PRODUCT DESIGN CHOICES IN AMERICAN CAPITAL GOODS INDUSTRIES, 1850 - 1925

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ABSTRACT

Standardization is a major theme in the literature of American industrial development with its focus on mass produced goods. By contrast, this article considers the viability of standard product designs in three lines of batch-produced capital goods — machine tools, steam locomotives, and stationary steam engines — from 1850 to 1925. Rigorous standardization could also offer notable advantages to builders of such heavy machinery. Yet it proved difficult to achieve largely because customers exerted a strong influence on design, blocking full product standardization. On the other hand, machinery makers found that true custom designs posed many production challenges. This article traces how American capital goods firms navigated between the conflicting demands of standard versus custom designs.

In his influential article on the machine tool industry, Nathan Rosenberg argued that the entire nineteenth-century capital goods sector was "engaged in custom work."[1] My own history of the Baldwin Locomotive Works, America's largest maker of capital goods, largely supports Rosenberg's view. That account argued that the design and production of custom capital goods represented an alternative industrial format — one distinctively different from that pursued by American System mass producers of standard consumer products.[2] Those American System firms have come, however, to dominate most accounts of nineteenth-century industrial history.[3] Without seeking to discount the importance of mass production, my present research project advances an alternate foundational account of industrialization. This book will survey a range of different capital goods industries to give a full portrait of the distinctive industrial format pursued by the makers of heavy machinery. By way of definition, heavy machinery or capital goods are those mechanisms sold to secondary firms for their use in producing goods or delivering services.[4] My focus technologies include: textile machinery, railway equipment and machine tools, steam power plants, woodworking machinery and printing presses, and iron or steel ships and bridges. In considering these cases, I am investigating whether capital equipment makers as a group faced common challenges over the nineteenth century in design, production, and marketing. If so, what key issues gave rise to this alternative industrial format? And can we draw broader conclusions about American economic development by comparing the courses pursued by capital equipment makers and consumer product manufacturers?

This article addresses these questions by focusing on a single issue: the extent to which the makers of capital equipment found standard product designs to be a viable or desirable strategy in design, production, and marketing. I also explore the views of capital goods purchasers regarding the pros and cons of standard machinery designs. These issues are considered here in three cases — machine tools, locomotives, and stationary steam engines — over the period from 1850 to 1925. By that terminal date, standard designs had come to dominate many markets for consumer products, so a focus on the pros and cons of standardization in heavy machinery seems an ideal way to contrast the two formats.

The term "standard product design" requires a bit of defining. In the sense used here, it means: A product designed by the maker, produced in volume sufficient to garner at least minimal economies of scale, and marketed to different users. In contrast to this paradigm, three other design approaches appear to have been at least theoretically possible. First: Standard designs that originated with one or more leading customers, but were produced in some quantity (i.e.: the maker loses control of the innovation function but garners economies of scale in production). Second: Semi-custom mechanisms designed by the maker, but modified or customized to meet particular customer demands (a shared innovation function). One-off or small batch lots; minimal economies of scale. Third: Custom machines (one-off or very small batch lots) designed by makers, or by users, or in collaboration. No economies of scale.

Each design avenue would suggest uniquely different influences or demands in the markets for heavy machinery. Each would result in very different conditions for the producing firm: in managerial discretion and policies, in the suitable mix of production factors, and in marketing tactics. At the most general level, therefore, this analysis of the pros and cons of standard designs for heavy machinery addresses these questions: who influenced the innovation function, how was that influence manifested, why did those actors have this power, and what were the results for makers, users, and the broader economy? Thus the article also sheds light on the evolving historical character of the firm itself, on conceptualizations of markets, and on the roots of innovation.

Rosenberg's assertion that custom design ruled the capital goods sector is the kind of generalization that invites a challenge. Even if true, the statement implicitly raises the question of why the machinery makers were driven into constant design ferment. Logic alone suggests that like the volume manufacturers, capital equipment makers of all kinds had powerful reasons to resist design collaborations with customers (leading to custom work) and to insist upon rigorously standard products of their own design. If a firm had to share design power with customers, it ran a real risk of losing ultimate control over the innovation function — the technical evolution of its own product lines. Conversely if innovation remained predominately within the producing firm, then it could launch new design departures at those moments that best suited the firm. By agglomerating design changes in successive versions of standard products (as with the annual model change in autos), the firm largely "tamed" incremental innovation to suit its own ends.

Standard designs would have eased the challenges of actually building large and complex capital goods. Finally, fixing design to standards was essential in garnering scale economies — as the American system mass producers ultimately demonstrated.

So let us now turn to the actual practices of machinery builders and users in three industries: machine tools, locomotives, and stationary steam engines. What pros and cons did their makers and users see in standard designs? Is there a broad pattern of design choice over the period from 1850 to 1925?

Machine Tools

Until the 1850s, machine tool production in the US was largely a sideline for general machine shops or textile machinery builders who built tools to custom designs. But in that decade the railroad industry finally provided a major market for tooling, as the carriers needed extensive metalworking capacities to build and maintain their fleets of cars and locomotives. Responding to that demand, two Philadelphia firms — William Sellers and Bement and Dougherty — became the first specialist tool builders in America. Did this initial broad market for tooling also lead to standardization in design? One example from the Sellers company suggests that it did.

In 1855 William Sellers patented a novel machine for threading bolts and nuts. His bolt threader offered twice the output of competing models, and it entirely de-skilled and automated a task that had required the best skilled craftsmen a generation earlier. With patent in hand and strong demand for this product, Sellers did achieve substantial product standardization — with consequent advantages in marketing, production, and internal management. In the matter of marketing, he went on to take out British, French, and Belgian patents on the same design. At home the firm eased its marketing challenges by building some threaders for inventory — a tactic that standardization alone made possible.

Sellers also derived internal advantages by standardizing this design. Unit costs declined substantially as managers and workers advanced along the learning curve associated with producing any novel product. The firm cut its production cost per unit by 53 percent in three years — from $771 to $352 by 1859[5] This decline also helped marketing efforts for Sellers met his own cost declines with cuts of a similar magnitude in the selling price of these machines. These cost figures suggest a noteworthy side benefit of product standardization — a detailed cost accounting system at the Sellers factory in the 1850s. Such a steep fall in the cost of production indicates that Sellers used extensive working drawings to rigorously subdivide and standardize work tasks on the factory floor. A standard product design also allowed these specialized workers to use gauges and templates in production, assuring that machines had interchangeable parts. This technical feature translated into another marketing advantage.[6]

The case of Sellers' threading machine illustrates many of the advantages which capital goods makers derived when producing standard products. But some caveats are worth noting. In the first place, William Sellers was a notably innovative mechanical engineer who possessed a strong rationalizing bent — evident in his sponsorship of a national system of standard screw threads for nuts and bolts. His patent also provided an important foundation for standardization. Such a monopoly grant kept competing designs at bay, while also discouraging Sellers himself from *ad hoc* tinkering or customization to suit the needs of individual customers. His success in standardizing the threading machine also resulted from astute timing: this broadly useful device came to market at just the right moment to exploit a large demand sector with deep pockets, the railroads.[7]

Although a successful standardizer in this instance, Sellers soon had to depart from a "one size fits all" policy. Different users of capital goods had quite varied needs, which they communicated directly to the machinery makers. Within a decade of Sellers' initial patent, he had developed screw machines in five standard sizes to meet the range of demands from the market.[8] Many of his other products — such as large diameter boring mills, riveting machines, railway car wheel chucks, and locomotive frame slotters — were custom machines, designed in collaboration with customers and built to order. The first cost of such unique designs exceeded by far the cost of a hypothetical standard version. But the purchase price was a secondary issue to many machinery users. Their chief interest lay in lowering their own production costs with tooling that ideally suited their operating needs.

Following the Civil War, the concept of rigorously standard products spread to a number of other tool builders. A Rhode Island firm, Brown and Sharpe, entered the machine tool market in the late 1860s with a line of standard milling and screw machines, all designed in-house and patented. The firm enjoyed great success in these and other lines — so much that it resisted taking on custom work.[9] In the last two decades of the nineteenth century, a constellation of new machine tool firms in Cincinnati wrested national leadership in tool building from the Philadelphia builders. The dual strategy of specialist firms making standard designs was fundamental to Cincinnati's success in the industry.[10] But such policies proved difficult to maintain as customers kept pressuring Brown and Sharpe and the Cincinnati builders to develop tailor-made solutions to their own production needs.

When national demand for tooling slumped (as it did regularly in this highly cyclical industry), individual buyers had more leverage in pressuring toolmakers to build entirely custom or customized machinery. For example the automobile industry used the tooling sales slumps of the 1920s to extract custom machine tools from Brown and Sharpe — designs suited to their "specialized requirements."[11] In essence these auto makers wanted to directly yoke the machine tool firm's knowledge and capacities to their own production problems. In bad times, the tool builders had to meet these impositions or forego the business. Even when demand picked up again, as it did by the mid-1920s, the Cincinnati builders found they had to switch their approach from "standard to . . . specialized [read custom] machine tools."[12] To meet the esoteric production requirements of the auto industry and other mass producers, in 1925 a Cincinnati lathe builder made over 100 different sizes and types of engine lathes, "each designed to perform a single task on a specific part."[13]

We can thus summarize the history of innovation in machine tools from 1850 to 1925 by noting that tool makers came to prefer standard designs as their markets grew in size. But many of their customers then sought specialized or custom production machinery to achieve further growth in their own sales by garnering economies of scale. While a unitary economic motivation drove both parties, this search for efficiency produced contradictory results for the tool makers and their customers.

Steam Locomotives

Similar economic calculations show up in our next case, considering the pros and cons of standard designs for steam locomotives. But in this instance, personal desires and professionalizing motivations also enter the story. As was true of machine tools, the whole industry of locomotive building owed its independent existence to the railway sector. But while railroads mostly bought standard machine tools, they came to prefer custom-designed locomotives.

In its first thirty years the locomotive-building industry followed a path similar to that of the early machine tool industry. Generalist machine shops took up locomotive production as a sideline, they developed standard engine designs which they marketed widely, and by the 1850s such firms as Norris and Baldwin came to specialize solely in locomotives. Their railway customers purchased their standard engines in increasingly larger batch lots by the 1860s.[14] The builders had apparently found the right strategy for business success; by 1855 the top firms in the industry — Rogers, Norris, and Baldwin — ranked among America's largest industrial companies, each employing upwards of 1,000 men.[15] As that number suggests, locomotive building was notably labor intensive. To improve internal productivity, the locomotive builders installed systems of design and production-control drafting by the 1860s, wringing further benefits from the decision to standardize their products. But in that same decade, their customers began making new demands on the builders for custom or semi-custom products.[16]

As with machine tools, economic factors help explain the growing demand of leading railways for locomotives that were tailor-made to their own specifications. By the 1860s, many major railroads were already experiencing the growth in traffic that would continue down through the century. To pull more and heavier trains across their lines, they sought novel locomotive designs. Put differently their growth in traffic forced the carriers to give much more concern to the operating expenses of locomotives, rather than their purchase price or repair cost. Standard designs might save them money initially, but custom locomotives that could pull more freight provided economies in operating expenses that continued for twenty-five years or more — the service life of the average engine. This was an easy choice for the railway mechanical officers, the "master mechanics," charged with determining mechanical policies on the carriers.

But economics alone is an insufficient explanation here, because the demand for more powerful engines could have been fulfilled by new standard models, *designed by the builders.* The locomotive builders took exactly that stance, responding to the changing market conditions by offering lines of standard engines across a range of sizes, weights, and power. Furthermore they built on their systems of design and production drawings by utilizing many standard components across different sizes and types of engines. This strategy kept an engine's initial price down, while still addressing a railway's desire to economize operating expenses with more powerful engines.

Some of the carriers did find this a happy median. After the 1860s, however, many larger railroads increasingly rejected even these builders-standard lines. Instead, their master mechanics took to designing their own engines and soliciting bids for these custom products. Builders could either adapt their business strategy to the new trend or lose sales to more venturesome competitors. By this time, the key conceptual patents in locomotive design had lapsed, leaving the builders with no legal bulwark to maintain standard designs and creating an unfettered field for innovation.

Why did many leading master mechanics reject standard models, preferring their own — often untried — innovative custom designs? The answer lies in a curious amalgam of ego, creativity, and aspirations to lead the mechanical engineering profession. These men took a self-conscious pride in their own technical expertise. Even their title, "master mechanic," amounted to a prideful boast. As the architects and managers of large and technically complex railways, they necessarily submerged much of their creativity in impersonal system-building. But the master mechanics' creative impulses could have free reign and tangible form in locomotives. Leading master mechanics achieved their professional stature through locomotive innovations that improved railway operating efficiency while securing their own reputations among their contemporaries. Of course not all of their innovations proved worthwhile. But an erring master mechanic could shunt his failures off to the roundhouse in East Oshkosh, thus preserving an unblemished reputation, albeit at no small cost to the railway.

This shift of influence over innovation represented a substantial loss of power for locomotive builders. They no longer had primary control over the technical content of locomotives, and they had far less ability to influence the overall rate and character of innovation in their own products. Not surprisingly, the builders disliked these constraints. They also found the custom trend to be a costly burden in production. Novel designs taxed the skills of workers and the capacities of production tools — with no guarantee of repeat orders to amortize the substantial expenses for the drawings, foundry patterns, jigs, and templates that each new design required.

But the builders learned to adapt and even thrive in a world of custom designs and constant innovative ferment. Just as "pioneering did not pay" in Andrew Carnegie's world, the locomotive builders found their leading customers now shouldering some of the cost of innovation. Builders then integrated successful design departures into the standard models they continued to make for less venturesome clients. Most importantly, the custom trend lessened price competition in the industry because it yoked particular customers and builders in a collaborative design relationship that often lasted for decades. Put differently, the custom impulse changed the market in a profound way. Innovation became a collaborative process between builders and buyers.

For our purposes, this portrait of the pros and cons of standard steam locomotives suggests the need to look beyond a rhetoric of efficiency calculations and rational decision making — whether spoken by nineteenth-century railway managers or present-day historians. The master mechanics had extensive technical expertise, and they served bureaucracies dedicated to the pursuit of profit. Economic calculations justified their innovations in locomotive design, an unfettered patent environment cleared their path, and direct contact with the locomotive builders improved their leverage. Yet ultimately their innovations rose out of an intensely human creative impulse.

Stationary Steam Engines

For the most part, technically-sophisticated firms purchased machine tools and locomotives. Those customers had the knowledge and varied incentives to seek custom designs that ideally suited their own operating needs. Such knowledge was not necessarily as common among buyers of stationary steam engines in the nineteenth century. Backwoods lumber mills, small-town printers, and big-city brick works all bought engines to power their operations. Even sophisticated customers — such as machine tool makers, locomotive works, and large textile plants — had few reasons to demand custom engines. Whatever key desiderata they had — regarding an engine's size, cost, power output, rotational speed, fuel economy, or ease of repair — theoretically all these requirements could readily be met with a builder's-standard design. And given the size and extent of the potential markets for their products, the engine makers had a real incentive to lower production costs and expand their marketing reach by maintaining a policy of strict standardization in design. A few key engine builders did just that, and they generally thrived as a result — albeit in the short run. But many makers paid indifferent attention to standardization which required initial investments in managerial and engineering controls. These unsystematic firms remained viable until the 1880s, when the standard-setters finally beat them out, for reasons I will describe.

So in this industry I am shifting the focus slightly. Rather than simply considering the choice of standard versus custom designs, we will explore why a standardized product was important to some makers and users, but immaterial or unattainable for others. In turn, I will consider if the choice to standardize its products aided a firm's long-term survival and growth.

An extensive Federal survey, the Woodbury Report of 1838, gives us a portrait of the early spread of steam power. By that time, every state in the Union had engines at work.[17] Most were located in cities; for example Pittsburgh and Philadelphia accounted for eighty percent of the 383 engines in Pennsylvania.[18] They were built by general machine shops that also turned out a wide range of technologies, firms like Philadelphia's Rush and Muhlenberg (successors to Oliver Evans' pioneering engine shop) and New York City's Novelty Iron Works. Many smaller blacksmithing and machine shops in cities and towns across the country also entered the trade, however, as engines of the period required little in the way of specialized tooling or expertise. In particular, no single firm or individual held any strategic patent advantage in steam engine design until the 1850s. These facts, coupled with the high shipping costs for finished engines, meant that very small shops could coexist in the industry with giants like the Novelty Works which employed 800 men in 1857.[19] In such a free and open industry, entrepreneurs seeking a competitive advantage could devote their energies to underselling the market by improving internal efficiency. Or they could attempt to fetter free competition by securing key patent positions. We will trace both strategies here, with a particular eye to their impact on standardizing engine design.

A Brooklyn firm, Burdon's Steam Engine Works, was among the first American engine makers to extensively rationalize its operations and designs. Founded in the 1830s, by 1856 Burdon advertised a line of standard engines, ranging in size from 3 to 40 horsepower, and available for immediate sale from a showroom stocked with over 100 models. Burdon showed great concern for rationalizing production, extensively subdividing labor tasks, and building standard engines in fifty-unit batch lots. A trade paper described the result: "By turning out work of uniformly reliable quality, and by keeping a large stock of engines of assorted sizes, but of uniform construction," Burdon found customers in "all parts of the country."[20]

Yet his success was incomplete. Through the 1850s, a sufficiently broad market for mill engines still eluded the firm, and it had to supplement that product line with a range of machinery — from quartz mills to sugar kettles.[21] These were largely custom products, made to order on an individual basis. Most likely, Burdon's core difficulty was that high freight rates for engines shipped outside the New York area wiped out most or all of the cost savings he derived from standardized designs. During the 1850s, engine builders in Rochester, New York and Springfield, Massachusetts emulated Burdon's approach, suggesting it had a general viability yet within a context of local market advantages. So at mid-century product standardization enjoyed only indifferent success among engine builders. Over the next three decades a handful of innovative firms would find patenting a far more effective method to achieve a competitive advantage in the industry.

The standardizing builders focused their efforts on small engines for which they hoped to find broad sales to urban workshops. Until the 1880s factory prime movers (over fifty horsepower) remained custom products, turned out individually on a made-to-order basis. While the initial cost of such machines was high, factory and mill managers were also concerned with the high cost of fuel. Every large engine powering a factory or textile mill required batteries of steam boilers that consumed mountains of coal — upwards of ten tons a day.

These managers took notice when the Providence, Rhode Island firm of Corliss and

Nightingale began to market a novel engine design during the 1850s. With their patented valve gears, Corliss engines achieved good operating efficiency, cutting fuel costs by an average of thirty percent compared to common mill engines. Thanks to such savings and effective marketing, the Corliss became the industry standard. Its pacesetting quality quickly became evident in the numerous patent infringement cases that the firm had to fight and in widespread sales throughout New England, New York, Pennsylvania, and further afield in its first decade on the market.[22] Customers' embrace of the Corliss type shows parallels to my earlier accounts of market preferences in machine tools and locomotives. The Corliss offered advantages in operating costs (fuel efficiency) of a kind that mirrored the railways' rationale for custom locomotives. And like machine tools, the Corliss engine had particular operating qualities that attracted customers: uniform power output throughout each engine revolution and an instantaneous governor that kept engine speed nearly constant even when the load varied widely and quickly, as was true in iron rolling mills.[23]

Given that Corliss engines offered real advantages to manufacturers in a range of industries, did George Corliss take the next logical step and standardize his products to build on the market power arising from his patent? In short, no. Corliss did market a range of engines, ostensibly in "standard" sizes from 35 to 200 horsepower.[24] Because the foundry reused its patterns whenever possible, a 100 horse engine of 1875 bore an outward resemblance to one made in 1880. But in fact the two differed as much as custom products, largely because of Corliss's total disregard to the benefits of rigorous standardization. In complete contrast to the Sellers company, Corliss lacked any system of cost accounting, he eschewed design and production drawings, and engines of the same size did not have any interchangeable parts.

This anarchic approach to running a company — it scarcely deserves to be dignified as "management" — arose from George Corliss's idiosyncratic character. Only his strong patent claim on a vital innovation enabled the firm to survive its proprietor's methods and grow to achieve a towering capitalization in excess of one million dollars by 1880.[25] Corliss was quite exceptional among large machinery builders of all stripes in achieving such success despite its lack of system and standards. But many small and medium-sized general machine shops muddled along in the engine market of the 1870s and 1880s making rudimentary low-horsepower engines for local markets.[26] Until the larger standardizing builders developed methods to market their products nationally, small companies could turn a profit despite their *ad hoc* methods and inefficient designs.

Corliss' patents expired in 1870, and other builders soon marketed quite similar fuel-saving engines for large factories and mills. A powerful competitor, the Harris-Corliss Company had the gall to take the innovator's name, but eschewed his approach to production. With extensive drafting and labor-management controls, it turned out standard mill engines that sold for less than the production cost of Corliss models of the same horsepower.[27] By the 1880s, other makers like the Atlas Engine Works (Indianapolis), the Straight Line Engine Co. (Syracuse), the Westinghouse Machine Company (Pittsburgh), and the Southwark Foundry (Philadelphia) also pursued rigorous standardization policies with extensive working drawings and gauges to ensure interchangeable parts.[28] Westinghouse and Southwark further strengthened their positions in the market with patents for novel high-speed engines, high rotational speed being the most important innovation in factory power since the Corliss valve gear. Another standard-setting builder, the Erie City Iron Works, devoted its primary attention to marketing, rather than innovation. By enlisting a national corps of consignment agents, Erie City became one of the nation's largest engine builders after 1880.[29] By this time, the Corliss company entered its terminal decline, hastened by the rise of these powerful competitors, the expiration of its key patents, and George Corliss's death in 1888.

By 1890 then, the engine building industry had demonstrated the advantages in design, production, and marketing of a standard product — often with the added benefit of patent protection. So what are we to make of this segment of my story? Was product standardization truly advantageous in this industry? In some ways the engine-building industry mirrors the portrait drawn by Alfred Chandler of the rise of volume manufacturers.[30] Engine makers like Westinghouse and Erie City invested in innovation (especially patents), internal management systems (like production-control drafting and cost accounting), and marketing arrangements (catalogue distributors or consignment agents). In contrast to their competitors, these firms grew to large size because of these policies. Product standardization was integral to each element of this triad strategy.

While these firms lend support to Chandler's story, that paradigm in turn is insufficient to explain subsequent developments in the industry. The standard-setting builders did kill off their smaller and unsystematic competitors, mostly likely by combining their higher productive efficiency with greater marketing reach and power. But their success was short-lived. Of the five standardizing firms named here, only Westinghouse remained in engine business forty years later (i.e.: 1920).[31] None of the others successfully rode the great technological transformations in factory prime-movers of the era — from reciprocating steam engines to steam turbines and diesel power as well as electric motors. No single issue authoritatively explains their demise, yet it seems reasonable to argue that their standardizing campaigns ultimately penalized these firms. Unlike design collaborators, builders of standard capital goods risked becoming inflexible and out-of-touch with novel technical approaches on the supply side and evolving needs on the demand side.

Furthermore, the standard-setting builders of 1880-1920 never vanquished many large custom engine makers, firms like E.P. Allis, Hooven-Owens-Rentschler, Mesta, Tod, Union Iron Works, and Worthington. Among their many other products, these firms made largely-custom engines for factories, steel rolling mills, the mining industry, and urban water pumping and electric generating stations. In these applications, customers found that the operating advantages (in technical qualities and running costs) of custom-designed power plants far outweighed any potential cost savings that builders could offer from standard designs. Allis, Hooven, Union, and Worthington also proved to be durable companies, surviving the decline of reciprocating steam engines by developing other product lines. In sum, the standardizing approach that consumer product manufacturers rode to success in the third of the nineteenth century demonstrated only limited viability in the engine building industry to 1920.

Evaluating the Pros and Cons of Standard Capital Goods

The three cases described here — machine tools, steam locomotives, and stationary engines — support a number of broad conclusions about the pros and cons of product standardization in nineteenth-century capital goods. At first glance, they bear out Adam Smith's incontrovertible assertion that the division of labor is limited by the extent of the market. Where broad markets beckoned or prevailed (Sellers' threading machines, Cincinnati lathes, and light stationary engines), specialized producers found it profitable to subdivide production tasks (internal specialization) and turn out standard products in quantity. Conversely, narrow markets for special production tooling, mainline locomotives, or larger mill engines greatly circumscribed external and internal specialization, and custom designs ruled in these sectors.

This view, however, masks as much as it enlightens. Most importantly, it overlooks the power relationships between sellers and buyers that markets mediate, hiding that key issue behind a seemingly apolitical rhetoric of efficiency through the operation of impersonal market forces. Both past and present makers of mass produced, standardized consumer products have had many reasons to keep the political nature of their market relations hidden. Henry Ford was quite exceptional in mandating that customers take their Model Ts in black. In most nineteenth-century capital goods industries, however, builders and buyers had to share design power.

This finding can inform economists' conceptions of markets generally. In neoclassical economics, the market is simply a price mechanism, which with perfect information flows will trend to equilibrium. What I have described here better reflects the classical economist's view of the market — characterized by Frank Machovec as "a nexus of *advantage seeking* forces."[32] Some builders sought production and marketing advantages in standardization, while others pursued an opposite course — achieving their institutional momentum in innovation and marketing through design collaboration and custom products. Firms like Sellers and Baldwin pursued both strategies simultaneously in different product lines. Their collaborations with customers also suggest a different view of markets than most economists or economic historians generally espouse. In addition to price-mediated interactions between firms and markets, this account shows how machinery makers side-stepped the pricing functions of markets by striking up collaborative design relationships with key players in their markets.

When the markets for heavy machinery became sites of design collaboration, the capital goods firms lost a measure of their control over innovation. This loss of design power points to the "political" character of market relations in heavy machinery. We saw the force of politics, specifically the power to decide a product's technical qualities, in the locomotive industry. By 1870 the domestic and international demand for American locomotives was quite broad, leading as Smith would predict, to specialist firms with extensive internal subdivision of labor and even the widespread use of standard parts. But customers balked at accepting standard products. Those purchasers often couched their rationale for custom engines with the rhetoric of efficiency. Operating efficiency for the carriers, however, translated into higher costs and other problems for the builders. We can acknowledge their real desire for operating improvements while also seeing the master mechanics as tinkering innovators, motivated by creative impulses and desires for professional recognition.

If some buyers blocked product standardization in capital goods, many builders also disliked the concept. More precisely, American mechanical engineers of the period 1850 to 1925 had highly ambivalent views of the benefits of standardization. Technological historians commonly emphasize engineers' support for standards. As Bruce Sinclair writes in his history of the American Society of Mechanical Engineers:

> In the drive to rationalize American industry . . . standardization was to the engineer what administration was to the manager. Within the technologically complex mechanical industries, especially, the creation of standard parts and uniform practices gave the engineer control over anomaly . . . as well as greater power over the work-force and the work-place.[33]

Here Sinclair astutely notes the political character of standardization. From William Sellers' plan of standard screw threads down to Taylor's time and motion studies, standardization occupied many of the best and brightest minds of mechanical engineering.

In the period from 1910 to 1929, advocates of standardization in the mechanical trades espoused that cause with ideological fervor — driven by Progressive impulses to curb waste and inefficiency, by the example of Fordism, and by Taylorite campaigns to pursue "one best way" of industrial production.[34] But when they dug beneath the sloganeering, contemporary engineers in industries making heavy machinery saw drawbacks to this campaign. Simply put, they feared that standards blocked innovation and technical progress. In a 1924 ASME journal article, an engineer from Brown and Sharpe offered, "a word of caution against the too eager adoption of ill-advised standards."[35] And during its first thirty years, the ASME itself was generally quite chary about endorsing national standards for engineering parts and practices.[36] Notably engineers from the capital goods industries entirely dominated the ASME — rather than representatives of American System volume manufacturers or mass producers of steel or other bulk products.[37]

The opponents to standards within the ASME generally argued for a kind of Darwinian evolution, under which open-market competition would select the optimal sizes for lathe tapers, pipe flanges, or screw threads. These men were not opposed to standards *per se.* Indeed they often depended on standard parts to secure a measure of efficiency in building custom products.[38] But they believed that engineering advances grew out of an empirical process of development, evolution, and refinement — with inputs from builders and buyers that were mediated collectively in the market place. Recollect that these engineers saw the market not as an invisible hand. Rather it was flesh-and-blood competitors and customers, with many of its participants engaged in continuous innovation. In pointing to market selection, they were underscoring the social and collaborative character of innovation in capital goods.

The examples presented here suggest that neither Rosenberg's custom designs nor Sellers' standard models represented the dominant design paradigm for nineteenth-century capital goods. While they did pursue many variants, the leading American machinery makers combined the two approaches, collaborated with their customers on design, and turned out semi-custom or specialized machines, using standard and interchangeable components wherever possible. This middle ground strategy preserved customers' influence in innovation while securing a measure of efficiency in production.

Business, economic, and technological historians commonly see innovation as an essential function of the firm — to be executed internally or purchased through patent rights or strategic partnerships.[39] In sharing design power with customers, nineteenth-century machinery makers had entered into a kind of collaborative relationship that lay beyond purely market-based transactions. What was the result? How can we characterize their record in innovation? In general, this collaborative approach excelled in sponsoring incremental technical change — both at individual capital goods firms and across entire machine-building industries. As a rule, radical innovations were rare in capital goods — as they are in general. And in some notable instances, such as the American textile machinery industry, the machine builders ceded nearly all the initiative for innovations to their customers.[40] But speaking generally, these design collaborations resulted in continuous innovation at the machinery makers and steady productivity gains for users and the economy at large. American machinery makers like Baldwin, Sellers, and Allis grew to great size on the strength of their innovative machinery designs, exporting them around the world. This record explains why capital goods makers and users mostly eschewed standard mechanisms in favor of continual design ferment.

Endnotes

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1. Nathan Rosenberg, "Technological Change in the Machine Tool Industry, 1840-1910," *Journal of Economic History* 23 (1963): 416.

2. See John K. Brown, *The Baldwin Locomotive Works, 1831-1915: A Study in American Industrial Practice*, (Baltimore: The Johns Hopkins University Press, 1995), intro.

3 .Leading works that consider the American System and other aspects of volume manufacturing include: Joseph Whitworth's *Special Report* in Nathan Rosenberg, ed., *The American System of Manufactures*

(Edinburgh: Edinburgh University Press, 1969); Alfred D. Chandler, Jr., *The Visible Hand*, (Cambridge: Harvard University Press, 1977); Donald R. Hoke, *Ingenious Yankees*, (New York: Columbia University Press, 1990); David A. Hounshell, *From the American System to Mass Production* (Baltimore: The Johns Hopkins University Press, 1984); Nathan Rosenberg, "Technological Change," 414-43; Merritt Roe Smith, *Harpers Ferry Armory and the New Technology* (Ithaca: Cornell University Press, 1959); and Richard S. Tedlow, *New and Improved*, (Cambridge: Harvard Business School Press, 1996).

4. This definition excludes farming equipment, an exclusion that some economic historians would likely oppose. In my view the design, production, and marketing processes of agricultural machinery more accurately place mechanisms like reapers and plows in the modern category known as consumer durables — which is likely the chief reason Hounshell considered reapers alongside of bicycles and autos (*American System*, 153-87).

5. Data provided on p. 1 of William Sellers, "Extension Account," Aug. 31, 1877, in his request for extension of patent granted on Dec. 1, 1857 for "Improved Machine for Threading Bolts," Patent Extension Files, National Archives, College Park, Md.

6. Evidence of Sellers' use of gauges and templates to make interchangeable parts comes from notations on Sellers design drawings from the 1850s in Sellers Drawing Collection, Franklin Institute, Philadelphia.

7. Railways amounted to over one-third of bolt threader sales during its first five years on the market. Data computed from Sellers, "Extension Account."

8. Sellers sold only two of his largest threading machines between 1864 and 1871 — which suggests that any division between custom and standard products is somewhat arbitrary. While this model was "standard," it also showed attributes of a custom product: made to order, built one unit at a time with no real learning curve, and with essentially no opportunity to amortize costs of drawings and patterns.

9. A 1905 memorandum to Brown & Sharpe's "traveling men [salesmen] and designers" said: "It is the general policy of this Company to manufacture and sell only standard designs of Milling, Grinding, Gear Cutting and Screw Machines. Business involving the adaptation of standard designs or the making of special machinery is not desirable; no proposals for such work shall be made without first consulting the Office in private." See memo of Nov. 1, 1905, in W.A. Viall Scrapbook (1898-1915), p. 36, Brown and Sharpe papers, Rhode Island Historical Society.

10. George A. Wing, "The History of the Cincinnati Machine-Tool Industry," (Ph.D. Diss., Indiana University, 1964). Also see Philip Scranton, *Endless Novelty: Specialty Production and American Industrialization, 1865 - 1925* (Princeton: Princeton University Press, 1997), 138.

11. Henry D. Sharpe, "What Buyer's Market Means to the Tool Industry," *Mill and Factory Illustrated*, undated clipping circa 1927 in Brown and Sharpe, Historical Data, vol. 2, Henry D. Sharpe Jr. Papers.

12. Wing, "Cincinnati Machine Tool Industry," 245.

13. Ibid., 245.

14. Brown, *Baldwin Locomotive*, 28.

15. "Locomotive Shops of the Country," *Colburn's Railroad Advocate* 2, no. 24 (Oct. 20, 1855): 2.

16. This discussion is drawn from Brown, *Baldwin Locomotive*, 69-73.

17. Carroll W. Pursell, Jr., *Early Stationary Steam Engines in America* (Washington: Smithsonian Institution Press, 1969), 89.

18. Ibid., 87.

19. "Iron Manufactures in New York City — Past and Present," *American Artisan* 9, no. 10 (Sept. 8, 1869): 147.

20. "Burdon's Steam Engines," *Colburn's Railroad Advocate* 2, no. 40 (Feb. 16, 1856): 4.

21. See advertisement for "Wm. Burdon's Steam Engine Works," *Colburn's Railroad Advocate* 2, no. 37 (Jan. 26, 1856), p. 5.

22. George Corliss, *The Steam Engine As It Was and As It Is*, (Providence, 1858), 41.

23. Louis C. Hunter, *A History of Industrial Power in the United States*, Vol. 2, *Steam Power* (Wilmington: Eleutherian Mills-Hagley Foundation, 1985), 268.

24. This is the product line described in Box 3 - Letterpress Copy Book, Corliss Steam Engine Co., Outgoing Correspondence, Nov. 29, 1876 to Sept. 4, 1878: CSE to Wanton Vallett, Little Rock, Ark, Feb. 2,

1877, p. 97. See also CSE to T.C. & A.E. Rowland, New Haven, Sept. 5, 1877, p. 480. Corliss's disregard for standardizing economies may explain why he ignored the market for small engines (under 35 horsepower) — a segment that other builders had locked up with low-cost standard designs.

25. Capitalization given in R.G. Dun credit report on Corliss Steam Engine Co., April 6, 1880, Rhode Island volume 11, p. 1i, Baker Library, Harvard Business School.

26. The continued vitality of general machine shops making a vast range of semi-standard or custom technologies is apparent in the firms listed in *United States Hardware, Metal & Machinery Directory for 1883-4* (Boston: Briggs & Co., 1883).

27. Corliss himself told Providence toolmaker Lucian Sharpe that Harris "can make nothing at the prices at which he takes work," but Sharpe believed that "Harris does much of his work cheaper than Corliss and has better facilities for producing the smaller parts." See letter of Lucian Sharpe to Wm. B. Bement & Sons, Mar. 17, 1880, Lucian Sharpe Letterbook (1872 - 1886), Henry D. Sharpe Jr. Collection.

28 . For Atlas, see Charles H. Fitch, "Report on the Manufacture of Engines and Boilers," 24-25 in *Tenth Census of the United States*, vol. 22 (Washington, D.C.: Government Printing Office, 1888). For Westinghouse, see E.S. McClelland, "Notes on My Career with Westinghouse," p. 3, in Charles F. Scott, ed., "Anecdotes and Reminiscences of George Westinghouse, 1846 - 1914," typescript (December, 1936) at Hagley Museum and Library. For Southwark, see Charles T. Porter, *Engineering Reminiscences* (New York: John Wiley & Sons, 1908), 577.

29. For Erie City's marketing efforts, see volume titled: "Sales on Consignment, 1887 - 1901," vol. 66 in Erie City Iron Works Papers, Hagley Museum and Library.

30. Chandler, *The Visible Hand*, intro.

31. The Westinghouse Machine Co. also made very large, semi-custom reciprocating engines.

32. Frank M. Machovec, *Perfect Competition and the Transformation of Economics* (London: Routledge, 1995), 1 (emphasis in the original).

33 Bruce Sinclair, *A Centennial History of The American Society of Mechanical Engineers* (Toronto: University of Toronto Press, 1980), 50.

34. The campaign for standardization and its limitations are described in Scranton, *Endless Novelty*, 235, 310.

35. See Luther D. Burlingame, "Standardization Versus Individuality," *Mechanical Engineering* (Sept. 1924): 642.

36. Sinclair, *Centennial History*, 49.

37. Twenty of the ASME's first twenty-five presidents had spent their careers in capital goods industries making such products as machine tools, stationary engines and boilers, pumping and marine engines, and materials handling devices.

38. Use of standard components in semi-custom locomotives is described in Brown, *Baldwin Locomotive*, 102-6. For the same approach in the Gilded Age wrought iron bridge industry, see Thomas R. Winpenny, *Without Fitting, Filing, or Chipping* (Easton: Canal History and Technology Press, 1996), 42-3.

39. The innovative function of firms goes unstated in R.H. Coase's influential article, "The Nature of the Firm," reprinted in Oliver E. Williamson and Sidney G. Winter, eds., *The Nature of the Firm* (New York: Oxford University Press, 1991). But innovative activity was a key internal function of the Schumpeterian firm, a view shared by subsequent writers like Nelson, Winter, and Teece who all include innovation among the "capabilities and routines" that firms execute internally or secure through joint ventures. For a summary of these views, see Richard N. Langlois and Paul L. Robertson, *Firms, Markets and Economic Change* (London: Routledge, 1995) ch. 2.

40. A close observer of the American textile machinery industry, Thomas Navin, found that those capital equipment firms paid "a heavy price for cooperating so closely with their customers." Because they ceded nearly all the initiative for innovations to customers, the machinery makers became little more than job shops, with very little ability to control their destiny or influence the broader course of technical change in the textile industry. See "Innovation and Management Policies — The Textile Machinery Industry: Influence of the Market on Management," *Bulletin of the Business Historical Society* 25, no. 1 (March 1951): 20-21). I make the same point about Baldwin Locomotive, a firm that maintained this balance for over a half century (1860-

1920), but then fell into a reactive posture in innovation (Brown, *Baldwin Locomotive*, 227-33).

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