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3 The Coordination of Business Organization and Technological Innovation within the Firm: A Case Study of the Thomson-Houston Electric Company in the 1880s

W. Bernard Carlson

3.1 Introduction

Most Americans assume that new technological innovations will revolutionize both the economy and society; they fervently believe that new products and processes will automatically enhance jobs, increase productivity, and make American corporations more competitive in global markets. Yet in order for a new technology to have revolutionary impact, it has to be linked with existing business practices. Managers and engineers often struggle to develop an appropriate business organization for manufacturing and marketing a new technology. Significantly, without an effective business organization, a new technology may not be used and may instead lie dormant for years.

Despite the importance of linking technology with business organizations, we know surprisingly little about how businessmen build business organizations. Few economists or historians have investigated how businessmen convert firms from the entrepreneurial startup characterized by one or two charismatic individuals to a more formal or elaborate organization where managers coordinate key activities.[1] During this crucial transition, the first generation of

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1. In historiographic terms, the unexplored territory lies between the entrepreneurial firm of Joseph Schumpeter (1934) and the managerial firm of Alfred D. Chandler, Jr. (1977). However, one should note that not all firms shift from the entrepreneurial to the managerial hierarchy emphasized by Chandler. Other firms acquire more formal structures without hierarchy or managers; for instance, as John K. Brown (1992) has shown in the case of the Baldwin Locomotive Works, many of the functions we associate with managers were handled by a group of partners who owned the Baldwin Works.

managers define the boundaries of the firm, selecting which activities the firm will undertake and which will be performed outside by suppliers, customers, or other intermediaries. Within the firm, the pioneering managers have to determine who will perform the key tasks and who will make decisions about different areas such as marketing, production, or research. Equally important, it is during the shift from the entrepreneurial to managerial stage that the firm defines its corporate culture, modes of internal communications, and ways of resolving differences between groups or departments. And finally, for the history of a particular technology, this transitional period is significant because it is then that inventors and their business associates often make a series of interrelated decisions about manufacturing and marketing an invention; because production and selling require substantial investments of capital, personnel, and resources, it is in this transition that the character of a technology and its impact on society are defined (David 1985).[2]

To understand how firms move from the entrepreneurial to the managerial stage, this paper investigates the rise of the Thomson-Houston Electric Company in the 1880s. Created by Charles A. Coffin and Elihu Thomson, this firm evolved an internal organization that allowed it to exploit successfully the new technology of electric lighting. Combining Coffin's vision of selling equipment to newly forming central-station utilities with Thomson's creation of new systems for generating and distributing electric light and power, Thomson-Houston played a major role in defining the electrical technology used in the United States during the past century. Thomson-Houston quickly came to dominate the electrical manufacturing industry, and in 1892, it absorbed the rival Edison General Electric Company to become the General Electric Company.[3]

In studying Thomson-Houston and GE, I have found that the intellectual challenge has been not so much understanding the technology as developing ways of thinking about the evolution of the business organization. The central question is to understand how Thomson, Coffin, and other members of this firm coordinated the key activities of marketing, manufacturing, and product innovation. To a certain extent, one can analyze their organization-building efforts in terms of rational actors who used economic or functionalist criteria to guide their choices. One can use Alfred D. Chandler, Jr.'s (1962, 1977) notions of strategy and structure to describe the evolution of Thomson-Houston, but I have been troubled that these concepts do not explain the dynamics of individuals and groups within the organization. In particular, the Chandlerian paradigm does not help explain why Thomson-Houston struggled to create an effective organizational arrangement for product innovation. In order to fill this

2. Frequently, historians of technology have treated this transition by focusing on what they call the development phase of technological change, a phase that they see as coming between invention or conceptualization and innovation or designing for manufacture and marketing. See Hughes 1976 and Staudenmaier 1985.

3. For a complete history of the Thomson-Houston Electric Company and how it became General Electric, see Carlson 1991.

gap between theory and data, I will introduce in this paper a model of the business firm as a coalition of interest groups and use this model not only to describe Thomson-Houston but to narrate the development of a specific product, an alternating-current system for incandescent lighting in the 1880s.

With these goals in mind, this paper begins with a section that briefly outlines the rational-actor approach and my model of the firm. Section 3.3 introduces the Thomson-Houston Electric Company and describes the interest groups within that organization. Section 3.4 narrates how the company developed its AC lighting system and reveals the problems that the managers and inventors encountered as they tried to coordinate business organization with technological innovation. In the conclusion, I discuss how the model allows us to sort out this complex historical case and enhances our understanding of the coordination of functions within the business firm. Thus, this paper should help link economic and historical studies of American business enterprise.

3.2 The Business Firm: Economically Rational Actors or Politically Motivated Interest Groups?

Over the past fifty years, economists have frequently considered business firms to be "atoms," or irreducible units of analysis. In taking this approach, they have created powerful and insightful models of how markets and industries behave, and they have been able to frame macroeconomic policy for American society (Temin 1991, 1–2).

Nevertheless, the view that individual firms are indivisible atoms works best when one is studying an industry or market in which numerous small firms are competing. It is an entirely different matter when one considers the more typical situation in American business history, an oligopolistic industry dominated by several large firms possessing complex internal structures (Galambos 1991). Made up of numerous groups and individuals, large business enterprises do not necessarily make decisions simply using the economics of supply and demand, but often make choices in response to a variety of internal and external pressures (Cyert and March 1963). Moreover, even a cursory comparison of American and Japanese firms reveals that businessmen using the same technology may organize their firms in substantially different ways, and this suggests that we need to know much more about how and why companies acquire their internal organization (McCraw 1986). Consequently, if economists and policymakers are going to develop more sophisticated models of markets and industries, then the next step is to move away from treating the firm as a black box and to look more closely at how firms evolve and acquire their internal structures.

To look inside the firm, one can turn to two extensive bodies of literature.[4]

4. The discussion in the next few paragraphs has been shaped by a reading of major treatises in economic and organizational theory and critical overviews of these two fields. As a historian look-

One can follow the lead of economists and business historians who often view the firm in terms of rational actors using economic or functional criteria to make choices. Alternatively, one can use the ideas of organizational theorists to interpret the inner workings of the firm in terms of political give-and-take among groups. Because these perspectives will be compared and contrasted in this paper, let me discuss what each contributes to investigating how firms select and coordinate functions in the transition from the entrepreneurial to the managerial stage.

The rational-actor approach begins with the assumptions that managers attempt to make reasonable decisions on the basis of the knowledge they have at hand and that they make decisions to direct their organizations toward specific goals. As Alfred D. Chandler, Jr. (1962, 1977, 1990) has argued, managers often articulate goals in form of a strategy that they then use to shape the structure of the organization. In the late nineteenth and early twentieth centuries, as managers took up new high-speed, energy-intensive industrial processes and pursued national and then international markets, the linking of strategy and structure required them to select carefully which activities or functions should be brought inside the firm. In coordinating a select group of activities, managers reduced uncertainty and improved efficiency and profitability. To select which functions to integrate and coordinate, managers presumably used some economic criteria such as transaction costs. As shown by Ronald H. Coase (1937) and Oliver Williamson (1985), a transaction-cost analysis consists of determining what it would cost the firm to contract with an outside agent to perform a task and then comparing that with what it would cost to perform the same activity internally. As Chandler (1990) has demonstrated, managers frequently lowered internal costs by exploiting the economies of scale and scope available through new production technologies, improvements in organization, and the opening of new markets. Acting in a rational manner, managers presumably brought into the firm those tasks that could be performed more cheaply and efficiently inside the organization.

Although I agree with Chandler's maxim that structure follows strategy, this maxim does not tell us much about the processes by which historical actors created and linked strategic goals with an effective organizational structure. How did the pioneering businessmen in a particular industry identify and develop an effective strategy? How did they choose which functions to emphasize and which to subordinate in their organizations? How did the first generation of managers draw on existing social structures to fashion new corporate hierarchies? And how effective were these new hierarchies? From their inception, did these organizations allocate resources and coordinate tasks effi-

ing into these two literatures, I recommend to other outsiders that they begin with the overviews provided by the following works: Davidson and Lytle 1982, 320–55; Allison 1971; and Pfeffer 1981, 18–33, especially table 1 on page 31.

ciently? Or in some cases, did early managers make mistakes in trying to link strategy and structure (Galambos 1979)? I would suggest that, while structure does follow strategy, the processes by which these were joined are not automatic but rather complex and contingent. Indeed, what is needed is a historically based model of how actors create and link business strategy and structure.

As a first step toward such a model, I find it is useful to think of the firm as a collection of interest groups, each with its own mind-set. Within a firm there are different aggregates of individuals promoting their own interests and, at times, seeking to control the organization. Each of these aggregates may be called an interest group, and they may be differentiated by their leaders, functions, or, most important, business-technological mind-sets. Each group may articulate ideas about how new technology should be used to capture particular markets or perform certain production steps and hence ensure the growth and prosperity of the firm. The central point here is that groups within the firm may possess very different ideas about how the firm should operate. For the firm to make a decision about technological innovation, marketing programs, or anything else, several of the interest groups must negotiate and compromise portions of their mind-sets and then direct other groups to implement the plan on which they agree. When the resources and rewards available to different intrafirm groups are ample, they often find it easy to negotiate and implement decisions. Similarly, groups work well together when they feel that their positions within the firm are respected by the other groups. Conversely, should a group perceive that its position in the organization is being challenged or that it may lose access to resources and rewards, then cooperation may give way to conflict and disorder.

This model of the firm is drawn from several sources. First, it is based on the social construction of technology approach of Trevor Pinch and Wiebe Bijker (1987).[5] These two sociologists have suggested that technological artifacts are defined and shaped through the interaction of social groups. Although I am impressed with Bijker and Pinch's model, I am troubled that it fails to locate social groups in a larger framework of relationships. Without understanding the positions of the groups relative to each other, it is difficult to comprehend how they will use and shape technology.

To offset this problem, one can turn to organizational theory. Within this intellectual tradition, scholars concentrate less on individual leaders and rational decision making and more on groups within the organization. The choices and activities of the organization are the result of the behavior of different internal groups. Within this field, there has been much debate on how groups interact. Some investigators have argued for a garbage-can model in which the interaction of groups is anarchical, and that choices made within an organization are based on the random confluence of needs and resources (March and

5. In analyzing how groups shape technology, sociologists of technology have also created a network approach. For example, see Law and Callon 1992.

Olsen 1976). Other theorists have posited a bureaucratic model in which each group within an organization has a task or mission to perform, and each group does whatever is related to or justified by its mission (Allison 1971). And still other scholars have proposed political or power models that reveal how groups may engage in political give-and-take wherein they compete for resources, bargain with each other, and create coalitions. Within power and political models, the choices of the organization are the result of intraorganization groups coming to agree or disagree with one another (Pfeffer 1981, 1992).

For the purposes of understanding the evolution of business firms, the political model of Samuel B. Bacharach and Edward J. Lawler (1980) seems especially appropriate. They emphasize that interest groups and coalitions are the basic units of analysis. Organizations make choices as a result of different internal groups bargaining with each other and creating alliances or coalitions. Once coalitions are created, the allied groups then select tactics to achieve their shared objectives. For instance, in his study of the founding of the General Electric Research Laboratory, George Wise (1980) demonstrated that the laboratory flourished because its first directors succeeded in integrating the professional aspirations of research scientists with the commercial needs of the company. Like Wise, I shall suggest that progress occurs in the firm when the leaders of groups strive for cooperation rather than overtly challenge each other.

Whereas Bacharach and Lawler's model implies that each group has a particular viewpoint, Bacharach and Lawler say little about how and why each group chooses to articulate different goals, needs, and perceptions. Consequently, a third idea informing this model of the firm is Reese V. Jenkins's (1975) concept of the business-technological mind-set. In his study of the photographic industry, Jenkins observed that major changes took place in the industry when entrepreneurs succeeded in matching new technology with new marketing techniques, thus creating what he called a business-technological mind-set. For Jenkins, a mind-set was a set of ideas and perceptions businessmen had of the market and of the potential of different technological options. Guided by their mind-sets, various entrepreneurs were able to create effective organizations and dominate the industry at different times.

One should note that while Jenkins attributed different mind-sets to individual firms within the photographic industry, in this paper I shall be arguing that different groups within the firm may possess different business-technological mind-sets. Several historians have investigated how different leaders and groups within a firm may articulate and act on different visions of what the company should do to grow and be profitable (Leslie 1979; Carlson 1992).

The business-technology mind-set is an important ingredient in the model proposed here, providing an element of purposeful behavior in an otherwise deterministic model. Without developing a way of talking about the values and goals of individuals within the firm, one is left with a model in which individuals are simply the pawns of larger political or economic forces that they cannot change. As I will show below, individuals within Thomson-Houston developed their own distinctive mind-sets about their work, their roles in the company, and the strategy of the company. In turn, individuals used their mind-sets to build groups, perform their key tasks, and move the firm in the direction of their mind-set. In this sense, I am trying to make room for individual choice in the face of economic and organizational theories that previously have been uncertain about how to include the individual.

3.3 The Strategy and Structure of Thomson-Houston

The interest-group model is useful because it permits us to trace how entrepreneurs and inventors in the Thomson-Houston Electric Company struggled to link business organization and technological innovation. This company was created in 1882 by a group of shoe manufacturers in Lynn, Massachusetts, to exploit the inventions of Elihu Thomson and Edwin J. Houston. Beginning in 1878, these two men developed an arc-lighting system. Unlike the Edison incandescent lighting system which powered hundreds of small, sixteen-candlepower incandescent lights, the Thomson-Houston system featured fifty to sixty large (2,500 candlepower) lights. Because of these technical characteristics, the Thomson-Houston system was used for lighting factories, department stores, and streets (Carlson 1991, 193–200).

Along with other early electrical manufacturers in the early 1880s, the Thomson-Houston Electric Company quickly realized that the challenge in electric lighting was to improve the technology while devising new marketing techniques. Initially, electrical manufacturers tried to sell lighting systems outright to customers, but there was a limited market for free-standing, isolated stations. There were few industrial or large retail concerns that had both the need for artificial illumination and the capital required to purchase a steam engine, dynamo, and lights. (Even the first lighting systems with four to six arc lights cost between $3,000 and $5,000.) Instead, it soon became clear that electric-lighting equipment required a new marketing arrangement. What was needed was a strategy that reduced the cost of lighting to each consumer by spreading the capital costs of the steam engine, generator, and distribution network across a large customer base. The marketing arrangement that answered these requirements was the central-station utility. Although pioneered by local businessmen in San Francisco in 1879, this strategy was promoted by Thomas Edison, who built a central station for incandescent lighting at Pearl Street in New York in 1882 (Carlson 1991, 173–75).

Although Edison is remembered in the history books for his Pearl Street station, the individual responsible for the perfection of the central-station strategy was the vice president of Thomson-Houston, Charles A. Coffin. A shoe manufacturer, Coffin built a successful firm in Lynn in the 1870s by taking advantage of new shoemaking machinery and by aggressively developing his marketing organization.[6] In 1882, he helped organize the Thomson-Houston Electric Company and focused his efforts on the problems of marketing the new technology of electric lighting. Rather than sell equipment for isolated plants, Coffin had Thomson-Houston concentrate on promoting central stations. Coffin perceived that the central-station strategy would permit the development of a substantial market for electric lighting. By offering an extensive product line of different-sized dynamos, the firm could provide the equipment needed to supply electric lighting to nearly every town and city. Furthermore, by selling both arc and incandescent lighting systems, it was possible to encourage utilities to add machines to expand their business to include lighting for streets, shops, and homes. From the standpoint of the manufacturer of electrical equipment, central stations were ideal customers in that they provided a ready demand for the product that was free of the risky business of convincing consumers to install lights in their businesses and homes. In that sense, the central-station strategy was similar to the manner in which Henry Ford externalized the risk of marketing his Model T by developing a network of franchised dealers who were required to purchase a certain quota of cars (Chandler 1977, 359, 457).

In order to implement the central-station marketing strategy, Coffin and his associates organized Thomson-Houston along functional lines (fig. 3.1). Just as American railroad companies in the 1850s had organized departments to carry out the tasks of operating trains, repairing rolling stock, and maintaining the roadbed, Thomson-Houston had groups that handled the key jobs of designing, manufacturing, marketing, and financing electrical equipment (Chandler 1977, 81–121). Significantly, the firm organized these activities because they were the functions that had to be performed in order to sell electrical equipment for use in central stations. Had Coffin, Thomson, and other managers conceptualized either their marketing strategy or their technology in other ways—for instance, had they chosen to build and sell isolated systems—then they would have created a different business organization.

At Thomson-Houston, three interest groups appeared in response to the central-station strategy. Each performed a key function, and each was headed by a strong individual who ensured that the function was performed properly. While Coffin handled marketing and finance at the Boston headquarters, Edwin Wilbur Rice, Jr., supervised manufacturing and engineering at the Lynn plant, and Thomson concentrated on invention and design in his Model Room. As each of these men pursued his function, each developed a mind-set that reflected his role in the firm and how he thought the firm should operate. Because the interaction of those mind-sets influenced how Thomson-Houston pursued product innovation, let us examine each group and its mind-set.

6. For biographical details on Charles A. Coffin, see his obituary in *Lynn Historical Society Register* 26, pt. 1: 32–33 (1934); and Wilson 1946.

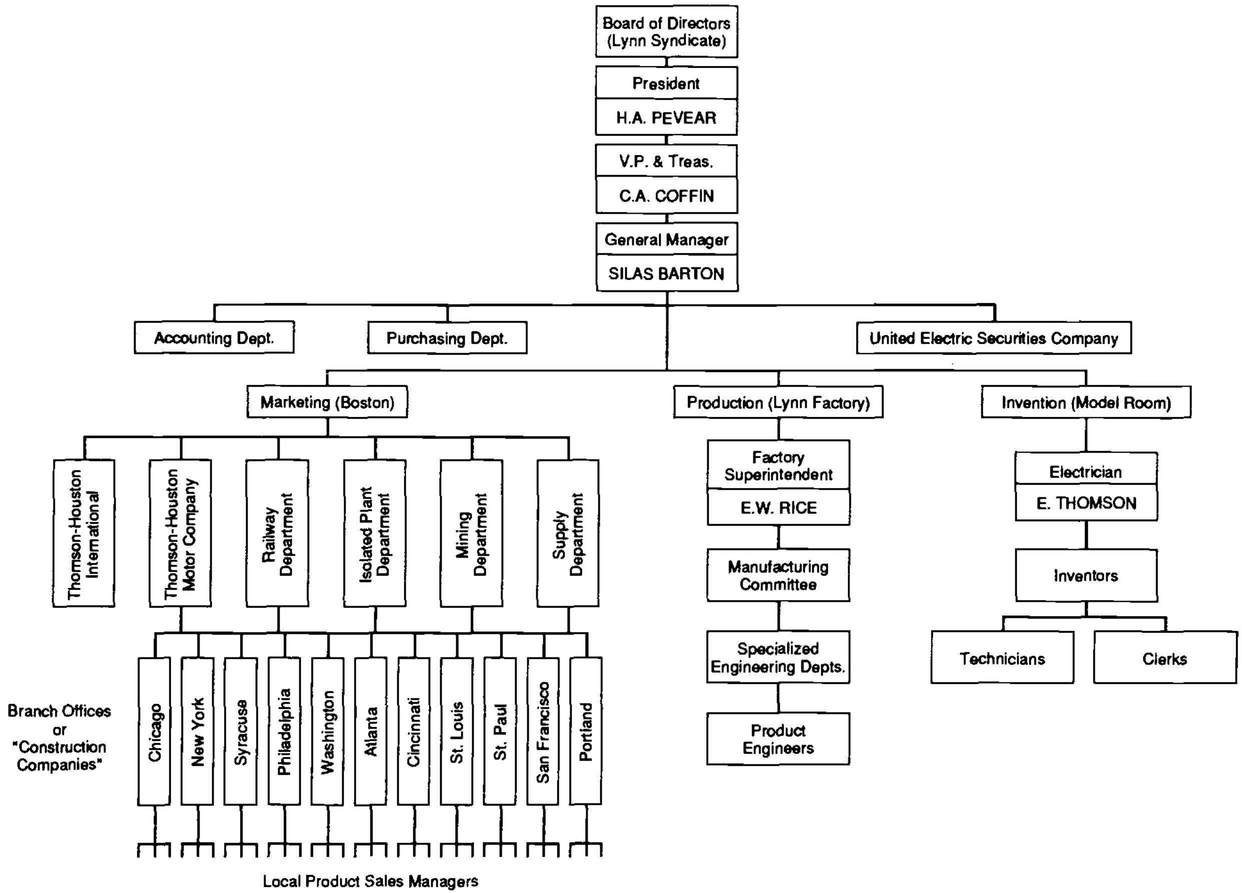

Fig. 3.1 Organization of Thomson-Houston Electric Company, 1883–92
Sources: Annual reports of Thomson-Houston Electric Company, 1888–91; various documents in Hammond File, General Electric Company, Schenectady, New York.

3.3.1 Selling Dynamics: Coffin and the Marketing Group

The central-station strategy led Coffin to establish a distinctive group around the functions of marketing and finance. This group was centered in the company's Boston office and thus physically and intellectually separate from the groups located at the Lynn factory. Coffin himself worked in this office, aided by four or five sales managers. Each manager was assigned to a product area, such as arc lighting, incandescent lighting, or street railways, and each manager worked with the Lynn factory to coordinate production with sales. Given that the company sold each product as a separate system, it made sense to have a manager for each; notably, this was quite different from the Edison organization, which at that time had seven sales managers at its headquarters, each of whom was assigned a selling territory in the United States. To assist Coffin and the sales managers, the Boston office also had a staff of bookkeepers and clerks who handled the details of advertising, sales transactions, and bond and stock issues.[7]

Beyond the Boston headquarters, Coffin established district sales offices in major cities. Each district office promoted Thomson-Houston products in the city and the surrounding region and handled the local details of each sale and installation. Because the district offices permitted the company to reach into new territory, Coffin carefully selected his district managers; for example, Coffin had Silas Barton move from being general manager to being the manager of the first district office in Chicago in 1885.[8]

Finally, below the managers in the Boston headquarters and the district offices were the salesmen, or "drummers." Traveling to towns and cities, they were the men who sold electric-lighting equipment to the organizers and operators of the new utility companies. In addition to selling equipment, salesmen were trained to help secure local capital, obtain the necessary franchise from the municipal government, and organize the operating company. Following the salesmen, an "expert," or construction engineer, was sent from the Lynn factory to install the electrical machinery. With this sales staff in place, the number of central stations using Thomson-Houston arc lights grew rapidly; whereas there were 31 companies using their equipment in July 1884, two years later there were 100 (table 3.1).[9]

7. "Methods of C. A. Coffin in Building a Commercial Organization: Story Told by J. R. McKee," 20 April 1927; "Recollections of C. B. Davis, J. P. Felton, and C. B. Burleigh, All of Boston Office," 29 May to 1 June 1925; both in John W. Hammond File, J757-8 and J194-8, General Electric Company, Schenectady, New York; Passer 1952, especially 382.

8. By 1890, Thomson-Houston had district offices in Chicago, New York, Atlanta, Washington, San Francisco, Kansas City, Saint Paul, Cincinnati, and Philadelphia; see "The Thomson-Houston Electric Company," [general catalog], 1 December 1890, Lynn Historical Society, Lynn, Massachusetts. See also A. L. Rohrer to J. A. McManus, 4 July 1945, Thomas Collection, General Electric Hall of History, Schenectady, New York (hereafter cited as Hall of History Collection); and "Further Recollection of T. A. McLoughlin . . . District Office Organization," 18 June 1925, Hammond File, L1028-9.

9. For information on how Coffin organized the sales staff, see "Further recollection of T. A. McLoughlin . . . District Office Organization," 18 June 1925, Hammond File, L1028-9. The num-

One of the most serious problems faced by many fledgling utility companies was raising sufficient capital to pay for equipment. According to one estimate, utilities in the 1880s had to invest between $4 and $8 in plant and equipment for each dollar of sales (Mitchell 1960, 45). Consequently, in building up his sales organization, Coffin was obliged to look for ways to help central stations finance their purchases. As one solution, Coffin had Thomson-Houston accept bonds as partial payment from utilities. Coffin then converted the local utility bonds into capital by organizing a series of trust funds that sold bonds representing local utility securities to Thomson-Houston stockholders. Using this financial innovation, Coffin prevented utility securities (some of which were of little value) from accumulating in the company's treasury, while at the same time generating $2.6 million in capital.[10]

Coffin used the income from the trust series and surplus profits to strengthen the firm. First, he plowed these funds back into the firm and enlarged the Lynn factory. As will be discussed later, the factory grew rapidly, with a new building added each year between 1884 and 1891. Second, Coffin used these funds to buy up smaller rival firms. Between 1888 and 1891, Thomson-Houston spent approximately $4 million to acquire eight electrical companies. Several of these companies, including Brush Electric, Fort Wayne, Schuyler, Excelsior, and Indianapolis Jenney, were competitors in arc lighting; others, such as Van Depoele Electric Manufacturing and Bentley-Knight Electric Railway, were purchased for their street-railway and motor patents. Several of the arc-lighting firms had encountered various problems in manufacturing and marketing their systems, but Coffin hastened their decline by having Thomson-Houston lawyers vigorously prosecute them for infringement of Thomson's patent for a dynamo regulator. It does not appear that Coffin undertook the merger campaign to acquire additional production capacity, because most of the purchased factories were closed. Instead, Coffin eliminated these rivals to increase Thomson-Houston's market share and secure control of key patents. Still another important benefit of the merger campaign was that it brought several inventors into the Thomson-Houston organization, and they were soon designing products and filing for patents for the company (Passer 1953, 52–56).

As Thomson-Houston was successful in selling arc lighting to central stations, Coffin had the company move into new product areas (table 3.1). With

ber of arc stations installed is from "Exhibit. The Following List of Thomson-Houston Plants . . . ," circa 1888, Notebooks, Elihu Thomson Papers, American Philosophical Society, Philadelphia (hereafter cited as TP). Hereafter, this pamphlet is cited as "List of T-H Plants."

10. Coffin appears to have structured each trust fund so as to include bonds from both high- and low-performing utilities. In this way, each trust fund probably paid a return to its investors, since the higher value of the bonds of the profitable utilities offset the unprofitable utilities. In this situation, the trust series served not so much to transfer risk from Thomson-Houston to the stockholder, as to function as another instrument for raising capital. See M. F. Westover, "History of the T-H Trusts, Series A, B, C and D," January 1916, Hammond File, J767; Passer, 1953, 29; Hughes 1983, 395.

Table 3.1 **Spread of Thomson-Houston Lighting and Street Railway Systems, 1883–92**

	Arc Lighting		DC Incandescent[a]		AC Incandescent[b]		Street Railways[c]		
Year	Number of Companies	Lamps	Number of Companies	Lamps	Number of Companies	Lamps	Number of Companies	Cars	Miles of Track
1883[d]	5	365							
1884	31	2,478							
1885	59	5,867							
1886	100	13,227							
1887	171	21,840	29	11,275					
1888	303	39,936	78	59,330	23	11,100			
1889	419	51,621	200[f]	120,380			30[f]	200[f]	
1890	587	68,203	400[f]	281,555			92	701	420
1891	755[e,f]	87,131		616,355			145	1,532	1,160
1892	873[e]	100,293		806,500			204	2,769	2,364

Sources: Annual Reports of the Thomson-Houston Electric Company, 1888–1891; *"Exhibit: The Following List of Thomson-Houston Plants,"* 1888, Thomson Papers, American Philosophical Society, Philadelphia.

[a]First introduced in 1886.

[b]First introduced in 1887.

[c]First introduced in 1888.

[d]As of 1 January 1883.

[e]These totals include both arc and incandescent lighting stations. Approximately five hundred companies operated both arc and incandescent systems.

[f]There is a discrepancy in the sources as to how many companies were using Thomson-Houston equipment in 1891. Whereas the *annual report* gives 755, Thomson-Houston also published a list claiming 666 central stations; see table 3.2.

the business organization in place to market, finance, and install arc-lighting stations, it was easy to have the same salesmen and engineers sell and service other electrical products. As early as 1883, Coffin asked Thomson to develop an incandescent-lighting system, and the company began installing incandescent plants in 1885. Similarly, Coffin took an interest in selling DC motors that could be installed on arc-lighting circuits, in building AC stations, and in entering the field of electric street railways. Anxious to expand and diversify their customer loads, utilities readily purchased such new products. Hence, the manufacturer was taking advantage of economies of scope, and the utilities were capitalizing on economies of scale.

These actions reveal that Coffin favored product innovation. Just as he had been willing to use new machines in his shoe factory to produce more shoes to reach new markets, so Coffin supported the development of new electrical products. With new products such as motors and AC lighting, he believed that he could better serve existing markets as well as expand into new areas. As Thomson recalled, Coffin frequently visited the Lynn factory to see the latest inventions, and he invariably asked, "How soon can you have that done?" or "How long will it take to do that?"[11] As long as product innovations facilitated market development (which they generally did), Coffin was an ardent supporter of Thomson's efforts. Thus, along with the development of central stations, Coffin helped establish production innovation as a key component of Thomson-Houston's overall strategy.

In sum, Coffin and his group possessed a market-oriented mind-set: respond to the market quickly, give the people the products they want, and, if necessary, devise the means whereby customers can finance their purchases. In general, they favored product innovation, because it promised to help them increase market share.

3.3.2 Manufacturing Dynamos: Edwin Wilbur Rice, Jr., and the Engineering Group

In implementing the central-station strategy, the marketing and finance group contributed much to the rapid growth of the Thomson-Houston Electric Company. But marketing and finance are not the only functions that a machine-building firm must perform; to be successful, it must also address a host of manufacturing and engineering problems. Frequently it is not easy to transfer a new invention from the laboratory to the factory floor. Often the invention must be redesigned to simplify manufacture. Occasionally it may require new materials and production methods. At Thomson-Houston, for instance, Thomson and the other engineers were obliged to find better insulating materials as well as to devise faster ways to wind the coils used in dynamos, transformers, and arc lights. Once any invention goes into production, raw materials must be

11. Elihu Thomson (hereafter cited as ET), "He Invented Methods of Business," in "Charles A. Coffin Mourned by Industry," *Electrical World*, 24 July 1926, 189.

kept in stock, machine tools installed and maintained, and workers hired, trained, and paid. As the volume of production grows, the layout of the plant and the work flow must be carefully planned, and cost accounting is needed to prevent waste and confusion. Naturally, if new inventions are introduced or existing products modified, then the entire factory process may have to be revised and reestablished.

Because neither Coffin nor the Lynn syndicate was familiar with the intricacies of electrical manufacture, Coffin and the syndicate willingly delegated responsibility for the company's factory in Lynn to Edwin Wilbur Rice, Jr. Rice had served as Thomson's assistant, helping out with the drafting, building models, and winding armatures. Working with Thomson, Rice learned not only the craft of electrical invention but also how to convert Thomson's inventions from experimental models to manufactured products. On coming to Lynn, he was put in charge of assistants in the Model Room, or Experimental Department, but in February 1885, he was promoted to factory superintendent.[12]

As factory superintendent, Rice was responsible for all the work done at the Lynn works. Referred to by the workmen as the Lights, this plant was initially run like other New England factories. Various rooms or departments were equipped for machining dynamo parts, assembling lamp mechanisms, and testing dynamos. As long as the firm's product line consisted only of dynamos, arc lights, and regulators, Rice probably supervised operations by watching and participating in the work on the factory floor; there was no need for specialization or formal procedures. Wherever possible, Rice sought to improve production by rearranging the machine tools, introducing better assembly techniques, and designing special-purpose machinery. As a typical factory superintendent, Rice strove to lower manufacturing costs, thus permitting the firm to cut prices or expand its profit margin.[13]

Changing circumstances, however, soon forced Rice and the factory crew to modify their routine. As the company's salesmen sold more arc-lighting systems, production had to be expanded. By November 1886, for example, the company had so many orders that Thomson estimated that the factory had a backlog of two thousand lights. In response to the growing demand, Thomson-Houston constructed at least one new factory building every year from 1883 to 1892 (see figs. 3.2 and 3.3). Each new factory had to be planned and built in a short time. During these years, the workforce jumped from forty-five to thirty-

12. "Career of the New President," *Electrical World*, 21 June 1913, 1345–46; testimony of E. W. Rice, in "Testimony for Thomson in Rebuttal," Patent Interference no. 9,421, Thomson v. Joseph Olmsted (subject: cutout apparatus for electric lamps), Records of the Patent Office, RG-241, National Archives, Washington Records Center, Suitland, Maryland (hereafter cited as NARS), 16–17.

13. "The Thomson-Houston Factory, Lynn, Mass.," *Electrical World*, 29 August 1885, 83; "Testimony for Thomson," paper 48, Patent Interference no. 15,876, Thomson v. Dyer (subject: insulating materials), NARS, 28 (hereafter cited as "Testimony for Thomson," Intf. 15,876); "Misgivings as to Business . . . ," Lynn *Item*, 24 October 1933, Lynn Historical Society; "Electric Light machinery. Sept. 1883. Completion of the Factory at West Lynn . . . ," Hall of History Collection.

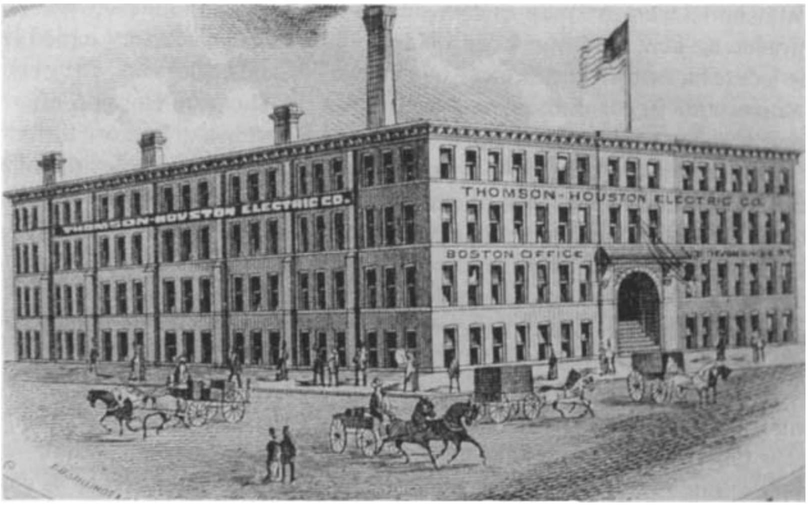

Fig. 3.2 Thomson-Houston factory in Lynn, Massachusetts, in 1884
Source: Scrapbook 1, Thomson Collection, Lynn Historical Society.

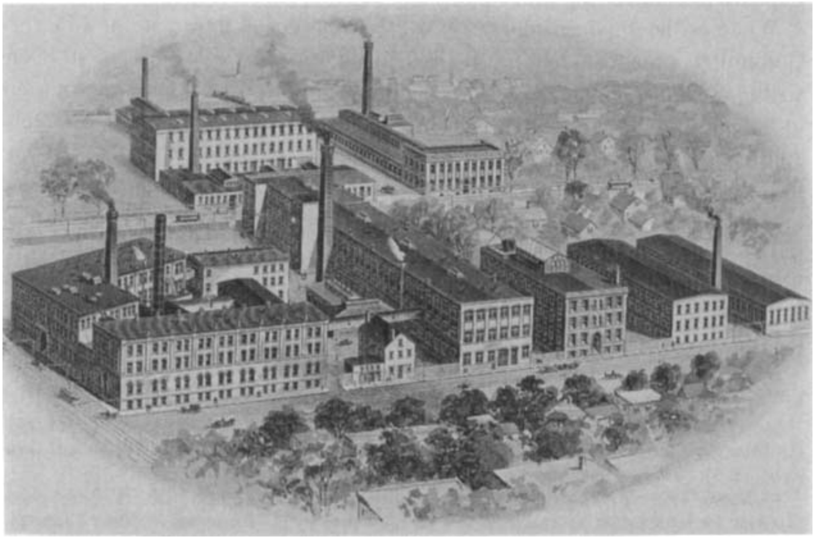

Fig. 3.3 Thomson-Houston factory in Lynn, Massachusetts, in 1891
Source: Scrapbook 1, Thomson Collection, Lynn Historical Society.

five hundred men. And just as demand was increasing, the company was also introducing new products; from 1885 to 1892, the Lynn factory turned out incandescent lamps, transformers, motors, meters, and trolley cars. To be competitive with Brush, Edison, and Westinghouse, Thomson-Houston offered those products in a variety of sizes and continually strove to improve them.[14]

To cope with the growing volume of production and the complexities of an expanding product line, Rice gradually created his own functional staff (fig. 3.4). To equip and maintain the factories, Rice selected Isaac F. Baker, an Englishman who had formerly installed incandescent stations for U.S. Electric, to serve as mechanical superintendent. Daniel M. Barton monitored the flow of work through the factory and ordered supplies. Making up the weekly payroll, which typically was over $40,000, was George E. Emmons.[15]

As the number of products manufactured in Lynn grew, Rice hired more engineers and assigned them to the major product areas. Again, that arrangement reflected the fact that the company sold different products for different applications. Walter H. Knight, a pioneer in electric traction, served as chief engineer. It appears that the product engineers were self-educated, but many of the engineers on thc staff below them were college graduates. By 1887, Thomson-Houston was regularly hiring young men from MIT's Electrical Engineering Department and Cornell's Sibley College of Engineering. Some novice engineers also served as "experts," who were sent out to install electrical plants. Through his staff of engineers, Rice was able to monitor the work flow, improvc manufacturing procedures, and design products.[16]

Whereas the engineering staff provided advice and information, a Factory Committee, organized by Rice in 1890, made decisions about operations. Consisting of Barton, Baker, and Emmons, the committee met at least once a week to handle employee problems, discuss new products, set production targets, and "exercise a general control over the foremen" (Shaw 1892, 657). Rice and the Factory Committee exerted final control over all aspects of the factory, and the managerial and engineering staff primarily played an advisory role in day-to-day operations.

In running the Lynn factory, Rice and his staff developed their own mindset. Deeply involved in the details of manufacturing, their basic premise was that they should help the firm earn money by reducing production costs. Wher-

14. ET to Edward F. Peck, 13 November 1886, TP, LB 9/86–3/87, 88–89; *Annual Statement of the Thomson-Houston Electric Company*, 2 February 1891 (hereafter cited as *T-H Annual Statement*, 1891), Historical File, General Electric Company, Schenectady, New York.

15. Shaw 1892, especially 655–56; memoir of Hermann Lemp, 2 July 1938, TP, Biographical Material; for information on Isaac F. Baker, see his testimony in "Testimony for Elihu Thomson," paper 129, Patent Interference no. 15,511, Pratt and Johns v. Thomson (subject: composition for insulating material), NARS (hereafter cited as "Testimony," Intf. 15,511); for biographical information on George E. Emmons, see his recollections, Hammond File, L13–19.

16. Shaw 1892, 658; ET to Theodore H. Seyfert, 23 September 1887, TP, LB 3/87–4/88, 489–90; E. E. Boyer, "Observations on Historical Notes . . . ," Hall of History Collection; C. B. Burleigh to J. W. Hammond, 20 June 1925, Hammond File; Wise 1979; Rosenberg 1984.

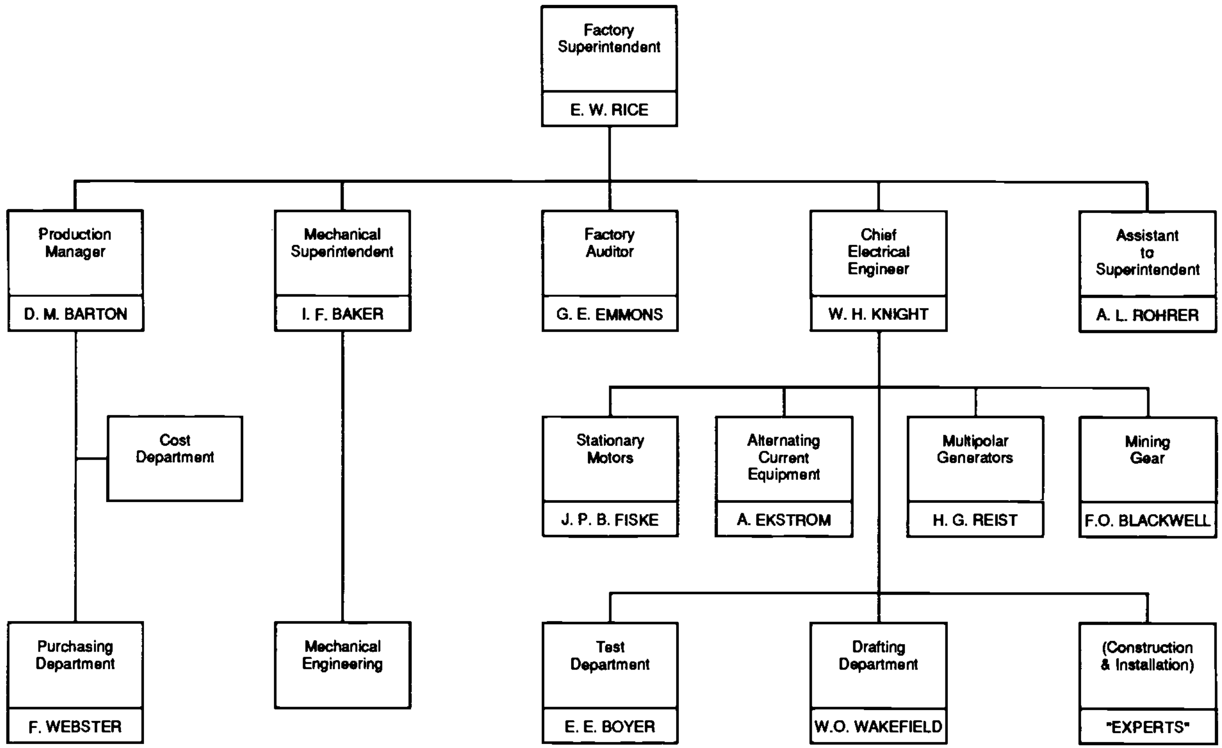

Fig. 3.4 Manufacturing and engineering staff at Thomson-Houston factory in Lynn, circa 1890

Sources: Shaw 1892; various documents in Hammond File, General Electric Company, Schenectady, New York.

ever possible, they strove to modify products so that they would be simpler to manufacture and install. The group also supported procedures that permitted greater control over the flow of work through the factory; Barton was quite proud of his system of wallboards, in which plugs were inserted to track the construction of large machines on the factory floor. Rice and the production managers also instituted a system of written work orders that allowed them to assign workers to specific projects and at the same time monitor costs.[17]

As to product innovation, however, Rice and the engineers were cautious. Although some innovations were necessary for the firm to remain competitive, Rice and his staff soon learned that other changes upset the factory routine.[18] Their tendency to approach product changes skeptically was exacerbated by the fact that the factory was continually expanding in order to meet demand. Consequently, even though Rice had worked closely with Thomson in developing new products, Rice's group was not always supportive of Thomson's efforts to improve his inventions. There was a limit to the confusion and change they could tolerate and still get the dynamos out the door.

3.3.3 Designing Dynamos: Thomson and the Model Room

Although Rice and the manufacturing group may have had mixed feelings about innovation, it was nonetheless essential to the well-being of the Thomson-Houston Electric Company. Throughout the 1880s, the firm generally supported product innovation. First, Coffin and the marketing group favored innovation because they saw it as a means to reach new customers and to acquire a larger share of the central-station market. Second, innovation was necessary for survival in a highly competitive industry. By the mid-1880s, there were nearly fifty arc-light manufacturers, all competing for a portion of the evolving market. Whereas creative financing arrangements and price cutting could be used to sell more equipment, customers also responded favorably to manufacturers with high-quality products. As Harold Passer (1953, 43–45) has observed, electric lighting was a capital good whose purchasers had to make complex calculations concerning both original investment and operating costs; consequently, they frequently chose equipment on the basis of its efficiency and reliability, rather than simply its price. In that situation, Thomson-Houston sought additional improvements and accessories that would accentuate those characteristics in their lighting systems. Third, but hardly the least important, the firm pursued innovation because of Thomson's presence. A key member of the firm, Thomson considered invention his personal domain, and he actively encouraged the company to make full use of his expertise.

Unlike Edison and Westinghouse, who took an active part in the manage-

17. Shaw 1892, 655–56; "Testimony," Intf. 15,511, 121–23; samples of the work orders can be found scattered throughout GE Transfiles, TP.

18. ET to F. P. Fish, 1 October 1889, TP, LB 4/89–1/90, 502–4.

ment of their companies, Thomson concentrated on invention and engineering. Having developed a distaste for business matters prior to coming to Lynn, he was content to leave the problems of raising capital and selling lights to Coffin and the Boston office. "I have as little as possible to do with the business of the Company," Thomson explained in 1888, "my work being in the line of development of apparatus and the production of new inventions."[19]

Instead of playing a prominent role in the day-to-day management of Thomson-Houston, Thomson created a niche for himself in the Model Room at the Lynn factory. Although his work area could have been called a laboratory, Thomson referred to it as his Model Room, because the primary work performed there was the construction of models for testing and patenting. The Model Room was equipped with machine tools, electrical instruments, and a special switchboard for supplying electricity at various current strengths and voltages. In addition, the Model Room had its own supply room, patent library, and offices for Thomson and his assistants. Although adjacent to the factory floor, the Model Room was "off-limits" to employees and visitors, in order to prevent industrial espionage.[20]

Assisting Thomson in the Model Room were skilled machinists and clerks (fig. 3.5). The machinists were responsible for constructing models of Thomson's inventions, and the clerks handled correspondence and the paperwork related to patents. Thomson's clerks followed with great interest the technical work in the Model Room and sometimes even made technical suggestions. For instance, J. W. Gibboney, Thomson's personal secretary, suggested using jeweled bearings in order to reduce friction and hence the current necessary to drive the earliest recording wattmeter. Supplementing the machinists and clerks were a draftsman and one or two office boys.

Although Thomson preferred to work with a small group of handpicked machinists, after 1888 he was joined in the Model Room by several inventors who came to Thomson-Houston as a result of Coffin's merger campaign. Whereas Charles Van Depoele appears to have worked independently on electric motors and streetcars, Merle J. Wightman and Hermann Lemp worked on projects under Thomson's direction. Unlike the machinists, Van Depoele, Wightman, and Lemp shared with Thomson the privilege of filing patent applications for their ideas.[21]

19. ET to H. B. Rand, 28 December 1888, TP, LB 4/88–4/89, 586.

20. Shaw 1892, 653, 656; "Testimony," Intf. 15,511, 53; "Recollections of A. L. Rohrer," Hammond File, J217–23, especially J221; ET to Charles A. Coffin (hereafter CAC), 12 April 1887, TP, LB 3/87–4/88, 37–38.

21. See the following letters in TP: ET to S. A. Barton, 19 February 1885, LB 5/85–8/85, 130; ET to H. C. Townsend, 6 September 1886, LB 3/86–9/86, 243–44; ET to James J. Wood, LB 4/88–4/89, 557–58; ET to CAC, 1 November 1888, LB 4/88–4/89, 431–33; ET to J. P. Caveling, 6 September 1890, LB 1/90–11/90, 841. See also "Recollections of L. T. Robinson," Hammond File, L1109–14; Lemp memoir; and "Testimony in Chief and Rebuttal on Behalf of Thomson," paper 94, Patent Interference no. 13,332, Edison v. Thomson (subject: incandescent-lamp cutout), NARS, 19–29.

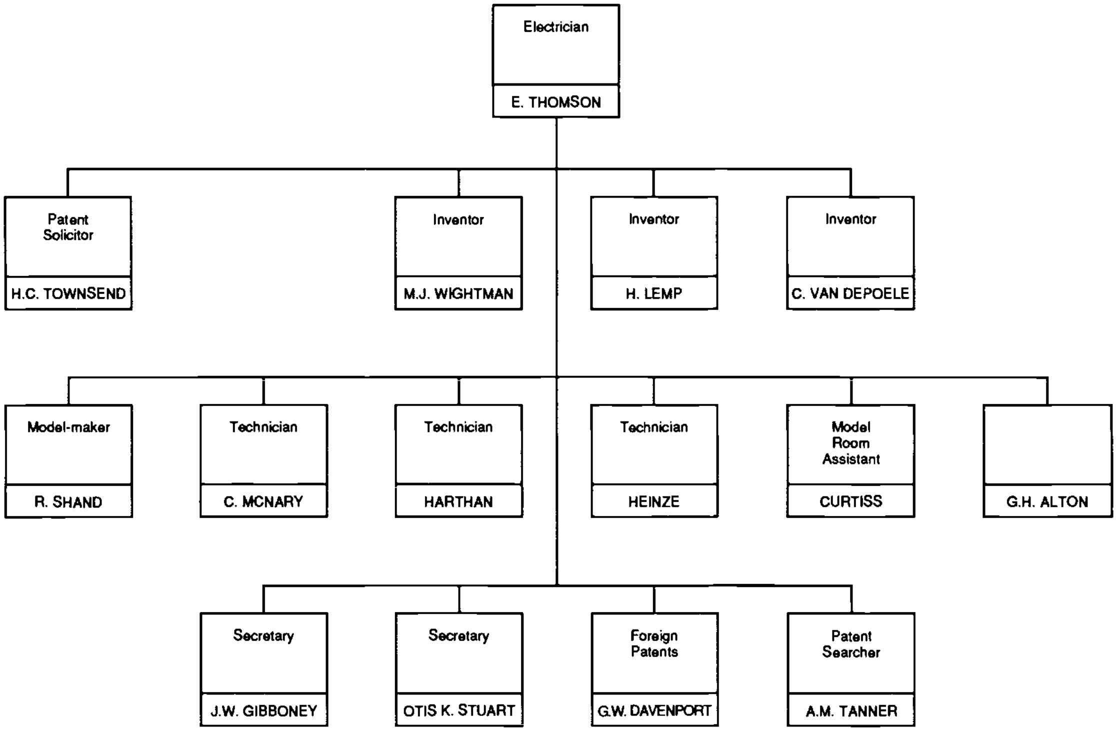

Fig. 3.5 Organization of invention and development at Thomson-Houston, circa 1888
Source: Various letters in the Elihu Thomson Papers, American Philosophical Society, Philadelphia.

Working with the Model Room staff, Thomson believed in building the best possible products. Thomson chose to design high-quality products because he found them personally and intellectually satisfying. Moreover, by being dedicated to regular improvement of the firm's products, Thomson ensured that he and the Model Room would have a continuing role to play in the company.

But beyond these reasons, Thomson was confident that the best product would, in the long run, capture the largest share of the market. Seeing that his arc-light system sold well because it was efficient and reliable, he strove to maximize similar characteristics in his other inventions. What is significant about Thomson's mind-set is that it was not shared by all groups within the firm. As has been suggested, the marketing and manufacturing groups had their own distinctive mind-sets about how the firm should operate and the role that product innovation should play in the firm's strategy. In sum, the management of Thomson-Houston was hardly monolithic, but rather made up of several groups, each with their own mind-set.

3.3.4 How Did Thomson-Houston Compare with Its Rivals?

Thomson-Houston became a leading firm in electrical manufacturing because it brought together marketing strategy, manufacturing capability, and product innovation. Led by the triumvirate of Coffin, Rice, and Thomson, the firm committed itself to selling electrical equipment to a customer it helped invent, the central-station utility. To help reach this new class of customers, the triumvirate organized Thomson-Houston along functional lines. Coffin personally supervised the marketing function and built a strong organization for sales and finance. At the same time, Rice built a large factory in Lynn for manufacturing dynamos and lights. Significantly, Coffin realized that to develop the central-station strategy fully it would be necessary for Thomson-Houston to offer a range of electrical products; in order to sell equipment to central stations in every town and city, the firm had to offer generators, lights, motors, and distribution networks suitable to a variety of needs. This realization led Coffin to encourage Thomson to invent new devices and systems.

Thomson-Houston's strength can be readily seen by comparing its performance with its competitors, both large and small. As table 3.2 reveals, Thomson-Houston surpassed all other firms in installing central stations. Not surprisingly, its substantial investment in a large sales force, factory, and product improvement allowed it to surpass and then absorb many of the smaller firms in the industry.

At the same time, Thomson-Houston performed better than its major competitors, Edison and Westinghouse, because neither of these firms was able to effectively integrate marketing, manufacture, and innovation. During the 1880s, Edison and his associates maintained a loose and poorly coordinated confederation of companies for manufacturing and distributing his incandescent system. Only in 1889 did Henry Villard succeed in welding these companies together as the Edison General Electric Company. Even then, however,

Table 3.2 **Electric-Lighting Central Stations, 1891**

Thomson-Houston	669[a]	Excelsior	25
Westinghouse	323	Sperry	24
Edison	202	National	16
Brush	199	Remington	4
Fort Wayne	144	Eickemeyer	2
American	67	Hawkeye	2
Western Electric	53	Standard	1
United States	51	Hochhausen	1
Schuyler	49	Beard	1
Heisler	49	Knowles	1
Waterhouse	41	Mayo	1
Ball	31	Keith	1
Van Depoele	31		

Source: "Electric Light and Electric Railway Statistics," *Electrical World,* 14 February 1891, 110.
[a]Presumably includes stations using arc, DC incandescent, and AC incandescent lights.

Edison General had difficulties with coordinating the key functions. Edison had opened a substantial laboratory at West Orange, New Jersey, which he assumed would be funded by Edison General but where he refused to work exclusively on the products needed by the company. Samuel Insull successfully created a national sales organization for Edison General, but he found it more difficult to improve manufacturing at the firm's Schenectady plant. Insull's efforts to enlarge the plant were limited by a scarcity of capital. Intent on gaining control of the utility industry through a holding company, the North American Company, Villard directed most of Edison General's assets in that direction, and left Insull in the difficult situation of paying for long-term factory improvements with short-term banknotes. Thus, while Edison General possessed a marketing organization, it was weak in terms of product innovation and production. Not surprisingly, Edison General was badly damaged when Villard's North American Company failed during the Baring financial crisis of 1890.

Like Edison General, the Westinghouse Company failed to integrate all three functions, but its problems stemmed more from finance and marketing. In shifting his attention from his railroad inventions (the air-brake and signaling systems) in the mid-1880s, George Westinghouse wisely hired a number of electrical inventors and engineers, including William Stanley and Nikola Tesla, and hence ensured that he had ready access to new technological developments. To manufacture the electrical systems developed by his inventors and engineers, Westinghouse built factories in Pittsburgh and Newark. However, his weakness was in marketing; Westinghouse depended on a small sales force working on commission out of offices in six or seven major cities, and he insisted on closing many of the major deals himself. Westinghouse also bankrolled the early development of his electrical company himself, which meant that he never developed the strong relationship with a banking house needed to float bond and stock issues or to help finance central stations purchasing his equipment. Consequently, again like the Edison organization, the financial crisis of 1890 found Westinghouse bankrupt, and he was only able to reorganize with the help of financiers August Belmont and Henry L. Higginson (Carlson 1991, 275–91).

Of the three major firms in the electrical industry, Thomson-Houston was thus the only firm that successfully coordinated all three functions. As a result, Thomson-Houston was able to take over Edison General in 1892 to form the General Electric Company. Moreover, throughout the 1890s and into the twentieth century, Coffin and GE were able to continually maneuver Westinghouse into a secondary position in the electrical industry.

The significant differences in structure and performance of Thomson-Houston, Edison General, and Westinghouse highlight the weakness of the rational-actor approach and the need for an organizational model. Following the rational-actor model, one would assume that the managers at each of these firms had access to approximately the same information about markets and technology and that the forces of competition would have led them to create similar organizations. Yet the historical record shows that the managers of these companies followed diverse paths, either because they perceived the markets and technology in different ways or because they were unable to build the necessary internal coalition of business and technical experts. Consequently, if we wish to understand how firms evolve their strategy and structure, we must look beyond a rational-actor model of the firm and supplant it with an organizational approach.

3.4 Taking an Organizational Approach: The Case of AC Lighting System

Although Coffin, Thomson, and Rice clearly made a series of sound decisions and brought the right functions inside Thomson-Houston, one should not assume that the decision-making process was smooth and orderly. Indeed, if we peek inside Thomson-Houston during the 1880s, we do not discover the logical world suggested by the organizational chart in figure 3.1, but rather one marked by the give-and-take of interest-group politics. To illustrate this, let us look at how the company developed an AC system for incandescent lighting. This system was vital to Thomson-Houston because it permitted the company to compete directly with Westinghouse and Edison for a new segment of the central-station market, namely, small cities and towns. In telling the story of this system, we shall see how the process of innovation at Thomson-Houston was strongly influenced by the interaction of the three groups within the firm.

3.4.1 Identifying AC Incandescent Lighting as a Product

Thomson had been fascinated by alternating current from the outset of his career as an inventor. In 1878, he and Houston had built a set of arc lights and a generator that employed alternating current and induction coils. The purpose of the induction coils was to render each lamp in a series circuit independent. In this way, Thomson and Houston solved the problem of subdividing the electric light. Previously, electrical inventors had been able to run only one large arc light from a single dynamo, but now they were able to use a dynamo to power several smaller lights. The two men drew up patent applications for their AC system, but they soon set them aside when two Philadelphia businessmen offered to fund a DC arc-lighting system (Carlson 1991, 96–105).

In 1885, after he had successfully introduced an arc-lighting system with Coffin's help, Thomson reviewed his earlier work with induction coils and began to sketch several new systems. Like other inventors, he sensed that it would be desirable to develop a distribution system whereby power could be transmitted to incandescent lights over distances greater than one or two miles, then the physical limit for existing DC systems. Because of this limitation, DC incandescent stations were erected only in towns and cities with sufficient population density to pay for the costs of installing large copper mains. To overcome these difficulties, in March 1885 Thomson sketched an AC system using induction coils with their primary windings in parallel, a system that would step the voltage down from 1,000 to 110 volts.

The advantage of using the higher voltage was that it permitted efficient transmission of power over long distances. Thomson also included several safety devices to minimize the danger of electrocution from the high voltage. On the primary or high-voltage side of the transformer, he inserted a fuse, and on the secondary or low-voltage side, he added a ground connection. In case of a short circuit between the primary and secondary coils, that ground connection would conduct the high-voltage current away from the electric lights. Inclusion of such safety devices was part of Thomson's business-technological mind-set: build a system that is both reliable and not harmful to the customer.[22]

In designing that system in early 1885, Thomson was not especially concerned with introducing it commercially; rather, he considered the invention as one of several projects he might pursue. Instead, it was Coffin who first realized the commercial potential of an AC lighting system. During a trip to Europe in 1885, Coffin saw a demonstration of an AC system developed by the Hungarian inventors Zipernowsky, Blathy, and Deri (ZBD). Although Coffin always claimed that he knew nothing of the intricacies of electrical technology, he quickly realized from the ZBD system that alternating current could be used to build central stations in smaller cities and towns. On his return, he urged

22. Foster 1920, especially 81; "System of Electrical Distribution by Means of Induction Coils, Mar 5. 85," Exhibit no. 12, "Testimony on Behalf of Elihu Thomson and Edwin J. Houston . . . ," Patent Interference no. 13,761 (subject: transformer distribution systems), Hall of History Collection, 307; ET, "Induction Apparatus Interf. with Gravier," July–August 1884, TP; ET to H. C. Townsend, 10 April 1885, TP, LB 5/83–8/85, 65–67, and 110–12; ET to J. A. Fleming, 12 October 1885, TP, LB 8/85–3/86, 82–83; ET to Townsend & MacArthur, 6 January 1887, TP, LB 9/86–3/87, 223.

Thomson to pursue his work with induction coils and to file additional patent applications for parallel circuits as soon as possible.[23] Through late 1885 and early 1886, Thomson tested an AC system.

Because safety was to be an important feature of his system, Thomson continued to improve the designs of the fuses and other safety devices. By June 1886, he had run an experimental AC power line between two buildings at the Lynn plant to deliver current to incandescent lamps. By the year's end, the company was advertising AC generators in its catalog, emphasizing that it could furnish power to incandescent lights over long distances using wires that were smaller than those used in DC systems. Although the catalog described four generator models, none had actually been sold or installed.[24] From an organizational perspective, work went forward on the AC system because two interest groups agreed that it was a worthwhile project: Thomson's group had already done preliminary work in the area, and Coffin's group had decided that an AC system would help them reach new customers.

In the meantime, however, George Westinghouse was making progress in developing his own AC system for incandescent lighting. First, with the help of Frank L. Pope, an independent consulting engineer, Westinghouse purchased the American rights to a transformer distribution system developed in England by Lucien Gaulard and John Gibbs. Second, Westinghouse supported William Stanley's research aimed at improving the transformer, which led to a successful demonstration of AC distribution in March 1886 in Great Barrington, Massachusetts. Westinghouse engineers followed up Stanley's success by redesigning the transformer during the summer of 1886. By intensively funding development in this way, Westinghouse was able to install its first AC system in Buffalo in November 1886.[25]

23. For a discussion of the work of Gibbs and Gaulard and Zipernowsky, Blathy, and Deri, see Hughes 1983, 86–98. For an early description of the ZBD system, see "Alternating Electric-Current Machines," *Electrical World*, 31 May 1884, 173–74. For Coffin's interest in European developments, see ET to G. Cutter, 7 October 1885, TP, LB 8/85–3/86, 76–80. and ET to H. C. Townsend, 23 October 1885, TP, LB 83–11/85, 249–50. On learning of the ZBD system, Thomson wrote to several people and claimed that the ZBD system was a duplicate of the one he had sketched in 1879; see ET to C. J. Wharton, 21 September 1885, TP, LB 8/85–3/86, 35–37; ET to Edwin J. Houston (hereafter EJH), [28 September–3 October 1885], TP, LB 8/85–3/86, 55–56; ET to Laing, Wharton & Down, 15 October 1885, TP, LB 8/85–3/86, 93–94; and ET to EJH, 17 October 1885, LB 8/85–3/86, 103.

24. ET, "Electric Induction Apparatus," 11 June 1886, TP, LB 3/86–2/89, 168–72; ET to CAC, 5 February 1887, TP, LB 9/86–3/87, 334–37; ET to Townsend & MacArthur, 6 January 1887, TP, LB 9/86–3/87, 223; ET to Townsend & MacArthur, 1 and 19 March 1888, TP, LB 3/87–4/88, 884, 921–22; "Extracts (or Summaries) of Testimony in Patent Infringement Suit of General Electric Co. vs. Butler Company," Hammond File, J457–59; "Catalogue of Parts of Apparatus Manufactured by the Thomson-Houston Electric Co . . . ," 1886, Thomson Collection, MIT Archives, Cambridge.

25. Frank L. Pope, in discussion of "The Distribution of Electricity by Secondary Generators," *Telegraphic Journal and Electrical Review*, 15 April 1887, 349–54, especially 349; Hughes 1983, 98–105; Rice 1929; Drew and Chapman 1985, especially 7–19; Wise 1988.

Westinghouse gained an important advantage over Thomson-Houston by securing a broad patent for an AC distribution system with transformers in parallel. In contrast, all of Thomson's patent applications for AC distribution were rejected in the fall of 1886. This put the Thomson-Houston Electric Company in the defensive position of having to contest or else bypass the Westinghouse patent.[26]

Thomson responded to the Westinghouse patent for AC distribution by filing additional applications based on his early work with induction coils and arc lamps. Thomson submitted these applications not only to claim what he thought he had previously invented but also to "render it inconvenient for rivals to get around them."[27] In addition, he continued to experiment in the Model Room with different circuit configurations, hoping to find a way to circumvent the Westinghouse patent

3.4.2 The Groups Bargain and Fight

Nonetheless, by early 1887 Coffin and the marketing group were beginning to wonder whether perhaps the Model Room was not working fast enough. Why was Westinghouse already installing AC equipment, and not Thomson-Houston? Had not Thomson been working on patent applications for several months before Westinghouse had even ordered a Gaulard-Gibbs transformer from Europe? In February 1887, Thomson admitted to Coffin that work on the AC system was proceeding slowly. First, Thomson explained that although they had been working as rapidly as possible, "the development of the system had outgrown the model room, which is only adapted to producing small models and nothing of very large size." Thomson would have drawn on the resources of the factory as a whole, but the production department was overwhelmed with filling back orders. In other words, manufacturing was too busy to help development. But rather than simply blame manufacturing, Thomson offered a second revealing reason: he was determined to introduce a complete AC system, with generators, regulators, lamps, transformers, and safety devices all matched to each other, and designing such a system would take time. He believed that an AC system designed as a single entity would be the most reliable; to quote him again, "when we enter this field we wish to . . . be sure of success from the start with a complete and economical system, and the pre-

26. L. Gaulard and J. D. Gibbs, "System of Electrical Distribution," U.S. Patent 351,589 (26 October 1886); Kennedy 1887; "Specification of Elihu Thomson, Lynn, Mass. Distribution of Electric Currents," 9 October 1886, TP, LB 3/86–2/89, 232–40; ET to T-H Elec. Co., 28 September 1886, TP, LB 9/86–3/87, 18–19; ET to Townsend & MacArthur, 19 November 1886, TP, LB 9/86–3/87, 95–96; ET to H. N. Batchelder, 8 December 1886, TP, LB 9/86–3/87, 133–34; ET to Townsend & MacArthur, 10 December 1886, LB 9/86–3/87, 141.

27. ET to CAC, 5 February 1887, TP, LB 9/86–3/87, 334–37. See also ET to H. C. Townsend, 9 November 1886, TP, LB 3/86–2/89, 241–43; ET to Townsend & MacArthur, 23 November 1886, TP, LB 9/86–3/87, 103; ET to Townsend & MacArthur, 21 January 1887, TP, LB 9/86–3/87, 279–81; and ET to EJH, 18 February 1887, LB 9/86–3/87, 376–77.

paratory work that we have done will, we think, tell in the end."[28] Here is a clear statement of Thomson's belief that the best-designed product will in the long run be the most profitable.

In terms of group dynamics, the situation had progressed to the point that marketing was mistrustful of development, and the development group responded with a statement of its goals. The situation might have deteriorated further, but Thomson improved matters by adjusting his technology to the marketing strategy. Rather than insist that innovation could proceed only toward his technically perfect system, Thomson redirected his efforts so as to improve the company's short-term marketing position. To reduce the threat of patent litigation, Thomson helped the company arrange a patent-sharing agreement with Westinghouse. During a meeting of the American Institute of Electrical Engineers in March 1887, Thomson met with Pope and discussed the desirability of cooperating rather than competing in the AC field. After several meetings, officials from Thomson-Houston and Westinghouse reached an agreement in August 1887. In return for a license to sell Thomson-Houston arc-lighting equipment, Westinghouse allowed Thomson-Houston to manufacture AC systems without fear of infringing the Westinghouse AC distribution patent. Although this agreement was terminated within two years because the Westinghouse patent was ruled invalid in court, it did give Thomson-Houston time in 1887 and 1888 to improve its AC equipment.[29]

Knowing that a patent-sharing agreement could be only a temporary expedient, Thomson next initiated a new strategy to bypass the Westinghouse patent. Because Westinghouse controlled the right to the broad principle of using transformers for distribution, Thomson filed patents in 1888 on the designs of the most efficient transformers. Thus, the Westinghouse company would be unable to use its rights to apply the broad principle, because all of the best transformer designs would be owned by Thomson-Houston. In pursuing that strategy, Thomson filed patents for transformers with laminated cores of different shapes, and he began using an oil insulation bath.[30]

Still another way in which Thomson directed invention toward short-term marketing needs was through the exploitation of what he called "the principle of induction-repulsion." In 1886 Thomson discovered how a magnetic field created by an alternating current passing through an electromagnet could be used to create rotary motion. Excited by this discovery, Thomson used it to develop an AC motor and improved measuring instruments. In staking out his

28. ET to CAC, 5 February 1887, TP, LB 9/86–3/87, 334–37; ET to E. F. Peck, 22 March 1887, LB 9/86–3/87, 470–71.

29. Frank L. Pope to ET, 23 March 1887, Collected Letters; ET to CAC, 24 March 1887, TP, LB 3/87–4/88, 1; Passer 1953, 145–47.

30. ET to Townsend & MacArthur, 18 January 1887, TP, LB 9/86–3/87, 265–66; ET to CAC, 20 November 1889, TP, LB 4/89–1/90, 729–30; Walter S. Moody to J. W. Hammond, 15 April 1927, Hammond File, L2598–99.

claims for these inventions, Thomson emphasized that he had discovered a principle, in the belief that it could provide the company with general control over the applications derived from it. Over the next two years, Thomson perfected these inventions, giving Thomson-Houston new AC products that helped it gain a share of the market.[31]

Thomson began to redirect his development work toward short-term marketing needs in early 1887 and pursued that approach into 1889. Early on, Thomson's efforts began to pay off. In May 1887, the firm shipped its first AC machine to the Lynn Electric Lighting Company, and by the year's end it had installed twenty-two more systems. The first Thomson-Houston AC systems were installed in smaller cities, such as New Rochelle, New York; Kansas City, Missouri; Putnam, Connecticut; and Syracuse, New York, where the population density was too low to offset the initial cost of a DC incandescent system. Anxious to show his confidence in the new system and to have a full-scale circuit on which to test new devices, Thomson installed one of the new transformers and incandescent lamps in his home in Lynn. Because of his concern with safety, he employed in his home all of the safety devices he had created—the grounded secondary, fuses, and lightning arresters. He offered to promote the completed AC lighting system by writing an article for *Electrical World*, but he did so asking "whether my time would be more valuable to the Company employed on new work and in new fields rather than in describing apparatus and arrangements that are comparatively old with us."[32]

As Thomson directed the work of the Model Room to suit the needs and expectations of the marketing team, he proposed that marketing help implement some of his ideals. In particular, Thomson was anxious to see that his notions about the safe use of alternating current be implemented. Maintaining that the best system was a safe system, Thomson remarked that "I am a believer in the establishment of all safeguards which conduce to the good working of a system, especially when they do not add greatly to the cost of making the installation." More than just fulfilling his technological idealism, Thomson was confident that his safety inventions should be part of the marketing strategy used to fight Westinghouse. Once Westinghouse's broad patent for transformer distribution had been ruled invalid, Thomson suggested that all central stations

31. [ET], "Specification—Alternating Current Motor Device," 22 December 1886, TP, LB 3/86–2/89, 265–76; ET to G. Cutter, 17 December 1886, TP, LB 9/96–3/87, 163–67; ET to CAC, 5 February 1887, TP, LB 9/96–3/87, 334–37; Thomson 1887a; H. G. Hamann and F. G. Vaughen, "Developmental Work by Prof. Thomson on Electric Meters," TP, Biographical Materials; [ET], "Specification [for liquid electric meter]," 14 October 1887, TP, LB 3/86–2/89, 19–36; ET to CAC, 12 March 1888, TP, LB 3/87–4/88, 913; J. W. Gibboney to S. C. Peck, 26 October 1889, TP, LB 4/89–1/90, 611–12.

32. ET to Thomson-Houston Elec. Co., 13 June 1887, TP, LB 3/87–4/88, 163–64. The first Thomson-Houston AC incandescent plants are from "List of T-H Plants." Descriptions of AC lighting used in Thomson's home can be found in ET to Chas. C. Fry, 7 October 1887, TP, LB 3/87–4/88, 522–23; and ET to Prof. S. W. Holman, 21 October 1887, TP, LB 3/87–4/88, 572–75; ET to Lynn Elec. Lighting Co., 8 May 1888, TP, LB 4/88–4/89, 13–14; J. A. McManus, memorandum, 6 March 1936, Hall of History Collection; and Thomson 1887b.

using Thomson-Houston AC equipment be fitted with the latest safety devices. The company should then emphasize in its advertisements how safe its installations were in comparison with the Westinghouse plants. As a result of adverse publicity, Westinghouse would then be forced to install safety equipment as well. Because Thomson-Houston controlled the patents for the best safety features, Thomson believed that such a strategy would block Westinghouse from acquiring a larger share of the market for alternating current.[33]

As Thomson soon learned, the difficulty with his plan was that it presumed that Thomson-Houston would encourage its customers to install safety devices. Unfortunately, that was hardly the case in 1889. Instead, it appears that Thomson-Houston customers frequently ignored safety equipment and careful installation procedures in the rush to get "on line." Pushed by investors to begin selling electricity as soon as possible in order to make a return on the capital invested, utility operators were forced to keep their construction and installation costs to a minimum. Utilities did not always purchase all the necessary safety accessories; they used poorly insulated wire, and their linemen often were careless and indifferent to the special requirements of alternating current. Although Thomson realized that such poor practices were influenced by the competitiveness of the electric-lighting field, they nonetheless offended his mind-set. "I do not believe in this kind of economy," he warned Coffin. "Rather it would be better not to have the business than incur the risks which are thus involved."[34] As an inventor, Thomson would have liked to have had control of his creations from the initial conception to the final installation, but he soon realized that the marketing group was unwilling or unable to help him accomplish this. In this situation, although Thomson and the development group had adjusted their efforts to suit marketing's short-term interests, marketing had failed to reciprocate by promoting development's ideas about safety.

In failing to endorse Thomson's ideas about safety, the marketing group soon discovered that it had lost a key ally needed for fighting in the AC-DC controversy. Lasting from 1886 to 1895, that controversy involved whether AC systems should supplant DC systems, and it was a debate that soon included not simply technical matters but political and emotional issues as well. The controversy became particularly heated in 1888 as it became clear that AC systems could be used to supply incandescent lighting to small cities and towns lacking the population density needed to support a low-voltage DC system. Unable to compete with Westinghouse and Thomson-Houston for that market, the Edison organization decided to challenge the AC system by questioning its safety.

33. ET to T. F. Gaynor, 7 March 1888, TP, LB 3/87–4/88, 900–901. See also ET to CAC, 11 December 1888, TP, LB 4/88–4/89, 547–50.

34. ET to CAC, 13 February 1889, TP, LB 4/88–4/89, 761–66. See also ET to CAC, 16 February 1889, TP, LB 4/88–4/89, 780–82; ET to John J. Moore, 19 October 1889, TP LB 4/98–1/90, 594–96; ET to Narragansett Elec. Light Co., 22 April 1890, TP, LB 1/90–11/90, 443–44; Thomson 1888.

The higher voltages required for efficient transmission by alternating current, argued the Edison group, were more likely to cause injury and death.[35]

By the summer of 1889 Coffin and the marketing group were anxious to participate in the AC-DC debate. In all likelihood, they saw it as an opportunity to surpass their two rivals, Edison and Westinghouse. Defensively, they also may have been concerned that the publicity about "deadly" alternating current might harm sales, and they wanted to reassure customers that it was safe to buy Thomson-Houston equipment. Because the company was already manufacturing safety equipment, all that was necessary for a strong position in the debate was to have a leading authority promote the general use of alternating current. Given his established interest in electrical safety, Thomson was the obvious choice for this public-relations effort.

In October 1889, Coffin asked Thomson to write an article titled "How to Make Electricity Safe." Along with addressing the general issue of the safety of alternating current, Coffin wanted Thomson to provide a defense for AC power in the wake of an accident that had recently occurred at a utility in New York City. The utility had been using a Thomson-Houston AC system, and it was short-circuited when a telephone wire fell across the 1,000-volt power lines. Much to Coffin's dismay, Thomson turned down the assignment. The utility had done a poor job of installing its AC equipment, and Thomson felt that he could not personally defend such work. Unsafe installation was unacceptable to Thomson, and what was more, Thomson-Houston would not have been in that unfortunate defensive position had they listened to Thomson several months earlier.[36]

At first, Thomson simply suggested that he should remain quiet rather than be "a stumbling block in the way of the Company's business transactions." However, when Coffin pressed for a general endorsement of alternating current, Thomson exploded. In anger, he informed Coffin that he felt like quitting, because "my position with the Company has no attractions for me if my ideas of what is needed to constitute good substantial work are not followed but personally neglected." In a letter written on Christmas Eve 1889, he advised Coffin that the firm would have to recognize that he was primarily an inventor and would not be distracted by writing articles for publicity purposes. With respect to the safety of alternating current, he refused to give a blanket endorsement. "I have no method" he wrote, "I have no panacea—for all the ills which may follow the use of high potential currents under conditions usually found in large cities. I can no more say how to make electricity safe in such cases than I can say how to make railroad travel safe, or how to make steamship travel safe, or how to make the use of illuminating gas safe, nor the use of

35. Hughes 1983, 106–9; Passer 1953, 164–75; [Harold P. Brown] to Spencer Aldrich, 6 February 1889, TP, LB 4/88–4/89, 771–74; ET to CAC, 16 May 1889, TP, Collected Letters.

36. [A. C. Bernheim] to CAC, 16 October 1889, TP, LB 4/89–1/90, 589; ET to CAC, 6 November 1889, TP, LB 4/89–1/90, 658–61.

steam boilers safe. No improvement of our modern civilization has ever been introduced but that involved considerable risk."[37] Because he had designed the AC system, Thomson knew well the risks involved in using it. He lived by the principle that the best system was a safe system. But when he found that the marketing group was interested only in promoting safety as a short-term, defensive measure, he refused to cooperate. They had not been willing to adapt marketing policy to his technological goals, and so he was unwilling to compromise his principles about safety. As a result, the Thomson-Houston Electric Company took no public position in the AC-DC controversy, leaving the debate to be settled by Edison and Westinghouse.[38]

Viewed in terms of the clashing of group interests, it is easy to see why Thomson and the development group came to refuse to cooperate. First, Thomson was finding it difficult to work with the manufacturing group. Previously, although they had been unable to help him with the development work in early 1887, they had, for the most part, been willing to manufacture AC equipment according to Thomson's designs. By 1889, however, the firm's business was rapidly growing and expanding into the new field of electric trolleys; as a result, the factory mushroomed in size, and the tasks of coordinating production became immense. These changes made the production engineers quite cautious about modifying and improving other products, because this would mean more confusion in the factory. Modifications might well mean that manufacturing costs would go up and reduce profits. Production's conservative outlook soon became apparent to Thomson, as when he tried to introduce an improved transformer design in mid-1889. Manufacturing turned it down on the grounds that the new form would cost more to make than the old version, an argument with which Thomson had to agree. Nonetheless, he was disturbed by the event because it signaled that it was becoming more difficult to introduce the minor improvements that would ensure that the company was manufacturing the best possible system.[39]

A second issue that concerned Thomson was that patent litigation was distracting him from working on new inventions. By 1889, Thomson had filed 375 patent applications, which had unfortunately led to a sizable amount of litigation. By the end of that year, he had been named in over sixty interference cases, many of which required extensive testimony. In addition, Thomson-

37. ET to CAC, 19 October 1889, TP, LB 4/89–1/90, 579–83; ET to CAC, 20 December 1889, TP, LB 4/89–1/90, 867–78; ET to CAC, 24 December 1889; TP, LB 4/89–1/90, 903–8.

38. Thomson-Houston's nonparticipation in the AC-DC controversy is sometimes credited to Coffin, who chose not to enter the public debate and instead concentrated on selling systems. See, for example, Woodbury 1944, 173–74.

39. Thomson summed up his difficulties in introducing new inventions as follows: "The more our facilities grow the harder it seems to be to get through any special work of a new character, simply because we have no department that is absolutely set aside for this kind of work outside of the model department." From ET to S. C. Peck, 30 August 1889, TP, LB 4/89–1/90, 422. See also ET to J. S. Bell, 21 January 1888, TP, LB 3/87–4/88, 791–92; ET to T. C. Martin, 16 August 1889, TP, LB 4/89–1/90, 363–65; ET to F. P. Fish, 1 October 1889, TP, LB 4/89–1/90, 502–4; and "Recollections of L. G. Banker," Hammond File, J677–83.

Houston was actively suing firms that had infringed Thomson's patent for an automatic dynamo regulator. Accustomed to having Thomson assist them with the infringement litigation, the Thomson-Houston lawyers soon began using him as an expert witness in other cases. Although Thomson understood the importance of defending his patents, he came to question his participation in litigation, as it took him away from invention. Eventually he informed Coffin that he would no longer testify. "If I am to act as *inventor* for the Company," he wrote, "I shall not hold myself in readiness to be called upon as patent expert and handy man . . . for the more I invent, the more will my inventions . . . embarrass me in the future. . . . [It] is simply wasting my time to have to do . . . patent expert work."[40]

More than his difficulties with manufacturing or the troublesome patent litigation, Thomson was troubled by a third issue in 1889: his role within the company. As the preceding quotation indicates, Thomson saw himself as the firm's chief inventor. Many of Thomson-Houston's products were his handiwork, and his creative efforts had yielded handsome profits for the firm. Yet there were signs that Thomson might be losing his position as chief innovator. Beginning in 1888, Thomson was joined in the Model Room by other inventors who came to Lynn as their companies were bought out by Thomson-Houston. Although Thomson was nominally in charge of their work, he may have been worried that his own inventions would no longer be highly valued by management.[41]

In addition to the output of these new inventors, Coffin and the marketing group began to purchase more outside patents in 1888. Thomson intensely opposed this policy, and in 1888 and 1889 he approved the purchase of only a few patents. His opposition appears to have been based on fear that such a policy would jeopardize his control over innovations within the firm. Not only might the company no longer need him, but the policy of purchasing outside patents diluted the firm's product line with worthless items. One questionable patent purchased by the company in 1889 was for "electric water." When he learned that the company planned to test this substance, Thomson was enraged. He wrote the Boston office: "If our Company should go seriously to work to expand any money in making tests . . . I should feel like resigning on the spot. I have plenty of material which I do not have the opportunity to work up."[42] The purchase of outside patents and the arrival of other inventors must have

40. Quotations are from ET to CAC. 24 December 1889. TP. LB 4/89–1/90. 903–8. See also ET to Capt. E. Griffin. 9 October 1888. TP. LB 4/88–4/89. 374: ET to Ernst Thurnauer. 26 October 1889. TP. LB 4/89–1/90, 613: and ET to T-H International Electric Co.. 4 January 1890. TP. LB 4/89–1/90. 945.

41. Along with Thomson. Rice. A. L. Rohrer. Wightman. Lemp. Van Depoele. and Priest filed patents in 1889: see J. W. Gibboney to Bentley & Knight. 6 June 1890. TP. LB 1/90–11/90. 597.

42. ET to Robert C. Clapp. 23 October 1889. TP. LB 4/98–1/90. 602–3. See also ET to Fish. 1 October 1889. TP. LB 1/90–11/90. 502–4: and ET to Capt. E. Griffin. 21 February 1890. TP. LB 1/90–11/90. 185–87.

suggested to Thomson that other members of the firm were implicitly challenging his control over innovation.

Thomson's decision not to accommodate Coffin may also have been informed by his contractual arrangements with the company. When the Thomson-Houston Electric Company was formed in 1882, Thomson agreed to serve as the firm's electrician in return for an annual salary of $5,000 and 15 percent of any new stock issued by the company. (Both the president of Thomson-Houston, Henry A. Pevear, and Coffin received stock when the company was formed, but the size of their holdings is unclear.) In 1887, Thomson signed a new agreement that extended his appointment to July 1890. In this agreement, Thomson gave up his share in any new stock issue in return for $8,000. Up to that time, the firm had not increased its capital stock, and Thomson may have concluded that he was better off taking the lump-sum payment. In May 1887, however, the company did increase its capital stock to $500,000. One source suggests that Coffin deliberately tricked Thomson into giving up his stock option, but I have not found any documents in which Thomson complained about losing his stock option. Nevertheless, by December 1889, Thomson may have decided that the early months of 1890 were the best time to put pressure on Coffin since it was then that they would have renegotiated his contract.[43]

Disappointed with the production group, tired of the patent litigation, and worried about this position as chief innovator, Thomson was in no mood to compromise his business-technological mind-set in the fall of 1889, especially as it related to the subject of safety. He had cooperated fully in the rapid introduction of the AC system and other products, only to find that other groups did not respect his efforts and authority. In fact, he even perceived them as undercutting his "power base" within the firm. And given that his contract was due to expire in July 1890, Thomson knew that it was time to force a change in his role with the company.

3.4.3 An Organizational Denouement

Even after his angry Christmas Eve letter, it took some time for Thomson-Houston managers to realize that Thomson expected to be treated differently. During the first months of 1890, he refused to evaluate any outside patents or to serve as an expert witness in court. Furthermore, Thomson expressed his anger by not corresponding with Coffin for nearly two months, even though previously they had exchanged letters and memos almost daily. Instead of coming in early and staying late at the Model Room, he spent more time at home and worked only half days. Using these tactics, Thomson communicated that he wanted his role within the firm to change.

43. [Agreement between ET and the T-H Electric Co.], 20 April 1887, TP, Collected Letters; *T-H Annual Report,* 1891; Pound and Moore 1931, 39.

Sensing Thomson's unwillingness to handle certain kinds of work. Coffin and Rice assigned routine product improvement to the engineering staff in the manufacturing group. and they established a legal department in 1891 to handle patent matters.[44] In the summer of 1890. Thomson replaced his contract with an informal agreement with Coffin by which he was permitted to work on projects of his own choosing. as well as those needed by marketing or production. Under this agreement. Thomson continued to develop new products, but he also looked for opportunities to direct his work toward scientific and professional goals. Although he filed for patents for improved transformers and electric welding equipment. Thomson also conducted research and published articles on high-frequency and high-voltage phenomena. Professionally. Thomson began to take a more active part in the affairs of the American Institute of Electrical Engineers. and he was elected president of that society in 1889 and 1890. To express his concerns about the safety of electric lighting systems. he served on the National Electric Light Association's subcommittee for overhead wiring. and he presented a paper. "Safety Devices in Electrical Installations." at their annual meeting in 1890.[45] In redefining his position. Thomson knew that he was relinquishing some of his power over product innovation within the firm: other inventors and engineers were becoming responsible for improving the company's products. However. he must have sensed that only by shifting his interests could he overcome the dissatisfaction he had felt so sharply in the fall of 1889.

Thomson's anger over the AC-DC controversy signaled to Coffin and others that the innovation function was neither fully understood nor properly located within the firm. Only after pushing Thomson to the brink did the firm realize that innovation involved a variety of tasks—inventing. patenting. giving expert testimony. and designing for manufacture—and that these activities needed to be institutionalized in separate departments. Furthermore. by buying outside patents and bringing in additional inventors. Coffin had wanted to expand the firm's sources of innovation. but he did so at the cost of upsetting the firm's original innovator. As a result of that experience. Coffin was much more circumspect about bringing in additional "star" inventors: for instance. Charles

44. See ET to Robert P. Clapp. 11 January 1890, TP. LB 4/89–1/90. 991–92: ET to Capt. E. Griffin. 3 March 1890. TP. LB 1/90–11/90. 220–22: and ET to Robert P. Clapp. 29 April 1890. TP. LB 1/90–11/90. 468. For the absence of letters from Thomson to CAC. see the first 175 pages of TP. LB 1/90–11/90. For the new patent department. see "Testimony." Intf. 15.511. 99.

45. For Thomson's informal agreement with Coffin. see J. A. McManus. confidential memorandum. 12 September 1935. Hall of History Collection. For his new research projects. see Thomson 1890a. 1891. Because of the demands placed on him by the company. Thomson was angry that he was not able to be more active as president of the American Institute of Electrical Engineers. As he complained to T. C. Martin. "this state of affairs is indeed very galling to me. and I hope to take steps to have the condition remedied sometime in the near future" (ET to T. C. Martin. 13 January 1890. TP. LB 1/90–11/90. 3–4). For Thomson's efforts to promote safety. see ET to Capt. Eugene Griffin. 27 December 1889. TP. LB 4/89–1/90. 902; ET to E. R. Weeks. 13 January 1890. TP. LB 1/90–11/90. 2: and Thomson 1890b.

Steinmetz came to the Lynn factory in 1892 only after he had been carefully interviewed by Thomson and Rice.[46]

These organizational changes meant neither a triumphant victory for Coffin and the marketing group nor a resounding defeat for Thomson and product innovation. Rather, as often happens in organizations, these two groups and their leaders made just enough adjustments to ease the immediate tension. Indeed, these changes marked the start of a decade of gradual reshuffling of various activities related to product development and engineering. During the 1890s, as Thomson-Houston became General Electric, Coffin and Rice continued to expand the engineering staffs at both the Lynn and Schenectady factories, assigning different engineering teams to improve existing products and production processes. Under the leadership of Albert G. Davis, the patent and legal office grew in size and importance. At the same time, the company continued to look to Thomson to develop new products. Because the depression of the mid-1890s curtailed the growth in the utility industry, GE asked Thomson to develop new products that used its existing manufacturing capabilities. Thomson designed an X-ray system that could be manufactured using the lamp production facilities in Harrison, New Jersey, and he experimented with automobiles, a product Coffin contemplated manufacturing at Lynn or Schenectady. However, in both cases, Thomson was frustrated that the equipment and manpower needed to build, test, and patent these new products was scattered across the company, making it very difficult to guide the development of these products. Consequently, in 1899, Thomson began calling for a central research and development facility in the company, and in 1900, GE responded by creating the industrial research laboratory at the Schenectady factory (Carlson 1991, 301–39). Although this laboratory brought together the resources and personnel needed for product innovation, its first leader, Willis R. Whitney, found himself in 1910s and 1920s bargaining and building coalitions for products much as Thomson did during the 1880s (Wise 1979, 1985).

3.5 Conclusion

Applying the interest-group model to the Thomson-Houston Electric Company reveals that it is possible to get inside the firm and trace how historical actors converted a small, entrepreneurial start-up to a large firm with a formal managerial structure. Significantly, this approach focuses our attention not only on how key activities were brought inside the firm but also on how these functions were coordinated by managers.

As the Thomson-Houston case reveals, the managers of this company responded to the challenges of electric lighting by taking up the tasks of organizing a national sales force, building a substantial factory, and undertaking con-

46. ET to CAC, 24 December 1889, TP, LB 4/89–1/90, 903–8.

tinual improvement and expansion of their product line. The triumvirate of Coffin, Thomson, and Rice perceived clearly the complexities of the market, organized these perceptions into an effective strategy and structure, and outperformed the rival Edison and Westinghouse companies.

Although the rational-actor approach suggests that a firm will acquire a particular structure to implement a particular strategy, form does not automatically follow function. Once functions are brought within the firm, there is no guarantee that the managers will know how to create a set of organizational arrangements that will permit employees to develop each function fully. Rather, managers such as Coffin had to make choices about which functions they could fully develop in the organization. Given finite resources and a rapidly growing market, Coffin chose to devote resources and personnel first to organizing marketing, not product innovation. Coffin understood marketing, and in a complex environment, businessmen tend to do what they know how to do best. Even though innovation was as important to the firm's well-being as marketing, neither Coffin nor Thomson fully understood all of the activities related to developing new products, and so they organized this function on a trial-and-error basis. Although the firm did establish the Model Room for Thomson, the company came to understand all of the tasks related to product innovation only after Thomson became overextended and angry in 1889. Thus, although it may be obvious to us with our functionalist hindsight that the marketing strategy of central stations called for having the firm perform the function of product innovation, the historical record reveals that members of the firm did not automatically or instinctively create the organizational structure needed to fully pursue innovation. Instead, based on a variety of factors—the personalities, skills, and perceptions of the actors—a firm may integrate different functions or activities at different times and different ways. Indeed, that the managers at Edison and Westinghouse presumably had access to the same information and opportunities but created very different organizations underlines the contingent nature of how managers chose to institutionalize the key functions associated with electric lighting.

To make sense of the contingency associated with how functions are coordinated within the firm, we need a organizational/political perspective. Using an interest-group model, we can see how the strong personalities in Thomson-Houston strove to create groups or departments to use their talents and implement their business-technological mind-sets. Choosing at times to bargain and cooperate with each other and at other times to disagree, these interest groups determined how the key functions of design, manufacture, and marketing were coordinated in the process of introducing a new product such as AC lighting. Clearly, the coordination of the functions within the firm did not follow automatically from any strict logic but rather was the result of the political give-and-take of interest groups.

It is important to note that while the give-and-take of groups within firms is highly contingent, the consequences of this interaction can be long-lasting and difficult to change. As entrepreneurs and inventors make the transition from start-up firm to formal managerial hierarchy, they create patterns of social interaction that can be difficult to alter. Once the members of the Thomson-Houston organization became accustomed to emphasizing marketing over product innovation, Thomson had to use rather dire tactics to alter his position in the company. Similarly, it took GE's brush with bankruptcy during the Panic of 1893 before Coffin and the other former Thomson-Houston managers were able to rethink their marketing strategy and move into new areas such as the electrification of factories (Carlson 1991, 304–11).

This observation of the conservative nature of organizational culture complements points made by Daniel Raff and Daniel Nelson in this volume. In his paper (chap. 1 in this volume), Raff suggests that the proliferation of compensation schemes in the U.S. auto industry in the 1920s must be explained in part by the tendency of firms to evolve their own internal practices in response to their own peculiar needs and customs. Likewise, Nelson (chap. 2 in this volume) reveals that while industrial engineering is a significant cultural and intellectual development in twentieth-century America, we should be cautious in assuming it significantly altered business practice. According to Nelson, managers tended to employ industrial engineering consultants to fix short-term problems and instead made decisions within the framework of existing corporate practice. Taken together, these three papers suggest that the need to pay attention to how the structure and culture of a firm influence its ability to change and take up new innovations (see also Mokyr 1992).

Using the interest-group model to study the development of the AC system also reminds us that there is no "one best way" to develop and use an innovation. Market forces may suggest some ways that a technology may develop, but only when groups within the firm perceive those market opportunities and link them to particular innovations. Moreover, within an organization, different groups will perceive markets and technologies differently, and a new product can only be brought to market when different groups negotiate and coordinate their efforts. As Langdon Winner (1986) has suggested, technological artifacts do have politics. Significantly, this political process—whereby a technological development is linked to interests of different groups—is not a "bad thing," in the sense that the technology is compromised. Indeed, if the story the Thomson-Houston AC system teaches us anything, it is that negotiation among groups is the only way that firms can ensure that a product will possess an effective set of attributes that will permit it to be manufactured and marketed. To some extent, this is a lesson that American engineers and manufacturers have relearned, given the recent interest in development teams and concurrent engineering (Wheelwright and Clark 1992).

In highlighting the importance of how individuals and groups negotiate within the firm, I am not denying the rational quality of the outcome. Thomson-Houston did perform better in the marketplace, beating out Edison General and Westinghouse, because its leaders created a winning combination of strategy and structure. Rather, in taking an organizational approach, I want to suggest that what is interesting is the *process* by which Coffin, Thomson, and Rice created and maintained the winning combination. To study this process, we need to integrate the analytical tools of the economist and the historian. From the economist, we need the perspective that presents the firm as a set of production possibilities and helps us to analyze how firms with various production possibilities interact in a market or industry. Within the firm, an economics perspective is also essential in making sense of mind-set of individuals and groups; how do groups organize their perceptions of markets and technology into a coherent set of practices? At the same time, we need the historian's perspective to identify the social dynamics of groups inside and outside the firm and to address the subtle and contingent roles that personality, values, and culture play in shaping business decisions. Thus, it is only by combining economics and history that we will be able to understand that central institution of capitalism, the business firm.

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Comment John Sutton

In an excellent recent book on Elihu Thomson and General Electric, W. Bernard Carlson developed a fresh and valuable perspective on a series of issues that have been much studied since the publication in 1953 of Harold Passer's *Electrical Manufacturers, 1875–1900.* In this admirable paper, he uses the history of the Thomson-Houston company to develop a new theme, which relates to the way in which early entrepreneurial firms grow into elaborate managerial

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organizations. Central to this theme is the notion that we must move away from the idea of the firm as a single maximizing agent, toward the more complex representation of the firm as a set of separate interest groups, with differing aims. These differing aims, the argument goes, may sometimes conflict, and may sometimes be reconciled. Only through an understanding of these processes can we hope to arrive at a satisfactory explanation of the firm's actions.

In Carlson's version of this approach, two ideas are emphasized: (i) progress occurs in the firm when the leaders of groups strive for cooperation rather than overtly challenge each other; (ii) the reason groups differ in their aims is that they differ in their "set of ideas and perceptions . . . of the market and of the potential of different technological options." Now as a description of how things are, this seems unobjectionable. What matters is whether our understanding of why things happened as they did is advanced by reference to this more complex model of the firm. Carlson argues that it is, and he does so by means of an appeal to two episodes in the firm's history.

The first episode relates to the success of Thomson-Houston in competing with Westinghouse and the Edison organization in installing central stations during the late 1880s. Carlson attributes Thomson-Houston's leading position to the fact that it successfully integrated its marketing, manufacturing, and innovation functions. That it succeeded in bringing these three groups into step is well established here, and I quite accept that this success was an important contributory factor in Thomson-Houston's rise. On the other hand, I am not convinced that this is the whole story.

The origins of Thomson-Houston's strength in this period can be traced to the arc-lighting era of the early 1880s, when it competed successfully against the two firms then dominant, Brush and Weston. Of the 6,000 arc lights in use at the beginning of 1881, 5,000 were made by Brush and the remainder by Weston (Passer 1953, 56). By 1890, Thomson-Houston, and the companies it owned or controlled, accounted for two-thirds of the 235,000 arc lights in service.

Thomson-Houston's success in this period can be attributed to several factors (Passer 1953, 57); it is arguable that two of these were crucial. The first lay in Thomson-Houston's strong focus on building up its position in the profitable "central-station" business; it was as a result of this that Thomson-Houston entered the next phase of competition—where its main rivals were to be the Edison organization and Westinghouse—with a head start. It had a strong position in supplying central stations, and usually placed clauses in its contract with the licensee company, requiring it to continue purchasing supplies from Thomson-Houston. The second factor distinguished Thomson-Houston from its less successful rivals: "After developing a workable system, Brush turned to other fields of interest and took out no arc-lighting patents after 1880. The Brush system of 1890 was essentially the one he had designed ten years before. Weston also turned to other matters and did almost nothing in arc lighting after 1880. But Elihu Thomson continued to improve and perfect his system all through the 1880s and the 1890s. He thus helped his company to secure and maintain its dominant position in arc-lighting equipment" (Passer 1953, 57).

Other factors also played a part; Thomson-Houston enjoyed the financial backing of a group of businessmen who were prepared to take the long view and to underwrite Thomson-Houston's policy of acquisitions, which played an important role in the company's growth. But whatever the view one takes of the relative importance of the several factors underlying Thomson-Houston's early growth, it is clear that the company was well established as a strong incumbent prior to the crucial period in the late 1880s when it had to face new competition from Edison and Westinghouse.

The interpretation of the events that followed, as developed in the present paper, goes like this: Thomson-Houston succeeded in fusing the aims of three crucial groups within the company, which dealt with marketing, manufacturing, and innovation. The Edison organization, by contrast, was a loose and poorly coordinated set of companies; it developed a sales organization but suffered from weaknesses in product innovation and production. Westinghouse, in spite of its strength in innovation, was weak both in marketing and in finance, where its lack of strong links to banks proved crucial in the crisis of 1890.

By the end of the decade, price competition intensified, while the pace of innovation demanded substantial investment. Increasing financial pressures, as Carlson has argued elsewhere (1991, 292–94), led to two initiatives by outside financiers to consolidate the industry. They first attempted to arrange that Thomson-Houston should take over the ailing Westinghouse. The failure of this initiative led them to encourage Coffin at Thomson-Houston, and Villard at Edison, to investigate a merger of their two companies.

So what, then, are we to conclude from this first example? We can certainly agree that it is important and arguably even crucial to long-term success that an integration of aims between functions should be achieved. But Carlson argues for more than this; his concern is to convince us that a proper understanding of how the industry evolves demands that we come to grips with his "intrafirm groups" model, rather than treat each firm as a "single agent." Relative to this argument, his first example is suggestive rather than convincing; much depends on how much importance we attach to the factors that he emphasizes in drawing up the strengths and weaknesses of the three main players on the eve of the financial reorganization of 1892, in which the future General Electric was born of a fusion between Thomson-Houston and the Edison organization.

The second episode that Carlson chooses to advance his thesis is more convincing; it relates to the approach taken by Thomson-Houston to the emergence of alternating current, where Westinghouse led the field. The issue is, why did Thomson-Houston take so long to make a serious commitment to this field? On Passer's interpretation, which fits nicely into a "single agent" framework, Thomson-Houston played a cautious, sensible, and successful low-risk strategy by being a "fast follower"; when, and only when, a first mover had shown that a new system could be established profitably in the market would Thomson-Houston then follow. Given the company's strength in the market, it could afford to wait, knowing that it could in due course establish itself in the new regime.

Carlson will have none of this: for him, the slowness of Thomson-Houston's entry into the field did not reflect the rational calculation of a single agent. Rather, it was born of an impasse within the company between people whose vision of the technology and the marketplace were in sharp conflict. Carlson's account of the differing priorities, preconceptions, and goals of Thomson and Coffin is telling. His interpretation of slow advance as the outcome of this stalemate is persuasive.

But, like Oliver, I would like to ask for more. Will this kind of example persuade economists to open up the black box that is their "firm," and delve into its internal organization, the better to understand the evolution of market structure? Perhaps. But I have some niggling doubts. Not only do we have to rule out Passer's "single agent" interpretation, but we are told by Carlson that the eventual outcome was, in some sense, a "good" one for Thomson-Houston. If I wanted to convince someone to adopt this more complex model of the firm, I would feel best armed if I had some examples in which the outcome was both difficult to reconcile with any reasonable "single agent" interpretation and was highly unsatisfactory to the firm in question.

The kind of example I would appeal to is well illustrated by Foster's discussion of DuPont's actions in the U.S. tire market in the late 1960s, when the dominant nylon-based tire was about to be overtaken by the technically superior polyester tire (1986, 123ff.).

DuPont was the market leader in nylon-based tires; it was also the leading producer of tire cord. It seemed ideally positioned to take over leadership in the new polyester-tire business. But it did not. Instead, the Celanese company, which had no interests in nylon, took a 75 percent share of the market with its polyester-based tires.

The reason for DuPont's failure lay in its internal organization. Foster gives a fascinating account of the internal maneuverings of the nylon department, which had a big investment in the "old" technology, versus the innovators in the polyester department, who wished to champion the new. All companies find it hard to accept that sunk costs are sunk, and the advent of a new technology means that we may have to write off investments whose true economic value has suddenly collapsed. These difficulties can be reconciled if there is a strong center, or if—in Carlson's framework—all groups are cooperating. In practice, there may be some game playing of the kind Foster describes at DuPont: First, the polyester champions develop a new product. The performance of the prototype is just below that of nylon, but is improving fast. This is met by a delaying tactic; the nylon department regards the case as unproven, and in the interval that intervenes before polyester really proves itself, a major new nylon tire plant is built. Now it becomes even harder to argue that sunk costs are sunk—and by the time DuPont moves, Celanese has taken the lead.

Before I close, I would like to turn to Carlson's final remarks, in which he takes up a question that is central to the present volume: Why should economists and historians talk to each other? Here I take a stronger line than Carlson. What is involved is not the usual sort of argument that we hear whenever "multidisciplinary studies" are mentioned: the point, for once, is sharp, specific, and should—for the economists at least—be compelling, for it derives directly from the central core of economic theory itself.

A decade of work on game-theoretic models in industrial organization has made it plain that, in representing any market of interest, there will usually be many a priori reasonable models, whose design differs in respect of features that we cannot observe, identify, or proxy empirically. As a result, many outcomes are "consistent with theory." Now if *all* outcomes are possible, we are in the historian's realm of accident and personality; and the business historian need pay little heed to what the economist has to say. But this is not, in fact, the case. Many outcomes are possible, but by no means all. It turns out that there are certain competitive mechanisms whose operation across *all* reasonable candidate models constrains the set of possible outcomes. These "robust" mechanisms include, notably, the process of price competition and the process of competitive escalation of innovative efforts—whose operation serves to delimit the set of outcomes that can emerge (Sutton 1991).

Carlson's first example, which he elaborated more fully in Carlson 1991, shows these two mechanisms leading to just the kind of breakdown of market structure that economic theory predicts (compare the story of Carlson 1991, 293ff. with that of Sutton 1991, chaps. 6 and 8, for example). What the economist has to offer the historian here is the statement that *some* shift of structure involving exit, merger, or consolidation was probably inevitable by 1890–92. This observation suggests that we should not try to explain too much by claiming that this firm was strong, or that one weak. Something had to give.

But many outcomes were possible: economic theory places only weak constraints on the data. And it is for this reason that the economist cannot do without the historian. Only by delving into the details can we hope to understand why one configuration emerged rather than another. Coffin's angry retort that he'd prefer to see Westinghouse go bankrupt rather than merge with him is hardly the kind of mechanism on which we can build models—yet it probably had as much to do with the emergence of the General Electric–Westinghouse duopoly, as opposed to a THW–Edison duopoly, as did anything else in this fascinating story.

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