path dependence.

A key motivation of this paper is to present a framework that links economic models of creativity and innovation with the field of knowledge representation. Knowledge representation provides a conceptual framework for describing concepts and their relationships (Sowa 1984, 2000; Wille 1992; Ganter et al. 2005). It is also useful for natural language based description (Helbig 2006); for example, Kaplan and Vakili (2013) have developed a text-based approach for linking patents. Lancaster's (1966) model of attributes is a well-known related approach in economics that also fits with the model in this paper. I develop a simple example of a knowledge representation framework of a field and use it to explore how the field develops; details are given in "Attributes and Elements" and "Creating New Elements." Specifically, I define elements in the field as strings made up out of basic "letters" or attributes. New strings are created by combining two preexisting strings according to defined rules. Success is uncertain: an element that is attempted has a probability of being viable. A viable new element has associated an output drawn from a distribution that defines its economic value; this distribution has the properties that are recognized as empirically important for the creation of innovations, specifically a long right tail so that there is a small probability of a very high value contribution.

The heart of the model is a rational, optimizing model of individual creative development. The model centers on learning, intuitive signals, and project selection choice guided by the signals. The signals pertain to subbundles of attributes that may be created when an element that embeds them is created. Thus, intuition is not necessarily about a fully defined final product, but about a "wish list" bundle of attributes, and the task is to find a way to create a new element that embeds this bundle. This captures the commonsense view of the creative process as guided by partial ("fuzzy") vision or simple insight that is then developed, filled in, and perfected. Each time period, a single individual enters the field and goes through a creative development process described in detail in "Creative Development." The model is non-stationary in that the field grows over time as new contributions are made, and the set of feasible new combinations changes and in general also grows over time. Lastly, the field has a public history that records for each individual who worked in the field in the past, his learning choices, as well as the creative project he attempted and its outcome. Probabilities about likelihoods of success in creating new elements and associated output levels are updated at the start of each period using this public history, including indirect inferences about intuitive signals individuals received based on their observed choices.

Overall, the model in this paper provides a basis for describing the dynamics of development of a field that is far more rooted in learning and rational choices than psychological models, including the Darwinian model of random variation and selection (Campbell 1960; Simonton 2003). The

Darwinian model does not incorporate a rational, forward-looking learning process; it has no explicit role for either intuition or expected value calculations being made to guide choices of what to learn and attempt to combine into new elements (Gabora 2005 offers a related critique).

I analyze the model through extensive simulations. I explore several different parameter cases, for each running both the full model as well as companion runs with no signals, which I call *clean* runs. For each simulation, I generate a *masterlist* that specifies for each potential new element whether or not it is viable and its value (output) if it is viable and is produced. I run each simulation out five periods, identifying every possible path of development of the field assuming that individuals follow the optimal creative development strategy; paths differ in the set of intuitive signals individuals receive, which guides their choices about learning and which new element to attempt to create.

The results generate a set of interesting results. A striking finding is the diversity of possible paths of development starting from a given initial state. A typical simulation generates several hundred paths and a substantial number of distinct field structures (multiple paths may lead to the same structure): many simulations generate more than 100 distinct field structures through five periods. In addition, the number of distinct structures itself varies widely across simulations: Thus, there is variability in the potential variability of development of the field, depending on parameter values and outcomes early in the history of the field. Linked to the diversity of structures, there is also substantial variance in the number of new elements created and generated output. There are many fewer paths when the model is run with no intuitive signals guiding choices. Thus, an important finding is that much of the diversity of possible paths of development of the field is generated by the intuitive signals, which lead individuals to attempt to make elements they would otherwise not attempt, in turn opening up new frontiers for future development.

A second finding is the high degree of path dependence. Comparing pairs of paths for which the element created (or attempted but not viable) in the first period is different, typically each path leads to new elements that are not created along the other path. This result fits naturally with the cumulative nature of creative development of the field, as individuals build on the work of their predecessors. A noteworthy feature, at least through five periods, is that once two paths diverge, they do not tend to reconverge, but generate substantially different sets of elements going forward.

A third set of findings concerns conditional output calculations and the dynamics of output. A basic distinction is whether a new element was successfully created or not in the preceding period—is productivity higher when a new element was successfully created? I address this question with the simulations. A second issue is whether the individual in the preceding period was guided by a signal in his choice of element to make—it stands to reason that when an individual has been guided by a signal and has been successful, this will open up new frontiers that might otherwise remain unexplored. Results in general confirm this, with conditional expected output greatest when a new element has been made in the preceding period based on a live signal. Thus, the model generates implications about the time series of output. Model results also speak to how frequently an individual attempts to build a new element using as a building block an element created in the immediately preceding period, versus an element created further back in time. I have also explored an extension in which individuals earn a royalty if an element they create is used in the future; I discuss this in the conclusion.

The remainder of the paper is organized as follows. The next section introduces basic terminology about the field, its knowledge structure, the creation of new elements, and valuation of new created elements. Section "Creative Development" describes the process of creative development of individuals working in the field, including their learning process, intuitive signals, and their optimal strategy. In "The Development of the Field" section, I describe the development of the field including its structure and how the history of the field is updated after each generation. In "Simulation Results" section, an extensive set of simulation results are presented and discussed. Section "Conclusion" concludes. An (online) Appendix (available at www.jonathanfeinstein.com) contains supplemental materials.

THE FIELD: ELEMENTS, CREATIVITY, VALUES

A field is defined to be a domain for human activity and engagement, comprising a body of knowledge and tangible elements. Knowledge may be taken broadly to include descriptive knowledge, theoretical concepts and definitions, attributions, assumptions, and theoretical statements or propositions; empirical knowledge, including facts, cases, data and examples, and heuristics; and tangible elements including materials, apparatus, and products that have been created in the field. In this paper, I use a very simplified representation of a field, in order to tie the model to a rational model of learning and creativity generation; but I believe the model can be extended to richer contexts. At a given point in time, a field includes both widely accepted knowledge as well as opportunities for the further creation of knowledge (an important extension of the model here would allow for contested knowledge that might be challenged in new work), including new products. In reality, the boundaries of a field are typically not sharp and individuals may draw on knowledge from "outside" the field to produce new elements in a field. I do not distinguish inside and outside but rather simply assume all relevant elements for creativity generation are included in the representation. A useful extension is to allow for some parts