Technology Matters—

The Cost of and Returns to Innovating Homes, or Not

Carlos Martín, PhD[1]

There is a less than optimal level of technology research and development in the US housing industry. Yet, there has been no analysis of whether the social returns to research prohibit that investment, nor how particular practices or institutions in the industry structure those social returns. This paper argues that current industry traits increase market spillover and, to a much lesser extent, knowledge spillover to the point where the individual innovative firm in housing cannot appropriate the social returns to its research investment. There is also only minimal evidence that firms receive non-financial benefits from innovating due to the same traits. As such, public intervention is necessary to increase investments both directly to research projects and indirectly through restructuring research practices.

The "Problem" with Housing Innovation

While no thorough or comprehensive studies have measured the total expenditures for housing technology research (let alone estimated the returns to or benefits from that research), it is commonly felt that the level of investment if suboptimal. Indeed, scholars, industry analysts, and numerous producers of housing have regularly lamented the lack of technological innovation in our nation's homes over the last half-century. It is argued that this innovation gap is especially

[1] Dr. Martín is a researcher with the Partnership for Advancing Technology in Housing of the US Department of Housing and Urban Development. 451 7th St SW, Suite 8134, Washington DC 20410. Phone: (202) 708-0614 x5845. Fax: (202) 708-5873. E-mail: carlos_martin@hud.gov.

true for detached, single-family housing—a market that makes up most of the housing stock. In fact, it can purportedly take anywhere from 10 to 25 years for a new housing technology to achieve market penetration.[1] As a consequence, the construction industry in general (let alone the residential construction industry) invests little in technological R&D in comparison to other industries.[2]

Though there is no consensus to this claim and little adequate data or analysis supporting it, the positive effects of innovation (as well as the negative effects of a lack of innovation) are well documented empirically, including in those studies that are particular to housing.[3] Historically, we know that both product changes (from indoor plumbing to air conditioning to energy-efficient features) and process innovations (from standardized material sizes to preassembled roof trusses to modular and panelized systems) have dramatically changed homes and their delivery. But, have they also changed housing markets?

Conceptually, we believe that these innovations provide benefits to numerous parties in numerous ways. Technological innovation provides homeowners with more functional options in their homes, often at reduced prices. They enable homebuilders to construct more quickly, safely, and cost-effectively. They also potentially provide for national benefits such as reduced energy-consumption, increased resistance to natural disasters, and improved affordability. If, according to some measures, homebuilding is a profitable industry but lags behind other industries that invest significantly more in research and development (see Figure 1), then it might be reasonable to suggest that technological innovation has played—and *could* play—a significant a role in increasing that profitability.

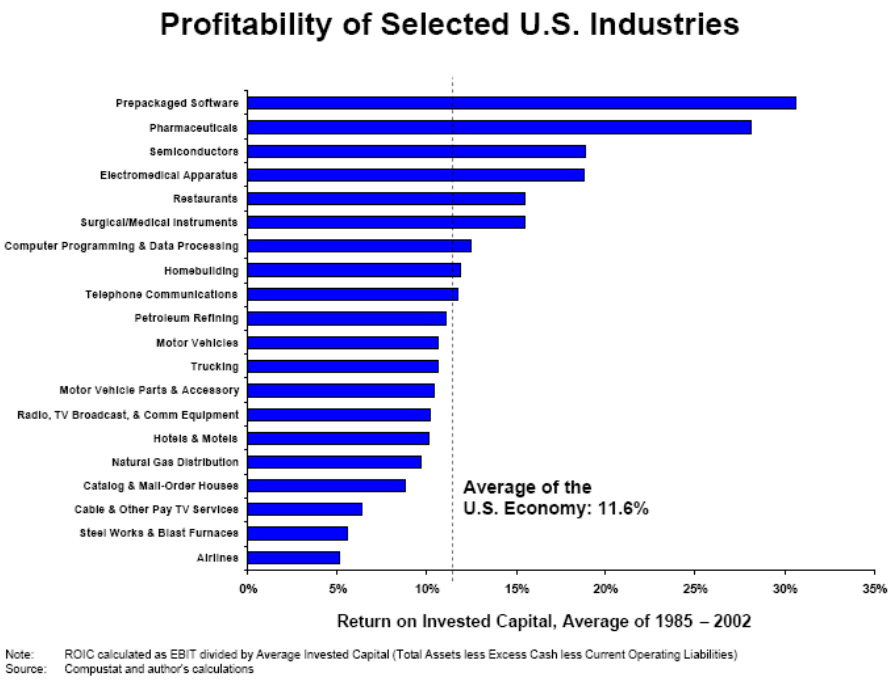

Figure 1. Profitability of Selected US Industries.

© Professor Michael E. Porter from "The U.S. Homebuilding Industry and The Competitive Position of Large Builders," a presentation to the Centex Investor Conference in New York, NY, November 18, 2003: http://www.isc.hbs.edu/pdf/US_Homebuilding_Industry.pdf.

However, there have been few attempts to measure the societal benefits from these technologies—let alone the estimated losses to society or the housing industry had these innovations *not* been developed. Similarly, the costs and returns to the innovative firm in developing them are not well documented, either. Construction management scholars—the only to focus attention on this issue—have focused their attention on describing the reasons why there is no housing innovation rather than measuring innovation's actual or potential impacts.[4]

These parameters for innovation in American housing (and in the economic of innovation) are noticeably complex, particularly when compared to other industries.[5] Despite much attention

being paid to the recent growth of production builders and "big-box" retailers nationally, homebuilding is still a very localized phenomenon, with local trades dictating schedules, local suppliers dictating materials, and local code officials dictating regulations and, in turn, construction practices. The industry is further complicated by the number of parties involved through the supply chain, which includes dozens of intermediaries between the product manufacturers and the builder and the builder and the homeowner. There has been some consolidation along all of these fronts, yet there is still significant fragmentation throughout the industry that prohibits both knowledge of existing innovations as well as the potential scale of sales that is necessary for justifying R&D in the first place.

A further complication arises in trying to define housing innovation itself; a typical, American stick-built house is composed of thousands of materials assembled into dozens of structural or system units. A change in one of these certainly has a technical effect on the whole system (though the science is still fuzzy on this), yet has an almost negligible change on the total cost of production and perhaps an imperceptible effect on the price and economic value of the home. So, that barrier, in turn, perpetuates a barrier for our study in that it is difficult to assess the added value from one technology for a whole house and then doing so for different housing participants.

This system complexity certainly distinguishes construction from other industries. It also leads to ambiguity of information and information sources that is also an industrial anomaly, though much less so. Information asymmetries mark virtually every step of the residential construction supply chain from the innovator to the builder, and the builder to the homebuyer or homeowner.

Bluntly stated, there are few impartial, credible information sources that rate the quality and value of new technologies, if any. Today's building codes are more of a historical, industrial artifact (and a barrier to innovation in many cases) than a benchmark for quality or arbiter of performance metrics. What is more, there are no product performance standards for many innovations, or even methods to compare market or economic performance for their diffusion. There is no public institution that adequately promulgates this.

There is also no financial impetus for one firm—or even a group of firms—to develop this public good. With no incentive to develop comparative methods, there is also little incentive for a firm to invest in research and development when that same firm will not be able to reap the full benefits of that work. Externalities such as this run throughout industrial innovation, but are particularly egregious in residential construction due to all of the above reasons.

All of these market failures have made measurement of housing innovation's costs and returns—whether at the societal, industrial, or firm level—difficult. But, let's try anyway. First, we look at how society as a whole benefits from innovation, and at possible measures for "costs" to society when innovation does not occur or is not occurring at its maximum potential.[6] Then, we review the same measures but for the individual innovative firm.

Societal Returns from Innovation

Numerous scholars have discussed the broader societal and industrial benefits to be gained from technological innovation; in fact, many argue that innovation is one of if not the most sustained source of economic growth.[7] Given the importance of the housing industry to the US economy

in general, it would seem that housing innovations would pose dramatic societal consequences. The qualitative benefits to innovation have already been described, though there are numerous other spillover effects. So, how have all of these benefits been measured?

Much of the literature to date has focused on estimating the rate of return to R&D investment in regressions of productivity growth.[8] When estimating the total social rate of return using more contemporary theories of growth, though, other scholars have demonstrated that the social rate of return to R&D is still very large—in fact, almost always larger than the private rate of return for the investing firm.[9] Further, as we know from our review of innovation's benefits, there are so many ways in which benefits accrue from investment beyond that measure. Adam Jaffe best defines the composition of this broader return:

> This excess of the social rate of return over the private rate of return enjoyed by innovating firms is described by economists as a positive externality or spillover. These spillovers flow through a number of distinct channels. First, spillovers occur because the workings of the market or markets for an innovative product or process create benefits for consumers and non-innovating firms ("market spillovers"). Second, spillovers occur because knowledge created by one firm is typically not contained within that firm, and thereby creates value for other firms and other firms' customers ("knowledge spillovers"). Finally, because the profitability of a set of interrelated and interdependent technologies may depend on achieving a critical mass of success, each firm pursuing one or more of these related technologies creates economic benefits for other firms and their customers ("network spillovers").[10]

The combination of these spillovers, ultimately, is the total social return from an individual firm's R&D investment (see Figure 2).

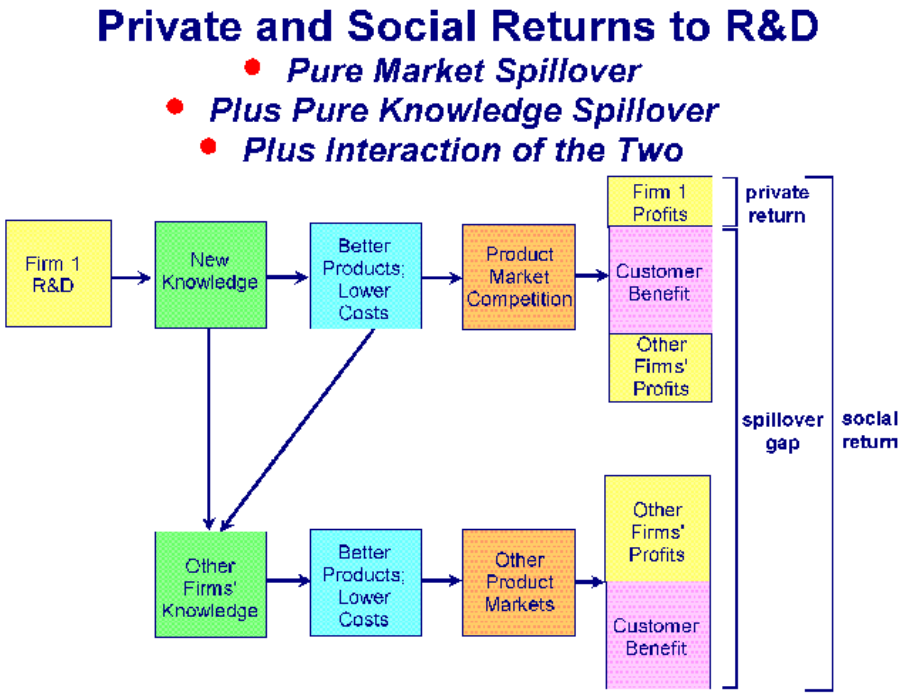

Figure 2. Private & Social Returns to R&D

From Adam B. Jaffe, " Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program," Unpublished Monograph for the Advanced Technology Program (December 1996).

So, what about housing innovation? What is the magnitude of this social return? Unfortunately, there is a painfully insufficient volume of data to examine the total investment in R&D, the firm profits from that investment, and the increased performance of homes from that investment. But if you can imagine the difference in energy consumption in homes built today from those built 30 years ago, or the rigidity of homes in Florida now versus before Hurricane Andrew, we know that there is something there. There are clear social returns to housing innovation, yet we have a problem in the allocation of those returns. Rather than attempt to quantify that social return, then, I will trace out each of these shares of total social return in relation to the practices and scale of the current homebuilding industry. In doing so, some of us (though certainly not all) might be surprised to find that there are unique ways in which these spillovers play out that

ultimately reduce the incentives for overall R&D investment.

First off, market spillovers are abundant in housing innovations. This is obvious not only in the marketing campaigns of some innovative product manufacturers and homebuilders, but also in the measured benefits for certain technologies—for example, reduced utility bills from energy-efficient construction techniques or house components. The vast majority of product innovations in the industry create direct benefits to buyers, albeit small benefits in most cases. Some process technologies are also sold as providing market spillover benefits because they allow the homebuilder to construct homes more efficiently and cost-effectively, thought it is not clear that homebuyers benefit correspondingly from those homebuilders' benefits.

Perhaps the most peculiar aspect of these spillover benefits, though, is that the fact that the consumer may or may not be fully cognizant of them. While it would appear that a rational consumer could determine the benefits from technology in reduced direct prices or utility bills or insurance premiums or general comfort and functionality, there is mixed evidence that this actually occurs with many housing innovations.[11] What is more, many housing innovators spend a disproportionate amount of resources in educating homebuilders and homeowners on product installation, maintenance, etc., usually all for free or a reduced fee. Some innovators will also offer reduced prices for the products themselves, though is not very common housing. So, consumers of innovation receive even larger benefits that are not captured by the innovator herself.

Similar to market spillover but with a far smaller magnitude, knowledge spillover is common in

housing innovation. As defined by Jaffe, this benefit comes simply from either different firms' application of knowledge from one research source for either similar innovations or new R&D for other innovations. This knowledge does not have to be technological necessarily, as when one firm chooses to end specific research or product commercialization and signals to others that it is unproductive, thereby sparing them the time and resources of undergoing the same process.

Innovative firms try to appropriate these benefits through patents and other intellectual property protections. While taking out patents is somewhat common in housing, patent infringement without legal prosecution is even more common. In fact, slight variations of innovative products and processes are the norm despite competitors' claims of proprietary knowledge. An example of this is structural insulated panels (SIPs), one of the most successful innovation introductions of the last decade. As depicted on the non-commercial housing technology site, ToolBase©, SIPs are the most common form of the wall panels that have increased in market share compared to more traditional stick-built construction or concrete and steel alternatives.[12] The installed panels form a structural envelope that eliminates the need for conventional framing, provides integral insulation, and can be assembled swiftly by less skilled laborers. SIPs speed construction and leave a thermally efficient, structurally light construction in the home.

Looking historically, however, we see that intellectual property protections mean little. Panel systems have been around since the 1600s, when panels were imported from England for colonial housing, and were popularized at the turn of the twentieth century through mail order "kit" homes. SIPs themselves were first developed in 1952 by the son of the founder of Dow Chemical. Despite the seeming availability to knowledge and standardization of the technique,

SIP manufacturers fought heatedly up until very recently about their proprietary variation based on different materials, factory production methods, or on-site assembly. As a technology competing with other structural forms, though, knowledge and information on SIPs is mature. In short, patents have not played the protective role from knowledge spillover in the housing industry as they have in others.

Two other factors suggest that there is the potential for tremendous knowledge spillover in housing. First, there are volumes of university research on housing technologies in particular and construction technologies in general that are available to any firm willing to explore, though these are not sufficiently diffused among manufacturers in any way. So, this stable of knowledge could conceivably be developed into technological innovations and commercialized without extensive effort. Second, there is a very high turnover of staff among homebuilders—though much less so among home product manufacturers—that might suggest a constant transfer of knowledge between firms.

But, one industrial idiosyncrasy keeps this spillover from reaching a higher magnitude, and this also stems from the localized and fragmented nature of the market; there is poor information knowledge transfer in housing technology. The SIPs example is a case in point; despite the near-century's worth of general knowledge on panels and a half-century's worth of SIP-specific knowledge, manufacturers continue to rediscover the wheel and homebuilders continue to repeat the same installation mistakes. The industry is replete with historical anecdotes about technologies that continue to surface with minor changes at different times and in different places. Evidence of poor documentation and transfer of knowledge is also demonstrated in the

skills gap and educational levels that mark the industry from on-site labor through professionals.[13] This lack of transfer, then, counteracts the potential knowledge spillover that appears to exist in the industry.

For this same reason and because of the technical diversity and complexity of housing, there is also little network spillover in the industry. Because so many of the potentially radical housing innovations require changes not just in whole systems but in the connections to other systems—i.e., the whole house, few innovators are willing to take the risk. In housing, structural, mechanical, plumbing, air, and electrical systems all interact in ways that are still not well studied. The liability that has risen due to specific technologies (like exterior insulation and finish systems, or EIFS) or from combinations of systems (like the moisture panic of the last decade) made the point of proceeding cautiously with innovations clear in housing. That legal risk translated to market risk and, in turn, the lack of potential profit returns from innovating.

One cause of this inability to coordinate innovation comes from housing's industrial and organizational structure—the homebuilder assembles all of the materials, innovations, etc., and would therefore take on much of the liability from the multiple innovations despite not being the original innovator. Since the homebuilder may or may not reap the payoff when selling the home or the remodeling project, they are likely not to adopt full system innovations. This structure partially explains why most housing innovations are incremental and oftentimes substitute or replace existing products, rather than having a higher likelihood of affecting other systems. Because the individual innovative manufacturer cannot collude or organizationally coordinate the innovative network, they look for innovative opportunities for which the payoff is

not dependent on other innovations or even existing technologies. As such, there is a network externality arising from this coordination that could be leading to misdirected research investments, to less-than-optimal market or knowledge spillovers, and to a reduced overall innovation rate—and there is plenty of evidence for each of these.

Aside from the various spillover effects, there is one remaining social return that I have not discussed: individual innovator returns. We know that individual firm profit is seriously hampered by all of the costs of investing in research and development and, more significantly, the costs of commercializing a technology in the contemporary American context. These barriers were presented previously, but it is important to note here that there is also a scale problem due to the nature of the housing market. Many variables influence a household's decision to purchase or remodel a home (particularly price) that constrain the potential total sales of any one product. Contrary to the back-of-the-envelope calculations of amateur housing innovators, the entire US housing stock is not a reasonable market audience. In fact, the number of households that can or would purchase a specific innovation (with the possible exception of appliance innovations) is much smaller. This reduced volume of potential sales, along with all the barriers and costs previously discussed, contribute to reduced potential profits.

In short, the social returns to housing R&D are likely almost all market spillover based on how the industry currently operates—that is, the consumer is most to benefit from these changes rather than competitors. Further, individual firm profits are likely to be significantly smaller than all spillovers; this is true of most industries but is particularly the case in homebuilding where firms face a decreased ability to appropriate these spillovers. Knowing this, why would anyone

even try to innovate in housing?

Firm-Level Returns from Innovation

Just as the microeconomic literature has focused on rates of return to R&D investments on productivity growth in somewhat limited ways, much of the same theory on the firm-level has focused on the opportunity costs associated with specific investment decisions.[14] Unfortunately, opportunity costs account primarily for very discreet decisions with limited information on the potential returns. While they may account for the immediate incentives for investment (like patent protections, increased immediate sales, or tax credits) they do a much poorer job of assessing all of the spillovers of investment, including dramatic changes in competitive advantage for the innovative firm. Indeed, attempting a quantitative measure or even a model for the opportunity costs for all housing innovations is futile given the qualitatively different kinds of innovation. So, we might learn more from tracing all of the ways in which firms attempt to appropriate the spillovers from their investment rather than tracing individual opportunity costs.

At a broad conceptual level, there are four important ways that firms appropriate the returns to R&D:[15]

- Legally keeping others from using their knowledge either through patents and other intellectual property protections or non-disclosure requirements in employment contracts;
- Maintaining secrecy about the product altogether;
- Developing knowledge that can only lead to innovations that require other resources (referred to as "cospecialized" assets); and
- Using their competitive advantage from being innovators to hold off as much possible

spillover as possible.

The first two methods were already discussed in the previous section as not being applicable to the housing industry—or, at least, relevant to its current context.

There are some examples of firms utilizing "cospecialized" assets along with specific technological innovations that might suggest that this is one reason why they choose to innovate. Large home product firms (especially appliance, window, and equipment manufacturers) often rely on brand recognition to secure not only current sales but also to launch new products. Their ability to control marketing content and channels due to their size can also be viewed as a cospecialized asset that they employ to secure the success of innovations; DuPont's Tyvek® house wrap or Whirlpool's Duet® are examples of these supported technology introductions. There are examples among homebuilders, too, as many of the larger production builders have been able to employ the one trait homebuilders did not have in the past to support new technologies: scale economies. The investment by Pulte Homes in panel and foundation factories and a broader process innovation strategy was partially justified with the expectation that these technologies would be embedded into Pulte's significantly number planned homes.[16] In both examples, having the basic financial resources to commercialize technology can be viewed as another such asset. In either case, the selection of innovations in coordination with other firm assets is an interesting potential reason for justifying innovation decisions in housing. If this is true, though, it still certainly does not shed light on the return to innovations since purportedly there are costs associated with maintaining the cospecialized asset.

Sustaining competitive advantage as both a method for appropriating returns and, ultimately, justifying technological investments poses numerous questions in the context of housing production. As discussed by many scholars, competitive advantage can be gained from numerous sources—innovation being only one. (Figure 3) The current housing industry is an interesting model give the rise of production builders as well as high-end custom builders.

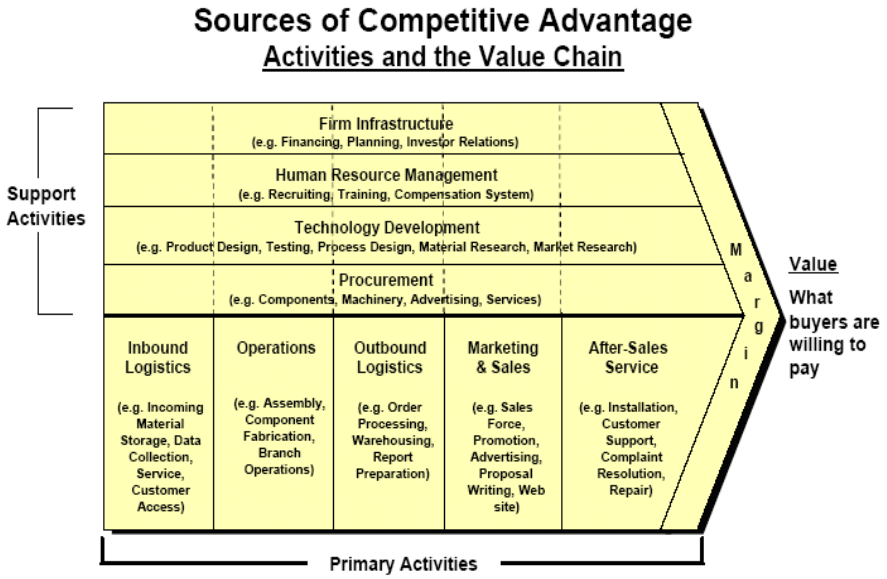

Figure 3. Sources of Competitive Advantage.

© Professor Michael E. Porter from "The U.S. Homebuilding Industry and The Competitive Position of Large Builders," a presentation to the Centex Investor Conference in New York, NY, November 18, 2003: http://www.isc.hbs.edu/pdf/US_Homebuilding_Industry.pdf.

In a 2003 presentation to Centex investors, Michael Porter argued that large builders were at an advantage competitively to smaller builders. Likely explanations for large builders' competitive advantage, he posed, include their material procurement advantages (in terms of cost and ability to negotiate directly with manufacturers rather than intermediaries), some labor cost advantages, access to capital, and from land regulations (ironically, larger builders have the staff and capital to negotiate with cities give them more advantage to go through hoops)—not because of technological changes either from the products they install or the ultimate product (home) they assemble. A similar conclusion was reached this year by a Deloitte and McGrawHill Construction study of homebuilders.[17]

There is some evidence, though, that are some builders of different sizes that utilize technology as a source of competitive advantage. In the most recent study of homebuilders' behavior with respect to technology, those firms identified as innovative were more likely to "stress being creative and the first to use new products" as factors for success, where late adopters associated success with land development.[18] In another study performed by Kermit Baker, there is further indication that local housing market conditions (specifically, the rate of local house price appreciation) and the organization of the local housing industry (namely, whether most production is concentrated in a few dominant builders) actually appear to matter more, though innovation as whole is still not seen as critical to success.[19]

One core reason that technology is not as central a competitive strategy to homebuilders as it is for other productive industries lies in the value assumption of competitive strategy—that is, that all of the potential strategy that firms employ must still result in a product for which buyers are willing to pay. In fact, in the study on builder behavior, the homebuyer "is often identified as an impediment to innovation" because of his risk-averse nature and desire to adopt only the "tried and true."[20] Barring process technologies for which the builders alone might benefit, there would seem little reason to adopt product innovations that either homeowners or homebuyers have not requested or are not willing to pay for.[21]

Among product manufacturers, though, it stands to reason that technology development plays a much stronger role in setting competitive advantage.[22] Provided the technologies can be easily adapted and are not cost-prohibitive, many manufacturers of all sizes structure—or, at least, depict—themselves as utilizing technology as a source of competitive advantage. The recent

perceived customers for "green" products, for example, has lead manufacturers of all kinds of technologies to change marketing and, in some cases, competitive strategies. There is significant evidence, though, to show that some of the large manufacturers are utilizing advanced customer delivery mechanisms, negotiated delivery contracts, ability to reduce liability through testing, and increased variety of product finishes as primary sources of competitive advantage.

So, if there are only a handful of reasons for why firms would both adopt technology as a core competitive strategy, and develop methods for insuring that they reap the maximum benefits from their investment, is it any surprise that individual firms do not innovate?

The Public Role

This economic review of R&D investments and returns in light of the contemporary housing industry supports what many construction scholars have been arguing for the past several decades. No individual firm can recoup profits—or overwhelming magnitudes of other benefits, like competitive advantage—sufficient enough to justify innovating technologically. In turn, this has lead to an industry-wide dearth of innovation. From a policy standpoint, the social returns are, therefore, also diminished. Putting aside the economic benefits to the innovative firm or to its competitors, this results in diminished public options and functions—like reduced energy bills, insurance premiums, more durable homes, etc.

When so many potential market spillovers are reduced in an environment where there are few individual firm profits to be gained, the historical response has been to invest public dollars in research efforts. In housing, there have been several attempts to do exactly that over the course

of the last half-century. The first noted US program in housing technology research was the Department of Housing and Urban Development's (HUD) experience with Operation Breakthrough from 1969 to 1972 (GAO 1976). Four years following the 1965 creation of the Federal Department of Housing and Urban Development and President Johnson's War on Poverty, HUD launched Operation Breakthrough and the building industry found itself with a redefined purpose, articulated roles and political skills, and a nation scrutinizing its entire operations.

Specifically, OB permitted HUD to accept proposals from various contractors, architects, engineers, and building component manufacturers for manufactured, large-scale housing "systems," which would then be used in the construction of public housing. Operation Breakthrough, however, chose to circumvent the very context that it was purportedly assisting; basic industrial practices and markets (like building codes, union labor, market cycles, and industrial R&D gaps). The proposals as well as subsequent housing had little to do with the housing production practices or housing markets that generated low technological investments. The Federal government ultimately decided that Breakthrough had failed to meet its overall objectives two years after the program was terminated.

More recently, several other initiatives have attempted to fill this research gap, though most have done this implicitly. The Department of Energy's (DOE) Building America program and corollary energy program along with the joint DOE-Environmental Protection Agency (EPA) program EnergyStar© are two recent Federal programs shed additional light on how best to structure Federal interventions in this field. These programs have altering levels of industrial

partnerships; the former relying on homebuilders primarily to assist with and apply research findings, and the latter using product manufacturers and homebuilders to jointly market the EnergyStar label. With its focus on improving energy performance, Building America has primarily funded basic and applied research for new technologies, thereby potentially improving the energy-efficiency and quality of housing. EnergyStar, though similarly focused on the ultimate energy performance of housing products, has relied on technical standards and marketing strategies to get current builders and consumers to adopt existing technologies.

Aside from the obvious difference with regards to energy focus, the HUD's Partnership for Advancing Technology in Housing (PATH) does not focus on the product of housing innovations but, rather, on the process of innovation. PATH is charged with dealing with the complexities of the full innovation process (from basic research to market penetration), and particularly with the institutional barriers to housing innovation. This mandate requires partnership with a unique breadth of partners, from research investors and peer Federal programs to local regulatory officials to home appraisers and financiers. Its success, as noted by its National Research Council, requires that "…cooperative relationships with both private and public sector partners be established."[23]

Conclusion

Indeed, preliminary planning for this AREUEA session on homebuilding technology came directly from PATH networks. As can be gleaned from these papers, there are numerous economic implications of housing technology: from consumer valuations of innovations; to the effects of building codes on technological innovation; to the effects of technological disasters as

well as technological mitigation for disaster; even to the effect of economic cycles on technological changes in housing, beyond this preliminary assessment of the returns to technological innovation.

As such, this article is less of an empirical review as it is an expedition between two fields of economic inquiry that have heretofore not been linked: the economics of housing and the economics of technology. In housing economic circles, the actual physical product (the "bricks and mortar") and the physical production (the materials and methods) are rarely scrutinized as factors in the consumption of that product, though we all know that housing is both physical structures and socio-economic phenomena. The assumption that housing design, construction, and technology have less to do with contemporary housing concerns than finance, planning, and community development has hindered this exploration. Changes in design, construction, and technology are of even less interest.

Scholars of the economics of technological innovation, conversely, have also focused on themes (such as patents, R&D funding and policy, organizational structure of R&D activity, etc.) that have little relevance or application in homebuilding. Not surprisingly, there is a validity and/or bias problem as the usual sectors considered in their studies include the "R&D-heavy" biotechnology, pharmaceuticals, software and communications industries. Needless to say, home product manufacturers and homebuilders do not exactly follow those industries' innovation patterns.

In either case, the economics of housing technology represents a significant scholarly omission,

and all of these papers demonstrate that *technology matters in housing*. It is with great pleasure that this burgeoning field is acknowledged here, and with much anticipation that we hope to see further work.

[1] This number was established by Burton Goldberg and Edward Shepard, "Diffusion of Innovation in the Housing Industry" an unpublished monograph (Upper Marlboro MD: NAHB Research Center) November 1989, and is regularly cited, though not adequately substantiated. However, the argument that there is a significant delay in the duration of time from a housing innovation's conception, though market introduction, and to some reasonable market share is generally agreed. Other studies that qualitatively describe the poor innovation development and diffusion rate in construction at large and housing in particular include: C. H. Nam and C. B. Tatum, "Toward Understanding of Product Innovation Process in Construction," *Journal of Construction Engineering and Management* 115:4 (December 1989); Bernstein and Lemer, *Solving the Innovation Puzzle: Challenges Facing the US Design and Construction Industry* (New York: ASCE Press, 1996); Blackley and Shepard, "The Diffusion of Innovation in Homebuilding," *Journal of Housing Economics* 5:4 (1996); Ball "Chasing a Snail: Innovation and Housebuilding Firm's Strategies," *Housing Studies* 14:1 (1999); Toole "Uncertainty and Home Builders' Adoption of Technological Innovations," Journal of Construction Engineering and Management 124:4 (1998); Koebel "Sustaining Sustainability: Innovation in Housing and the Built Environment," *Journal of Urban Technology*, 6:3 (1999); Menanteau and Lefebvre, "Competing Technologies and the Diffusion of Innovation: the Emergence of Energy-Efficient Lamps in the Residential Sector," *Research Policy* 29:3 (2000); and NAHB Research Center, "Commercialization of Innovations: Lessons Learned" (Washington: US Department of Housing and Urban Development) 2001. It should be noted that other scholars have disagreed with this assumption: Slaughter, "Models of Construction Innovation," *Journal of Construction Engineering and Management* 124:3 (1998).

[2] The most commonly cited statistics come from the Research and Development Statistics Program within the National Science Foundation's Division of Science Resources Statistics.

[3] It is important to note now, however, that housing innovations can come from numerous sources since "homebuilding" as an enterprise involved numerous parties. For purposes of simplification, we can consider product manufacturers and homebuilders as being the primary sources of innovation (the former usually for product innovations and the latter for process ones), and the technologies in question involve any material or process change that either changes the non-aesthetic, engineering performance of a home or decreases the costs of achieving current performance.

[4] Hassell, Scott et al., *Building Better Homes: Government Strategies for Promoting Innovation in Housing* (Arlington, VA: RAND) 2003 describes this literature, though it also takes issue with using the term "barriers" for these reasons.

[5] For the most recent review of these barriers, see Partnership for Advancing Technology in Housing, "Overcoming Barriers to Innovation" (Washington: US Department of Housing and Urban Development, 2003), available at http://www.pathnet.org/sp.asp?id=14223.

[6] Here, we use the term "costs" loosely, and define it as the absent potential returns from investment (beyond the opportunity costs) rather than the costs of actual investment.

[7] Fundamental work in the economics of innovation begins with Joseph Schumpeter, *The Theory of Economic Development* (Harvard University Press: Cambridge, Mass, 1934) and Schmookler, "Economic Sources of Inventive Activity," *Journal of Economic History* Vol. 22 (1962). Broader econo-historical reviews of these theories were then developed by Nathan Rosenberg, *Technology and American Economic Growth* (New York: Harper & Row, 1972) and *Inside the Black Box: Technology and Economics* (New York: Cambridge University Press, 1982); and Giovanni Dosi *Technical Change and Industrial Transformation* (New York: St. Martin's Press, 1984) and *Technology and Enterprise in a Historical Perspective* (Oxford: Clarendon Press, 1991); among others.

[8] For example, Zvi Griliches, "The Search for R&D Spillovers" *Scandinavian Journal of Economics* 94 (1992).

[9] Charles Jones and John Williams, "Measuring the Social Return to R&D" *The Quarterly Journal of Economics* (1998): P 1119-1135.

[10] Adam B. Jaffe, " Economic Analysis of Research Spillovers: Implications for the Advanced Technology Program," Unpublished Monograph for the Advanced Technology Program (December 1996): http://www.atp.nist.gov/eao/gcr708.htm#II.A.

[11] An excellent review of the "willingness-to-pay" literature can be found in David Dacquisto, Paul Emrath, Joseph Laquatra, and John Laitner's "The Value of Energy Efficiency in Housing: Review and Analysis of the Literature," a monograph sponsored by the U.S. Environmental Protection Agency (December 14, 2001).
[12] SIPS are made from an expanded polystyrene (EPS) core and adhered to oriented-strand board (OSB) or plywood skins. The foam alone has little strength, but when bonded to the plywood, acts as a bridge, or web, to augment structural capacity and resist buckling. See http://www.toolbase.org/techinv/techDetails.aspx?technologyID=114.
[13] Again, see Partnership for Advancing Technology in Housing, "Overcoming Barriers to Innovation" (Washington: US Department of Housing and Urban Development, 2003).
[14] Richard Nelson (ed) *The Rate and Direction of Inventive Activity* (Princeton: Princeton University Press, 1962); Bronwyn Hall "Innovation and Diffusion" in Jan Fagerberg, David C. Mowery, and Richard R. Nelson (eds.), *The Oxford Handbook of Innovation* (Oxford: Oxford University Press, 2004); P. Dasgupta and J. Stiglitz, "Industrial Structure and the Nature of Innovative Activity" *Economic Journal* Vol. 90 (1980); Everett Rogers, *Diffusion of Innovations* (New York: Free Press, 1983).
[15] Richard C.Levin er al., "Appropriating the Returns from Industrial Research and Development," *Brookings Papers on Economic Activity* (1987) 783-831; and David Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," *Research Policy*, 1986.
[16] Pulte Homes, Inc. was listed as the first builder in housing revenues for 2005 and 2006 by Reed Publishing/Professional Builder. See http://www.housingzone.com/index.asp?layout=giants.
[17] Deloitte and McGraw Hill Construction, "Staying Competitive in Today's Homebuilding Industry" (2006): http://www.construction.com/AboutUs/2006/HombuildersSurvey.pdf.
[18] C. Theodore Koebel et al., *The Diffusion of Innovation in the Residential Building Industry* (Washington, DC: US Department of Housing and Urban Development, 2003) for the Partnership for Advancing Technology in Housing.
[19] Unpublished presentation by Kermit Baker titled "Harvard Distribution Study: Key Findings from the Survey of Homebuilders" to the Policy Advisory Board Meeting, Washington DC (February 2, 2006).
[20] Koebel et al. (2003), P. 39.
[21] To this end, the Partnership for Advancing Technology in Housing has launched a variety of initiatives to explore consumer behavior, including soon-to-be-released proceedings of a Market Research Symposium cosponsored by McGraw-Hill Construction and a new study on technology and house price valuations to be completed in 2007, among other efforts.
[22] The author is familiar with no full surveys of homebuilding product manufacturers completed to date. The Partnership for Advancing Technology in Housing is currently implementing an extensive survey instrument with this segment, but the results will not be available until early 2007.
[23] National Research Council, *The Partnership for Advancing Technology in Housing: Year 2000 Assessment* (National Academies Press: Washington, DC, 2001).