The Diffusion of Energy Saving Technologies in the Building Industry: Structural Barriers and Possible Solutions

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ABSTRACT

Energy-saving building technologies offer the best available opportunity to reduce GHG emissions with positive net present value and rapid payback. However, very little progress has been made in implementing them. This is a missed opportunity. There is no lack of energy-saving technologies with positive short term paybacks for both new and existing buildings. Rather, we argue, the extremely slow diffusion of these impactful technologies is a result of the horizontally and vertically fragmented structure of the building industry, its susceptibility to extremely large fluctuations in demand, its tradition of partitioned competitive bidding, and the broken agency between decision-makers involved in capital vs. operating decisions in this industry. In this paper, we develop a set of propositions about the key organizational, inter-organizational, and industry barriers to widespread adoption of energy-saving building technologies, as well as possible solutions to overcome these barriers.

KEY WORDS: Integral Innovations, Innovation Diffusion, Building Industry.

Buildings emit more CO_2 and consume more energy globally than any other sector (DOE). Moreover, the existing stock of buildings—and many new buildings—use energy extremely inefficiently. This has created a tremendous opportunity to reduce energy use and attendant greenhouse gas emissions. The past three decades have seen a surge in the development of new energy-saving technologies for use in existing or new buildings (USPTO, 2009). With the technologies that exist today, energy use could be lowered by 25 to 30 percent by 2030 (NAS, 2009). In fact, increased implementation of energy-saving technologies is widely agreed to be the nearest-term, lowest-cost way to reduce for our nation's energy consumption. Furthermore, many of these energy-saving technologies represent attractive investment opportunities: they are NPV-positive, have a payback period of two to three years, and are likely to remain competitive in the future (NAS, 2009). Yet NPV-positive opportunities worth over $130 billion go unrealized, because many promising, technically-feasible innovations diffuse very slowly, or sometimes not at all, through the building industry (Choi Granade, et al., 2009; NAS, 2009). Not only are opportunities foregone, but energy intensity has recently (1985-2004) increased by 12% in the commercial buildings sector (DOE).

Why do so many technically-feasible, energy-saving technologies fail to diffuse through the building industry? Our thesis is that the highly fragmented structure of the construction industry, together with large amplitude demand fluctuations, decision making plagued by "broken agency" between building design and construction vs. operations, and a culture of low cost competitive bidding all play important and interconnected roles in inhibiting the diffusion of energy-saving building technologies.

INNOVATIONS IN THE CONSTRUCTION INDUSTRY

There are surprisingly few studies that have examined structural, market-level variables in this large and important industry. Most organizational research on innovations focuses on firms' *willingness to adopt innovations*. However, industry barriers can hamper firms' *ability to implement innovations* (Taylor & Levitt, 2004). The few studies that consider market-level variables have found that almost all the innovations that have successfully diffused in the building industry are *modular* in nature (Arditi & Tangkar, 1997; Lutzenhiser & N., 2003; Taylor & Levitt, 2004). In contrast, *integral* innovations diffuse very slowly through the industry (Taylor & Levitt, 2004).

Modular innovations

Modular innovations affect only a single module within a product and have no effect on the way that the module is integrated with other modules within a product. These innovations affect a single *"swim lane"* through the supply chain with negligible impacts on product or process attributes of other supply chain nodes (Henderson & Clark, 1990; Taylor & Levitt, 2004). A *swim lane* includes and bounds the supply chain nodes involved in all phases of producing a building component that corresponds to a specific division of the Construction Specifications Institute's *MasterFormat* product breakdown (CSI), such as structural steel, ornamental ironwork, or roofing. An example of a modular innovation might be an improved window design with lower emissivity or a compact fluorescent light bulb that fits into a standard light socket. A modular innovation can increase the energy-efficiency delivered by the component that emerges from the individual swim lane through which it flows, but tends to have a relatively small effect on overall lifecycle energy use of a built system.

In our discussion of modular innovations, we focus on the locus of innovation (within a single module or subsystem) without considering the effect size of that innovation. Thus, our definition encompasses Henderson and Clark's (1990) incremental and modular innovations, Taylor and Levitt's (2004) incremental innovations, and Gatignon and colleagues' (2002) generational innovations. We use a different term because we believe that our term best captures the essence of this type of innovation.

Integral Innovations

To optimize global building energy performance, the entire supply chain needs to be taken into account (Ulrich, 1995). The implementation of many of the most significant energy-saving innovations that we have examined requires coordination between two or more supply chain nodes spanning across swim lanes in the construction supply chain. These innovations affect the way that modules are integrated rather than individual modules. Put another way, they affect the linkages between the subsystem within a larger system, rather than the subsystems themselves.

We have not found an appropriate term in the organizational innovation literature for this type of innovation (Gatignon, et al., 2002; Henderson & Clark, 1990; Taylor & Levitt, 2004). We have therefore coined the term *integral innovations,* for innovations that affect the way that subsystems within a product are integrated and whose implementation therefore requires coordination between nodes in at least two separate component swim lanes in the supply chain. Our definition encompasses Henderson and Clark's (1990) architectural and radical innovations, Taylor and Levitt's (2004) systemic innovations, and Gatignon and colleagues' (2002) architectural innovations. One of the main reasons that we chose not to adopt one of these prior definitions is that they are inconsistent with one another. For example, Henderson and Clark's use the term architectural innovation to express both the locus of innovation (linkages between subsystems) and effect size (small), whereas Gatignon and colleagues' use the term architectural innovation to specify only the locus of innovation (linkages between subsystems). Taylor and Levitt use the term systemic innovation to focus on the locus of innovation (linkages between subsystems) as well as the entities affected (multiple firms). Our term refers only to the locus of innovation (linkages between subsystems), without consideration of effect size (could be small or large) or entities affected (a single or multiple organizations). Further, our definitions – modular and integral innovations – describe most precisely the types of innovations that we are studying.

An example of an integral innovation is an integrated building control system that manages multiple aspects of the use of energy, access and egress, fire safety, etc. for a significant sized building such as Y2E2 at Stanford University. This type of building control system has linkages across multiple swim lanes in the building industry supply chain, including sensing and control hardware and software, window manufacturing and installation, heating, ventilation, air-conditioning, electrical, flooring, fire safety, security and the like. Integral innovations, by definition, cut across multiple swim lanes and require the coordinated efforts of the network of firms involved in the design, construction, and operation phases of a project. As such, they necessitate multiple, interacting changes in the supply chain that require multiple firms to learn and implement changes in their existing work processes, division of labor, division of costs, and division of profits. This generates switching, start-up, and learning costs for some firms, shifts the locus of costs and benefits between firms, and potentially reduces or even eliminates the role of others (Taylor & Levitt, 2004).

Integral innovations like integrated building control systems are the ones that typically enable the most substantial long term savings in operating costs and attendant energy-efficiency of the resulting product, but they are much more difficult to implement and are therefore slow to diffuse, especially in fragmented industries such as construction (Taylor & Levitt, 2004). In fact, because of the real and perceived risks associated with integral innovations, competitors often "not only resist innovative threats, but actually resist all efforts to understand them, preferring to further entrench their positions in the older products" (Utterback, 1996, p. xxvii). We hypothesize that this problem of supply chain orchestration and learning across firm boundaries is one of the primary barriers to more rapid diffusion of many kinds of integral innovations related to energy efficiency in buildings. Finding ways to overcome this challenge has the potential to unleash many large-scale energy saving integral innovations.

Further, although modular innovations are easier to diffuse, the incentives to adopt and implement them can be undercut by some defining characteristics of the construction industry. To better understand the relatively slow diffusion of both modular and integral innovations that have the potential to save vast amounts of energy, we develop a broader theoretical framework for understanding the structure and functioning of this industry.

THEORETICAL FRAMEWORK

The project-based construction industry is fragmented both "horizontally" in terms of discipline/trade (i.e., mechanical, electrical, structural) and "vertically" in terms of project life cycle (i.e., project shaping, design, construction, commissioning and operation). Based on our initial analysis, we tentatively propose four primary mechanisms that retard the diffusion of both integral and modular innovations. The first is the learning disability that results from industry's horizontal fragmentation. The second is a culture of competitive bidding in a horizontally-fragmented industry. The third is the broken agency that results from vertical fragmentation. The fourth is the high level of demand fluctuation that strands capital and provides a disincentive to make capital investments. The first mechanism primarily impacts integral innovations, while the following three impact both integral and modular innovations.

Learning Disability

The top 400 construction firms in the US account for less than 15% of industry volume (ENR, 2009). The US construction industry includes close to two million small, specialized local firms, fifty percent of which have zero employees (Census, 2004) and are thus "mom *or* pop" firms! Moreover, in the liberal market economy of the United States, relations between clients and contractors, and between contractors and subcontractors, tend to be one-off and arms-length, relative to those in more coordinated market economies like Finland or Japan (Hall & Soskice, 2001; Taylor & Levitt, 2004). Many clients, including virtually all public construction buyers, require general contractors to submit lump-sum bids and then choose the "lowest qualified bidder"[1]. General contractors, in turn then solicit lump-sum bids from multiple specialized subcontractors, either at large, or from a list of approved prequalified subcontractors.

Thus, individuals and firms at every node in the supply chain tend to select the bidder with the lowest price for each component's materials and subsystems rather than working with the same set of players across industry swim lanes from project to project (Taylor, 2006). As a result, the makeup of the core team of architects, engineers, building contractors, subcontractors, and component suppliers required

[1] "Qualified bidder", in this context, means simply a contractor that can secure a surety bond guaranteeing completion of its work and payment of its subcontractors and vendors on the project.

to deliver significant building projects tends to change significantly from project to project, even in the same metropolitan area. Therefore, much of the tacit knowledge gained from installing an innovative integral energy-saving building technology—or any other integral innovation—on a given project is lost when teams disband, so the learning cannot be transferred to future projects.

Culture of competitive bidding

Bidding for a building project is typically done separately by component/sub-trade—i.e., the lowest bidder for each building component on a typical project is chosen to supply and install that component. This fragmented competitive bidding process blocks any inter-component cross-subsidies that might be positive in the aggregate, so the best overall solution may not be chosen. For example, ConXTech's innovative steel structural system has a higher cost than traditional structural systems, but can be installed at the rate of one floor per day (vs. about one floor per week) and allows for significant savings on mechanical and electrical systems. It thus provides a substantial reduction in overall project cost and time. However, when bids are awarded separately by subtrade/component, contractors using lower cost traditional structural systems can underbid ConXTech and displace the innovative, and globally more optimal, integral structural system (ConXTech).

Broken Agency

Separate individuals, different departments with an organization, or different companies incur the risks and benefits associated with each phase of a building project's life cycle, so no individual or firm on the project has a truly multidisciplinary, life cycle perspective. In particular, the individual or firm that bears capital costs does not usually bear the full lifecycle operating costs. Overall project benefits may conflict with individual participants' self interests and so tend to be ignored. This "broken agency" is present in each phase of a building's life cycle as a result of vertical fragmentation of the industry (Henisz & Levitt, 2009). A Lawrence Berkeley National Laboratory study that measured differences in implementation of energy-efficient technologies by principals and agents (sellers and purchasers, owners and users) found that in just four of the major energy end uses in the US residential sector alone, the magnitude of this broken agency problem totaled over 3,400 trillion BTUs in 2003, which equaled 35% of site energy consumed (Martishaw & Sathaye, 2006).

Stranded Capital

An exceptionally high level of demand fluctuation—several times greater than the overall business cycle—plagues the building industry. This is an additional constraint to diffusing innovative building technologies, because investments become *stranded capital* when demand turns down, as it did so viciously in 2009. This severe demand fluctuation renders building industry firms unable to service long term debt or justify external investment[2]. This forces them to finance their growth out of retained earnings and operate with extremely low fixed overheads. Even modest investments in equipment or training needed to implement integral energy-saving innovations are difficult for building firms to justify. Moreover, horizontal integration to address the learning disability described above can be risky, as firms must then bear a larger percentage of overall costs and must struggle to balance workloads for multiple disciplines or trades in the face of these severe demand fluctuations. George Romney, an ex-auto industry executive who was US HUD Administrator under President Nixon, launched "Operation Breakthrough" in the early 1970s to encourage investment in producing modular housing units. When demand turned down after the end of the Vietnam War, the newly formed modular housing component manufacturers failed, in large part, due to *stranded capital*. "Project Hus" in Denmark met a similar fate in the early 2000s.

POTENTIAL INTERVENTIONS

We propose three possible types of interventions to help to overcome the critical market failure of the slow diffusion of energy-efficient integral innovations: (1) Policy and incentives; (2) Corporate strategic actions; and (3) Consumer education.

Policy

Intervention by government – through regulations, codes, incentives, or other policies – is generally justified in circumstances in which market failures result in outcomes that are less than optimal for society. In some cases, regulation can be quite effective; in fact, codes are a standard solution to deal with the problem of broken agency. And a voluntary standard such as LEED, even if not always as effective as it hopes to be (Newsham, Mancini, & Birt, 2009), does increase public awareness of environmental issues and is likely to have a positive long-term effect.

[2] Note the very low number of publicly listed construction companies among the scores of US construction firms with revenues over $1 billion.

However, codes alone are not enough and do not necessarily increase the rate of diffusion of innovations (Gann, Wang, & Hawlins, 1998). Even states like California with aggressive green energy codes see relatively slow implementation of energy-saving building technologies. Moreover, in some cases, codes can even decrease rate of innovation diffusion (Oster & Quigley, 1977). For example, building owners may decide not to retrofit existing buildings – an area that holds the greatest opportunity for energy saving – if doing so will require them to comply with costly new codes. Finally, codes do not solve the coordination and learning problem that we described; while codes and voluntary assessment regimes like LEED may require or induce firms to implement energy-saving technologies, they do not guarantee that the technologies will be implemented correctly to achieve their energy saving potential. Thus, we are currently analyzing when – and what type – of regulatory policy or voluntary standard is most productive.

Innovation Strategies for Firms

There are several strategic actions that building industry firms can take to increase the rate and magnitude of diffusion of energy-saving innovations. For example, to counter the learning disability caused by horizontal fragmentations, firms could reconfigure their supply chain by horizontally integrating the interdependent nodes required to implement an integral innovation. In our interviews at a an innovative new green construction company in the SF Bay Area, we learned that they are employing this strategy of bringing many of the key design and construction steps in-house to reduce uncertainties and learning costs by retaining important knowledge within the firm.

Integrating the supply chain, however, can increase the risk of stranded capital when demand turns down, as we previously explained. A strategy that addresses the learning disability but takes into account the possibility of demand fluctuation is creating multi-project joint ventures or alliances. This is another strategy that the green construction company that we have been studying is attempting to employ. They are trying to create a network of professionals for processes that cannot be internalized. To counter the dangers caused by demand fluctuation head on, firms could employ innovative finance strategies, as Ryan Homes did in the 1970s. These are just a few examples of the kinds of strategies that we are studying.

Consumer Education

Increased interest in and understanding of the benefits of building energy saving technologies by consumers will incentivize firms to overcome the market barriers and implement these new technologies. Consumer interest is rising due to several factors, including a general increase in consumer awareness of global warming; higher energy costs that begin to become significant even for commercial office tenants; LEED certification; and other factors.

DISCUSSION

In this paper, we laid out our theoretical framework and propositions for the four primary structural barriers to the diffusion of energy saving innovations in the building industry and three types of solutions to overcome these barriers. Accelerating the adoption of energy-saving technologies in new buildings, and especially for retrofitting existing buildings, is widely agreed to be the single most effective and lowest cost way to reduce greenhouse gas emissions in both developed and developing countries. The world is poised for an unprecedented boom in construction over the next few decades as multiple large cities with more than 1 million inhabitants spring up in India, China and other developing countries, and the developed world finally gets down to renovating its existing buildings and infrastructure stock. If we are to have any chance of meeting aggressive GHG emission reduction targets to ward off serious climate change, we have to learn how to build and retrofit more energy-efficient buildings in the face of the time-proven challenges of doing so. We believe that through the strategies we are working to identify, both the rate and magnitude of diffusion of energy-saving technologies can be increased.

The construction industry is structured relatively similarly to the US in all market economies around the world. Firms are mostly small, local, labor-intensive and light on investments in anything, including innovation. Their supply chains are equally convoluted and many of the major equipment suppliers such as elevator or air-conditioning manufacturers are global businesses. Thus the findings of the study should apply in most of the world's countries, and can readily be adopted globally.

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