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Drivers of technology adoption — the case of nanomaterials in building construction

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ABSTRACT

With the building and construction sector contributing significantly to global greenhouse gas emissions, there is great demand for resource- and energy-efficient construction materials. Manufactured nanotechnology products (MNPs) are expected to realize resource and energy efficiency through performance improvements in the strength, lightness and insulating properties of construction materials. However, the actual adoption of MNPs has lagged. This article examines how the construction sector in the United States assesses MNPs for adoption. Through patent analysis and interviews, we gauge the supply of MNPs and identify actors' roles in technology adoption. Results indicate that awareness of MNPs is more extensive than anticipated. Yet, MNP adoption is limited by a multi-component technology assessment process focused primarily on the technology's applicability to project-based outcomes. We conclude that barriers to MNP adoption can be overcome through intermediary activities such as product certification, comprehensive technology assessments, and "real-world" demonstrations.

1. Introduction

The building and construction sector, including through the use of its stock of completed homes, offices, and multiple other types of buildings, accounts for 40% of greenhouse gas emissions globally [1] and 48% of greenhouse gas emission in the United States [2]. In 2011, President Obama cited improved energy efficiency in buildings as "one of the fastest, easiest, and cheapest ways to save money, combat pollution, and create jobs" [3]. Manufactured nanotechnology products (MNPs) are expected to realize resource and energy efficiency through increased strength, lightness, corrosive resistance, and other performance improvements of construction materials [4–6]. Yet, the building construction industry, which generates $989 B of annual output in the U.S. [7], is often criticized for its recalcitrant approach to new technology adoption [4]. The industry is generally considered more risk-averse and fragmented than other sectors of the economy [8,9].

This article examines how the construction sector in the U.S. assesses MNPs for adoption. This case contributes to explaining how knowledge and learning, networks and strategic linkages, institutions, and market forces drive technology innovation and adoption. In its simplest form, through knowledge acquisition, firms incorporate technological inputs to generate products and/or services. While demand plays an important role in the shaping and selection of new technologies [10], sectors change over time in response to technological innovations [11]. Our study pays special attention to the barriers to the adoption of potentially advantageous technologies, accounting for technology transfer between sectors and transitions from one underlying knowledge structure to the next as mediating factors in

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overall innovation system capacity [9,12]. In particular, we investigate how the construction sector responds to evolving product demand and the rapid development of technological inputs, asking three questions:

(1) How do firms obtain knowledge about evolving technologies?
(2) In which ways do industry and organizational factors enable and constrain the adoption of new technological inputs?
(3) What is the role of market demand, voluntary programs, and public policies in the adoption of new technological inputs?

We address these questions through a mixed-method approach, which examines survey and transcript responses of 19 interviewees. In addition, we capture technology supply through a descriptive overview of MNP patents relevant to building construction. Our results show that knowledge of MNPs is more extensive than anticipated, yet structural barriers endemic to the industry preclude widespread adoption.

This paper contributes to three domains of innovation research. First, with the focus on firm-level decision-making as a precursor to sectoral change, the study contributes to evolutionary economic research regarding the factors that enable and constrain search processes [13–15]. Second, the study contributes to research on sectoral systems of innovation by evaluating the impact of high technologies, such as nanotechnology, on supplier-dominated industries that experience limited incentives to adopt new technologies [9]. Third, this research contributes to the literature on the diffusion of innovations [16] by examining a critical transition phase in the innovation pathway when patented prototypes are assessed for wider uptake by firms who are hesitant to act as first movers.

The paper is organized as follows. First, we review the literature on the functional role of MNPs in building construction inputs, accounting for potential determinants of MNP adoption. Second, we outline our methods, and third, we present results from the patent analysis, surveys, and interviews. Finally, we discuss implications for public policy, limitations, and potential avenues for future work.

2. Literature review

Several streams of literature set the foundation for our analysis of MNP use in building construction. We draw upon work on firm capabilities and industry effects; forms of organizing; market demand, policy, and standards; and characteristics of the technology as determinants of – and barriers to – adoption.

2.1. Intra-firm capabilities and industry effects

The building construction industry can best be characterized as supplier-dominated [9]. The firms in the sector are often distant from science-based research, with those innovations used by building construction firms typically produced exogenously in other industries such as material manufacturing or instrumentation. Building construction is the 9th largest industry in the US, employing over 5.5 M people and contributing about 4% to gross domestic output [7]. Firms may specialize in services outside of on-site construction, e.g. architectural and civil engineering firms, to produce designs and construction specifications and to ensure that plans and renderings comply with local building ordinances. Principal architects, engineers, and lead contractors can be viewed as system integrators [17]. Thus, building construction is an amalgamation of manufacturing and services, with innovation in the industry occurring across "a wide variety of economic and productive arenas" (Marceau et al., 1999, as cited by [8]).

The average firm size in the building construction sector, as measured by the ratio of total private sector employment to number of establishments, was just over 10 in 2007 [18]. Consequently, most building constructions firms, which generally employ small workforces, are limited in their R&D capabilities and absorptive capacity [8,19]. Absorptive capacity refers to the extent to which a firm can assess and then assimilate exogenously generated information to internal applications or problems for commercialization purposes [20]. Without absorptive capacity or in-house R&D talent, builders find it difficult to identify new inventions and/or understand the full implications of incorporating new innovations into their projects [8]. At the same time, firms will resort to ad hoc problem solving if a cost–benefit analysis cannot justify investments in higher level operating routines that give rise to innovative capabilities (c.f. [21]).

Architecturally sophisticated projects, however, may require firms to develop absorptive capacity and improved ad hoc problem solving, leading to the inclusion of new technologies. Technological progress may inform the cutting-edge of possibility in certain contemporary and experimental designs. It is equally plausible that firms conceiving avant-garde architecture search for new technologies to fulfill their development and esthetic goals. Poole [22] discusses how innovative designers look to work closely with engineers in an effort to push beyond the existing boundaries of their design. This approach led to novel structural designs for the Millennium Wheel in London and the Bridge of the Future, a design concept for a bridge across the Grand Canyon. In such cases, architectural design explores the adoption of multi-functional materials that reduce resource and energy consumption [23].

As an alternative to developing absorptive capacity, some firms may exploit knowledge about emerging innovations through interactions with lead users, who incorporate and modify products to solve context-specific problems [24,25], even in "low-tech" fields such as construction [26]. In sum, search processes for new information may be diverse, mediated by costs of acquisition and processing and subject to project requirements.

2.2. Contracts and new forms of organizing

Economic activity is typically organized through markets, hierarchies, or networks [27], though scholars frame such phenomena in diverse ways. For example, Williamson [28,29] argues that transactions characterized by recurring interactions under high levels of uncertainty and asset specificity are better exploited by firms than by markets. In addition, firms may be more efficient than markets because agents cannot write contracts to address all possible