Why Isn't the Housing Stock More Efficient?: Organizational Networks and Technology Transfer

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Models assuming optimizing consumers and rational firms fail to account for market resistance to cost-effective energy-efficiency improvements. This paper looks for clues in social science research on organizations and technology change. An alternative model derived from those literatures is proposed which focusses on the role of organizational networks in shaping and constraining innovation. This perspective is applied to data from a study of residential cooling, in which we find that producer networks routinely limit technology transfer in a variety of ways. Some of the influences of market factors, industry structure, technical knowledge, and ancillary network actors (e.g. architects, appraisers, realtors, lenders, utility managers, and code officials) on building technology choice are explored. Non-energy developments that are likely to influence future energy-efficiency choices in these systems are also considered, and research and policy recommendations are offered.

Introduction

To date, little empirical research has considered how the residential construction industry influences the energy efficiency of housing (Lutzenhiser 1993). This paper explores some of the features of industry organization that impede efficiency innovation in housing. These are suggested by the literatures on organizations and technological change, analysis of the trade press, and exploratory interviews with industry actors. The larger study from which this paper derives is a multi-disciplinary research and development project designed to demonstrate the feasibility of non-air conditioned housing in regions of California where compressor cooling is a relatively recent arrival.[1] Although cooling is used as an illustrative case, the discussion has broader application to organizational processes that are likely to influence the adoption of innovations in building design, windows, materials, mechanical systems, and production technologies.

The industry networks of interest are made up of the following sorts of organizational actors: land developers, construction companies, subcontractors (e.g., heating and cooling, plumbing, electrical, etc.), architects and plan services, realtors, lenders, appraisers, title and other insurance companies, the secondary mortgage market, local and state code officials and land use planning agencies, and trade/professional associations. Research to date strongly suggests that these entities both act in concert and constrain one another's actions—slowing the transfer of more efficient technologies and building designs.

Research on Organizations, Networks and Innovation

This section and the next discuss the nature of organizational networks, the problem of technological change, and some features of the residential construction industry that are likely to influence energy efficiency innovation in that system. The final section offers some policy recornmendations that follow from an organizational view of markets for efficiency.

The Rational Action Model

Policy analysis usually assumes that economic action and technological innovation follow a rational action model. This means that consumers and firms are self-interested, knowledgeable, and take a calculative orientation (e.g., regarding costs and benefits) toward economic decisions. While consumer rationality may be limited in the evaluation of energy costs and technology choices (Kempton and Montgomery 1982), firms are usually assumed to more closely follow a rational model. Complex organizations have greater resources and are presumably skilled at marginal cost and future price calculations. They would only seem to need to see the potential competitive economic advantage of innovation to move toward energy efficiency. Industry choices made on behalf of less-knowledgeable buyers should optimize the latters' utility and minimize their costs by substituting more efficient ways of satisfying needs for "energy services" (such as heating, cooling, or water heating). A wide range of more efficient technologies has been available for some time (Lovins 1977), but markets have often failed to deliver innovations that are clearly both cost-effective and socially and environmentally beneficial.

I argue that this "market failure" has little to do with the workings of neo-classical markets, because the rational action approach fails to appreciate two critical points. First, innovation, organization and technological substitution are socially regulated matters, and as such they are shaped by a host of non-economic factors. Second, while current technologies may be less than optimally efficient in energy and environmental terms, they enable a highly integrated network of industry actors to produce housing and profits in uncertain environments.

Economic Action Embedded in Social Relations

It is a mistake to assume that either firms or consumers act in markets solely on the basis of rational self-interest. Economic calculations take place in social and cultural contexts. Studies of economic behavior suggest that all forms of exchange are strongly influenced by social obligations (e.g., to friends and family) and normative expectations (e.g., community standards). These commitments historically predate the emergence of market economies and they continue to play an important role in regulating economic outcomes (Etzioni 1988). Intendedly rational economic calculations are also influenced by a range of considerations other than monetary costs, benefits, or returns on investment—e.g., social status attainment and risk avoidance. And even the most dispassionate economic actions by firms' agents are routinely executed through personal relationships with the agents of other firms-rather than through anonymous bids or auctions. These "boundary-spanning" relationships both regularize inter-firm exchanges and create numerous problems for organizations.

Economic sociologists speak of economic action, then, as "embedded" in social relations (Granovetter 1985). Some analysts argue that the natural evolution of even the most intendedly rational organizations involves the absorption of rational ends into a framework of cultural means (e. g., Selznick 1957). Others see organizations as the tools of managers, whose ends are not necessarily congruent with those of owners, employees, or the long term welfare of the enterprise (Perrow 1986). Still others see managers as largely propelled by organizational trajectories over which they have little control. In short, organizational theorists find themselves engaged in a continuing debate over how "rational" organizations can possibly be—whether in situations of freewheeling competition or in markets dominated by few firms.

Barriers to Change in Organizations

The social processes that determine the fates of firms (from electric utilities and construction companies, to appliance manufacturers and land developers) are not well understood. Rationally-appearing organizations frequently make serious missteps, bad investments, and poor management decisions. Many are dissolved each year, and others are absorbed. The literature suggests that firm size may offer some protection, but it may also constrain innovation and ultimately place the organization (e.g., GM) at a disadvantage compared to smaller more nimble competitors. The behavior of firms seems to be shaped by a combination of cultural, institutional, macro-social/economic, and technical factors (see Perrow 1986, and Scott 1992 for critical reviews of the literature).

Many of these factors are likely to influence the ability of organizations to innovate-one of the most widely-recognized being the bureaucratic form of the modern firm. Bureaucracy, while protecting the rights of individual members and providing a rational structure of accountability, also produces rigidity. Layers of authority and segmentation of work introduce inefficiencies and dilute management control. Bureaucratic organization also spawns informal structures of social relations. Some observers think that this "informal organization" can be harnessed to meet formal ends, while others see it as an inertial brake upon change. It may actually serve as a source of necessary linkage between the organization and the outside world.

The internal subdivisions that complex organizations use to structure work also create intra-organizational competition for resources and power. Sub-units develop their own bases of expertise, connections with established professions (accounting, finance, marketing, engineering), informal communications networks, cultures, and rituals. Some of the stresses that result can be managed by "decoupling" parts of the organization. But when this occurs, internal divisions often drift further apart. And, sometimes the interests of subunits are so divergent that their aims and purposes come into open conflict. Management becomes a matter of negotiation between warring factions.

Organizational Environments and the Development of Networks

How then can organizations innovate? Part of the answer lies in the world outside of the organization, which continually generates stimuli for change. But the response need not be particularly rational, since organizational decision-making is often characterized by "garbage can processes" (Cohen, March and Olsen 1972). Rather than carefully assessing opportunities and threats in the environment and then crafting suitable responses, sub-units tend to advance pre-existing "solutions" (e.g., programs, plans, investments) that have yet to be implemented because of lack of political support. The resulting organizational responses (pulled from the garbage can) are often sub-optimal.

Other changes are also not imagined by a rational model. "Institutionalization," for example, is a process by which organizations adapt themselves to meet environmental challenges. But often changes are made to bring the organization into congruence with cultural norms or to mimic the behavior of other organizations-adding little functionality, aside from securing a reputation as "normal" or "up-to-date." Historical examples include the establishment of personnel and affirmative action departments, the incorporation of small businesses, the use of educational credentials in hiring and promotion, investment by banks in imposing buildings, the use of public hearings and consumer research, and, most recently, corporate "downsizing" (particularly by firms who are highly productive and control large shares of growing markets). Once such changes have been made, however, the new organizational obligations will influence (positively or negatively) the possibilities of future adaptation.

But organizations also successfully stabilize and control their environments. Network building is one important instrument and result of those efforts. For example, uncertain elements of the environment are often internalized-so that corporate accountants are available to deal with government and bank accountants, and corporate lawyers or engineers can deal with other lawyers and engineers. One consequence is the creation of cross-cutting status groups with their own professional associations and loyalties. Another is dependence upon personal ties that bridge organizational boundaries.

Formal contracts also link organizations, and sometimes these arrangements can be so long-lived, with the fate of each party so bound up with that of the other, that several firms really operate as one entity. Efforts to remove the unwanted effects of these linkages through the use of markets (e.g., bidding purchases and subcontracts) have been pursued with some success. But even the largest and most competitive firms maintain numerous long-term ties with bankers, suppliers and so on (Baker 1990). The opposite pattern-intentionally establishing long-term relationships of mutual dependence (e. g., in strategic partnerships, technology-sharing, value-added chains)—is also pursued by groups of firms in industries as diverse as computers and automobiles. In the home construction industry, the "smart house" consortium of builders, appliance and wiring manufacturers, and heating, ventilating and air conditioning (HVAC) firms was the first to exploit amendments to U.S. anti-trust laws that allow large-scale monopoly collaborations on advanced technology projects. Semi-conductor, advanced battery, and automobile technology consortia are more recent examples.

But the stabilizing effects of organizational networks are not limited to large firms or advanced technology sectors. More mundane business linkages abound. Franchises, exclusive distributorships, manufacturer-reseller support relationships, cooperation between firms with the same parent company, joint-ventures, wholly-owned subsidiaries, interlocking directorates, and cross-ownership represent a few. Organizational networks have emerged as a central feature of modern societies. They provide the structural foundations of more or less stable sociotechnical systems—systems that one might reasonably expect to both spawn and inhibit innovation.

Change in Large-Scale Sociotechnical Systems

What are the implications for technical innovation of these densely-woven networks of firms, regulators and financiers that underlie markets for housing, technology and energy? Historians and sociologists who are interested in how technologies are shaped by social forces offer several models of change. Hughes (1989), for example, observes that societies have increasingly taken the form of large-scale "sociotechnical systems" made up of machines, energy and material flows, organizations, consumers, and governments. These "heterogeneous" systems (comprised of dissimilar elements) evolve by building upon pre-existing knowledge, technologies and social institutions. Competition, events, environmental conditions, and national cultures stimulate change in these systems. But "progress" is neither inevitable, nor is it steady in pace. The historical record shows that it proceeds in fits and starts, is frozen in some cultures in some time periods, and expands explosively in others. Ayers (1989) offers something of a more progressive model focussed on long-wave business cycles driven by revolutionary changes in basic technologies over the past two centuries. Other students of technical change have more modest aims.

Complex societies and their technologies (whether these are houses, air conditioners, automobiles or space shuttles) are dependent upon sets of tools that work together. I call these "local ensembles" (e.g., computer, electrical wiring, surge protector, desk, chair, etc.), which are, in turn, dependent upon more distant linkages (to power grid, postal service, software firms, etc.). Both local and distant systems require functioning social institutions (a job, state services, industrial production, scientific journals that publish papers, an energy efficiency movement, and so on)—and all of these subsystems, of course, rely upon the natural environment. Hughes' model of sociotechnical change (which derives from his studies of the evolution of electric power grids in the United States, Britain and Germany) sees these systems as possessing considerable "momentum." They propel everyday life and offer resistance to change. There are change agents in these systems, of course, and emergent events may make innovation desirable (perhaps inevitable)—but not in any predetermined way (Kranzberg 1986). Some innovations have been successfully resisted, while others have been eagerly embraced. Useful case studies documenting the twists and turns of sociotechnical change have considered, for example, the development of fluorescent lighting (Bijker 1992), the success of compression refrigeration over absorption technology (Cowan 1984), and the succession of home heating fuels (Cowan 1989).

Significant differences in "technological style" (Hughes 1989) are also evident in the development of similar technologies in different societies. We need only compare housing in the United States, Europe and Japan to see the differential effects of climate, culture and political economy in system momentum and change. Hughes also suggests that change in large-scale systems may be slowed by technical or social factors in critical subsystems. When these "reverse salients" are finally altered, rapid evolution of the whole system occurs. A contemporary example might be the ways in which technical problems and less-than-enthusiastic institutions now slow the development of the electric automobile.

Innovation as the Social-Shaping of Technologies

Innovation is also shaped by smaller-scale organizational processes and dominant ways of thinking about technical problems. Bijker (1992) points out the importance of the "technological frame''—the available ways of imagining technical possibilities. Maytag realized, for example, that he could design a machine that would move water through clothing (rather than moving clothing through water—as does hand washing and earlier washing machines). Carrier's train platform insights into the behavior of latent heat and Tesla's vision of rotating fields in an alternating current motor are other examples of the necessary breaking of conventional understandings (paradigms, mind-sets, frames). Bijker argues that, as frames are broken in the innovation process, "interpretive flexibility" appears—i.e., a wider range of competing ideas and designs are entertained. Each possible invention is not equally satisfying to every interest involved, however. One innovative cooling system may excite utilities, anti-CFC activists, environmental policy makers, and design engineers, for example. But it also may represent unwanted change and risk to manufacturers with secure market niches, their installers, planning and zoning officials, appraisers and lenders. Bijker points out that public and private struggles between "relevant social groups" (interest configurations) often result in the political negotiation of ultimate designs and some final "degree of stabilization" in the shape and function of the artifact. In the case of household refrigeration, a single design dominated. In the case of transportation, the automobile competes with older forms such as the bicycle, bus/trolly, train and the "human machine" (walking). If and when fully stabilized, "closure" is achieved for the new frame-which limits the ability to marshall resources to re-examine the nature and usefulness of the item.

While the focus of this research is primarily upon producer influences on innovation, it is useful to note that consumers and their advocates play a role as well. Cowan (1989) shows how key consumer-producer system nodes (the "consumption junction") influence the form and rate of technical change. Rogers' (1983) well-known model of uneven diffusion of technical innovation distinguishes among early and late-adopting consumer subgroups (e.g., "opinion leaders" and "laggards"). I would propose a third model of producer-consumer interaction that identifies five diffusion-adoption stages: (1) boosterism ("You've got to have it!") vs. skepticism ("Who needs it?"), (2) playing around with the device (early adoption and experimentation), (3) overuse (since engineers cannot anticipate the full range of possible uses for any innovation, many uses are "found out" in the field and in the competitive failure of some designs), (4) adjusting pre-existing social and technical arrangements to accommodate the innovation (it becomes part of the "normal" landscape), and finally (5) re-casting the past so that the innovation seems to have been an inevitable answer to long-standing "needs" and "wants." This model provides a good fit to the histories of radio, television, the microwave oven, video recording technology, and the personal computer.

The Residential Construction Industry: Network Elements and Barriers to Innovation

Why do markets for energy efficiency fail? Because economic action is always embedded in social relations, it is culturally shaped and institutionally constrained. Firms are faced with myriad concerns other than economic optimization or technical innovation-including internal competition for resources and control, goal conflicts, informal relations, and institutional inertias. Changing organizational environments offer opportunities for innovation, but stabilizing network connections can inhibit technical change and slow its transfer. Large-scale systems exhibit considerable momentum, but evolve at uneven rates under the influence of contending interests and ways of thinking.

The following discussion applies this broader perspective to the problem of energy efficiency in new residential construction, with a focus on technological alternatives to compressor cooling. Some elements of the model outlined above are not applied. The role of bureaucracy, which may constrain innovation in regulatory agencies or large HVAC manufacturing firms, is ignored. So is the consumer side of the system. While industry actors profess to believe that they only supply compressor cooling because consumers demand it, empirical evidence shows a wide range of cooling technologies and behaviors in use (Hall, Hungerford and Hackett 1994). The discussions of network constraints and inertias that follow are also somewhat limited. But the purpose of this paper is not to present a definitive analysis of the industry. Rather, it intends to illustrate the utility of an organizational approach to the problem of innovation.

Business Cycles and Industry Activity

Not only do markets often fail to deliver efficiency, but sometimes they introduce uncertainties that make innovation risky. For example, market fluctuations in interest rates rapidly affect actors throughout the housing industry. And it is the first sector to feel Federal Reserve money supply controls, with the slowing of construction serving as a primary instrument of anti-inflation policy. As a result, activity in the industry is highly cyclical. This cycling results in material shortages, unpredictable fluctuations in prices of materials, land and labor, and relatively rapid expansion and contraction of business activity and industry employment. Firms' efforts to counteract market-based uncertainties include diversification into land development, rental housing, and the provision of ancillary services in the construction network. Industry cycles drive other firms out of business, however, and create unstable conditions for construction workers and their families—and therefore provide incentives for the most skilled workers to leave the industry in their most productive years.

Industry Structure and Organization

The structure of the industry represents, in part, an adaptation to market cycling. It has long been characterized by a high degree of subcontracting, and the proportion of subcontracted labor and services has increased throughout the past decade. Contracts run their course on a job by job basis. They, at least theoretically, represent less costly alternatives to in-house employment. But long-term relationships between builders and subcontractors offer predictability to both—at the price of mutual obligations and dependencies that may be difficult to dissolve.

New home construction can be classified into several institutionalized types, with each presenting a somewhat different set of barriers to innovation. These include: (1) the "spec" house (built on speculation for future sale), (2) buyer selection of lot and house design from small number of models (with some choice of details and materials), (3) buyer selection of lot and house design from a large selection of plans (with some modification possible), and (4) buyer selection of lot, orientation, landscaping plans, and architect-designed "custom" house plans. These are ideal types, which in practice may be more difficult to differentiate. Standard elements do constrain custom designs, and the selection from a set of house "models" often provides little better choice than selection from among pre-built houses. In most markets, " spec" house builders are likely to be less prone to risk taking. Selection from a large number of plans means that many of these will be poorly designed for cooling, particularly those originally intended for other markets. Custom designs may, or may not, be super-efficient, depending upon the buyer's desires and the cleverness of the designer in working with building codes.

Firm size may also significantly influence innovation. Small volume builders (25 and fewer units per year; about 75% of all U.S. builders in 1991) may be more likely to engage in custom trade-up home building. They also often lack the capital or credit necessary to produce speculative-built homes, and they require larger profits from each unit produced. Access to financing and economies of scale may make the largest builders (over 100 units per year) better able to innovate. But, while advantaged by sales volume and organization size, the uncertainty of markets and the drive for short-term gains means that these advantages generally translate into higher profits or lower selling costs, rather than innovations in quality or efficiency. Medium builders (26- 100 units per year), who might be expected to be more innovative because of less organizational rigidity, have declined both in number and market share over the past decade.

Many of the largest firms operate on a regional or national basis. They deal with large tracts of land, favor standard designs, and use mass production techniques. The compressor air conditioner represents a significant advantage to these builders. Rather than tailoring housing to local conditions–which vary widely across the U. S.–the air conditioner allows mass builders to site standardized units with little regard to topography, orientation, weather conditions, regional aesthetics, or occupant use patterns.[2]

Competition and Risk Aversion

Competition between groups of manufacturers and suppliers (e.g., of wood, metal, cement, plastics and masonry building materials and systems) may stimulate technical innovation at the local level, as competing systems engage in a social struggle to recruit adherents. But large-scale manufacturing and distribution systems can also act as inertial brakes on change. Their investments in equipment, raw materials, and skilled labor establish organizational trajectories that require protection—including efforts to disable competing technologies through action in the market and regulatory arenas.

Local competition may inhibit builders from experimenting with innovations that might be perceived as risky. Ironically, complacency resulting from market dominance may also reduce the perceived benefits of innovation. As a result, the social and economic conditions most conducive to risk-taking and cost-reduction may appear only in odd niches of housing markets, and/or during odd times (e.g., periods of uncertainty and rapid industry-wide change).

But these periods have often failed to stimulate adoption of cost-effective building innovations such as insulated concrete form systems, flexible gas piping, manifold plumbing systems, energy efficiency improvements to the building shell, and more efficient appliances and HVAC systems. Throughout the past 20 years, the trade press has reported a wide range of promising, but to date unadopted, innovations. It is unclear just what technical and/or social qualities of innovations influence their diffusion-why some (e.g., insulated forms) are slow to be adopted, while others (e.g., low-E windows) are rapidly diffused.

Common builder reservations about alternatives to compressor cooling include the belief that consumers will accept only standard air conditioning, fear of damage to reputation if alternatives do not work properly, and unknown costs of design, equipment and installation. Compressor air conditioners are a proven technology, which are supplied by known HVAC dealers with the necessary expertise and factory support. The builder, the dwelling, and the air conditioner are all embedded in a web of social expectations and obligations that make innovation risky.

HVAC subcontractors might be expected to offer stiff resistance to alternative technologies—although we've noted some resignation regarding the ultimate fate of the compressor as a result of the CFC phase-outs (which have placed unwanted burdens on HVAC firms to account for and recycle CFCs). Perceived costs and risks from their point of view include: questions of reliability of alternatives (e. g., evaporative coolers); maintenance problems, call-back complaints, and risk of damage to reputation; uncertainties regarding requirements and costs of gearing up; uncertain sources of supply and technical support from wholesalers and manufacturers (particularly foreign sources); and existing exclusive distribution agreements with air conditioner manufacturers. Training is also required for the workers who would install unconventional systems.

This leads to the question of labor. The role of formally and informally-organized labor in influencing the willingness to innovate may be significant. If so, we would want to better understand the role of collective bargaining agreements, work rules, and trade licensing standards in shaping housing projects. Labor is not simply a constraint, however, since increased skill requirements in an increasingly technologized industry (e.g., facing potentially serious future skilled labor shortages) suggest that some parts of the industry may be supplied with the type of labor necessary to pursue a wider range of building options.

Information, Technical Frames and Industry Culture

The dynamics of information flow through industry networks may significantly affect innovation. We need to better understand how technical information is generated and disseminated, the degree to which it is trusted, and how it is used. When the industry establishes a high-cycle rhythm in a "boom market," all parties are working to smoothly deliver the materials, labor, and services required to produce a conventional product. In these periods, communication channels function primarily for scheduling purposes. But these channels can also deliver information about innovations in materials, building systems, designs, and organizational issues. This information may be of considerable importance in non-boom periods, when attention might be turned to non-conventional housing possibilities. Control of network information is also a salient issue because it shapes product knowledge, limits the sharing of experience, and manages the perception of risk and opportunity in the network.

The concept of technical frame can be applied to system actors' knowledge and mental models of heating, cooling and building performance-which have been shown, in other settings, to vary significantly from the understandings of engineers and physicists (Kempton 1986). For example, the principles of evaporative cooling, excluding heat from structures, and cooling by radiation may be rare in industry technical frames. Poor conventional ducting practice and the poor condition of duct systems (presumably as a result of lack of knowledge) are common cases in point. Builders, developers, installers and buyers who move into new geographic areas are often unfamiliar with the range of local climate conditions. In applying their conventional understandings to the problem, they are quite likely to over-cool structures.

Finally, industry management is dominated by middle-class white males who share a common culture (i.e., values, interests, understandings). Workers have a somewhat different culture. Except in the cases of mass-market large-scale production, the organization of construction work requires constant project-specific planning, shifting work assignments, and a significant degree of labor independence. The culture tends to be aggressively entrepreneurial, and is driven by short-term financial constraints and contract deadlines. It is likely that most builders are interested (at least as an ideal) in some combination significant profits and the prestige of building houses for the "top of the market. " As a result, elements of this culture may strongly discourage concern for other goals, and the imperatives and identities fostered in the culture may limit the capacities of actors to understand or identify with energy efficiency concerns.

Other Network Factors: Design, Finance, Real Estate, Government, and Utilities

The dependence of smaller builders on architectural plan services for standard designs, and a lack of readily-available design expertise in the area of energy efficient housing, may also inhibit builder interest in innovation. Building to stock plans for the middle of the market requires relatively few architectural services, and computerized design programs have largely eliminated the need for incidental outside drafting work. House plans and cooling equipment that are produced for mass consumption will, therefore, not be optimized for local conditions (e.g., of temperature and humidity). Only in specialized niches are builders and designers likely to join forces—opening the possibility of architectural influence on design for improved efficiency. But architects are also often unfamiliar with non-conventional cooling technologies or buildings designed for passive cooling (e.g., with high internal mass, high albedo, or shading). Few have state-of-the-art formal training in the evaluation of thermal performance, and HVAC design is often the most vague element of architectural plans, with the (sometimes critically important) installation details being left to subcontractors in the field.

Builders and home buyers are usually dependent upon local lending institutions, and indirectly upon larger financial systems, to secure the capital required for short-term construction costs and long-term mortgages. Risk aversion by mortgage bankers and brokers can limit innovation, as can conservative requirements imposed by governments, mortgage insurers (public and private), and secondary mortgage markets that housing be "conventional." Loans destined for secondary markets are governed by more conservative building and appraisal standards than are mortgages held by local lenders. Appraisers are central in establishing market price and setting values on innovative features. Title insurance companies, realtors and real estate attorneys play ancillary roles in the construction of value. Services provided across the entire complex of firms in the real estate system are generally required for home construction and sale. To date, their relative influences and respective abilities to limit innovation have received little attention. Under most conditions, they can safely be assumed to be conservative.

The processes by which building codes, equipment/materials standards, and model zoning statutes are developed and implemented also affect the legitimacy and perceived riskiness of efficiency innovation. Although a good deal of engineering uncertainty may lie behind technical standards, once codes based upon them are legally adopted, their origins and assumptions are rarely questioned. Government action can constrain or encourage innovation in a variety of other ways as well. In the compressor cooling case, some of these include: the impacts of federal efficiency standards, requirements for rapid CFC phase-out, funded research and development for alternative coolants and systems, state and local regulations, codes and standards, as well as local government land-use planning, growth control, and aesthetic standards. California's Title 24 conservation codes hold uncertainties for cooling innovators, as do national/international technical standards (e.g., ASHRAE assumptions about temperature, humidity and human comfort). The real-world enforcement of codes and standards is also an issue, with actual building and inspection practice always somewhat at odds with rational regulation. We have encountered, for example, cases of slavish (and unusual) adherence to code requirements (e.g., that all plumbing be copper) that effectively block non-compressor alternatives (e.g., that require the use of plastic pipe in thermal storage systems).

Finally, utilities can also both encourage and erect barriers to efficiency innovation-in their rate structures, marketing efforts, DSM programs, preferred technologies selected for development (electronic price signaling, direct load control), interest in expanding natural gas sales, and reservations about the system effects of technical innovations (e.g., system harmonics created by variable speed drives). In short, the ancillary service and regulatory sector of the industry may pose more serious barriers to innovation than do markets, the organization of firms, contractor-subcontractor dependencies, or technical frames.

Countervailing Forces: Critics/Opponents of Current Technology

While a wide range of uncertainties and rigidities are built into the system, the history of change in sociotechnical systems suggests that their evolution is inevitable. The nature and pace of change remain to be seen, however. A number of developments now visible in other parts of the society are certain to have some impact on the housing industry in the future. Here I have in mind growth in environmental concerns (e.g., regarding CFCS, ozone depletion, global warming, SO_2). Growing environmental activism can potentially influence actors throughout the system—the current example being the decline in wood supply, as more environmentally sensitive management of timber lands is mandated. Utility concern for load factor has stimulated interventions in the system (from incentives to adopt efficiency technologies, to demonstration buildings). Changing demographics and economic restructuring will affect consumer demand for housing of various sorts, and changing settlement patterns and community design preferences are likely to impact the industry as well. The most striking change may result from the assault on the privileged position of dimension lumber in the home by manufactured lumber, steel, concrete and plastic materials. In the midst of these changes, openings for a more radical efficiency improvement in housing may occur. Ultimately, the "quality house" may come to be defined as one that is highly energy efficient.

Research and Policy Recommendations

A significant amount of research remains to be done before effective policy interventions can be constructed in this area, however. This work might usefully focus on three aspects of the system: markets, institutional/cultural processes, and organizational network dynamics. Each affects the behavior of actors in the system, but in different ways and with different policy implications. Markets make a significant difference, for example, in the costs of credit, labor, materials, land, and in resale values. Social and cultural (institutional) factors influence design choice, knowledge, trust and risk assessment, definitions of quality (non-economic attributes salient to buyers and industry actors), community standards, and issues of identity, status, and stigma that are of central concern to builders and buyers alike. Organizational networks are likely to have their greatest impacts in the areas of codes, design standards, appraisal, financing, insurance requirements, network dependencies, industry supplier interests (e.g., competing technologies), and competing macro-political imperatives (affordability, environmental struggles). Understanding the functioning of these three sets of factors and their interactions is a prerequisite for effective policy intervention.

With this said, I will point to a few areas in which we have accumulated some experience, and tentatively suggest policy interventions that are likely to improve new housing efficiency.

- While industry and utility actors prefer incentives (cash inducements), building codes and regulations (e.g., California's Title 24, global CFC conventions, federal window rating requirements) work fairly well in creating change. Solar orientation—a key efficiency element—was politically negotiated out of Title 24. In the cooling case, one would want that provision reinstated—although it would be hotly contested by the industry because it would require novel land subdivision designs and might (although this is far from certain) reduce densities and therefore profits. To be workable, orientation requirements should be accompanied by increased flexibility in subdivision design, with attention to the creation of usable outdoor spaces and community amenities. We have found that, in general, communities, rather than individual houses, are either hot or cool. Here, inducements might be coupled with code requirements and relaxation of regulations.

- Barriers to cooling design innovations should also be removed in the secondary mortgage market (in which the federal government is a key actor). For example, at present below-grade living space such as basements (a valuable non-compressor cooling design element) are allowed no value in appraisal calculations. Serious attention should also be given to energy-efficiency mortgages. Appraisers, lenders, insurers and builders should be provided the tools (e.g., building rating systems) to adequately evaluate the contributions to affordability that efficiency provides.

- Difficult political efforts are required to increase energy prices to reflect the true marginal costs of supply—including environmental and social externalities. Equity adjustments are necessary for those with the lowest incomes, of course, and there is reason to be skeptical of the ability of the U.S. policy process to either adequately take into account embedded energy dependencies (Lutzenhiser and Hackett 1993), or the perversities of existing delivery systems for environmental equity payments (Higgins and Lutzenhiser 1994). But the real costs of energy use must be paid at some point. One socially acceptable way to explain the situation to consumers might involve surcharges on energy bills for "environmental damages" associated with their energy use. Regardless of the social meaning of rising energy prices (and this is an important issue), significantly higher energy costs (with reinvestment of damage receipts) would probably yield long-term economic benefits, and would likely serve as a stimulus to efficiency innovation in the home construction industry.

- Rates that reflect load-based energy costs would also stimulate innovation. Time of day rates have been instituted with good effect, and with surprisingly high consumer acceptance (Heberlein, Linz and Ortiz 1982). But caution is also warranted, since overall consumption and environmental impact could actually increase if these rates simply stimulated the diffusion of load-shifting technologies.

- Efforts to sell efficiency solely on the basis of cost savings offer extremely weak inducements to status-conscious buyers and builders. These have been largely unsuccessful in an era of stable energy prices, regardless of the objective economic advantages of investment. Serious work should be undertaken to better associate energy efficiency with "high quality" housing. Policy might, for example, require or induce the best and biggest housing to be the most efficient.

- Serious efforts should be undertaken to explore and demonstrate the advantages of design, as opposed to mechanical, solutions to efficiency problems. Here direct research and demonstration investments should be combined with training for architects, evaluation of efficiency opportunities in the designs of popular plan services, and regulations and inducements intended to encourage the optimal use of passive design solutions.

- The role of human action—by consumers, organizations, network actors—is central and controlling in energy use and sociotechnical systems. Ironically, it is one of the least well-understood aspects of energy use and technology transfer (Lutzenhiser 1992). Investment in research concerning the human dimension of technical change is long overdue, and necessary in order to reduce the impacts of consumption on energy systems and natural environments. That work is necessarily interdisciplinary, requiring the involvement of, at least, sociologists, architects and engineers.

- Strategic policy analysis is also needed in order to assess the prospects of emerging trends in environmental protection, materials competition, affordable housing, sustainability, community planning, and industrial ecology (green business). European and Japanese advances in building efficiency and urban design should also be seriously considered. Effective long-term tax and investment policies might then be proposed, along with relations and new technology development consortia (e.g. national laboratory-private industry research partnerships focussed on sustainable housing).

Acknowledgements

This research was supported by the California Institute for Energy Efficiency and the Washington State University Agricultural Research Center. Comments on earlier drafts were provided by David Hungerford, Bruce Hackett and anonymous reviewers.

Endnotes

1. The research is sponsored by the California Institute for Energy Efficiency (CIEE)—a consortium of California utilities and the California Energy Commission. The project team includes modelers, architects, mechanical engineers, and sociologists recruited primarily from Lawrence Berkeley Laboratory and California Universities. The team is currently refining design tools, simulating and field testing non-compressor cooling technologies and advanced materials, examining the conventional assumptions about human comfort, and mapping the organizational landscape of the residential construction industry. In the next stage, the project will design, build and test owner-occupied housing units that can keep their "coolth" in many California climates without air conditioning—units that builders will build and buyers will buy.

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