



Identifying the sources of technological novelty in the process of invention



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ABSTRACT

Much work on technological change agrees that the combination of new and existing technological capabilities is one of the principal sources of inventive novelty, and that there have been instances in history when new inventions appear with few antecedents. The many discussions across research communities regarding the relative roles of combination and origination as sources of technological novelty have not provided much in the way of formal identification and quantification. By taking advantage of the technology codes used by the U.S. Patent Office to classify patents, we discretize technologies and identify four distinct sources of technological novelty. The resulting *technological novelty taxonomy* is then used to assess the relative importance of refining existing technologies, combining existing and new technologies, and *de novo* creation of technological capabilities as sources of new inventions. Our results clearly show that the process of invention has been primarily a combinatorial process accompanied by rare occurrences of technological origination. The importance of reusing existing technological capabilities to generate inventions has been steadily rising and recently overtook recombination as the source of novelty for most new inventions.

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1. Introduction

Three perspectives dominate the discussion about the sources of novelty in invention technological change. Many researchers studying invention agree that combinations of new and existing technological capabilities are a principal source of inventive novelty. Under this combinatorial view of technological change new technologies are constructed from existing technologies, which in turn become available as building blocks in the construction of other new technologies (see e.g., Auerswald et al., 2000; Basalla, 1988; Fleming and Sorenson, 2004; Hargadon and Sutton, 1997; Henderson and Clark, 1990; Levinthal, 1997; Ogburn, 1950; Rosenberg, 1982; Usher, 1954; Von Hippel, 1988; Weitzman, 1998). A second, prominent perspective of human technological development, taking the long-view from the time of hunter-gatherer societies to the present, has been gradualism – the slow accumulation of variations and improvements in the features of tools and technologies, the result of both deliberate modifications and accidental tinkering (Boyd et al., 2011; Lawrence, 1997; Pacey, 1990; Purcell, 1982; Richerson and Boyd, 2004; Russo, 2004). A third body

of research points to instances of new technologies appearing with few antecedents that originate technological pathways rather than extend existing ones (Arthur, 2009; Christensen, 1997).

The many discussions about the processes underlying technological development, and the relative roles of combination and origination as sources of technological novelty, have not provided much by way of quantification. The paucity of formalization is not surprising given the difficulties in discretizing technologies and classifying technological novelty systematically across a broad set of technologies. Here, we present a *taxonomy of inventive novelty* (as instantiated in patented inventions) based on how the U.S. Patent Office classifies the technological novelty of patents. We use this taxonomy to quantify the relative proportion of inventions that originate new technological capabilities, combine new or existing technologies in novel ways, or reuse existing capabilities as sources of inventive novelty. As McNamee (2013) reminds us, taxonomies – used to categorize and differentiate entities based on relevant criteria – are crucial in efforts aimed at understanding complex phenomena.¹ The taxonomy we have developed can be used to

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¹ The scientific study of organisms and biological systems can be dated to the introduction of the Linnaean taxonomy in 1735. As there is still no widely accepted technological taxonomy the study of technological change is in a sense still in a pre-Linnaean state.

non-arbitrarily distinguish significant improvements from incremental ones in inventive activity, a subject of long-standing interest and debate.

Patented inventions are one manifestation technological novelty, and what is novel about an invention is described by its inventors, in precise, technical detail, in a patent's claims.² The United States Patent and Trademark Office (USPTO) classify inventions by encoding information contained in the claims using a system of numerical codes, the *patent technology codes*. At any given time, the existing set of technology codes available to a patent examiner is essentially a description of the current set of technological capabilities. With each new patent application a patent examiner must decide which existing codes to use to capture the technological components responsible for the patent's novelty, and whether or not new technology codes are required to capture the invention's newness. The introduction of a new technology code sets in motion a retroactive reclassification of all previous patents that may have embodied the newly recognized technological capability. The Patent Office's technology codes thus, constitute a set of consistent definitions of technological capabilities spanning over 200 years of inventive activity. The technology codes are the crucial empirical ingredient in the construction of our taxonomy of inventive novelty.

The discussion is organized as follows. The next section sets the conceptual framework and poses the research questions. Section 2 describes the use of patent technology codes to classify the technologies embodied in patented inventions. Section 3 develops the taxonomy of technological novelty and presents the main empirical results, among them the relationship between the types of inventive novelty constituting the proposed taxonomy and the citations profile of these novelty types. In Section 4 the validity, or perhaps more accurately, the sensibleness, of the novelty taxonomy is assessed through an examination of how the taxonomy classifies a set of historically and economically significant patents. Section 5 concludes.

2. Conceptual framework and data

2.1. Research questions

What is a *technology*? According to Romer (2010), technologies are ideas about how to re-arrange matter, energy, and information; for Arthur (2007) technologies are means to fulfill a human need or purpose. In the present discussion, we similarly define technologies as functionalities – artifacts, devices, methods, and materials – available to humans to accomplish specific tasks. An invention is a unique or novel device, method, composition, or process. Distinct from technology, an *invention* integrates distinct technological functionalities. It is important to note that *technological novelty* is not the same as *inventive novelty*. Technological novelty arises, and technological change occurs, when new technological functionalities are introduced into the existing repertoire of technologies. Inventive novelty – new artifacts, devices, processes, materials, or compounds – may not necessarily embody technological novelty.

The technology codes used by the Patent Office as identifiers of distinct technological functionalities makes it possible to describe, and rank, *inventive novelty* as resulting from the development of new technological capabilities, the combination of technological capabilities in ways that had not been previously witnessed in the patenting record, or from the reuse of technologies. Using the

technology codes for empirical support, we address the following specific research questions:

Q1. What are the sources of inventive novelty (as revealed through patents)?

Q2. What roles have combination and refinement played in the development of new inventions?

Q3. Have the rates at which the various sources of technological novelty arise been changing over time?

Q4. In the case of patented inventions, whose novelty resides in the novel combination of technological functionalities, how similar or dissimilar are the technologies brought together?

Perhaps the most pressing and obvious question, namely whether the taxonomy is meaningful, valid, and/or sensible, is the most difficult to answer directly. A measure of validity would seem to be inherited from the taxonomy's reliance on the Patent Office's mandate practice of identifying the technologies responsible for an invention's novelty. We inquire as to the relationship between forward citations, a common indicator of a patent's importance or influence, and the different types of inventive novelty identified by our taxonomy. And we also classify over one hundred significant patents, whose significance has been attested by historians and experts, using the taxonomy presented here. But we readily acknowledge that we do not have an independent validation of how meaningful the taxonomy is. How useful the taxonomy is will be validated through use by the research community.

2.2. Patent data and technology codes

U.S. Patent Law specifies four categories of inventions or discoveries that are eligible for the protection of a patent: processes, machines, manufactures, and compositions of matter. Additionally, the U.S. Supreme Court has reaffirmed the patentability of business methods, computer programs, and mathematical algorithms (561 U.S. Supreme Court, 2010). The United States Patent and Trademark Office (USPTO) grants three types of patents: utility patents (also referred to as a patents for invention) which are issued for the invention of new and useful processes, machines, artifacts, or compositions of matter; design patents, which are granted for the ornamental design of a functional item; and plant patents which are conferred for new varieties of plants or seeds (over 90% of the patents granted since 1790 by the USPTO are utility patents). U.S. patents therefore, encompass a very broad array of technologies and the taxonomy presented here takes full advantage of this diversity.

A patent is intended to be limited to only one invention consisting of several closely related and indivisible (i.e., integrated) technologies that, acting together, accomplish a specified task (in patent law this is known as the unity of invention). In simple terms, this means is that a jet engine cannot be patented, but the numerous individual components that constitute a jet engine can. The Wright Brother's 1906 patent for a flying machine, for example, is actually for a method of controlling the direction and altitude of a flying device, not for the concept of an airplane. In the case of inventions which accomplish multiple and separable tasks, the inventors can be required to file separate patent applications for each distinct task or component.

What an invention is and what it does is described by a patent's authors in the numbered claims which also serve to define the scope of the legal protection granted by the patent. The USPTO uses a system of technology (or classification) codes to identify and classify the technologies invoked by approved claims which embody the invention's novelty. The codes constitute a classification system that groups patents together according to similarly claimed subject matter (allowing for patents to be searchable), and are used by patent examiners when searching for relevant prior art during a patent application examination process. The classification

² A patent however does not identify precisely what is novel about the invention, nor are inventors legally required to clearly highlight in the claims (which legally define the patent) where the novelty of the invention lies (Lemley, 2011).

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