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Will Homebuilding Finally Evolve? Lessons from the American Experience with Factory-Built Housing

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In this report, we examine the history of attempts to disrupt site-built single-family housing in the US to learn about the potential for the homebuilding industry to increase housing affordability through innovation. We argue that greater reliance on mass production is unlikely to be a source of significant cost savings for the kinds of homes that most Americans live in today. We highlight the potential for factory-built housing to provide more significant cost savings if smaller-size and reasonable but lower-quality construction is permitted, as is the case with manufactured housing. While the entire home is rarely prefabricated in the US, we do find an increased reliance on prefabricated components in site-built housing over time, resulting in some cost savings and increases in construction quality. Finally, we argue that the history of homebuilding demonstrates that rapid adoption of prefabrication or more efficient production processes by homebuilders are more likely to be driven by market competition than by economies of scale within consolidated firms or by government intervention.

In the aftermath of the last housing crisis, the homebuilding engine has been frustratingly slow to restart. Single-family housing starts in 2018 attained only 80 percent of the long-run average rate and remained below half of peak rates observed in 2006 (Figure 1). The surprising lack of building, along with expanding mortgage debt, has helped sustain strong year-over-year real home price appreciation well into the upstroke of this housing cycle. The average age of the US residential housing stock is now nearly 35 years old, higher than at any point in almost a century, and the real value of residential fixed assets per adult is below its long-run trend. Our single-family housing stock is not being adequately updated or expanded enough to meet rising demand.

Although much of the recent public debate over housing affordability has focused on supply-restricting land use regulations, policymakers and market participants looking to promote more affordable housing are searching for ways to encourage more building by driving down construction costs in what is widely perceived to be an inefficient sector. In particular, they are looking once again to factory production as the key to improved efficiency in single-family homebuilding. As recent examples, Softbank has made big investments in Katerra Homes, as has Amazon in Plant Prefab. Bay Area developer Holliday Developers and construction firm Cannon Construction have partnered to found Factory OS. KB Homes is working with

Entekra, an Irish company that manufactures structural components offsite, to build new subdivisions in Northern California. Fannie Mae and Freddie Mac point to manufactured housing as a key component of their "duty to serve" mandate.

As fast as advocates highlight the potential for factory-built housing to solve the "housing squeeze" (Dougherty 2018), skeptics respond that prefabricated housing has been prematurely hailed as the "holy grail of design" for much of the past century (Lerner 2018). The scarcity of factory-built housing in the US is not due to a lack of trying. Since the advent of balloon framing in the 1830s, which allowed homes to be built with lightweight materials by low-skilled labor, homebuilders have sought to improve efficiency and decrease costs by assembling a home in one place and erecting it in another.

In this report, we examine the history of prefabricated housing in the postwar period to learn about the potential for the homebuilding industry to increase housing affordability through innovation. We focus on six case studies that illustrate the key trade-offs

Some Definitions

The following terms are used throughout the report.

Manufactured Homes. These have a chassis and wheels for over-road travel and are built to conform to the national Housing and Urban Development building code first effective in 1976.

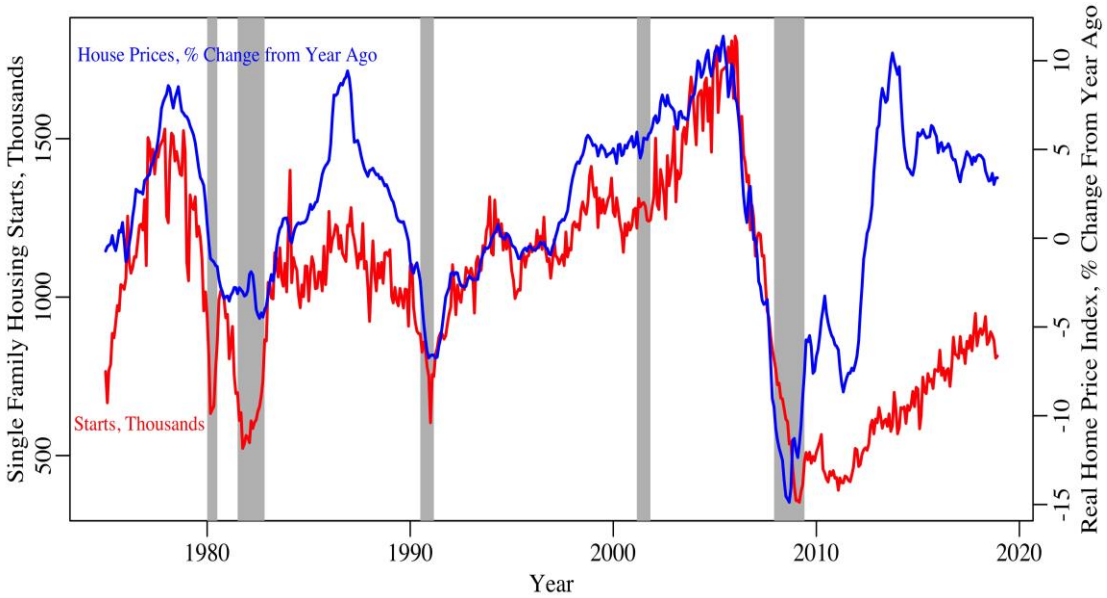
Mobile Homes. These generally refer to the class of homes built on trailers that predate 1976.

Prefabricated Housing. These are at least partially built in a factory setting but must meet state and local building codes. We distinguish between panelized and modular housing as two main types of prefab. Other factory-built housing types that are often included with prefab contain sectional, precut, and log homes.

Panelized Housing. These are usually shipped from the factory as components—floor systems, wall panels, and trusses—to be assembled and completed on-site.

Modular Housing. These typically involve a greater degree of preassembly and are shipped in three-dimensional sections connected together at the site.

Figure 1. Housing Starts and Home Price Changes, 1975–2018



Note: Recessions are shaded.
Source: Shiller (2015); US Census Bureau, "New Residential Construction"; and authors' calculations.

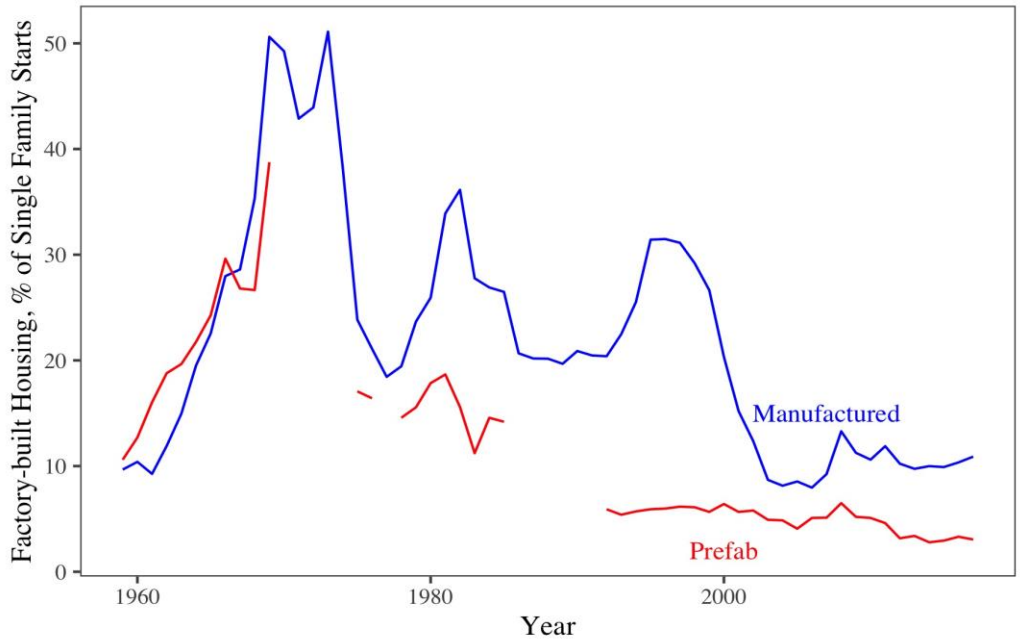
associated with greater reliance on factory-built housing. Serious private-sector efforts, some supported by large government subsidies, have long sought to increase the productivity of home construction through prefabrication and mass production. Industry participants and policymakers have learned that promised cost savings are not realized, restricted flexibility in on-site assembly introduces uncertainty into the production process, and customers are indifferent at best between factory-built and site-built construction, even if the former are of higher quality. Instead, the most significant cost savings in single-family homebuilding in the postwar era have been the result of management innovations that facilitate the efficient assembly of increasingly prefabricated components. For these reasons, industrialized housing has never provided serious competition to site-built housing as the dominant method for erecting single-family homes in the US (Figure 2).

We conclude that greater reliance on mass production is unlikely to be a source of significant cost savings for the kinds of homes that most Americans live in today. We highlight the potential for factory-built housing to provide more significant cost savings if smaller-size and reasonable but lower-quality construction is permitted, as is the case with manufactured housing. While the entire home is rarely prefabricated in the US, we do highlight that increased reliance on prefabricated *components* in site-built housing over time may result in some cost savings and increases in construction quality. Finally, we argue that the history of homebuilding demonstrates that rapid adoption of prefabrication or more efficient production processes by homebuilders are more likely to be driven by market competition than by economies of scale within consolidated firms or by government intervention.

Homebuilding Innovation in the US: A Saga of Failed Disruption

The homebuilding industry has long been derided as antiquated and inefficient. A common joke among housing market observers is that "if Jesus were to return to earth . . . the only thing he'd recognize is the home-building industry" (Frieden 1982). This state of affairs is even more remarkable since experiments with prefabrication in the US have been ongoing for at least two centuries. In the postwar era, the private sector and government have more than once made massive investments in factory-built home production. Homebuilders

Figure 2. Factory-Built Share of Single-Family Starts, 1959–2017



Source: HUD (1974); Field and Rivkin (1975); Daniell (1979); OTA (1986); US Census Bureau, "Shipments of New Manufactured Homes"; US Census Bureau, "Survey of Construction"; and authors' calculations.

learned that prefabrication offers no apparent cost savings, brings outsized risks, and receives a lukewarm reception at best from customers. Put differently, the homebuilding industry has remained relatively low-tech for many reasons that, as we describe more fully below, are not easily surmounted.

Experiments with housing prefabrication in the US date at least to the 1800s. Settlers in remote areas and prospectors during the gold rush lacked the raw materials and skilled labor required for traditional construction methods, creating demand for panelized homes manufactured on the East Coast that could be shipped west by rail, wagon, and mule (Bock 2006; Herbert 1984). Nineteenth-century panelized homes were an innovative solution to the problem of barren land, scarce skilled labor, and the need to erect new homes quickly and affordably.

"Prefabricated housing is an idea whose time has come, and gone, and come, and gone again, and (at present) returned" (Martiini 2009).

Prefabricated housing entered the mainstream at the turn of the 20th century, when Aladdin, Sears and Roebuck, and Montgomery Ward, among many other firms, produced the next generation of prefabricated kit homes or mail-order homes, which were sold through catalogs and more generally classified as "precut houses." Nothing was preassembled. The kits provided all the materials needed to build a home, including precut lumber, nails, and even paint. The value of precut systems came from having a fixed number of standardized designs from which the many parts could be pre-stocked, packaged, and shipped to the consumer at a fixed price. Kit housing was in such wide use by the 1920s that Buster Keaton's comedy *One Week* lampoons a hapless newlywed couple attempting to erect their new house. Bruce and Sandbank (1945) estimate that at least 250,000 precut units were sold by the mid-1940s.

During the prewar era, most homes were built by small-scale speculators or by contractors hired by individual families, the antithesis of the movement toward greater production efficiency in other parts of the US economy. An attempt to coordinate and standardize the dimensions of building systems began with Albert Farwell Bemis in the 1920s. In Bemis' introduction to *The Evolving House*, his three-part survey of homebuilding technology, he maligns that "the means of providing homes in modern America and elsewhere have been strangely out of date," particularly, in comparison to the automobile (Bemis 1934, vii). Bemis emphasizes that the boom in manufacturing productivity during the 1910s and 1920s had entirely escaped homebuilding:

> It is quite true that individual building materials—nails, cement, steel, bricks, shingles—have reached manufacturing efficiencies comparable to those in most of our major industries. But the process of further manufacturing and building these materials into a house has lagged behind, has not reacted to the stimulus of the Industrial Revolution (Bemis 1934, 250).

The view that homebuilding was woefully inefficient was also supported by a new wave of modernist architects during the interwar period. The Bauhaus School in Germany, established by Walter Gropius, one of the first modernist architects, was particularly influential in the US following World War I. Gropius and a number of the school's teachers and students came to the US and brought with them Gropius' long-standing interest in mass-produced housing (Davies 2005; Herbert 1984).

Alongside precut wood homes, experimentation with concrete and steel occurred during this era as well. Revolutionary ideas about the nature of housing, its structure, and its form were also born. Buckminster Fuller imagined the Dymaxion house "suspended by wires from a central mast" and hexagonal in shape with air-conditioning and an automatic laundry (Kelly 1951, 26). In addition to being produced like an automobile, according to Fuller's student Jay Baldwin, "The Dymaxion House was to be leased, or priced like an automobile, to be paid off in five years" (Baldwin n.d.).

The experience of the fledgling prefabrication movement in the 1930s previewed many of the

challenges would-be disruptors faced again and again during the rest of the 20th century and in the early 21st century. Public interest in inexpensive, mass-produced housing grew in response to the housing crisis during the Great Depression, and promoters of prefabrication believed that factory-built housing could help fill idle factories. However, the kinds of imaginative prefabricated housing prominent architects favored had little public appeal. And the inexpensive housing built for the government during the New Deal and the war effort was "often stereotyped in the public mind as a dreary shack" (Kelly 1951, 62).

"What housing needs is a General Motors" (Grebler 1973).

The kind of prefabricated housing that did gain market acceptance, which was mainly comprised of premade wall panels assembled on-site, looked little different from housing built using conventional techniques. Bruce and Sandbank (1945), in their review of prefabrication through the early 1940s, comment that "from the standpoint of the consumer, there is almost nothing to distinguish most of the houses now being prefabricated from the typical, site-assembled, two bedroom war housing unit built for the same purpose" (70). They conclude their survey with an open question: "While there are obvious economies in factory assembly methods, it has not been established that these are sufficient to counterbalance the additional shipping costs and complications of panel construction—especially as compared to the large-scale production of houses at the site" (70).

Prefab Versus Site-Built in the Postwar Era

In the postwar era, most researchers and industry specialists have answered no to Bruce and Sandbank's question about whether the benefits of prefab outweigh the costs (e.g., Kelly 1951; Field and Rivkin 1975; Quigley 1981; GAO 1982; NAHB 1998). Whatever savings arise from productivity gains associated with prefabrication are offset by higher transportation costs, plant overhead, and marketing costs for all but manufactured housing.

However, rather than an indictment of factory-built methods, the relatively lower cost of site-built housing is at least as much a reflection of significant innovation in the industrial organization of the homebuilding industry in the late 1940s and early 1950s. During this period, improved access to financing, easy land acquisition, and improvements to transportation infrastructure set the stage for homebuilding to become big business. Single-family housing became increasingly built by large production builders on subdivided lots located in sprawling suburbs. By 1960, more than 70 percent of housing was built by firms producing more than 100 units per year (Eichler 1982). In many growing markets, the presence of multiple competing builders promoted management innovations that sought to maximize the productivity of labor and minimize materials costs (Eichler 1982).

Site-built production since the 1940s has sought to balance the desire for economies of scale with the need to be flexible to the local requirements of individual projects. On the one hand, firm scale provides advantages in financing, especially in accessing public sources of finance. On the other hand, the main inputs to home construction—land, labor, and materials—are locally or regionally organized markets. Building codes and consumer tastes vary considerably across regions. Delays in land purchasing, permitting, materials acquisition, and construction create outsized risks for homebuilders, as homes under construction are large capital investments and local housing markets are notoriously volatile.

Therefore, the evolution of homebuilding firms has been away from vertical integration of the construction process itself and toward outsourcing and specialization. Firms in the homebuilding industry are first and foremost construction *managers*. By using mainly subcontracted labor, homebuilders can rapidly adjust to fluctuations in the number and timing of projects, to opportunities in new markets, or during a recession. This method for producing a home maximizes flexibility.

The downside of site-built construction, however, is that economies of scale are limited at a few

hundred or a few thousand units. Beyond that, administrative overhead, challenges with on-site coordination, and sacrifice of local knowledge add costs and risks. As a result, even today, large, national production builders do little construction management on the corporate level, instead delegating these responsibilities to geographically dispersed divisions, which delegate the actual process of building the house to an array of contracting firms.

Six Attempts at Disruption

Even as production builders ascended after the 1950s, there remained influential groups of architects, innovators, and policymakers who believed that greater reliance on mass production could produce better homes and cheaper prices. In this section, we examine six attempts to challenge traditional methods. Five of the attempts, including two government programs that sought to subsidize factory production, ranged from abject failures to modest successes. The sixth—the surprising success of mobile and manufactured housing—occurred despite the federal government's indifferent reception toward the lower-cost, mass-produced alternative.

Lustron Homes: Why You Cannot Build a Home Like a Model T. With a looming housing shortage caused by veterans returning from World War II and factories dedicated to wartime production needing to be repurposed, the government passed the Veterans' Emergency Housing Act. Enacted in May 1946, it produced a huge package of incentives for prefabricated housing production designed by the new housing expediter, Wilson Wyatt. Kelly (1951) notes that the ranks swelled from fewer than 100 prefab to 280 companies by the end of 1946.

The Lustron Corporation was a poster child of this brief era in both its massive government backing and the extent of its attempt to industrialize the homebuilding process. It invested more than $39 million in capital, the vast majority of which was financed by the federally funded Reconstruction Finance Corporation (RFC), to produce homes out of porcelain-enameled steel (both inside and out) in a former aircraft factory at a projected rate of 100 per day. Architect Carl Koch, who was a consultant to the company, described Lustron's mass-production methods.

> The houses themselves started at one end as rolls of steel bar stock, or other elementary metal shapes, and from there were moved by conveyor; sliced, punched, stamped, or otherwise bashed; welded, riveted, bolted, as the case might be; or sprayed and baked—finally issuing at the other end as packages of three thousand component parts, loaded on special trailers and ready to go (Koch and Lewis 1958, 111–12).

Lustron's business model relied heavily on achieving economies of scale. However, to do so, it made huge capital investments in specialized equipment. Koch recalls the machine invented to produce bathtubs.

> The press had been procured at enormous expense to turn out individual tubs very cheaply, something like $15 as opposed to a wholesale lot price of around $45. But it soon developed that in order to operate efficiently, and amortize the original cost, it would have to turn out 120,000 a year—40,000 of them for Lustron houses, the rest to be sold on the open market. However, the tubs it made to fit the Lustron house were five feet, one and a half inches long. And almost nowhere in the world can you sell a bathtub of that size. Five feet even, yes. Five feet, one and a half inches, no (Koch and Lewis 1958, 112).

Because the tub was not a standard size, Lustron could not sell it to other wholesalers, and the tub's production was not profitable.

Lustron believed at the time that customers would flock to any home built with high-enough quality at a low-enough price, as had been the experience in the car industry in the prewar era. The customer desire for customization and the irregularity of the land on which these homes were to be erected, however, were not taken seriously in the design process, nor were the shipping costs associated with the Lustron homes' large size and heavy weight. Further, Lustron's production process was extremely complicated, involving thousands of components with few alternative uses, making the company extremely vulnerable to declines in housing demand. Wartime production of prefabricated housing had a single, stable consumer: the government. During the postwar building boom, firms

like Lustron were poorly prepared to undertake the marketing, distribution, and sales effort it would take to establish a constant flow of demand.

Lustron ended up building around 2,500 homes before the RFC decided to stop lending the deeply indebted company any more money, which forced Lustron into bankruptcy.

Acorn and Techbuilt: Stumbling Toward Lean Manufacturing. Techbuilt, likely the most successful postwar experiment with prefabrication, drew on the lessons of the prior failures of Lustron and the prewar building systems to build a home that had the look and feel of a site-built house while using leaner production methods. After failing to market the Acorn House and closely observing the issues at Lustron, architect Carl Koch realized that prefabricated housing need not be mass-produced like a car or an airplane. Instead, by outsourcing the home's components to existing prefabricators, Techbuilt could flexibly adjust supply to prevailing market conditions.

Koch, a contemporary of Walter Gropius, first experienced the failure of the Acorn House, which he described as "his 'best' idea: one that in any reasonable world would have brought comfort to millions" (Koch and Lewis 1958, 74). In 1947, Koch and John Bemis, the son of Albert Farwell Bemis, partnered to build a house that had a lightweight, stressed-skin exterior that could fold into an 8- by 24-foot core. Unable to find financial backing or a partner willing to build the house, Koch and Bemis built the house themselves in a makeshift factory in Boston.

The Acorn House was intendedly unconventional, because "conventional methods and materials could never offer the same results, strengths, or economics." It faced significant opposition from local building regulators who were "elected to stop the building of cracker boxes" (Koch and Lewis 1958, 100). As a result, the company evolved to use wood construction, instead of stressed skin, and—while it never achieved its lofty goals—it continued to produce prefabricated homes in New England through the end of the 20th century.

Learning from his "ten-year record of mishap, rude practical education, and artistic successes qualified by insolvency" (Koch and Lewis 1958, 146), Koch founded Techbuilt Homes in 1953. The home was designed using plywood-stressed-skin panels that could be set up by four men in two days. Unlike its predecessors, Techbuilt permitted substantial customization in terms of the interior layout and orientation of the house on the site. The look of the exterior and the materials used to construct the homes were familiar to consumers and local building regulators.

> "Somewhere in this experience are the keys to better and cheaper methods of house production" (Bruce and Sandbank 1945).

Just as importantly, Techbuilt was an assembler, rather than a manufacturer. Exterior shells and wall panels were built by contract at factories that specialized in prefabrication. Pre-hung doors and other components were purchased at volume through regular distribution channels. The components were then shipped to the local builder-dealers, who completed the house to fit the local market. Although by no means an unqualified success, Techbuilt Homes did sell over $2 million in houses by the mid-1950s. However, sales tapered during the 1960s, and the struggling company was purchased in 1970.

The "Ten Wide": Low-Cost Disruption from Unexpected Places. Housing shortages during the 1960s led to a resurgence in consumer interest in factory-built homes in the form of "mobile homes," as coined by inventor Elmer Frey. The vision of the trailer in the American imagination had seen peaks and troughs during the early 20th century. It started as a fashionable way to see the country in the booming 20s. It was then viewed as a last resort for the poor and unemployed during the Depression before it received greater acceptance as temporary housing for wartime workers. It finally reemerged as a symbol of freedom and prosperity in the 1950s. From the 1950s through the early 1970s, competitive pressures driven by low barriers to entry and the absence of nationwide regulation promoted a wide variety of exterior and interior

designs, ranging from single-wide units with futuristic, airplane-like exteriors to double-wide and expandable units that sought to mimic site-built homes in appearance and internal layout (Wallis 1997; Bernhardt 1980).

In the late 1940s and early 1950s, what kept trailers from becoming serious competition with the burgeoning market for tract housing, however, was the 8-foot-width limitation so it could be allowed on the roads. Frey's Marshfield homes' radical innovation was to build a trailer 2 feet wider. The Ten Wide was a home built in a factory that was capable of being wheeled to a site but designed to remain in place for the home's lifetime. Unlike prior trailers, the interior of a Ten Wide had the feel of a tract home, but for a lower price. Although the home was called mobile, it required a special permit to be allowed on the roads, making frequent moves impractical. Consumers still flocked to the cheaper alternative to traditional housing, and trailer companies soon retooled factories to accommodate wider frames (Wallis 1997). By 1969, 12- and 14-foot-wide mobile homes had been introduced that looked increasingly like site-built housing, paving the way for an explosion of demand for mobile homes, which reached 500,000–600,000 shipments per year in the early 1970s.

The existing distribution channels for mobile homes were just as important to their rapid growth as their low price. The original sales network for mobile homes grew out of existing networks for cars and trailers. According to surveys done in the early 1970s, 74 percent of mobile home dealers originated in recreational vehicles, automobiles, mobile home manufacturing, or mobile home parks, compared with just 18 percent that originated in land development or real estate (Bernhardt et al. 1976). Few mobile home dealers during the boom in sales in the 1970s also sold modular or panelized homes. A more common source of diversification was to expand into mobile home park operations (Bernhardt et al. 1976).

Intent on regulating their over-road travel and wary of the sometimes shoddy construction of mobile homes, Congress in its 1974 act authorized the Housing and Urban Development (HUD) "to develop construction and safety standards for manufactured homes and to oversee the enforcement of the standards through inspections and reviews of building plans" (GAO 2014). Now known as the National Manufactured Housing Construction and Safety Standards Act of 1974, the act defines a manufactured home as a dwelling built on a permanent chassis, and the national standards HUD established preempt state and local building codes.

Initially, Congress planned to expand the national code to apply to modular housing as well, but legislators were ultimately unable to adapt the code to prefabricated structures without a chassis (Willman 1977). To this day, the HUD code with its national preemption distinguishes manufactured homes from prefabricated housing.

Operation Breakthrough: The Government Steps in Again. Data from HUD's Housing Policy Review report in the early 1970s suggest that prefab was also booming, reaching about 440,000 starts in 1972. Notably, real construction costs for 1968–72 were also steeply accelerating, increasing by about 6 percent per year. In response, a HUD-backed program called Operation Breakthrough was launched in 1969 and designed as a government experiment to lower barriers to innovation and to demonstrate that mass-production techniques could lower housing production costs. According to HUD (1969):

> To introduce efficiency in housing production on a large scale will require the assembly of substantial local, regional, and perhaps national markets. With larger markets, producers can realize economies of scale not now available, they can recover the large investment in research and development and plant and equipment necessary to engage in a sizeable scale of operations.

A key concern among policymakers was that local jurisdictions adopted a wide variety of building codes. While efforts were already underway to encourage states to adopt statewide codes and more similar codes between them, Operation Breakthrough came up with its own approach. It had the National Bureau of Standards develop Guide Criteria "to permit program builders wide latitude in design, materials, and construction methods and by supporting statewide codes for industrialized housing" (GAO 1976). The codes were based on performance criteria, instead of

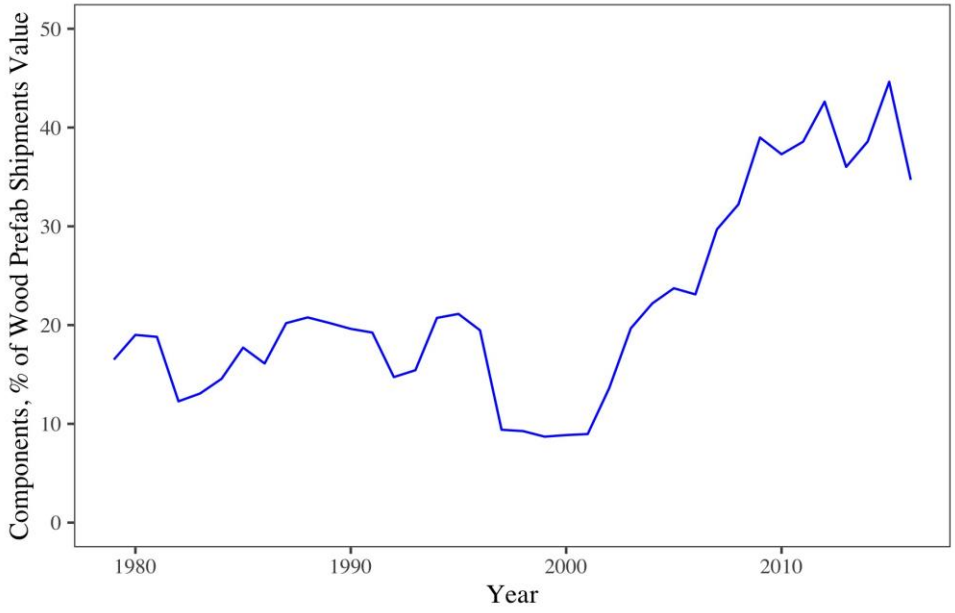
prescriptive rules, and the hope was that the Guide Criteria would provide local jurisdictions reassurances of rigorous testing by the federal government. The time for HUD to establish, and participants to meet, Guide Criteria was too compressed, however, and delays rippled through the program. Further, the Guide Criteria did not always smooth the way with localities, and local approvals still caused major delays for builders.

Despite participation in eight locations countrywide by 22 housing system producers that included some of largest companies in the US—such as General Electric, Alcoa, Boise Cascade, Boeing, and Levitt Building Systems—and federal investment in the program of nearly $72 million, the GAO (1976) concluded that little was actually gained from the experiment beyond drawing attention to some potential technologies and encouraging states to adopt new model building codes. The GAO's review found that Operation Breakthrough failed to demonstrate any cost savings from mass production, in part because of program design flaws and a premature end to subsidies intended to support demand. None of the building systems developed during the program experienced widespread adoption.

Empyrean: Testing the Outer Limits of Prefabricated Components. One positive legacy of Operation Breakthrough was the successful demonstration of prefabricated components. By the mid-1970s, for example, pre-engineered roof truss components had become the norm for framing gable roofs on single-family homes. By the mid-1980s, most component manufacturers had begun to produce roof and floor trusses, and many also produced wall panels and door units (OTA 1986). This trend toward greater reliance on prefabricated components continued in the early 2000s (Figure 3).

Surveys with builders demonstrate that market conditions, rather than economies of scale, tend to drive the adoption of building innovations such as prefabricated components and advanced supply-chain management (Abernathy et al. 2012). Due to the regional management of home construction, larger and midsize builders in the same markets tend to build homes the same way. There is scant empirical evidence for what Abernathy et al. (2012) call the "virtuous circle hypothesis": that builder consolidation will produce scale opportunities, which will promote innovation, further improving the competitive position of larger builders.

Figure 3. Components as a Share of Overall Prefab Shipments, 1977–2016



Note: Excludes shipments not specified by kind.
Source: US Census Bureau, "Annual Survey of Manufactures"; and authors' calculations.

The innovations that diffuse fastest among homebuilders are those that do not require fundamental changes in the production of a site-built home (Taylor and Levitt 2005). For example, prefabricated roof trusses, which require no additional training or materials to install quickly, are used in the majority of new single-family construction (Home Innovation Research Labs 2018). Components that require specialized training to install have diffused less quickly. Costly investments in training by builders are risky when each prefab panel manufacturer uses entirely different technology to connect panels together. For example, in Sweden, massive government investment beginning in the mid-1960s and strict performance standards for government-subsidized mortgage lending supported increased investment in factory-built homes. As a result, panelized factories quickly learned the importance of having skilled teams in charge of on-site assembly. As a result, Swedish prefabricators either install building components themselves or train their own building crews (OTA 1986).

Another issue with reliance on prefab components is that on-site building techniques and the pervasive use of wood in the US provide for a great deal of problem-solving versatility in the field. The flexibility that exists in the design stage of prefabricated homes ends once the panels or modules leave the factory (NAHB 2002). This means that any mismeasurement or in-transit damage that renders a part unusable may leave the builder unable to proceed until the manufacturer is consulted and the part is repaired or replaced. Depending on the amount of finishing work already done to a component, this can be a particularly complicated and time-consuming process.

One of the most radical experiments with reliance on prefabricated components was undertaken by Empyrean International in the early 2000s. Empyrean was formed as a rebranding of the merger between Acorn and Deck House, the latter a New England post-and-beam prefabrication company that was founded by two former employees of Techbuilt. Empyrean offered independent architects the opportunity to design prefabricated homes using the existing components from their catalog. The combination of computer-aided design and a restricted set of prefabricated components offered customers an unparalleled level of customization.

The ambitious project drove the company to bankruptcy, partly due to problems adapting the designs from the outside firms (Lin 2008) and partly due to a spate of postponed and canceled orders following Lehman Brothers' collapse (Coach 2008). The Empyrean experience again emphasizes the difficulties associated with managing housing cycle risks for prefabricators and the challenges associated with introducing customized designs into factory production.

Pulte Home Sciences: A Higher-Quality—but Not Lower-Cost—Factory-Built Home. Pulte Homes, then the second-largest homebuilder in the US, experimented with vertically integrated prefabrication within a limited geographic range in Northern Virginia in 2004. Called Pulte Home Sciences, the initiative sought to build panelized houses that could be "put together like Legos" in a massive, nearby plant in Manassas, Virginia (Deane 2004). Pulte estimated that they could build all the walls for a 3,500 square foot house in four hours in a factory, as opposed to eight days on-site. As a result, Pulte was less likely to face delays due to bad weather, generated less construction waste, and required fewer skilled workers on-site.

Unlike prior attempts at prefabrication, the homes Pulte Home Sciences built were not intended to be more affordable than site-built homes. Although discounts to early customers spurred uptake for the factory-built alternative, Pulte planned to charge more for these homes, which were advertised as being quieter and airtight and having straighter walls and a "more solid feel" (Deane 2004).

However, due to the heavy weight of their walls, roofs, and foundations, the homes could only be trucked within a 125-mile radius of the factory. These sorts of issues with transportation, large fixed capital costs, lack of consumer demand for the high-quality product, and the weakening of the housing market led Pulte to close the plant in 2007 after only producing 850 homes, a far cry from the 1,800 homes per year that were planned when the plant opened (ElBoghdady 2007). At those low volumes, the high capital costs involved with building the factory could not be justified. According to a Pulte spokeswoman, "We brought the concept to

Manassas as a test and in the end, it didn't prove out" (ElBoghdady 2007).

Discussion and Conclusion

Our investigation of attempted disruptions to US homebuilding illustrates the challenges would-be innovators face. The grandfathers of prefab, Bemis and Koch, long ago recognized the fundamental issues at hand. Bemis saw that, as a result of broad efficiency gains from industrialization, materials and building components were rapidly improving in quality and price but that the *process* of assembling these parts into a whole resisted change. While modern materials and prefabricated components continue to evolve, his observation is as apt today as it was in the 1930s.

Koch recognized a second crucial reason why affordability has not improved as a result of attempts at prefabrication: The homebuilding industry essentially continued to build the same product, whether inside the factory or out. Eschewing "unconventional" methods and products, consumers, regulators, lenders, and homebuilders have crafted a norm for housing in the US that has been difficult to disrupt. At the same time, conventional building techniques are flexible and capable of wide-ranging customization, which appears to be prized in US markets.

Despite repeated and varied attempts by prefab firms, factory production has failed to consistently demonstrate that its benefits can offset its greater costs of transportation and other on-site complications for single-family housing. In fact, the story of failed disruption tends to explain why production homebuilders are organized in such a decentralized manner, in which firms act as financiers and managers of the building process but otherwise employ few construction workers. While often maligned as antiquated, production homebuilders have efficiently adapted to the market challenges they face (Willis 1979).

The cases also illustrate the government's failure to either spark or support homebuilding innovation. Both major attempts by the federal government to subsidize scale in factory production ended as expensive failures that primarily served to reinforce existing homebuilder biases against prefabrication. The moderately successful attempts at lean factory production, as in the case of Techbuilt, result in traditional homes with only modest cost savings, little of which is generated from scale economies. At the same time, traditional homebuilders have gradually incorporated a range of prefabricated components, in some cases making distinctions between prefabricated and site-built housing less clear.

> "Too great dependence has been placed upon the achieving of cost reduction through prefabrication and industrial reorganization, the prospect of which is not immediately present" (FHA 1936).

Lower-cost factory production has been achieved for an alternative to the traditional home that sells at a lower price point. The remarkable tale of factory-produced mobile homes in the 1960s and 1970s revealed a viable market for more uniform, smaller, and lower-quality housing units. Cost studies confirm that on a per square foot basis, manufactured housing costs less to build than a modular or site-built home does (e.g., NAHB 1998). Presumably, lower quality is feasible due to the existence of a national HUD code that preempts local building code requirements. Lower costs are also supported by only limited customization as compared to modular housing, which is often built by the same firm but which demonstrates far less cost savings.

The fact that many manufactured housing producers also build modular homes using similar production processes, but at a cost comparable to site-built homes, leads us to conclude that the observed cost savings are less a result of scale economies driven by factory production than the accumulated savings from these other factors. Further, as a matter of policy, we find it strange that in order to be permitted to build a house for less money, a homebuilder must first attach a largely superfluous chassis. We expect that if all factory-built housing were subject to an equivalent nationwide building code, we

would see greater adoption of modular and panelized single-family homes and less adoption of manufactured housing.

Returning to the question of whether factory production can meaningfully increase affordability of traditional US housing, we think the answer remains no. Of course, alternative disruptions may come along that could change both the process and the product in a dramatic fashion. (3D printing, for example, would require an on-site "printer" and would use concrete-like material to form homes.) In the interim, multifamily housing is experiencing an increase in modular construction that may result in innovations that could influence single-family production. In the least, demand for prefabricated multifamily housing should increase capacity for producing prefabricated housing components for single-family homes.

However, the historical record is clear that federal government interventions to support factory production of homes are unlikely to bear fruit. In particular, we fear that possible policies seeking to spur innovation will have the unintended effect of reducing those competitive pressures that have improved efficiency and driven down customer costs in the past. It is hard to predict when disruption will occur or which technology will finally unseat an industry standard. Over the past century, while the government sought to bring down costs by subsidizing large firms to achieve economies of scale, cost savings in homebuilding have instead come from markets and products with many firms competing to drive down prices, with low barriers to entry and exit, and in which consumers have a great deal of choice.

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