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A History of the Christiana Machine Company, 1863-1920

by Ferdinand L. Molz

with editorial assistance of Donald J. Summar

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CHAPTER I

THE EARLY YEARS 1833 TO 1877

The initial reason for the erection of a foundry at Christiana, Lancaster County, Pennsylvania was the announcement by the Philadelphia and Columbia Railroad that it would build a line that would pass through what was then McClarronville to connect Philadelphia with Columbia, Pennsylvania, situated on the Susquehanna River. The year was 1833 and William Noble, a local entrepreneur and the first to initiate business activities in the area, built a foundry, a blacksmith and machine shop, a waterwheel house, and a warehouse near the railroad route.[1] Between 1834, when Noble commenced operations, and 1863, when Isaac Broomell purchased the business, it followed a typical pattern of receivership, new partnerships and idleness. In fact, operations completely ceased between 1844 and 1846. From this latter year, however, the firm has been in continuous operation down to the present day. The Civil War and the entrepreneurial talents of the Broomell family were responsible for bringing order out of chaos.

Isaac Broomell was born at Doe Run, Chester County, Pennsylvania on November 23, 1813. He lived the first eighteen years of his life on the family farm, and was educated at the Green Lane Academy. In 1831, he left home and spent some time in Camden, New Jersey, learning the millwrighting trade. He returned to Chester County and in 1838 married Rachel H. Wilkinson. The issue of this marriage was five sons and two daughters. Two of the sons, Edward and Henry, were to dominate the Christiana Machine Company until 1916. Isaac was not content with the millwrighting trade; therefore, in 1852, he built a machine shop at Homeville, Pennsylvania, where he manufactured agricultural implements such as threshers.[2]

In the fall of 1862, James Boon, then owner of the foundry at Christiana and partner of James D. Reed, owner of the tools and equipment, approached Isaac Broomell about trading their property at Christiana for his property at Homeville. After giving the proposition "very careful consideration," Isaac decided to accept because "the boys were beginning to want to spread themselves."[3] The exact terms of the transaction are somewhat in doubt because the deed of transfer has the sum of $5,000 listed for real estate, but in a speech delivered in celebration of his fiftieth wedding anniversary, Isaac quoted the selling price as $5,500. In addition to this, he paid James Reed $1,500 "for all the tools, machinery and fixtures," making a total selling price of $7,000.[4] The 1860 Census lists the

capital invested in the business for both the foundry and machine shop as $6,000.[5] While it is impossible to tell from existing records which figure, $5,000 or $5,500, is correct, it seems certain that in either case Boon and Reed lost nothing on the transaction.

The depression in the early years of the Civil War did little to encourage Isaac; and, as he himself states, "most of our friends thought we were making a bad move this time, and it did look discouraging indeed . . ." Upon arriving at the plant at Christiana his hopes sank to an even lower ebb when he found "nothing doing in the machine shop and only two men in the foundry. We brought what tools we had in use at Homeville, added them to the few that were here, and with our own force commenced on the same kind of work we had been doing at Homeville."[6]

But the same Civil War which had made Isaac Broomell's move to Christiana look so risky soon gave the new venture the financial stability that the old foundry and machine shop had lacked since 1834. The three war-related factors responsible for this were the expansion in the agricultural sector of the economy, the cutoff of sugar molasses from the south, and increased demand for castings. Isaac had been producing agricultural machinery at Homeville and the plant at Christiana was also set up to produce this type of equipment, especially threshing machines. The 1860 Census shows that the plant produced twenty threshing machines valued at $2,500 and fifteen sorghum mills valued at $1,500, out of a total output of $9,100.[7] Thus when the demand for this type of equipment increased because of the war, Isaac was ready to meet it. Even more important was the loss of sugar molasses from the south because this created a demand for a mill to extract juice from sorghum. Isaac Broomell purchased the manufacturing rights for such a mill from Samuel Lewis Denny, the inventor and one-time owner of the foundry at Christiana. For these manufacturing rights Broomell paid Denny $500 and then sold the mill extensively in Maryland and Pennsylvania. Added to all of this was the fact that iron castings were in great demand because of the war, "all of which" according to Isaac "helped us financially, and led us to conclude that we had not made such a bad move after all. Money was abundant, such as it was; it took 185 cents to buy a gold dollar."[8]

The Broomells were staunch Quakers but tempered their religion in favor of the northern cause during the Civil War. Edward, in fact, was out twice with the militia but only got as far as Hagerstown, Maryland, before sickness forced his return. Isaac took consolation in the fact that he probably "did not shoot anybody."[9] At the age of 23, the tunes of glory behind him, Edward Grubb Broomell was given a partnership in the firm on April 1, 1864. Admission of a partner necessitated a change in the company name to I. Broomell and Son.

With the end of the Civil War, the demand for sorghum mills suddenly ceased, leaving a number of machines to be remelted and cast for other uses. After the war, and until 1868, the company

manufactured various kinds of agricultural implements, threshers and plow castings being most notable. Among the best customers of the foundry were the old forges on the Octorara stream from which I. Broomell and Son drew its power. All of these forges had been driven to the utmost capacity during the war and for some years thereafter, thus each required many tons of castings yearly to keep them in good repair.[10] The order books for the period 1863 to 1877 have not survived, so it is impossible to tell the exact magnitude of production over this period. But between 1863 and 1868, the Broomells purchased real estate amounting to $3,000 for both personal and business use. Also, according to Isaac, "the increase of work" required more power; therefore, the old breast water wheel was replaced with an overshot wheel eight feet wide and eight feet in diameter. It was made mostly of iron and was "an expensive job," Production must have been expanding because this wheel met the firm's power requirements "for several years."[11]

In 1868, the Broomells made a major shift in production when they contracted with Nathan F. Burnham to produce his turbine water wheel. Along with this occurred an expansion into mill machinery and power transmission equipment. The shift in production required the following changes. First, the substitution of two turbine water wheels (thirteen and one-half and eighteen inches) for the overshot wheel. This made the power source more reliable by eliminating the problem of ice clog in the winter. Secondly, an outlay "of several thousand dollars" was made for new patterns and machinery. Thirdly, in 1870 the Company constructed in addition to the machine shop, "consisting of a stone structure 70 feet long, 28 feet wide and two stories high" (the first floor was for the machine shop; the second floor for pattern storage). Fourthly, the labor force was expanded from nine to thirteen men in April, 1869.[12]

Table 1 shows the changes which occurred in the company over the period 1860 to 1880, as reported in Census data: capital investment increased five times, labor inputs two and one-half times, wages four times, and the value of final output more than four times. Falling price levels in the national economy between 1860 and 1880 make these increases larger in real terms than indicated by the monetary values in Table 1. This is a reasonably good record considering the situation prior to 1863.

On April 1, 1871, Thomas W. Broomell was admitted to the partnership, and the firm's name was changed to I. Broomell and Sons. But Thomas stayed only two years and withdrew from the firm on April 1, 1873, at which time Henry Broomell took his place. This arrangement continued until the fall of 1877, at which time a partnership was formed between the Broomells and Burnham. For six months the firm was known as Broomell and Burnham, but this was changed on January 14, 1878, when the Christiana Machine Company was formed with the purchase of half the real estate by Burnham. An undivided half interest cost Burnham $5,500. He paid

TABLE 1

CENSUS DATA FOR CHRISTIANA MACHINE COMPANY
1860, 1870 and 1880

	1860		1870		1880	
Capital Investment	$6,000		$17,468		$30,000	
Labor Employed	11		14		27	
Yearly Wages	$2,280		$ 3,763		$ 9,000	
Final Output and Value	20 Threshing Machines	$2,500	50 Turbine water wheels	$ 4,500	Value of Product	$38,000
	15 Sorghum Mills	1,500	44,000 pounds of Mill Gearing	3,520		
	30 tons of Castings	2,100	90 tons of Casting	5,200		
	Miscellaneous	3,000	Repairs	2,000		
		$9,100		$15,220		

Sources: U.S., Bureau of the Census, Seventh Census of the United States: 1860. Original Marshall's Report, Schedule V, p. 1; U.S. Bureau of the Census, Eighth Census of the United States: 1870. Original Marshall's Report, Schedule IV, p. 1; U.S., Bureau of the Census, Ninth Census of the United States: 1880. Original Marshall's Report, Schedule III, p. 1.

Isaac Broomell $4,962.37, and the remaining $537.63 went for payment of a widow's dower against the real estate.[13] The Christiana Machine Company retained this partnership structure until 1889, with occasional changes being made relative to the individual interests of the Broomells. Edward was made Secretary and Treasurer, and Burnham President of the company, at the time of its formation.

The existing records give no indication why the Broomells decided to shift from agricultural equipment to hydraulic turbines, but the decision seems to have been a wise one. Burnham had been in the turbine business since 1856 and patented his first turbine in 1859. He had developed a system of millwrights in the South and Middle Atlantic States to market his turbine. Thus, the Broomells had contracted to make an established product with an established market, which was readily adaptable to the plant's foundry and machine shop technology.

Nathan F. Burnham has been born in New York City on March 13, 1822, of English-Irish and French descent. His father was a millwright and Nathan worked with him in Orange County, New York until he was sixteen years old. He then turned to a series of occupations including watchmaker, mercantile clerk and bookkeeper. In 1856, he purchased manufacturing rights to the Van Dewater turbine, and produced it for three years at Laurel, Maryland. On February 22, 1859, Burnham patented his own turbine and later in the year sold his interest in the Van Dewater turbine, and moved to York, Pennsylvania. How he became acquainted with the Broomells is impossible to determine. Burnham had two sons, Frank and William, and together they organized Burnham Bros. of York, Pennsylvania to sell the turbines manufactured by Christiana.

In addition to his half interest in the Christiana Machine Company, Burnham was founder and president of the Drovers' and Mechanics Bank of York, Pennsylvania; was the largest stockholder and a Director of the York Opera House; and the largest stockholder in a local newspaper, the York Gazette. These other business interests limited his active participation in the day-to-day managing of the Christiana Machine Company; however, he did participate actively in the making of decisions concerning the manufacture of his patented products, expansion of the plant, and the setting up of branch offices.[14]

There is no record of the partnership agreement between Burnham and the Broomells. The Broomells each had a one-sixth interest in the partnership; together they held one-half interest. The actual management of the business was in the hands of the Broomells. Burnham never spent more than a week at a time in Christiana, but rather conducted his turbine business from an office in York, Pennsylvania. His major function, therefore, was control of the turbine aspects of the business. This included making estimates, taking orders and planning advertising campaigns. His role in the

decision-making process was limited to major decisions usually concerning products for which he held patents. Since he lived in York, business was conducted through the mail. The point to be emphasized is that his products were manufactured by Christiana on the basis of a written contract. With these products he exercised considerable authority in the decision-making process. But for products for which he did not hold patents, his role was of less impor-

A picture of Nathan F. Burnham from a Burnham catalog, circa 1889. Mr. Burnham died in 1890 and it is probable that this picture is of him as a younger man, for he was seriously ill for several years prior to his death. (Courtesy of Robert M. Vogel, Smithsonian Institution)

tance. At the shop in Christiana the following duties were divided among the Broomells: Edward kept the records, conducted the correspondence, and did most of the actual day-to-day managing; Henry's functions ranged from draftsman to engineer to pattern-maker, according to the need; and Isaac supervised the installation of turbines and mill machinery when the company's sales contracts called for this.

The Broomell family owned the foundry and machine shop at Christiana for all but eleven years (fall of 1877 to January, 1889) between 1863 and 1915. They purchased Burnham's half interest

in January, 1889, and the firm remained under their control until they sold it to the Bond Foundry and Machine Company, Manheim, Pennsylvania, in 1915. In the early 1920's, the Christiana Machine Company became part of the Charles Bond Company, Philadelphia, Pennsylvania.

CHAPTER II

NEW PRODUCT DEVELOPMENT, EXPANSION AND DESTRUCTION—1878 TO 1883

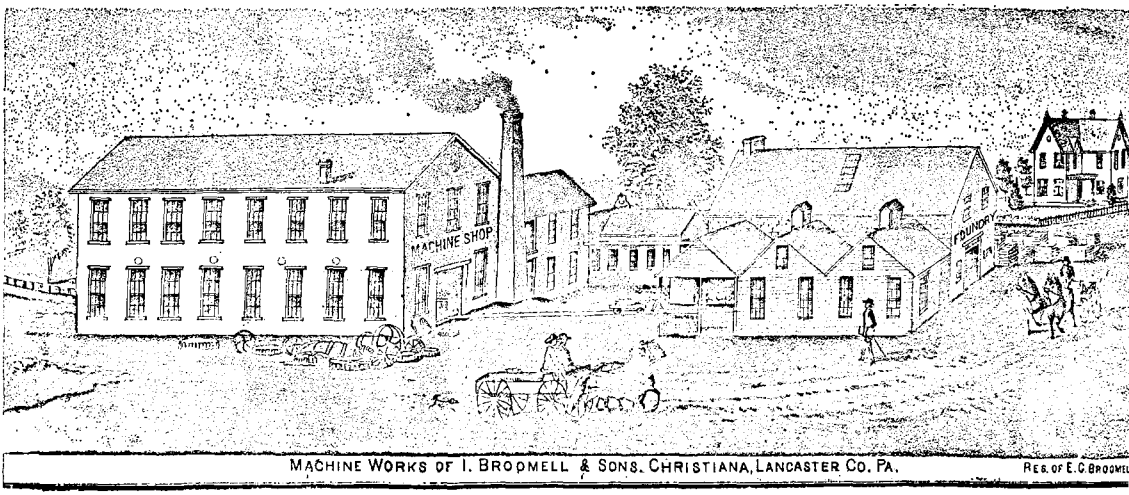
This chapter deals with the firm's expansion of its mill machinery products and machine tools. The standard production items before 1878 were hydraulic turbines and power transmission equipment. Between 1878 and 1883 the Broomells decided to integrate vertically by producing and selling a slide valve horizontal steam engine, a circular saw mill with a sixty-inch saw capacity, and a vertical flour mill. Boring and turning mills were also sold, but their introduction developed from the production of machine tools for the firm's own use. Burnham seems to have had a very limited role in making the decisions concerning these products.

The first mention of the slide valve horizontal steam engine came on February 2, 1880, when the firm offered to duplicate one it was making for its own shop. This was a ten by eighteen inch cylinder model with twenty horsepower, and "a new adjustable cutoff arrangement" by which the exhaust valves could be more closely regulated. Evidently the company needed more power and did not want to spend the required funds for a new steam engine, if it could be made more cheaply at its own plant. Wanting to save capital on both a new steam engine and a boring and turning mill, the company simply proceeded to design, cut patterns, and cast them. Once this was done the patterns could be used to make saleable items. The next step according to Edward was to get "a few of these engines in at prominent places" thereby stimulating demand by a demonstration effect. The engine was to be priced as low as possible consistent with a "fair profit."[1]

Once it was decided to make the engine commercially, patterns had to be cut for a full line of sizes if an inventory was to be built up and orders supplied promptly. This was very expensive, since pattern makers were the company's most expensive labor input, earning between $2.00 and $2.25 for a ten-hour day, compared to the $1.80 usually paid to machinists and moulders. The sales policy, therefore, was to try to sell engines of the size of the pattern already made, and not to make new patterns for other sizes until an actual order was received. With no inventory build-up or outlay for patterns, investment in the engine was at a minimum. A customer could expect prompt service if he happened to need a ten by eighteen-inch, twenty-horsepower engine; any other size would require a lengthy wait. With an inventory, delivery could be made

within a week; but if patterns had to be made, engines cast and machined, and then assembled, the customer could expect a delivery date several months after the order. The engine was to be in two styles, either automatic cutoff or plain eccentric slide valve, and was to range between three and seventy-five horsepower, with a price of $125 for the smaller and $1,750 for the larger engine. In spite of the above plan, total sales reached only two engines, and total production only three.[2]

One does not have to look far to discover why more of the new engines were not sold. Orders had to be turned down for lack of production facilities. The following letter, dated September 24, 1881, illustrates this situation:



From Everts and Stewart's 1875 Atlas of Lancaster County

> We are sorry we are not in shape to build such an engine as they will need, and will not therefore name price for it. We are so pushed and have so much more to do than we have facilities for that we have been compelled to decline some very good jobs, owing to this push, we have not got our cut off engine (automatic) completed but our H. Broomell is working on it and thinks he will bring it out. We hope by another season to be better prepared for business. Thought when we enlarged our works we would be able to do all that was offered, but are just as needy for room and machinery as we were before.[3]

Although only two engines were sold, Christiana could have sold many more if it had had the productive capacity. Plant and equipment were expanded substantially during this period but Christiana still could not keep up with all the potential orders. With only three engines made it is difficult to judge their overall quality, but the correspondence contains no complaints from the two custo-

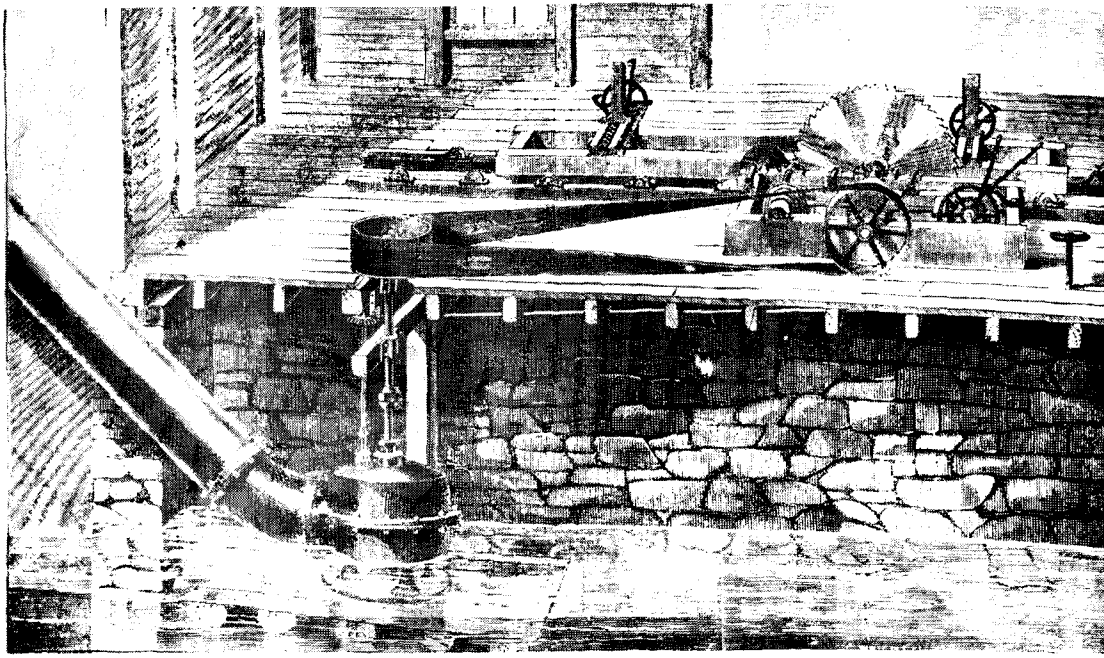
mers or from the partners about the one in the shop. In summary, the slide valve horizontal steam seemed to have both a potential market and a high level of performance.

The second new product of the period and one which fits in well with the firm's concentration on turbines and milling machinery was a circular saw mill. Estimates were given out for saw mills in 1877 and 1878, but the records indicate the first orders were received in 1879. The first mention of a new saw mill comes on April 23, 1880, with the following statement, written in reply to an inquiry about a mill: "Our circular saw mills have recently been changed and improved and we have no cut of them prepared yet."[4] This model was for very heavy work, using a saw sixty inches in diameter and sold for about $325 exclusive of circular saw. Eight months later a lighter version was introduced suitable for a fifty-inch circular saw. According to Edward: "This mill has been gotten up almost exclusively to supply the demand in southern states for a light cheap mill.[5] In total twenty-two saw mills, of both the lighter and heavier models were sold between 1879 and 1883.

The third new product of the period, a vertical flour mill, cannot be discussed in detail because little information is available about it. From the order books it can be ascertained that eighteen were ordered between 1878 and 1883; that it was a small farm type mill used to grind flour; and that it sold for about $100 list price, $85 net price, and $80 in lots of a half dozen. It was named the "American Farm Mill," and Edward considered it "so much superior" to "other mills of its class."[6]

Throughout the years 1878 to 1883, Christiana had expanded both its plant and equipment. Various machine tools were added and when these could not be obtained in the desired quality and price, they were made at the plant. As in the case of the steam engine, once the patterns were made any number of machines could be cast. Thus, as an incidental benefit from the construction of an eight foot boring and turning mill for their own shop, Christiana acquired the capacity to make them for other shops.

The Broomells' first approach was to try to buy machine tools secondhand. Edward summarized their view as follows: "Our object in asking for secondhand tools is this, to get good tools at low price. We know there are many tools standing idle that are almost as good as new and we think they can be had for less."[7] This policy lasted less than a week when, in response to their inquiry, they were offered a lathe secondhand for just $2 less than "the very best make in the country, of the latest improved design everything complete and perfect and a new tool," price $795.[8] Edward conceded in a letter to Burnham "no offer of boring mill (secondhand) at all and very few shafting lathes, none that would suit us. All prices named on secondhand tools are more than we can purchase same size for new."[9] Inquiries were sent to half a dozen machine tool producers, including William Sellers & Co., Inc. in Philadelphia, and the Niles Tool Works in Hamilton, Ohio.[10] Finally, it was decided to build an



This shows the layout of a typical sawmill powered by a Burnham turbine built by the Christiana Machine Company. Note that the turbine (lower left) drives a vertical shaft. The power is transmitted to a horizontal shaft to drive the saw, the blade of which is over five feet in Diameter. (Courtesy of Robert M. Vogel, Smithsonian Institution)

eight-foot boring and turning mill, because "we could find nothing that suited us in both machine and price."[11]

An eight-foot mill was finished in March 1897, and was an impressive tool, weighing 19,000 pounds and capable of trimming a pulley ninety-nine inches in diameter with a sixty-inch face. In a somewhat ironic decision, the Broomells opted to buy rather than to produce the step cone pulleys and back gears, concluding that "it will be cheaper to buy the articles than to make them."[12] In ten years, however, the Christiana Machine Company would be selling this type of power transmission equipment to the machine building industry to the exclusion of almost every other type of endeavor.

Almost two years passed before Christiana had time to make a boring and turning mill for an outside firm. As will be noted, the company made more turbines in this period, than in any other years of production. It was only after a doubling of plant capacity that the mills were made for outside firms. In October, 1880, Christiana had circulars printed of their mill, relating the necessary specifications to a potential purchaser. On January 22, 1881, Christiana's boring and turning mill was the subject of the lead article in the *American Machinist.* The pulley capacity of the machine described was still ninety-nine inches in diameter, but face size had been reduced from sixty inches to fifty-four inches.[13] Most probably, however, the mill was essentially the same as that made by Christiana in 1878-1879. A total of ten mills had been made, three for the company's own machine shop, and seven for outside firms. The

mills were sold in two forms: complete, that is, cast, machined and assembled, ready for installation; or alternatively, the rough castings alone on which the purchaser would do the machine work and the assembly. Only two mills were shipped outside the state of Pennsylvania, and both were complete machines.

At this point an attempt must be made to assess the quality of Christiana's boring and turning mills. It is most probable that their tool was equal to anything on the market. Although it was not a perfect copy of the Niles mill, the similarity between them is substantial. The Broomells had seen a Niles mill in operation in Philadelphia and felt quite sure they could make one comparable, but less costly. Niles' mill was probably one of the best in the country, since E. P. Bullard (a manufacturer who later became the leading producer of such machine tools in the country) did not have his mill in production until 1885.[14] One measure of a tool's quality is its life duration under conditions of heavy use. The Christiana Machine Company used their eight-foot mill to bore and turn thousands of pulleys. In busy periods it might run twenty-four hours a day, yet it was only removed from the machine shop in 1950, and was still operational after seventy-one years.[15]

Why the Broomells decided to sell mills two years after having the patterns cut is understood from the dates of the orders: four mills were ordered in the month of January, one in each of the months of December and February, and only one in the month of May. The mill was used to augment production in the winter months, or the "dull season," as Edward called it. Turbines and mill machinery were not in great demand in the winter, so in order to keep their labor force of about thirty men intact, the boring and turning mills were made. In the summer and fall, orders for the mills were refused in favor of turbines and mill machinery. During busy winter months the mills suffered the same fate as the steam engine: "We are at present doing nothing in Boring and Turning Mills and could not offer you one for some months. Have been unable to increase our facilities fast enough to supply all demands and were compelled to drop off something for a short time."[16]

Even when orders were not declined outright, the price was made so high and the delivery dates so distant that the order was often lost on the first inquiry. For E. P. Bullard, Edward named a price of $3,300 for the eight-foot mill, and $2,200 for the five-foot mill, with a discount of 10 per cent, and he wanted a delivery date almost five months in the future.[17] Needless to say, he made no sale to Bullard under these circumstances.

Some concluding observations on these products are in order at this point. They were developed during a period of frenzied expansion in the firm's productive capacity. All of them had one distinctive characteristic, that of being divorced from the firm's regular product line of turbines and power transmission equipment. The steam engine never really proceeded beyond the planning stage. Although the first engine was for their own shop, both Henry and

Edward evidently wanted to develop its commercial possibilities even before the shop engine was made. This was not so with the boring and turning mill: it was developed at first strictly for the shop, and only after letters of inquiry were received did the Broomells see its commercial possibilities. Both these items were viewed by the Broomells as an adjunct or supplement to their regular product line. When production could be optimized in their regular product line, the steam engine and boring and turning mill were "dropped off."

The years 1874 through the middle of 1879 were ones of depression. Business conditions improved in the latter part of 1879 with continued prosperity until the latter part of 1883. Christiana thrived throughout this period maintaining a high level of sales in its regular line of products. It sold 640 turbines, more than in any other six-year period for which data are available. Sales of other products included 2,590 pulleys, 1,068 pairs and 799 separate gears, 273 hangers, and 20,613 feet of shafting. Substantial demand for their regular products presented the Broomells with the problem of having to turn down orders for steam engines and boring and turning mills.

The saw mill and flour mill were complementary additions to the regular product line, and both were developed to meet conditions of a particular market. For the saw mill, motivation came from the Southern lumber industry with its need for a "cheap light saw," and for the flour mill it arose in the demand of "country mills" for a mill to grind small quantities of flour for a local market. All the patterns for these products were destroyed by the fire in 1883.

As already stated, both the steam engine and the boring and turning mill were developed as part of Christiana's expansion between 1878 and 1883. Over this five-year period the list of improvements is impressive. The first new structure was an office building with a fireproof vault, built in 1878. Debate over the second building began in December of 1879, and continued through the winter of 1880. The idea of building a new foundry seems to have originated with Burnham. Isaac Broomell was evidently not very happy with building prospects, as Edward's letter to Burnham would indicate: "Father got your letter concerning building and will give it attention think he is not much in notion of building now if it is not absolutely necessary."[18] But Burnham had the logic of excess demand on his side and Edward was forced to support him against his father. In reviewing the order books, Edward noted in a letter to Burnham on February 24, 1880, that they had among other orders, requests for thirteen turbines with additional machinery and concluded that ". . . we are going to be hard run when we have so much at this season."[19]

On May 3, 1880, the firm awarded a contract for building the stone work of a new foundry and machine shop. In order to save capital the firm contracted separately for each aspect of construc

tion, with competitive bidding on stone, lumber, roofing slate, box windows with sash, and even paint. Stone masons, bricklayers, carpenters, and all other necessary labor were also contracted for by competitive bids. A separate building account was set up in the books, and each of the partners in the real estate, Isaac Broomell and Nathan Burnham, paid half of building cost. Relations between the Broomells and Burnham must have been very good at this time because no formal articles of agreement were drawn up. On June 17, 1880, the last heat was run in the old foundry built by William Noble in 1834, and it was promptly torn down.[20] In order to avoid any loss of time for casting, the new foundry was built right around the old. Isaac describes this process as follows:

> On May 24th, 1880 the masons commenced on the walls of the new foundry, which was to be 88 feet long, 50 feet wide, and 22 feet high to the square, with a back building 54 feet long, 18 feet wide and 16 feet high to the square. We build nearly all around and over the old foundry, taking down the walls of the old and building the stone in the new, keeping the old foundry going until we had nearly all the walls of the new building up. Finished the roofing on July 13th, and the moulders commenced to work in the new building. About 600 perch of stone walls laid up in six weeks.[21]

The machine shop was begun on August 10, 1880. It was a building made of stone, fifty feet long, thirty-four feet wide and two stories high. In a month less four days the masonry was done. Both the foundry and machine shop were finished before freezing weather set in, and a smith shop was added in the spring of 1882, which necessitated the purchase of more land. Total cost of plant expansion was $3,500 for the foundry and machine shop, including a new cupola, and $1,500 for the smith shop exclusive of the $1,000 for the land. The total investment in expanded plant capacity, including land, was $6,000.[22]

For economists, the index of entrepreneurial skill is profit; and while the journal books for the firm have not survived, some information on profits can be gleaned from correspondence among the partners. Each partner received a salary, and any cash surplus was divided among them in proportion to their interest in the partnership. Burnham received $62.50 per month salary and the records indicate a cash dividend of $300 on January 24, 1882; $2,000 on December 29, 1883; $2,000 on January 15, 1884, and $600 on March 31, 1884.[23] This indicates substantial returns on his investment, and there is some evidence of the exact proportion. During one of those periods of "unpleasantness" between the Broomells and Burnham, they pointed out to him the following financial facts. His investment in the firm over the six-year period averaged $8,500, and his return was $12,796, which gave him a net profit of a little over 25 per cent per annum. Most of this return, of course, was in the form of an appreciation in the value of the business through reinvestment of earnings. This includes $2,500 in cash withdrawals but excludes a $2,000 insurance payment resulting from the fire, and rent payments to Burnham totaled $2,034 over the six-year period.[24] Deducting a 6 per cent opportunity cost, the rate of return

Edward Broomell and his wife Mary. Picture taken in York, Pennsylvania, in August, 1913. Mr. Broomell was a partner in the Christiana Machine Company for many years. (Courtesy of Mrs. Kenneth P. Jordan)

to Burnham, by the Broomells' figures, is still 19 per cent. An opportunity cost of 6 per cent was used because this was the rate of interest Christiana was charged when it borrowed from the local bank. Also mill owners were charged 6 per cent when Christiana financed the construction of a new mill or the installation of new machinery. These figures are probably fairly accurate because Burnham did not see fit to dispute them and quickly signed a five-year contract for the exclusive manufacture of his turbine at the Christiana Machine Company.

If it is assumed that Burnham's share of the profit is half the profit earned by the firm, then it would seem reasonable to double his profit to ascertain the firm's total profit. This total would amount to $25,592 for six years—a reasonable amount when compared with

the net profit for 1883, or $4,879.32.[25] As a rate of return on the total sales of $33,727 for 1883, net profit reached a respectable 14 per cent.

The two most important points to be made here are: first, profits over the period 1878 to 1883 were substantial with 1881, 1882, and 1883 being very good years; and second, all expansion and technical changes over the period were internally financed with the exception of an additional investment totalling $6,000 by Isaac Broomell and Burnham in 1880. In his speech, Isaac makes the point that "we must have made some money about these times, as we paid for all of these improvements as we went along."[26]

At 3:00 a.m. on October 1, 1883, the Christiana Machine Company had its machine shop burned and most of its patterns destroyed in what was presumed to be a case of arson.[27] The fire would have been much worse but for a fire pump driven by a turbine in the basement of one of the wooden buildings. It had two-inch iron pipes running out in various directions to plugs situated throughout the plant. To each of these plugs a two-inch fire hose was fitted, which was always ready for operation and could be started without going into the building. This display of Broomell ingenuity probably saved most of the plant from burning to the ground. Although the machine shop building was badly damaged, the machine tools inside were saved by being drenched with water. Edward estimated the cost of the fire as follows: "loss on patterns, $13,300; machinery stock, $5,088; buildings, $5,000. Total $23,833."[28] As already mentioned total insurance coverage was $11,000.

Most of the pulley patterns and some of the turbine patterns were saved by being in the buildings which did not burn, but Christiana was eliminated from the machine tool industry through the destruction of its boring and turning mill patterns. The reason why these were not replaced will be the subject of the next chapter. The machine shop was back in operation on a limited scale by October 26, 1883, and in full scale operation by November 11, 1883. It took fifty men working on the building and seven pattern makers working fourteen hours a day to accomplish this. In the short run, the effect on the firm seems to have been negligible and the Broomells treated the whole incident in a very matter-of-fact manner, giving the men "credit for their promptness in taking hold and working through good and bad weather, to do what they could to help us out of this difficulty."[29] It was in the long run that the fire had its most profound effect on the firm and on the men who controlled it.

CHAPTER III

THE BURNHAM AUTOMATIC STEAM ENGINE

In the six years prior to 1884, the Christiana Machine Company introduced four marketable products. All were destroyed prematurely in one fiery holocaust and were not reintroduced thereafter; instead an automatic steam engine designed by Burnham was introduced. Burnham, in a letter to Edward written two weeks before the fire, described his new automatic steam engine. Edward replied that three considerations prevented the company from manufacturing the engine at that time. First, the engine had never been tested; second, the company had no reserve funds to increase production facilities; and third, another member of the company was working on a similar engine.[1]

Most of 1884 passed with only occasional reference to the automatic engine. The main thrust of activity was directed toward making patterns for an advanced version of the Burnham turbine. Not until July, 1885, the depths of the depression, was it decided to exhibit two of the engines at the Novelties Exhibition in Philadelphia. Total cost for making and shipping the engines, including Thomas Broomell's expense in supervising the display at the exhibition, amounted to $297.33.[2] For this amount Edward could report to Burnham that Thomas said ". . . the engine is performing admirably and attracting much attention. All admitting that it gives the steadiest light of anything they have tried."[3] Perhaps it was this report that convinced Edward that the engine had real merit; Burnham of course needed no convincing.

Burnham suggested separating the production facilities and having Edward manage the turbine shop, and Thomas the engine shop. Edward advised Burnham that ". . . one man could easily handle the men for all until the business grew to be much larger than it would likely be for a year or two."[4] Burnham pressed the issue and Edward finally agreed to hire an assistant foreman in anticipation of "a business of some proportions" in automatic engines.[5]

What makes this so difficult to understand is that sales were declining in all of the company's products because of the depression. Total sales fell from $33,727 in 1883 to $22,287.14 in 1884, and, although no figure is available, the drop in 1885 was probably even more severe.[6] The obvious question arises of who was going to purchase the automatic engine.

Edward's first move was to turn away potential work which would have replaced engine sales. He had been approached twice about manufacturing a water motor, a small device that could be attached to a spigot from the city water supply to generate small amounts of power, but decided against manufacturing it.

The second move involved preparation for production. A drafting room was set up, and a steam coil was added for comfort. Ma-

chine tools were acquired with little regard for cost: a new lathe was ordered from Bullard for $400; a thirty-six inch engine lathe from Putman for $1,000; and a special combination plainer and shaper from the Walker Brothers in Philadelphia which must have been expensive though no price was mentioned. The third and final move was production for inventory and the creation of a marketing system for the engine.

With every contingency apparently anticipated, the partners awaited the verdict of the market. Nothing can bring an entrepreneur back to reality quite as fast as a lack of sales. Christiana sold only seven engines, five of these between December, 1885, and August, 1886. The first one gave so much trouble that eventually it had to be returned to Christiana. By May, 1886, Edward seemed desperate due to the lack of orders, but in June, when Burnham was ready to concede that he had made a mistake, Edward reversed himself and was not quite ready to give up. Edward's tenacity notwithstanding, the engine proved a worthless invention, and by January, 1887, even he was ready to admit defeat.

Burnham had a contract with Christiana to make his engine, although it may have been oral because no copy of it appears in company records. A statement of his engine account indicates that he did pay Christiana for the inventory made. In final settlement of Burnham's engine account, Edward was more than willing to accept $1,028.94, in his words "as full settlement for the engine business to eternity."[7]

The engine was a commercial failure, in part because it had never been technically perfected. Edward's first argument against the engine was that it had not been tested, but after he himself became financially involved, he saw little need for testing. The only report of testing is a casual mention of a two-week test of the engine in the shop which proved inconclusive.

Burnham had been experimenting with the engine, at least on drafting paper, in the early 1880's, and received a patent for a cutoff mechanism on March 27, 1883.[8] Close regulation of the cutoff valves would supposedly economize on fuel, and this was purportedly the purpose of the invention.

In February, 1886, Burnham filed for three patents simultaneously, all of which were granted on February 23, 1886. These three together with the previous one were the components of the Burnham automatic engine. The first was for an automatic centrifugal governor, the second was the vertical engine itself, and the third was a lubrication system. In Burnham's own words the engine was "to provide a cheap, simple, durable and effective automatic cutoff engine capable of running at a speed by means of a self-regulating governor, to provide a continuous, effective and automatic lubricating and to prevent the escape and waste of the lubricating materials."[9]

As Burnham and the Broomells soon found out, the engine was not cheap, simple, durable, or effective. The lubrication system was central to the operation of the engine. Proper lubrication of the crank shaft and bearings was essential because they were designed to operate at a constant high speed. It was here that the engine failed. After prolonged use, the bearings developed a loud knocking sound and the engine eventually ground to a noisy halt. The lubrication system was modified several times, and Thomas Broomell eventually eliminated the problem, but by that time Edward had had enough of the engine business to last him an "eternity." A second technical criticism was the fact that the engine's mechanism was not, as Burnham thought, simple; it was, in fact, rather complicated when compared with the horizontal slide-valve engine in common use.

Besides technical considerations, there was an even more important reason for failure. Given abundant time and effort both Burnham and the Broomells commanded enough technical knowledge to make the engine work properly, but reducing the cost of the engine to a competitive level proved to be the insurmountable obstacle. Miscalculation of cost of production was a serious blunder; the margin of error ranging from $10 to $92 and even though the estimated cost of the five by five engine differed from the actual cost by only $10 ($150 estimated, $160 actual), Burnham thought they would have to be made for $85 to $100 to be competitive. Edward saw this as impossible unless they reduced cost by "making great numbers of them."[10] After a number of the engines had been made it became apparent to the Broomells that the cost was excessive because of the engine's complicated design. Thus because of its inability to produce the engine at a sufficiently low cost, the Christiana Machine Company gave the responsibility for the engine's production to Burnham, who in turn gave it to his sons, and there it died.

The decisions concerning the Burnham engine were primarily made by Edward because Henry had withdrawn from the partnership in February 1885 and Isaac had retired from active participation in the firm in January 1885. Thomas still had an interest in the firm but acted as the general foreman in the shop and did not seem to take an active role in developing the engine. This situation continued until Burnham's share of the firm was purchased jointly by Isaac and Edward in January 1889. Early in the 1890's, Henry again joined the partnership and participated actively until the firm was sold in 1915.

At this point we must analyze why so many wrong decisions were made by the company's management. Before the fire Edward had been very skeptical about the automatic steam engine, but afterwards he began to see its possibilities. The production facilities of the shop were relatively undamaged and quickly repaired. Also, the shop was equipped in such a way that it could produce a wide variety of capital goods, from machine tools to hydraulic turbines.

The fire did destroy the patterns and a system of priorities had to be established to get back into production. Patterns had to be made immediately for those orders already entered in the order books, and then for gearing and turbines, the mainstay of production since 1868.

The depression of 1884 made investment in any innovation look very risky. Given Burnham's assurances that concentration on turbines and steam engines would give the firm all it could do, manufacture of them seemed to be the easiest way to reduce or eliminate the risk involved in reintroducing the earlier products. If the firm were operating at maximum capacity, it would indeed have been a waste of money to invest in patterns for a horizontal engine, saw mill, flour mill, or boring and turning mill. Even if the four pre-fire products had been emphasized rather than the automatic engine, however, it is doubtful that the firm would have fared much better in the short run, due to the adverse effect of the depression.

In the long run, however, the boring and turning mill would probably have been a much better investment than the automatic engine. With the end of the depression, inquiries started coming in about the mill. In fact, two previous purchasers, Craig Ridgway & Son and Edward Allis & Company, Milwaukee, Wisconsin, each wanted another mill, a good indication of its quality. Inquiries continued to come in to such an extent that the Broomells seriously considered reintroducing the mill, but the reason that this and the other pre-fire products were not brought back in the long run had nothing to do with lack of decision or with the insistence of Burnham. Instead two shifts in the firm's market and product line account for the lack of interest in reintroducing the pre-fire products. The first was a shift in market from the Southern milling industry to the capital goods industries concentrated in the Middle Atlantic States. The second, a concentration on a different type of power transmission equipment. After 1887 Christiana's products were used predominantly in the manufacture of machine tools, cement mixing and brick forming machinery, and iron foundries and steel mills.

CHAPTER IV

THE BURNHAM TURBINE

The Broomells incurred substantial losses in introducing the Burnham improved standard turbine in 1884 because of a fear of losing Burnham's turbine account. To understand the basis for the Broomell's fear, it is necessary to understand the importance of the Burnham turbine for the firm between 1868-1884. The logical starting point is Burnham's involvement in the company and its decision-making apparatus. First, he owned one-half of the real estate, from which he received quarterly rent payments. Secondly, he held an undivided half interest in the company, meaning the partnership. Thirdly, and perhaps most important, he held exclusive patent

rights for his turbine.

His turbine account was kept separate in the company books. Burnham was charged for each turbine sold at a contracted shop price but his selling price was a substantial mark up over shop price. If the customer paid Christiana, which was usually the case, the turbine account was credited with the shop price plus Burnham's royalty. If the customer paid Burnham's office in York, Pennsylvania, the turbine account was debited for the shop price. Quarterly, the account was balanced either by a royalty check to Burnham or a bill for turbines shipped. Burnham was not charged for inventory. Although the company cut the patterns and manufactured the turbine, the original design and patent rights were Burnham's exclusively. Thus he could threaten to remove the firm's major production item in order to get his way. Since he owned the patterns and would not have to get new ones cut, this could be done almost instantaneously in the absence of a legal contract to the contrary, if he could find another shop to cast, machine and assemble them.

Christiana started manufacturing the Burnham turbine in 1868, and the 1870 Census provides some information on its relative importance. A total of fifty turbines valued at $4,500 were sold, in addition 44,000 pounds of mill gearing valued at $3,520. Repair services were valued at $2,000. Not all the mill gearing or repair services were sold with turbines but probably a substantial amount. Total sales amounted to $15,220; therefore, turbines and products and services sold directly with them account for about one-half to two-thirds of total sales.[1] Company records provide more exact information for the period 1878-1883. In all, Christiana sold 640 turbines, but equally important was the large quantity of power transmission equipment ordered with them.

The Broomells had a very strong incentive to placate Burnham in order to retain his turbine account, thus when technical problems developed with the new turbine introduced in 1884, the resulting losses from the technical problems were absorbed by the company. Instead of trying to handle the risk arising from the uncertainty of introducing a turbine of their own, they kept on producing, modifying and repairing Burnham's turbine. The depression of 1885 probably did much to make them emphasize the security of an established product rather than develop one of their own.

Burnham had worked on turbines for many years receiving his first patent on February 22, 1859 for a modification of the runner or wheel itself, that part of a turbine upon which the water reacts.[2] The turbine was a substantial invention and one which became standard, with some modifications, on all the turbines produced by Christiana. Not only did it increase the machine's efficiency when operated with a partially opened gate, but also, according to one of Christiana's later catalogues, "the water acting against it has a lifting tendency thus reducing the friction on the step bearing."[3] The step supported the runner, vertical shaft, coupling, and bevel gears or pulleys. Given the weight of these parts, and the fact that the

step was made of "hardwood," Burnham's contribution becomes obvious.

Burnham spent the next fifteen years developing and perfecting this turbine, and incorporated into it not only his own improvements but also those of other inventors. Five patents were issued to him between 1859 and 1872, all of which culminated in the Burnham standard turbine, introduced in 1874. This turbine attained a level of performance comparable to the turbines of the leading firms in the industry.[4]

First mention of a new turbine came in February, 1883, when Burnham inquired if the shop was able to start work on a new model. Plans were made to start work on it, but little was done until after the fire, when introduction of the new turbine was pushed ahead rapidly. It would have been senseless to cut patterns for the old style (1874) turbine with a new one already patented.

Unfortunately the gate, which regulated the amount of water flowing into the turbine, never attained the level of performance the turbine itself achieved. This became the major field for Burnham's inventive endeavors in the 1880's. Pressure toward constant improvement in the efficiency and operation of the turbine was unending not only from other firms but also from Edward Broomell, who felt that the 1874 model turbine was becoming obsolete:

> We know of course that the time is not far distant when your present wheel cannot be sold at very high prices and are desirous of doing what is best for all concerned . . . as soon as you have a wheel perfected that will give good results all through and not be worthless on account of its many parts and liability to wear out in short time we will be ready to join you in bringing it into use.[5]

Burnham received letters of patent for his new turbine on March 27, 1883, and again the object of his invention was increased efficiency, especially at part gate.[6] According to a Burnham Bros.' catalogue, Burnham had tested the turbine's efficiency quite deligently. "Whole gate" efficiency increased by 3 per cent and "part gate" efficiency between 2 and 10.7 per cent, but the turbine's efficiency had never been in doubt.[7] It was the performance of the gate mechanism which needed testing, and this was not done.

Burnham wasted no time in getting his new turbine from the drawing board to the production line, but while doing so he made several serious mistakes. He started much of the "unpleasantness" between himself and the Broomells by constantly pushing them to complete the patterns for the new turbine and at the same time insinuating that they did not appreciate the importance of his turbine trade. Edward replied that he doubted if Burnham "appreciated the immense amount of work we have had to do to get things in good shape for business in so short a time."[8]

To make matters worse, Burnham complained bitterly about the high cost of having patterns made at Christiana. Edward was completely unable to understand Burnham's reasoning, as Burnham

was charged only for labor and lumber. Those parts made of iron and brass were not charged to him nor were the plates on which the turbines were cast. Edward had four pattern-makers working on Burnham's turbines and was willing to add as many as the shop could accommodate if Burnham would pay the extra expense. This, however, he refused to do. An agreement settled the initial charge to Burnham for the new patterns, but by establishing a contract price based on completed patterns Edward unwittingly trapped himself. When problems arose with the gate in the new model turbine, Christiana eventually had to bear considerable expense of pattern modification.

As already illustrated, one of the reasons the automatic engine did not succeed was the failure to perfect it technically before placing it on the market. In his haste, Burnham made the same mistake with the turbine. Managerial decisions were not very sound during the depression of 1884, but the failure to test the new turbine can be taken as the most serious entrepreneurial error.

Burnham's 1884 turbine was considerably larger than the 1874 model; it was made to be deeper and thus produced one-half more power but with proportionately less water. Increasing the size of the turbine made the problems with the gate much more acute thus to combat this, Burnham developed a system of rollers to open and close the gate. It was here that the turbine failed to perform properly. The old model gave Christiana very little trouble, but the new turbine was so much larger that the gate became a major technical problem. A second difficulty, arising from the increased size of the turbine, was how to cast it without getting spiderweb cracks. These two problems did much to dissolve the relationship between the Broomells and Burnham.

By September, 1884, Edward had worked up a large inventory of turbines with the rollers, but three months later the "bugs" had still not been worked out of the gate mechanism. Christiana was carrying an inventory of between forty and fifty turbines, all of which had been changed twice at Christiana's, not Burnham's expense and still needed "further changes."[9] To make matters worse, the Broomells' system of customer payment made them, not Burnham Bros., feel the brunt of any customer dissatisfaction because they were often forced to extend credit to obtain the sale. If the turbine's performance was not satisfactory, Christiana suffered the loss not only on it and on any power transmission equipment or mill machinery sent with it but also freight to and from the factory.[10] When the roller gate mechanism gave a customer trouble, Edward tried to blame Burnham Bros., but to no avail, he could see no reason why the company should bear this kind of loss. Needless to say, Burnham Bros. thought that bill collection was the Broomells' responsibility, and here the impasse developed. There was much heated debate over this issue, but in the end the Broomells conceded the point by sustaining the cost of making the wheel as good as it was guaranteed to be.

The technical problems involved in correcting the gate mechanism were quite formidable, even the smaller turbines operated very poorly, and all that were shipped had to be sent back to Christiana for repair. Edward made the point to Burnham that the rollers on the ten and one-half inch turbines "that came back were every one stuck fast and took a good deal of work to get them so they would turn at all."[11] Over the next three years several different systems were adopted for a short time, including one system of staying arms and another of posts to control the gate, but none proved satisfactory. It was this problem which set the stage for Henry Broomell's balanced-gate turbine.

Alienation of millwrights and mill owners must have been serious, because Burnham Bros. emphatically reassured the milling trade that the problem had been solved, while Edward wrote many letters to millwrights reassuring them of the turbine's quality, while at the same time disassociating his firm from it and from the Burnhams:

> How is trade with you we notice you send us no orders this summer, has our work not been satisfactory? We trust the trouble you had with the Burnham wheel is not operating against us. We make the wheels for them, but they are always made as directed. We never liked the roler sic arrangement and said all we could (not to make ourselves obvious) against them. We think the wheel as now made will and is giving entire satisfaction. If you can't patronize Burnhams in the purchase of wheels, we would at least like to have some of your orders for machinery.[12]

Burnham's final solution to the gate problem was a worm gear housed between the cover plate and the curb of the turbine, which was patented May 1, 1888.[13] This arrangement proved too powerful for the mechanism involved:

> We are very sorry to hear of the misfortune with the worm gate gear. We had hoped there would be no more trouble with this arrangement and that we could go right along and put up a stock of wheels. Now it looks as though the arrangement is too powerful and that if anything should get in the gate the gearing will be very likely to be broken. A man's strength applied in such a way is sufficient to either break something or shut the gate.[14]

The gate proved a continuous source of difficulty for Burnham Bros. Nathan's illness and death in December, 1890, prevented his technical skill being fully brought to bear on the problem. His sons, Frank and William, did not possess their father's inventive skill; thus it was left to the Broomells to find a reasonable solution. The Burnhams eventually rationalized that the gate problem was the Broomells fault and resulted from improper construction. Edward assured them that this was not the case:

> We are in receipt of your favor of yesterday, and note what you say in reference to the probable reason of your gate working hard, being that the gate and stay arms do not fit properly. We assure you this is not the case, we are very particular and every piece is turned to gauge.[15]

Cost of the various changes in the turbine patterns was very

high. Edward estimated the cost of pattern changes from rollers to staying arms, to guide posts, back to staying arms, and finally to the worm gear mechanism, equal to "as much as the original cost of patterns."[16] Christiana bore the cost of these pattern alterations, but the point was finally reached at which Edward warned Burnham "it will be impossible for us to stand all the losses of various kinds, alteration as innumerable as in the past . . . we ask nothing unreasonable but would like to do your wheel work so there will be a little profit in it . . ."[17] Burnham's refusal to pay for pattern alteration, except as a part owner of Christiana, explains much of the animosity between the two families in the late 1880's.

The gate problem is not only important in terms of the development of an invention (Henry Broomell's balanced gate turbine), but also as an illustration of incorrect decision making. The period between 1884 and 1889 was characterized by too much dependency upon Burnham's judgment. Edward allowed himself to be maneuvered into a contract price for pattern work based on Burnham's reassurances that the gate, as first designed, would work properly. When it did not, Christiana bore the increased production costs to insure retaining Burnham's account after the technical problems were solved. Little is gained by dwelling on the point and perhaps the increased costs can be viewed as the price Edward paid for a "business education." Nevertheless it is worth noting that Edward was not one to repeat his mistakes. After the partnership's dissolution he was soon to learn that Burnham's opinions were not missed and that his turbine was easily replaced.

In the light of subsequent events, the Broomells handled uncertainty improperly with regards to the Burnham 1884 model turbine and the automatic steam engine. The most rudimentary steps to hedge against the risk of loss were not taken. Product testing, cost control, determination of potential market, and others, were precautions which could have reduced the substantial losses the firm took on Burnham's inventions. The losses the firm experienced during the 1880's resulted in dissolution of the partnership and corporation. From the tone of the letters among the partners in the last months of 1888, bitterness must have been running high. At one point the Burnhams held a board of directors meeting without bothering to invite the Broomells. Edward and Isaac, of course, rejected the results of such a meeting: "Your favor of the 18th inst. recd., and in reply we wish to say that any action taken by our board of directors at a regular meeting will be duly considered. Your communication signed by individuals you of course cannot expect to be regarded as the action of the Association."[18]

In spite of the petty "difficulties," or more accurately because of them, the stockholders met on January 14, 1889, to work out a settlement. During this meeting, Isaac purchased Burnham's shares of the stock at par value, a total cost of $15,000, as well as the Burnham half-interest in the real estate for $10,000.[19] To pay for this, Isaac issued $21,000 first mortgage bonds bearing 6 per cent inter-

est. All of these bonds were sold to local people, except for a $4,000 block which the Burnhams took. There is no indication in the records why the Burnhams took $4,000 worth of bonds instead of insisting on cash. The company's books at this time showed an undivided cash surplus of $1,651; the accounts receivable and the accounts payable about balanced each other, and the book value of the firm, real estate included, equalled $51,651. Isaac completed the transaction by selling half of the real estate and company to Edward which made them equal partners. The corporate charter was allowed to lapse.[20]

CHAPTER V

THE BALANCED GATE TURBINE

Thus far the dominant figure in the development of the turbines produced by Christiana has been Nathan F. Burnham; but in 1889, Henry Broomell patented his own version of the Burnham turbine. First mention of the new turbine in company correspondence appeared exactly two weeks after the Broomells purchased Burnham's half of the firm. Yet the development of the balanced gate turbine, as it was called, had been in process for the previous four years. In fact as early as January 1885 both Henry and Edward had seemed quite willing to share with Burnham their solution to the problem of the gate rings, at that present stage of development. Edward wrote Burnham: "We have Henry's plan for opening water wheel gates made to put on a 30" wheel and will have it attached in a day or two and want you to come and see it when ready. It is very simple and does seem to be the right thing and if adopted would simplify the wheels very much . . ."[1] A second letter, written three days later, confirmed the above statement and even described Henry's balance gate invention.[2]

Burnham wanted no part of it, and within a month Henry had left the partnership, while Burnham pursued as many inadequate solutions as he could contrive. He evidently did not believe the Broomells had the inventive capacity to solve such a problem. In less than four years he was to learn otherwise.

Between 1885 and 1889 the Broomells were exposed to all the data essential to modifying the gate mechanism and various other features of Burnham's turbine. The Broomells probably did enough testing to realize that Henry's solution in theory (which must have been its form in 1885) would work in reality. They had been exposed to Burnham's experiments and had the benefit of knowing what would not work. The Broomells, as the actual builders of Burnham's turbines, were in a much better position than Burnham Bros. to understand not only what was technically feasible, but also the requirements of the milling trade. The problem of the gate arose because:

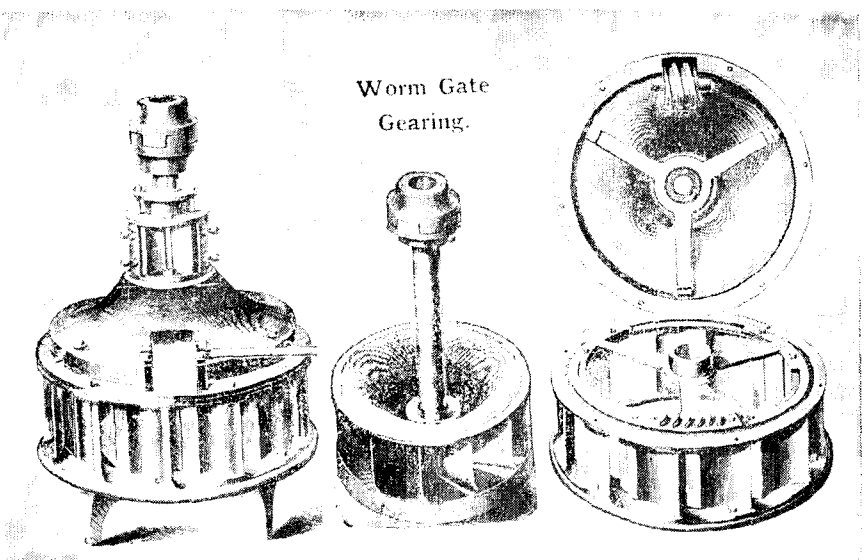
> All wheels of that style have a side shaft, what is the gate is opened

by some device on one side of the wheel and the motion tends to make the two large surfaces of the gate and curb rub together—to alleviate this they are all made with gate and staying arms, intended to centre the parts and keep them from rubbing, but very soon the action of the water on the iron and the motion especially where a governor is used wears the gate arms. And then the large surfaces comes in contact and the result is that the gate is very difficult to operate . . . The wheels are now made with a worm to open the gate which makes a powerful motion but does not do away with the defective principle of the side draft.[3]

To eliminate this problem a gate mechanism had to be designed which would operate the gate by bearing on two diametrically-opposite points with equal force during the act of turning. The mechanism also had to be "self adjusting in order to compensate for slight irregularities in construction or those due to wear, thus maintaining a balanced draft."[4]

The modification of Burnham's basic style turbine, which Christiana introduced in 1889, involved more than an adaptation of Henry's balanced gate mechanism. Several other changes were made and proved of substantial value. The Broomells did away with the packing-box formerly used "to prevent the water from gaining access to the wheel through the shaft-space," and substituted for it a collar called a splash ring.[5]

A second change was in the follower-box, which was mounted above the splash ring at the top of the turbine proper and was used



Pictures showing details of the worm-gear gate on a Burnham turbine. This type gate was one of several employed in an effort to overcome the gate problems that plagued the 1887 model Burnham turbine. (Courtesy of Robert M. Vogel, Smithsonian Institution)

to steady the shaft between the runner and the coupling. Inside the box were spacers, called followers, whose tension on the shaft could be adjusted by three set screws extending through the follower-box against the followers. The Broomells changed the followers from wood to brass because "our experience is that few persons pay any attention to tightening up the follower, hence the shaft gets loose, and wears itself and box and follower."[6]

The third change is difficult to explain because the problem which led to it had not appeared in company records before the Broomells brought out their own turbine. Edward told a customer that Burnham always had trouble with the water discharging from the "bottom of the wheel." Edward explained the problem:

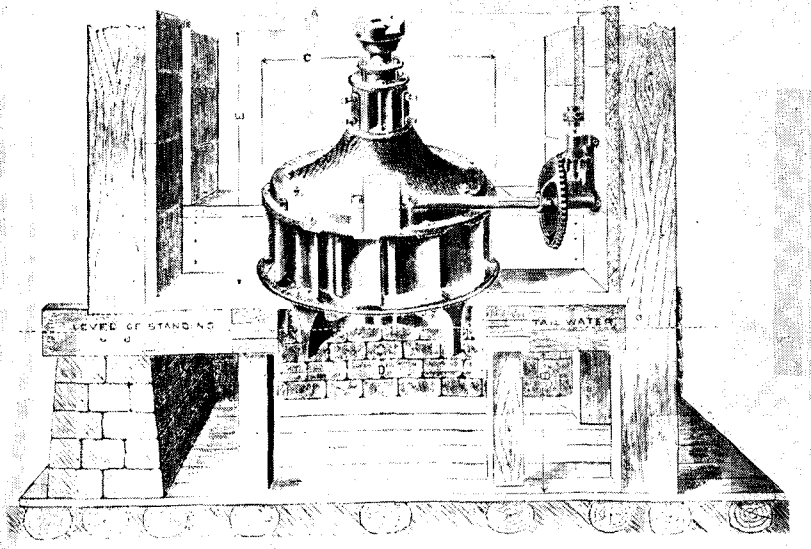
> We also changed the form of the wheel proper and did not run the buckets so near the center, and in order to get ample discharge, and to avoid the objection urged by many, that the band catches grass, etc. and clogs the passage, we extended the lower part of the wheel below the gate, that is putting the band beyond reach of anything, thus giving the water a wide and free discharge and instead of putting the wrought iron band on the wheel from the bottom which we found from experience, was not a good plan, owing to their dropping off in many cases, we put it on from the top and rested it on a turned shoulder and with the outer edge of the buckets curved, as you see by cut, which makes a very handsome and strong wheel.[7]

The fourth change was in the design of the case. Those turbines sold in iron cases were so designed that, after four bolts had been removed, the entire turbine could be taken from the case. The change involved making the "outer case with a deck plate" which could "be taken off, and the wheel put in and taken out without removing the case from the pipe."[8] This change facilitated maintenance and parts replacement. A reduction in the depth of the turbine was the fifth change. Edward claimed that Burnhams':

> . . . object in changing their patterns when they came to be renewed after our fire, was to compete with other wheel makers by giving an equivalent amount of power for a given diameter wheel. You know there has been a craze among wheel men for deep wheels, and they thought necessary, or at least advisable to make their wheels deeper than before, so they increased the depth one-half . . .[9]

The Broomells saw Burnham's increase in the size of his 1884 model turbine as a serious mistake. Given a chance to compare both the 1874 and 1884 models, they realized the earlier one had given much better service. They reduced the depth of the wheel "about 1/9, thus giving it 8/9 of the power and discharging 8/9 as much water as the Burnham."[10]

The sixth, and final, change was not a change in technology but rather a change in production policy. Over the course of years Burnham had changed many times the dimensions, chute design and gate mechanism of his turbine. Christiana, as manufacturer, was faced with the problem of supplying replacement parts for a bewildering array of various Burnham turbines. When the Broomells decided to produce their own turbines they were not going to repeat Burnham's experiences. Edward outlined the new policy in October,



A vertical turbine with worm-gear gate as it appeared when installed in a Penstock. Note that gearing to control the gate is at right of turbine. (Courtesy of Robert M. Vogel, Smithsonian Institution)

1889, before many of their wheels had been sold:

> All the wheels from the start will be made so any part can be duplicated, this has always been difficult to do in the case of the Burnham wheel for they have changed so often.[11]
>
> Another important matter that we propose to see to from the start is that any piece of one wheel will fit any other wheel. This we were never able to do with the Burnham because of the numerous changes and complications.[12]

In summary, the Broomells made five changes in the design of Burnham's 1884 model turbine, not including the major change in the gate mechanism. Besides these, a policy change was made in the attempt to inject more uniformity of design and thus to facilitate parts replacement.

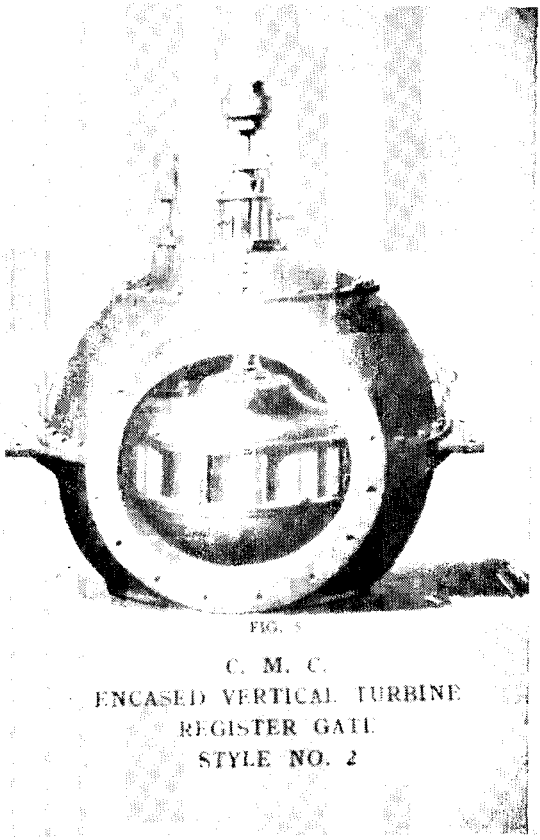
Previously, when Burnham had made a misjudgment, either of a technical or of a business nature, the Broomells seemed to suffer more than their share of the consequences. This time, however, things were different. When Burnham had made his first sales offer in 1883, it was with the provision that the Broomells neither make nor sell turbines. By 1889, he evidently thought it unnecessary to include such a condition in the terms of sale. Nine months later he discovered his error! One can only imagine Burnham's surprise, if

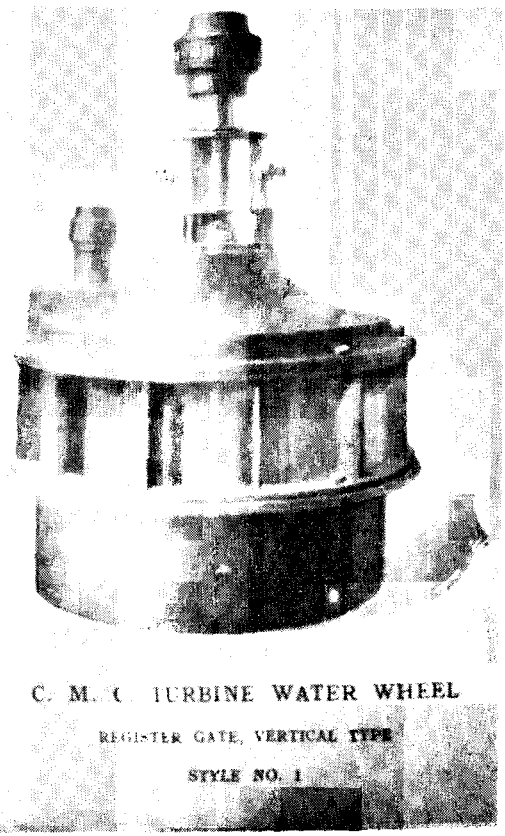
not shock, as he sat in his Presidential office of the Drovers & Mechanics Bank, of which he was president, founder and half owner, to learn that his $75 per month ex-partners had outmaneuvered him. He evidently found out from one of his millwrights and hastily dispatched a letter asking for confirmation. Edward replied stating the Broomells' position:

> You have been correctly informed in reference to our commencing to advertise a Water Wheel in the Oct. number of the American Miller. We have been working on this wheel quietly, for some months and received letters patent on it, Sept. 3, patent referring principally to the arrangement for opening the gate. We have attempted, we think successfully, to avoid infringing on any ones patent, in getting up this wheel of which I think you will be fully satisfied when you have a chance to read the description of it, which you can see in the American Miller above referred to. At present we have no printed matter of any kind to send you, having used what prints we had from cuts in arranging for circulars etc. Several things have had their influence to induce us to bring out this wheel: one of the particular ones being that we had no permanent arrangement made with your sons to manufacture their wheels, and the price received for them considering the fact that we have to carry as much stock, and sell comparatively little, is not sufficient inducement to tempt us to try to make a permanent arrangement with them. We feel also that water wheels are directly in our line of trade and it seems almost a necessity to have some one to build or sell.
>
> Of course, when we start in on this new wheel, we cannot expect your sons to remain longer with us, but while they are here, we will do everything we can to furnish the wheels promptly, and assist them in every way possible in their business, until they are established elsewhere. You remember that all through the earlier part of the season the water wheel orders were comparatively nothing, and it was quite discouraging in view of the fact that we had so many wheels on hand ready to put up. Still we waited several months before we decided to go into the building of another wheel, but now have our minds fully made up, and while we do not expect to push it very hard at first, we hope to build a trade finally. As soon as we have some printed matter, we will send you a copy.[13]

It is impossible to tell how much of this letter Burnham actually believed, but it is possible to determine what parts of it were for his benefit exclusively. In the first place, the attempt "to avoid infringing on any ones patent" was aimed directly at him, since Christiana's turbine was a direct imitation of his, with some important modifications. Edward made this point to one of Burnham's customers, "our wheel is not radically different in general features from other register gate wheels, and is very similar, in many respects to the Burnham wheel we have built for a number of years."[14] Secondly, instead of their having worked on the new wheel for "some months," Edward confided to O. J. Seibert, that the new wheel had been "planned for two or three years, but we had no intention of bringing it out or putting it on the market while Burnham's were in our Co."[15] Given Henry Broomell's patent, granted September 3, 1889, there was nothing Burnham could do but accept the fact that he had one more competitor.

If the Broomells had been planning to bring out a new turbine "for two or three years" why did they wait so long? Again the an-





A Burnham turbine with worm-gear gate, circa 1889. This was one of the last models of Burnham turbine manufactured by the Christiana Machine Company. (Courtesy of Robert M. Vogel, Smithsonian Institution)

Right: A vertical turbine with register gate, shown encased. (From the author's collection)

swer seems to be a security motivation as opposed to a maximum profit motivation. The introduction of a new innovation in 1886 would have contained a sizeable risk factor because of general business conditions. The Broomells' "general expectations" about business conditions were such as to exclude breaking into an industry already overcrowded with firms. James Emerson's testing records indicate at least eighty-three firms.[16] These, of course, were only the firms which had their turbines tested at the Holyoke testing flume, Holyoke, Massachusetts, and many did not.

By 1889, business conditions had improved, Henry Broomell had solved the problem of the gate, and the Broomells had the City markets (discussed in chapter VII) as alternatives if the new venture did not succeed. Yet in terms of handling uncertainty, the Broomells made several serious misjudgments. First, the technical problems of gate mechanism seem to have been solved as early as January, 1885; instead of dropping Burnham's turbine and concentrating on their own, they continued to produce his and take the losses. Second, if they had developed the balanced gate turbine in

1885 and 1886, they would have been in a good position to take advantage of improved business conditions in 1887. As it turned out, they did not sell more than thirty-six turbines in any year before 1898. Between 1889-1915 they sold 661 turbines, just twenty-one more than the 640 Burnham standard turbines sold between 1878-1883. This brings us to the final and most serious error in judgment—the size and purpose of the balanced gate turbine.

Christiana's new turbine was designed to be a primary power source in small milling firms. It had been reduced in size and power by about one-ninth of the 1884 Burnham turbine. Yet the national trend was in the opposite direction, as noted in the 1900 Census:

> While the number of water wheels in use had decreased from 55,404 in 1880 to 39,182 in 1900, a loss of 16,222 wheels, or 29.3 per cent of the number in use in 1880, the aggregate power of the wheels in use increased during the same interval from 1,225,379 horsepower to 1,727,258 horsepower, a gain of 501,879 horsepower, or 41 per cent. This very large decrease in the number of wheels and great increase in the aggregate power points to the large increase in the size of the units, which in 1880 averaged only 22.1 horsepower each, but which in 1900 was 44.1 horsepower, or twice as large. This is due to the abandonment of many small wheels of antiquated type and the substitution therefore of fewer units of larger size and greater efficiency. In many instances, too, it has been necessary to abandon entirely the use of waterpower, either because of failing supply or the larger requirements of expanding industry, and this has removed a considerable number of wheels, mostly of small size.[17]

The implications for the turbine for generating electricity at the beginning of the twentieth century were literally unlimited. By 1960, turbines drove "about 95% of all electrical power-producing generators in the world."[18] To take advantage of what has been called the "second industrial revolution" would have required extensive and continuous changes in Christiana's turbine technology. The Broomells made some changes in their turbine technology to take advantage of the shift to hydroelectricity, but all their turbines sold specifically to drive generators were comparatively small units.

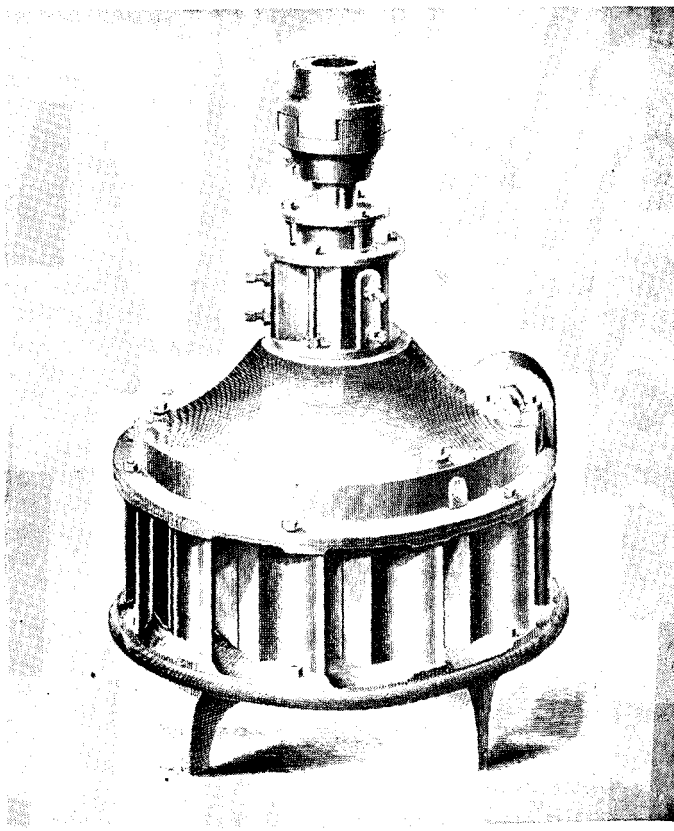
No record exists showing how many of the Burnham turbines were used for this purpose, but Edward claimed a "number" were used to drive dynamos. Christiana's records for the balanced gate turbine permit a more exact estimate to be made. Christiana developed a horizontal turbine, so designated because the drive shaft extended horizontally from the machine. It was designed primarily for high water pressure and high speed to drive electric generators. The company made its first horizontal turbine in 1895, and made in all 144 of them.

Yet in spite of this the Broomells did not want to expand their production facilities to accommodate the larger turbines. Edward explained the situation to Burnham Bros. in 1892:

> We have some doubt whether we could handle a 42″ Horizontal Wheel made as shown by plate #3 on page 8 of your catalogue. This is an awful heavy arrangement, weighing, according to our esti-

mate, about 18,000 lbs. The case would have to be so large in diameter in order to get the necessary capacity or space around the Wheel that we do not believe we could turn it on our lathe. We have not made an actual drawing to determine this, but have made a rough sketch, and this is the conclusion we have reached. It would require a Base Plate something like 16' long, and, of course, it would have to be heavy in proportion to the weight of the Wheel set on it. If we can make it at all the cost would be in the neighborhood of $900.[19]

This was a fundamental error in the Broomells' assessment of the future demand for turbines. They were unwilling to handle the uncertainty of expanding their plant and equipment to produce large turbine units. Yet the firms which concentrated on the large units for hydroelectricity underwent the greatest growth, i.e., James Leffel, Springfield, Ohio; S. Morgan Smith, York, Pennsylvania; and I. P. Morris, Philadelphia, Pennsylvania. Each of these firms started in the turbine industry by producing small units for the milling industry, but because the dominant firms by concentrating on the larger units for hydroelectricity.



A vertical turbine with register gate, built by the Christiana Machine Company, circa 1910. (From the author's collection)

The balanced gate turbine represented an attempt to maximize security instead of profit. It was designed to service a market that Christiana had catered to since 1868—the milling industry concentrated in the Middle Atlantic and Southern States. But that market was in decline and a new one, hydroelectricity, was rapidly taking its place. The Broomells' failure to develop their capacity to make large turbines probably accounts for the firm's lack of growth compared with the industry's leading firms. Thus, while the balanced gate turbine was a legitimate innovation for the firm, it did not go far enough in meeting the economy's requirements for a larger, more powerful turbine technology. The Broomells' timidity in developing this type of technology goes a long way in explaining why the firm's growth was severely limited.

CHAPTER VI

DISSEMINATION OF CHRISTIANA'S TURBINE INNOVATIONS

This chapter has a two-fold purpose: first, to describe the dissemination of Christiana's turbine innovations; and second, to prove that Christiana's turbine development represented legitimate technological improvements. The actual technical improvements were discussed in great detail in the previous chapter. Here the objective is to show how extensively those technical improvements were disseminated, thus indicating their worth by the degree of acceptance of the milling industry.

An innovation can be evaluated in two ways: first, on the basis of physical distribution; that is, the quantity sold in a national or international market, or within a particular geographical or industrial sector of a national market; and second, on the basis of the number and the importance of the firms which imitated the innovation. Each one of these points will be discussed in turn; but initially it is necessary to determine the economy's aggregate demand for water power, or, conversely, its demand for turbines, as well as the total number of turbines Christiana sold.

The total production of horsepower by water "grew from 1,130,000 to 1,765,000 horsepower between 1869 and 1919," but this was dwarfed by the increase in horsepower produced by steam, which grew from 1,216,000 horsepower in 1869 to 13,840,000 horsepower in 1919.[1] During the same period, water power decreased from 48.2 per cent to 6.0 per cent as a source of the primary-power capacity in manufacturing. What this meant for Christiana was a continuous decline in demand which eventually reached a point where turbines could not be sold at any feasible price in relation to the cost of production. In the milling industry, most flour and grist mills, saw mills and textile mills, had shifted to steam or electricity. Since this represented Christiana's major market, the effect on its turbine trade is obvious. A review of the company's sales data illus-

trates the decreasing demand for hydraulic turbines.

The Broomells had started producing the Burnham turbine in 1868. For the next ten years they produced the smaller sizes with Burnham having the larger ones produced in York. With the formation of the partnership in the fall of 1877, Christiana began to produce the Burnham turbine exclusively. In May 1878, Edward wrote the Pennsylvania Railroad, inquiring if a crane could be installed at the Christiana station, because "we have now ordered a number of heavy water wheels, and they will be difficult to load without a crane."[2] Christiana continued to produce the Burnham turbine exclusively until at least 1889. It is impossible to determine from company records when Burnham Bros. began production at Glen Rock, or if the decline in Christiana's output in 1892-1893 was the result of the move to Glen Rock or of the oncoming depression of 1895. In any event, Christiana completely ceased production of the Burnham turbine in 1893.

A total of 1,291 Burnham turbines were sold by Christiana between October 29, 1877 and December 31, 1893. The most Christiana sold in any one year was 128 in 1881; it sold 100 or more in four successive years, 1879 through 1882. The 1890 Census indicates that 13,988 turbines were in use by flour and grist mills, saw mills and cotton ginning. If all of Christiana's Burnham turbines sold between 1878-1889 were in operation at the time of the Census, then Christiana's share of the market would amount to 7½ per cent.[3] This seems an appropriate share of the market considering that there were more than eighty-three firms in the industry in the 1880's. As for the balanced gate turbine the company records indicate that 805 turbines were sold between 1889 and 1948. In the four years between 1879 and 1882, Christiana sold one hundred or more turbines in each year. Sales peaked in 1881, with 128 turbines sold. But from 1883 until Christiana sold its last turbine in May 1948, the company never regained the level of sales of the 1878-1882 period. After 1907, Christiana never again sold as many as twenty turbines in any one year. The economy's shift from water power to steam and electricity as prime movers in manufacturing was the major cause of Christiana's declining sales of turbines.

With the quantity of turbines sold by Christiana established, it now becomes possible to discuss their geographic distribution. But before proceeding, it is necessary to present, for purposes of comparison, the distribution of water power in the national economy between 1869-1919. The economy's demand for water power peaked in 1909 in all geographic divisions and declined slightly by 1919; in terms of importance the North comprised of New England, the Middle Atlantic States, the East North Central States, and the West North Central States was most important in the use of water power increasing over the period from 81.9 per cent in 1869 to 84.4 per cent in 1919, with the absolute increase in horsepower more than doubling for New England and increasing over 60 per cent in the

other areas which comprised the North. The South, composed of the South Atlantic States, the East South Central States and the West South Central States, increased its use of water power a little over 9 per cent, while its relative position in terms of total water capacity declined from 16.3 per cent in 1869 to 11.4 per cent in 1919. By contrast, the West, composed of the North Pacific States tripled its use of water power and increased its percentage of total water capacity from 1.8 per cent in 1869 to 4.2 per cent in 1919.[4]

Based on these aggregate data of the economy's use of water power, the major market for turbines should have been New England and the Middle Atlantic States, but Christiana's distribution contradicts the national trend. The principal reasons for the unusual geographic distribution of Christiana's turbines were the early business activities of Nathan Burnham in developing a system of millwrights to act as manufacturer's agents in the South; the high concentration of the milling industry in the South before the Civil War; and the development of a turbine technology to meet the specific needs of the southern milling industry. Contrary to the aggregate national trend in the use of water power, Christiana shipped 60 per cent of its Burnham turbines to the Southern States —and an even higher percentage in individual years. By contrast, New England and the Middle Atlantic States together received only a little over 29 per cent of Christiana's Burnham turbines for the period. The Middle West and North Pacific coast states received only 7 per cent of total sales. The international market, which included Europe, South America and Canada, received a little less than 4 per cent of total sales.

To conform to the national trends Christiana would have had to ship the bulk of its output to New England and the Middle Atlantic States, which utilized about 83 per cent of the nation's water capacity. The South's use of water power, between 1879-1889, actually declined both in its absolute and in its position relative to the rest of the nation. Horsepower declined from 194,000 to 185,000, or from 15.8 per cent to 14.8 per cent of the nation's total water power.

The situation changed after Christiana started selling its own turbines. The South still received the largest percentage of any geographic area—42 per cent; but this is a considerable decline from the 60 per cent for the Burnham turbines. In the distribution of Christiana's balanced gate turbine, New England and the Middle Atlantic States received a little over 38 per cent, and the North Pacific States increased slightly to 8 per cent of Christiana's sales. The international market, comprising South America almost exclusively, increased to 12 per cent of Christiana's total sales. The most notable shifts in the data would seem to arise from a decline in the southern market, especially after 1901, and a movement into the South American market after 1900. There was also a noticeable shift to the Middle Atlantic States. Of 1291 Burnham turbines, Christiana shipped 271 to the Middle Atlantic States; but from 805 of their own turbines, Christiana shipped 268 to the Middle Atlantic

States. Proportionally, Christiana shipped 21 per cent of the Burnham turbines as opposed to 33 per cent of its own to the Middle Atlantic States. It would seem that the data for Christiana's own turbine conforms more closely to the national trends in the use of water power.

The unusual geographic distribution of the Burnham turbines is explained by the early business activities of Burnham. In 1856, Burnham, with S. P. Heath, a partner, purchased manufacturing rights for the Van Dewater turbine in the State of Maryland. Burnham Bros.' catalogue claims that Burnham and Heath operated at Laurel, Maryland until Burnham sold out in 1858, purchased manufacturing rights for Pennsylvania, and moved to York.[5] The patent records in the National Archives, however, contradict this by showing Burnham's address as Laurel Factory, Maryland. Patent files contain personal correspondence between Burnham and the patent office dated February 2 and 7, 1859, with the Laurel address.[6] This means that Burnham may have produced the first version of his own turbine in Maryland, not in Pennsylvania as is stated in the catalogue.

Burnham patented his first invention on February 22, 1859; less than three months later, he sold "one of our 22-inch Improved Jonval Turbines" to Brightwell & Davis of Farmville, Virginia.[7] It is easy to understand how Burnham became interested in turbines, since his father, with whom he worked until 1838, was a millwright. He was not one to miss an opportunity; therefore, drawing on the millwrighting experience of his youth, he must have been impressed with the turbine as a potential substitute for the old style waterwheels.

The initial impetus for Burnham to start production of the Van Dewater turbine at Laurel, Maryland is explained by the high concentration of the milling industry in Maryland and Virginia. By 1860, Baltimore was both a great milling center and flour market. Approximately one million barrels of flour were marketed annually, about half of which was milled in that city, with the rest brought in from the surrounding counties.[8] In 1860, the state of Maryland had 424 flour mills and, while the number of mills decreased, "capitalization grew larger, machinery more specialized, technique more skillful."[9] Kuhlman concludes with the statement that "in 1825, it was claimed that Baltimore was the largest flour market in the world. In 1860, it was second only to New York."[10] Richmond, Virginia, ranked third in importance with 400,000 barrels of flour milled annually. Among other things:

> Her chief advantages were the water-power of the James River and the wheat supplies of the James Valley and the interior valleys of Virginia. Just before the Civil War, Richmond was drawing wheat from eastern Tennessee, western North Carolina, and northern Georgia. Her mills were the largest of the time and the first to illustrate the advantages of large scale production.[11]

It was not coincidence that Burnham started production in

Maryland and sold his first patented turbine to a flour mill in Farmville, Virginia. Burnham's decision to move to York was probably caused by the unsettled political conditions prior to the Civil War. After the war, he continued to cater to the southern market. Since the majority of Burnham's turbines were sold through millwrights, a network of millwrights in the south explains why the bulk of turbine sales occurred in that area. Burnham's desire to cater to the southern market is well illustrated by his attempt to set up a sales office in Richmond, Virginia, in 1878. Edward summarized Burnham's plan as follows:

> You propose to rent a store in Richmond Va., and make it head quarters for the sale of your wheels. You propose also to keep in stock wheels belonging to Christiana Machine Co., together with samples of various other articles manufactured by same Co., and that in order to conduct the business to advantage for the Co., as well as yourself, you ask that the Co. furnish two assistants in the persons of your sons Frank and Willie, and that they be allowed and paid for their services by the Co., the same as though employed here, and be subject to same article of agreement as entered into when our Co. was formed.[12]

It was not until October, 1879, that Burnham actually moved to Richmond and set up his office. But by January, 1880, "his wife's health failing he moved back to York, Pa."[13]

A third reason for the concentration of Burnham turbine sales in the south was that Burnham's turbines were designed to meet the specific needs of the southern milling industry. They were small units, built with a vertical shaft to operate under low water pressure. By contrast New England's textile industry required large turbine units, built with a horizontal shaft to operate under high pressure and produce large quantities of horsepower per unit. As already noted, Christiana's failure to develop such a turbine technology was a major misjudgment.

The importance of the millwrights is seen in Edward's constant attempt to get a foothold with other firms' millwrights: "We notice you are agt. for the Leffel Wheel but you may now and then come across parties who will not buy it and in such cases you can recommend our wheel as first class."[14] As long as business conditions were prosperous, the Broomells and Burnham made every effort to protect the millwrights by refusing to sell to the mill owner directly at less than list price. But with the onslaught of a depression, the situation changed radically. In March 1886, Edward wrote J. M. Seibert assuring him that they would do what they could to protect their millwrights by making their prices as competitive as possible:

> Our prices thus far for present year are about as they were last year. We made nothing last year and as materials and labor are no less in price but a little more on many things there seems to be no chance to get down much on our goods. At same time we want to retain your trade and will do the best for you we can at all times. And when you have any considerable order to place we will be glad to have a chance to put you in competition with others, and if beaten will not complain.[15]

Yet two months later Edward wrote Burnham that protection of the "middle man" was impossible, given business conditions:

> . . . I am confident as you say that the time is about past for selling any kind of goods where there is any competition at fancy prices or even at prices that will afford much for 'Middle Man.' Times are extremely dull as all admit, and manufactures will do anything to make a sale hence those who attempt to protect agts. in good fat commissions are left almost every time. So it seems to me that some arrangement should be made to sell at a reasonable profit on manufacturing prices and sell more goods to make up the difference.
>
> . . . Now if you can think of any plan by which goods can be sold direct to consumers at fair profits and in good quantities let us 'go for it'.[16]

So much for protection of the trade. But the millwrights, even when directly "cut out" of a commission on a contract, tried to get something for their "influence." Edward, mindful that when the "dull season" was over the millwrights would again order much of his turbine output, usually made some concession. The following letter illustrates this situation, and it is also a splendid description of the lack of collusion in the industry:

> Burnham Bros. have sent us the correspondence between you and them concerning quotations on Machinery to Cherokee Falls Mfg. Co. We are very sorry our trade in general, cannot or will not adopt some fixed rule of discounts to consumer and the trade so that the trader could have certain protection. As it stands everyone works on his own book and sells all he can at what he can get. Hence when it is not known there is a millwright interested all are very likely to cut close to secure the order. We are sorry we could not have known you were interested in this cash. As it stands, if this order when received is such that it will offer you anything we will be pleased to give you a little on it.[17]

With the end of the 1884 depression, Edward set about the task of rebuilding his network of millwrights. The split in the partnership in 1889 provided him with an excellent opportunity to blame everything on Burnham Bros. There was also the added incentive of attempting to induce Burnham's millwrights to patronize Christiana's balanced gate turbine. The fact that Christiana sent 42 per cent of its turbines to the South is a good indication that Edward was at least partially successful. Below is part of a letter to D. J. Hyden, Lyndhurst, Virginia, one of Burnham Bros. best millwrights:

> You will remember in June, 1886 Burnham Bros. commenced to advertise that they were selling their wheels at "Cost at Manufacturing and Advertising" (rather a thin statement to make as they have since learned). Well this had the effect to almost kill their business for the past two years and to regain it, they were forced to advance prices and reemploy their mill wrights, and allow them a fair commission, hence they felt they should manufacture their own wheels and save that little profit our company was getting on them. So now that we have bought them out and declined to build the wheels at prices they offered they are about buying an old defunct Co. at Glen Rock near York which they will put in shape and as soon as our stock of wheels is worked off they will be made there. We will continue the business under the same name and management as heretofore and will serve our customers with the very best goods in our

line at reasonable prices. And we are preparing to put a water wheel on the market in which the objectionable features of their wheels will be as far as possible avoided. If you are under no obligation to Burnham Bros. or their wheel we will be glad to explain about what our wheel will be and as soon as we have some printed matter ready will supply you. We have always considered you **our** customer and hope to retain you.

Please treat this confidentially and drop us a line, whether or not you must continue to sell the Burnham wheel if we can satisfy you we have something better.[18]

It would be interesting to know who Burnham Bros. blamed for circumventing millwright commissions — most probably the Broomells. Edward, of course, was blaming the Burnhams for something for which he had seen the necessity two years earlier. When the depression of 1896 struck, and firms in the industry cut prices to restore sales, Christiana was forced into the same situation. Having no one to blame, Edward had to concede it was company policy: "You know, of course, how it was during these times, everybody is fighting to make sales and will cut rates as low to consumers as to dealers often in order to make a sale, and to protect ourselves we have to do some of this same kind of work."[19]

The Broomells were responding to an industry structure and market conditions totally beyond their control. Emerson's description of the industry's "ruinous competition" was no empty phrase. When sales dropped and prices were lowered to check that trend, the millwrights were the first to feel the squeeze. The fact that after every depression Christiana went back to dealing through millwrights is a good indication that they provided a valuable marketing service that only a depression could negate. Since the Broomells had no traveling sales force in the South, the millwrights became in effect manufacturer's agents. At one point the Broomells were considering using one of their employees as a traveling salesman, but this idea did not materialize because Burnham refused to give them exclusive control of Pennsylvania and New York for sale of his turbines. They proposed this because S. Morgan Smith and other turbine manufacturers were visiting various mills in an attempt to expand sales. Thus, Christiana's dependency on the millwrights was substantial, and this explains why they were only "cut out" when depression conditions made drastic price cutting necessary to maintain a minimum amount of sales. By 1914, the economy had shifted almost entirely to steam or electricity, and Edward, looking back on the demise of the millwrights, eulogized them as follows:

Referring to this water wheel business, some few years ago, the trade was nearly all handled by local mill wrights, who sold them to their customers and received a small commission on the wheels, and generally they sold in connection with them quite a bunch of machinery for milling purposes of various styles. You know of course that the local milling business, as far as flour making is concerned, has almost ceased, and that work is done by large mills principally in the West . . .[20]

A break down of industrial users of Christiana's turbines by

type of manufacturing operation was constructed from testimonial letters which appeared in one of Burnham Bros.' catalogues and one of Christiana's. A total of 176 letters were printed in the two catalogues, and of these 98 contained a notation of the type of firm using Christiana's turbines as a power source, including 96 in flour and grist mills, 38 in saw mills, 18 in cotton gins, and 4 in cotton presses. There is double counting in the sense that some turbines were used to drive machinery for more than one of the manufacturing operations. For example, J. S. Gramling & Bro. of Gaffney City, South Carolina stated that "we run a saw mill under 8 foot head, also a grist mill and a cotton gin under the same head."[21] This was not an uncommon practice, for twenty-one letters mention a combination of the manufacturing operations. Also, the use of more than one turbine was not uncommon—twenty-five letters mention more than one turbine in use. One saw mill in Ontario, Canada was "using six of your wheels, all sizes from 9 to 36 inches, under heads varying from 16 to 33 feet . . ."[22]

While this is a very small sample of the total number of turbines sold by Christiana, it does present at least some empirical data on industrial users. It also seems to conform well to aggregate national data for the use of turbines. In 1889, the use of turbines was concentrated in "flouring and grist mill products;" this industry had 10,157 turbines producing 234,310 horsepower out of a total of 752,365 horsepower being utilized.[23] Second in importance was "lumber and other mill products from logs or bolts" with 3,763 turbines producing 112,218 horsepower out of a total 961,316 horsepower being utilized in the industry.[24] This is notable because sawmills were one of the first, and the largest single users of steam power as early as 1838.[25] Thus as late as 1889, sawmills used turbines to produce about 12 per cent of the industry's power capacity. Census data for cotton ginning show only sixty-eight turbines producing 961 horsepower out of a total of 28,731 horsepower.[26] These data would seem to indicate that the industrial users of Christiana's turbines conformed closely to the national data.

The testimonials also mention a variety of other industrial activities. A thirty-six inch turbine was used to power "wheel and spoke machinery" for the Penn Yan Wheel Co., Penn Yan, New York.[27] H. W. Jewett & Co., Gardiner, Maine, was using three turbines and "sawing over 10,000,000 feet of long lumber a year, with one rotary saw, with a 48-inch wheel under 14 foot head; two shingle machines and Clopboard machine on 36-inch wheel; gang-edger and double lathe machines on 42-inch wheel . . ."[28] Two letters claimed Burnham's turbines drove "wool-carding" and "woolen machines," also "planing and notching machines"; and finally, two cotton factories, a knife factory and a paper mill were also mentioned.

With such a large number of firms in the industry and so many styles of turbines, it is impossible to determine exactly how extensively Burnham's innovations were imitated. Both Burnham and

the Broomells were well aware, however, that patent infringement was rampant throughout the industry, and company records contain some discussion of the situation. Product differentiation was limited in some cases to catalogue advertising. An interesting example of this is the Lancaster Wheel Company, Lancaster, Pennsylvania. This firm imitated Burnham's 1874 model turbine to the extent that on two different occasions it ordered outer cases for its turbines from Christiana. The records are marked "1-15" Old Style Outer Case" and "1-18" Outer Case from Old Pattern."[29]

A second imitator can be traced directly to Christiana's own foundry. The name of the firm was the Mercer Wheel Company, West Chester, Pennsylvania. Edward wrote the following about the Mercer Company:

> . . . we manufactured the Burnham Turbine Wheel for 25 years or more and while we were building it a man by the name of Mercer who was one of our molders in the Foundry, conceived the idea of getting up a wheel of his own. He copied the Burnham wheel we were then making as closely as possible to evade any patents, and having no means to conduct the business he sold out to T. B. Mercer, a man of the same name but not at all related. This man had the wheels made by some machine shop in West Chester, Pa., for a few years, but the establishment was burned out and all of his pamphlets, patterns, etc., destroyed. As his business had been very limited it did not seem worth while to continue it so it was dropped entirely.[30]

The firms presented thus far were small, serviced a local market, and lasted only a few years. For example, the Lancaster Turbine Wheel Co.'s catalogue lists forty-five turbines in the testimonials covering the period 1885-1893. Of the forty-five turbines, thirty-four were sold in the state of Pennsylvania, and only eleven elsewhere.[31] But the third imitator, S. Morgan Smith, York, Pennsylvania, was the exception. Bidding against Smith, Edward noted a patent infringement by Smith on the Burnham turbine:

> Replying to your fav. concerning Turbine Wheels would say the Success sold by Mr. Smith of York, Pa. is for anything we know a fairly good wheel, it is a combination of several. We know it to be an infringement on the Burnham and was so decided by legal process and he now pays Mr. B. a stated sum on each size wheel sold. Mr. S. has the reputation at home of being a sharper, and as one of his neighbors (a Mr. Small) remarked, if you deal with him at all have all down plainly in black and white or he will take advantage of you.[32]

Using Burnham's basic innovations, and those of other entrepreneurs, Smith developed a turbine technology suitable for hydroelectricity. Unlike the others, S. Morgan Smith became a major firm in the turbine industry. In 1907, a local history of York County described the firm as follows: "This company, employing 500 men, has installed a turbine outfit in the city of Jerusalem, in the Holy Land, and many of them in Japan and Russia. A number of these wheels are in use in the Niagara Falls power houses, being the only American make of wheels in those plants."[33] S. Morgan Smith was purchased by Allis-Chalmers in 1959.

The fourth imitative firm was the Christiana Machine Com-

pany, with its balanced gate turbine, introduced in 1889. Enough has been said elsewhere to make repetition unnecessary here. It must be noted, however, that from Christiana's balanced gate turbine there appears the fifth and final imitator mentioned in company records. Technically, this imitator differed from the others in that he paid voluntarily to use Henry Broomell's balanced gate turbine. Of course, Henry had never compensated the Burnhams for their father's "earlier" contributions to his turbine. On May 20, 1901, Henry received a letter from Carlos Mendizabal, Baracaldo, Bilbao, Spain, inquiring if he would sell manufacturing rights for his turbine in Spain. Henry had been receiving 10 per cent of Christiana's selling price as royalty for his balanced gate invention and this was his initial offer to Mendizabal.[34] After some hard bargaining, Henry eventually settled for 5 per cent.[35]

On September 24, 1901, Henry sent Mendizabal the drawings and a contract for his signature. Henry heard nothing from him until June 3, 1903, when he was informed that Mendizabal had built a "modern and up-to-date plant" and had started manufacturing "Turbine Wheels and other machinery." Henry was "a little surprised" to learn that Mendizabal's first turbine was a "double one," because he had supplied no drawing for that style.[36] How many of Christiana's turbines were made in Spain, it is impossible to determine; although Henry did receive a royalty check for $21.48, and furnished turbine blueprints of "our latest improved construction."[37] No further information appears in company records, although Henry may have carried on a private correspondence. In the last letter to appear in the copy books, Henry wrote Mendizabal "so far as our dealings are concerned, it is an individual matter and the name of my company need not appear on anything that you may have occasion to send me."[38] With this statement the matter disappears from Company records.

What has been presented is information on only those firms which imitated Burnham's inventions and whose imitations were mentioned in company records. Undoubtedly, there were many other imitators but exact information is lacking. In Burnham's personal statement to his customers he warns them that "an inventor is 'one who finds out something new.' A patentee is 'one to whom a grant is made, or a privilege secured by patent.' In the wheel business there are few of the former, but many of the latter, with worthless claims."[39]

CHAPTER VII

THE SHIFT IN MARKET AND TYPE OF POWER TRANSMISSION EQUIPMENT 1887-1914

The year 1887 was a landmark in the firm's development. Decisions concerning new products and markets determined the trends in the firm's production to the present day. These decisions offer

a contrast to those made concerning the Burnham automatic steam engine and the Burnham improved standard turbine. The depression of 1884 had made Edward Broomell very security orientated; however, by 1887, business conditions had improved: "There certainly can be no reason why we can't make some money if times are at all fair and the indications all point to good times in the near future."[1]

Which of the partners first suggested attempting to cultivate the Philadelphia "trade" it is difficult to say, but from the tone of the letters it was most likely Burnham. He suggested setting up an office in Philadelphia, and while Edward conceded "that a place in Phila. if properly handled would pay the Co.," he also added it "would have to pay its way or it would soon swamp us since we have no money now days to spare."[2] Unlike the automatic steam engine, everything from the beginning was "properly handled." The first things that had to be done were the redesign of pulley patterns and a general canvass of the Philadelphia market. Edward had been corresponding with individuals in Philadelphia concerning Christiana's pulley patterns as early as September, 1886:

> We are glad to have the suggestions concerning our pulleys. We have known for some time that some of our small pulley patterns were not just what they should be when it came to factory work which we presume is where you use most of them. So we will have patterns overhauled and try and make them suitable for your trade.[3]

Before 1887, Christiana's pulleys were designed to transmit small quantities of power in the milling industry. But the capital goods industries, manufacturing machine tools, cement mixing machinery, brick machinery and steel mills required greater strength and accuracy of design to transmit the greater horsepower necessary to drive such machinery. Adaptation of Christiana's pulley patterns to meet the needs of the capital goods industries was a major technological change in the long run. Besides modifying pulley patterns, Edward wrote Burnham that "Thos. is going down [to Philadelphia] this afternoon or tomorrow morning to run around and see what he can do in way of finding new customers . . ."[4]

The results of these preliminary activities confirmed Burnham's prognostication and convinced Edward that the Philadelphia market had great potential. John Seibert, one of Christiana's employees, was sent to Philadelphia to rent office and store space commencing January 1, 1887. It was decided to rent "a half interest in the room and basement store" at 206 North Fourth Street, Philadelphia from the J. D. Petty Co. "for $325 annual rent and one half the gas bill."[5] Expectations for the success of the new venture were running very high. Edward estimated that the expansion into the Philadelphia market would mean "at least doubling our business."[6] To illustrate further Edward's expectations of success, the following letter to Burnham shows what Edward expected and how he expected to accomplish it:

> Now if we put two men in Phila. (a larger place than Christiana, and many more chances to strike good jobs) whose duty shall be

solely to work up trade I fail to see how it can result otherwise than at least doubling our business. Then if we can reasonably expect to double our trade, we should be making preparations to fill the orders that may come promptly. We should have men enough in the Foundry to cast every other day and shortly every day. And enough in machine shop to use up the castings as fast as made aside from what we ship in the rough. Which should be a good deal in a short time. I think we should make the work and then force the sales, not make the work after sales are made, except of course such as must of necessity be made after it is ordered. To do all this we must have more working capital. I would say we should have $5,000 cash capital so we can work to good advantage, carry a good stock of sum and work up everything in lots. After we are started we should either borrow money as a Co. or get some one to take stock to above amount and I think the first would likely be best. There certainly can be no reason why we can't make some money if times are at all fair and the indications all point to good times in the near future. Already many large concerns have orders for months ahead, and this is all the better for small establishment.[7]

What makes this situation so different from the episode of the automatic steam engine, for example, is that Edward completely underestimated the demand for pulleys in Philadelphia and the other city markets. By June 1, 1887, Edward wrote to a local customer that "we have a big run on pulley castings and are shipping hundreds weekly to New York, Phila., Wilmington and other points."[8] Notations in Order Book 2 such as "E. G. Broomell says we will reach 500 orders by July 10 / J. M. Seibert says we reach 500 orders by July" and **"3368 pulleys to date"** (notation underlined by Edward) indicates the surprise of the firm's management at the extent of its new-found market for pulleys. The Philadelphia office of the Christiana Machine Company lasted only a year and was closed in December, 1887. From then on, Christiana's sales efforts were conducted directly from the office at Christiana and from Henry Broomell's home in Philadelphia.

At no time did Christiana sell as many as a thousand pulleys in any year before 1886. In 1886, it sold a total of 1,144 pulleys, but after that year pulley sales increased substantially. A total of 3,904 pulleys were sold in 1887; a peak of 6,834 pulleys sold for the period was reached in 1890. Pulley sales dropped below the 1886 sales level in only one year between 1887 and 1912 (1908, 894 pulleys sold). Total sales for the period amounted to 99,033 pulleys, with 93 per cent thirty-six inches or less in diameter.

Christiana's pulley sales peaked in 1890, and although a declining trend was present, sales remained fairly high until 1905. The recession in 1906-1907 caused a sharp drop in pulley sales which was never recovered. Technological change in the capital goods industries was primarily responsible for the decline in pulley sales. Manufacturers of such equipment as machine tools, cement mixing and brick forming machinery, and paper mill machinery were shifting from belt driven to direct-drive, gear-controlled machinery. The increasing sales of Christiana's gears, discussed later in this chapter, was part of the shift in the type of power transmission equipment utilized by the capital goods industries.

Although only 7 per cent, or 5,390 of the pulleys were thirty-seven inches in diameter or larger, their individual weight ranged between five hundred pounds to several tons. Therefore, even though quantitively small as a percentage of total sales, individually they were very large units of output. To understand the order of magnitude involved, Order Book 5 contains an order from the Johnson Forge Co., Wilmington, Delaware, for a sixty by thirty-inch double brace, double arm, split pulley with an eleven-inch keyseat, two inches wide, made "extra heavy for band service will carry a 28″ D. belt [sic] 140′ long run about 400 (revolutions per minute)."[9] This pulley weighed 2,890 pounds finished. In economic terms, the large pulleys were more profitable than the small ones. Edward estimated the profit on a 2,525 pound pulley selling for $100.00 to be $39.00.[10]

The importance of the city markets, especially Philadelphia, should be noted. Out of a total of 99,033 pulleys sold, Christiana shipped 55,604 to Philadelphia; of considerable less importance were Wilmington, with 4,790 pulleys, and New York, with 3,359 pulleys. Christiana sold 56 per cent of its total pulley output to Philadelphia firms, and 64 per cent in the four city markets of New York, Philadelphia, Baltimore and Wilmington combined. This trend began in 1887, and in no year between 1887 and 1906 did Christiana ship fewer than 1320 pulleys (1897) to Philadelphia. In the peak year of 1890 alone, Christiana shipped 5,027 pulleys to Philadelphia out of a total yearly output of 6,834.

In terms of the geographic distribution of Christiana's pulleys, the Middle Atlantic States held a dominant position throughout the period. A total of 91,839 pulleys, or 91 per cent of total sales, were sold there. The South received 6,167 pulleys, and shipments to other areas were negligible. It is interesting to note, however, that 448 pulleys were sold in South America, most of these after 1895. This was more than were sold in the New England States, which was probably due to Christiana's turbine shipments to South America after 1895.

Besides pulleys, Christiana also sold over a 100,000 feet of shafting between 1877 and 1914 and made a wide variety of other products associated with shafting, including hangers, pillow blocks, packing boxes, couplings, shafting boxes and collars. But it was gears that became the single most important type of power transmission equipment made by the firm. The basic types of gears made were spur gears, spur mortise gears, miter gears, miter mortise gears, bevel gears, bevel mortise gears, rachet gears and sprocket gears. When the company's turbine catalogue contained the statement that "we manufactured every style and size of gears," it was no overstatement of the situation.[11]

The "mortise gears" had wooden teeth or cogs made of sugar maple which was thoroughly seasoned and subjected "to a dry kiln heated by steam for about two or three week"; this wood had to be

"straight grain, white wood, the hardest that can be had."[12] Although the cogs were made of wood, these gears could transmit great horsepower; for example, Christiana made a pair of miter mortise gears to transmit 350 horsepower at 100 revolutions per minute.[13] The gears other than "mortise" were solid cast iron with either machine or hand-cut teeth.

Christiana sold a total of 11,895 pairs of gears and 31,814 separate gears between 1877 and 1914. Spur gears were the largest single item sold, with bevel gears second in importance. As was true for the other types of power transmission equipment, the year 1887 marks a sharp increase in total sales. The firm's concentration on this type of equipment resulted in a continuous rise in sales throughout the period. After the turn of the century, Christiana began to concentrate more and more on gearing and was constantly changing and improving its gears. In spite of a complete loss of all gear patterns in the 1883 fire, Edward claimed in 1889: "Our list of Gearing is we think unequaled by any shop in the state."[14] The economy's constant demand for more horsepower required the means to transmit it, and thus the Broomells were constantly increasing the strength of their gears.

The major city markets became most important after 1887 for the sale of gears; however, New York, and not Philadelphia, was the leading sales area. Total sales in New York amounted to 1,022 pairs and 4,950 separate gears; Philadelphia received 755 pairs and 3,513 separate gears; Baltimore received 668 pairs and 1,714 separate gears; and in last place was Wilmington, with 14 pairs and 38 separate gears. Increased gear sales in New York after 1900 were caused by the declining importance of Philadelphia as a center for the production of capital goods and the increasing importance of New York for such equipment as cement mixing and paper mill machinery. For example, in the paper and pulp industry "New York ranked first, not only in the number of establishments, but also in amount of capital invested, in number of wage-earners and wages paid, in cost of material, and in value of products."[15] Individually, some orders from firms in the city market were very large. The Ransome Concrete Machine Co., New York City, ordered at one time 525 cut spur gears in 1907. The importance of the city markets is indicated by the fact that, together, sales in these four cities amounted to 20 per cent of the pairs of gears sold and 30 per cent of the separate gears sold between 1877 and 1914.

The bulk of gear sales occurred in the Middle Atlantic States, with that area receiving 7,528 pairs and 26,011 separate gears. The South was second in importance with 3,698 pairs and 4,094 separate gears, followed by New England and the Middle West. Other areas purchased only negligible amounts of gears; however, the South American market had some unusual product requirements. Because of poor transportation facilities in the South American countries, some of the equipment sent there had to be "sectionalized"

for "mule transportation." Christiana, for example, made for Marcus Mason & Co. a spur gear twelve feet in diameter, with a five-inch face, weighing 1,464 pounds. This gear was made in eight segments.[16]

One does not have to look far to discover the motivation involved in the decision to produce pulleys for the city markets. Clearly, profit was the motive. As evidence for this, Edward sent the following cost analysis to the office in Philadelphia:

> We would like to have a run on fly wheels and pulleys in such weights and sizes as we can handle well. To give you an idea how we can come out on large pulleys I will give cost of the 98 x 26 split sent to New York a few days since:

Casting in rough	2525 lbs. cost of Iron	$27.50
Moulding, 57 hours @ 20c		11.40
Moulders help		3.00
Melting		2.50
Splitting, turning, cleaning & bolts		9.25
Help		2.35
Paint		1.00
		$57.00
	Freight to New York	4.00
		$61.00
	Price	100.00
	Profit	$39.00

> It was a splendid pulley. This memorandum may serve you as a guide sometime. In this case everything went off well. Split nicely and turned nicely and required no balancing. We might make it again and not do so well so on all heavy work we must have a fair margin or we are liable to lose. We must have been lower than other bidders or we would not have gotten it. Our bid was $95.00 for 98 x 25, they added 1" in width and $5.10 to price.
>
> Make it a point if you can to get some orders for finished pulleys. We know they pay. And we can turn them out pretty fast.[17]

The reason Christiana was able to expand its sales of power transmission equipment, as opposed to the poor showing of Burnham's engine, lies in the Broomells' handling of decisions involving uncertainty. Attempts were made to determine the potential demand for power transmission equipment in the city markets. For the first time company records indicate that the Broomells attempted to hedge against the risk arising from uncertainty. Before an investment was made in new machine tools or an office in Philadelphia, the market was canvassed to determine the potential demand. No such precaution was taken with Burnham's engine. The existence of a market for power transmission equipment grew out of the process of "technological convergence" and the concentration of the machine tool industry in Philadelphia.

By 1880, the capital goods industries were beginning to shift

from multi-dimensional firms producing a variety of products, to firms specializing in few closely related products. The best example of this process is the machine tool industry which became a "distinct branch of industry," according to the **American Machinist,** in 1879.[18] The phenomenon of "technological convergence" made this possible. A few types of machines, doing a relatively small number of operations: turning, drilling, milling, planing, grinding, polishing, etc., but which were applicable to the production of a wide variety of consumer and capital goods, made possible a collection of firms all producing such tools.[19] Moreover, according to Rosenberg, "all machines performing such operations confront a similar collection of technical problems, dealing with such matters as power transmission (gearing, belting, shafting), control devices, feed mechanisms, friction reduction . . ."[20] Each one of these technical problems, in turn, gave rise to firms specializing in products which provided a solution. For the Christiana Machine Company it was power transmission equipment which became its specialty.

Conditions seemed to be perfect for Christiana to develop its role as a specialized producer of power transmission equipment. As early as 1860, firms in Philadelphia were specializing in heavy, high-priced machines for forming metal. The largest of the early machine tool producers, William Sellers & Co., Inc. and Bement & Dougherty, were located in Philadelphia, and together produced machine tools worth $240,000 in 1860 and $675,000 in 1870. In 1882, Philadelphia still held "its dominant position as a producer of large tools."[21] One contemporary observer reported ten firms employing 1289 hands and turning out $2,225,750 worth of "iron working machine tools" in 1882.[22] Although Philadelphia firms produced at least 30 per cent of the nation's entire output of machine tools between 1860-1870, the geographic center of the industry shifted first to New England, especially Connecticut, and then to the Midwestern states of Ohio and Illinois. However, the Middle Atlantic states and Philadelphia still remained important producers of both machine tools and metal working machinery throughout the period 1877-1914.[23]

When Thomas Broomell and John Seibert visited various manufacturers of capital goods, metalworking machinery producers, for example, they found a ready market for unfinished pulleys. Such firms as the Newton Machine Tool Co. and the Philadelphia Machine Tool Co. in Philadelphia; the Remington Machine Works, the Standard Tool & Machine Co., and the Delaware Machine Works in Wilmington, Delaware; and finally E. P. Bullard, the Globe Machine Co., and the Edison Machine Works in New York all made large purchases of Christiana's pulleys. A wide variety of other capital goods producers of such things as cement machinery, brick machinery, wool and paper mill machinery, and iron and steel foundries and roller mills also provided a ready demand for Christiana's equipment.

In November, 1882, the **American Machinist** published a fairly

complete list of machine tool builders in the United States. Out of a total of 132 firms, forty-eight, including Christiana, were located in the Middle Atlantic States; four in New York City; sixteen in Philadelphia and Germantown; and two each in Baltimore and Wilmington.[24] This concentration of the machine tool industry within easy reach of the Christiana Machine Company provided a ready market for its power transmission equipment, and especially for its pulleys. As Ross Robertson's research indicates, the firms in the Philadelphia area were probably the largest individual producers of machine tools in the country in the 1880's.[25] Technological convergence and industrial concentration made possible Christiana's role as an ancillary support firm for other capital goods firms, especially machine tool producers.

Even with a canvass of the city markets, the Broomells could not have known the exact extent of the market. Based on his information, Edward estimated "at least doubling our business" but as the sales data indicate, the increase was considerably more than that.[26] Technical changes initiated before the full extent of the market was determined involved considerable risk. Modification of pulley patterns in 1886 can be taken as a case in point. Yet the considerable reward in terms of increased sales seems to have justified such a procedure.

Related to modifying their pulleys for a particular market was an aggressive sales policy to cultivate that market. Setting up an office in Philadelphia was a considerable change from previous marketing policies. Before 1887, all goods were sold through a system of local millwrights scattered throughout the Middle Atlantic and Southern States. Christiana advertised in the standard trade journals. After 1887, Christiana had, through the Philadelphia office, a traveling sales force in Edward's words "to strike good jobs" and "force sales."[27] The office in Philadelphia was closed, but Henry Broomell, who lived in Philadelphia, continued to act as Christiana's sales representative in the Philadelphia and New York area.

Christiana, when bidding against other firms for pulley orders, seemed to have a cost advantage. While company records are fragmentary concerning the development of special machine tools to make power transmission equipment, some information is available. Christiana purchased a pulley lathe from the Putman Machine Company, Fitchburg, Massachusetts, in December, 1881. The Broomells immediately noticed several defects, among them that "the cone in counter shaft runs nearly $\frac{1}{8}$ inch out of true at large end and about half as much at small end."[28] More serious was the limited 1/16 inch cut of the tool, and Edward made it quite clear that they expected at least a $\frac{3}{8}$ inch cut. At the prices received for finished pulleys, Christiana could not hand file them if a 1/16 inch cut was not sufficient to trim them.[29]

It must have been quite exasperating for Putman, one of the most experienced machine tool producers in the United States, to have this small town machine shop tell them how to build a pulley

lathe. Putman's troubles with this tool were only beginning, for eleven days later they received a second letter cataloguing more defects, including a "looseness of journal in main bearing," which caused a loud "chattering."[30] Even though S. W. Putman came from Massachusetts to inspect the lathe, Christiana received little satisfaction. So in March, 1882, the lathe went back with the following letter:

> Since Mr. S. W. Putman was here we have given the pulley lathe still further trial, with results so unsatisfactory that we have determined to return the machine to you. We can't afford to pay so large a price for a tool that will do so little and at the same time work that is so unsatisfactory when done. In fact it would not pay us to keep it at any price since the expense of running it is just as much as it would be to operate a tool that would do two or three times as much. Mr. S. W. understands well its defects as the matter was all talked over when he was here, we are disappointed that the lathe is not satisfactory as we need the use of one all the time, our foreman abandoned the tool some time since saying it didn't pay to waste time on it.[31]

At this point the Broomells' ingenuity came to the surface with their "special pulley boring mill" on which they began work in February, 1882.[32] There is no record of a description of this machine, and it was never patented; but in April, 1883, Edward made Craig Ridgway & Son the following offer: "We have new special pulley boring and turning machinery by which we are able to finish large number in short time and can offer you finished pulleys at 20% off our list of 79 on all sizes above 20 in. diameter, 10% for smaller ones."[33] If this letter is any indication, it must have taken Christiana about a year to develop this tool to the point where it was advantageous to make a special discount on finished pulleys to good customers.

In 1901, Christiana's sales of gears exceeded 500 pairs and 1000 single gears per year for the first time. Faced with this increased demand, the Broomells contemplated purchasing a Brown and Sharp automatic gear cutter by 1904. A year later they were still "considering the matter of buying a gear cutter," but thought the Brown and Sharp machine "pretty high priced" although "about the best."[34] True to their earlier behavior pattern when faced with a similar situation for pulley machinery, they proceeded to make their own gear cutter. It is difficult to determine if this tool equaled or excelled Brown and Sharp's in the amount or quality of work done, but obviously the Christiana tool represented a substantial savings, on the basis of initial investment, over the Brown and Sharp machine. The quality of Christiana's gear cutter is indicated by the fact that it was removed from the machine shop, still operational, in the early 1950's.[35] Its total length of service had been almost fifty years.

Why the Broomells never had any of their own machine tools patented is a mystery about which company correspondence offers no solution. One has only to consider that the Broomells were not hesitant to patent anything with commercial prospects, as for ex-

ample, Henry Broomell's improved animal trap, pencil sharpener, and street sweeper.[36] Not patenting tools is not unique to the Broomells, for American history has examples of this from the earliest days of the march toward industrialization. Eli Terry in the early clock industry had nine patents for changes he made in clock mechanisms but not one for improvements he made in his machinery for making clocks.[37] One possible explanation was a fear by the Broomells that once their tools were patented and thus made public, other pulley producers would imitate them and enjoy the same cost reductions.

One very sharp point of contrast between the decisions made in trying to develop Burnham's engine and those made for power transmission equipment was a much greater cost consciousness. Edward warned the "boys in Philadelphia" that a miscalculation of "1/10 of a cent per pound on 5000 lbs. would be a loss in money of $50 besides the loss in time that should make us much more than that."[38] This new awareness of the importance of cost control was most distinctively exhibited in the reorganization of the labor force in the foundry.

On January 31, 1887, Edward wrote Burnham that "we have hired three of our former moulders making us 8 which is as many as we need just now."[39] The situation had not changed much by March because the firm had "plenty of moulders now to run a full heat every other day."[40] The wage rate for moulders, as of March 25, was $1.80 for a ten hour day. But by the end of April, the firm needed "more moulders badly" and the wage rate had reached $2.00 for a ten hour day.[41] The firm was faced with the situation of a drastic increase in the demand for pulleys due to its expansion into the Philadelphia market, on the one hand, and on the other, difficulty hiring additional skilled moulders which resulted in a substantial increase in the wage rate. To get around this impasse, the Broomells developed a system of platooning to reduce this most expensive labor input in the foundry. Edward explained the new system to Seibert, who was at the Philadelphia office:

> The 5 tons per day will be all right after a little but we must get our force together to do it and want to avoid disappointing new customers in time as much as possible. We have arrangements made to have a gang go right in as soon as castings are poured and take them out and cut up same during the night so the moulders will have nothing of this to do but go right to moulding in the morning. This will make it possible to do with fewer moulders. We can get plenty of Laborers but moulders are hard to get unless we were in shape to pay more wages than other places, this we can't do until we can work prices up a trifle.[42]

The plan must have been a success because by May 20, Christiana had thirty men in the foundry alone. Yet demand was increasing beyond the capacity of the firm to meet it: "Have recently put on about 30 additional hands and still have trouble to keep up with orders."[43]

This system enabled the Broomells to use to a much greater

extent their cheapest labor input—apprentice labor. Under Christiana's apprenticeship system, first year apprentice boys in the foundry got 50 cents per day to unload pig iron, handle heavy castings and clean castings. The second year they received 75 cents per day to clean castings and paint finished work, and the third year the boys received $1.00 per day to learn the art of moulding.[44]

Adult laborers, who did about the same thing as the apprentices in the first two years of their apprenticeship, received about $1.50 for a ten hour day. This was Christiana's second cheapest labor input; therefore, the more apprentices and laborers the firm could use in place of skilled moulders, the lower its labor cost per unit of output in the foundry.

The Broomells could have reduced their labor cost even more if they had adopted machine-moulded pulleys, but although the idea was much discussed, it was never carried through because of the high initial investment, the loss on patterns already made for cast iron pulleys, and the belief that the moulded pulleys were not as good as the cast iron pulleys for the type of market Christiana supplied. The "organizational improvements" made by the Broomells in an attempt to reduce their labor cost illustrates how cost conscious they had become. The problems with the automatic steam engine and the 1884 model Burnham turbine probably did much to instill this pattern of thinking in their decision-making. It is worth noting that when this awareness entered their thinking, they were able to take advantage of the specialization occurring in the capital goods industries.

To develop the city markets, Burnham decided more working capital was needed. The Broomells concurred in this decision and Christiana was incorporated January 14, 1887. This lasted until Burnham was bought out two years later. The articles of incorporation contain the following list of stockholders:

	Shares of Stock
Nathan F. Burnham	140
Edward G. Broomell	100
Isaac Broomell	50
John M. Seibert	5
Frank A. Burnham	5

The amount of capital stock was "30,000 divided into three hundred shares of the par value of $100.00," and officers of the corporation included four directors—Nathan and Frank Burnham, Isaac Broomell and John M. Seibert, and Edward Broomell as Treasurer.[45]

As the market for pulleys declined because of the shift by the capital goods industries from belt driven to direct-drive gear-controlled equipment, Christiana shifted production to gears. Thus, by 1916 Christiana had become a firm specializing in the production of gears. This is a very important point because it explains why the firm, although in financial trouble in 1915, did not go bankrupt.

The Broomells were able to sell the firm because of its extensive facilities for making gears. Christiana's present management stated that other products such as hydraulic turbines and bakery machinery, were not considered in the purchase, although production of these items continued after 1915.[46]

CHAPTER VIII

CONCLUSIONS

For economists the function of the entrepreneur is to hedge conditions involving large degrees of uncertainty by making decisions in which the probability of success can be rationally calculated. Success or failure in decision-making results in either profit or loss and the degree of either becomes the index of entrepreneurial efficiency or inefficiency. For the Christiana Machine Company in the period 1863 to 1914, the most noticeable trend in decision-making was the increasing importance of security. Between 1863 and 1883, the Broomells seemed to be aggressive in their handling of uncertainty. The move from Homeville to Christiana during the Civil War, in the face of objections from friends and depressed conditions in business, indicates their willingness to assume the risk associated with handling uncertainty. The sorghum mill, Burnham turbine, flour mill, saw mill, horizontal slide valve steam engine and the boring and turning mill all indicate that the Broomells were not timid about handling the uncertainty of introducing new products.

But between 1884 and 1889, security began to appear as a motive in decision-making as opposed to maximum profit. The emphasis placed on holding onto an established product, instead of trying to cut losses by dropping the Burnham turbine and introducing one of their own, was the first indication that security had become dominant in decision-making. This trend became clearly established by 1890 and was noticeable in the introduction of the balanced gate turbine and the Broomells' decision to limit the size of their turbine units. But the Broomells appear to have been not completely adverse to handling uncertainty. The shifts in market and product associated with the expansion into power transmission equipment serves as the exception to the trend beginning in 1884.

By the end of the nineteenth century, however, security became completely intrenched in the decision-making process. The Broomells became more unwilling to handle uncertainty. To illustrate this point note the following letter to the Lukens Iron and Steel Co., Coatesville, Pennsylvania:

> We have your letter of yesterday in reply to our quotation of the 14th inst. We note that our prices were too high and that you have placed the order elsewhere. The situation with us at the present time is such that we cannot do near all the work that is offering; hence we bid up a little on a good deal of work at this time because we are not very anxious to get it. We are sorry, however, that we are in

such a position because we should like very much to make all of your repairs.

We have had under consideration for some time the building of an additional foundry with capacity for heavier work. If we had this at the present time it would help us out very much. If some arrangement could be made to take a contract with you for say four or five years on a basis that would be mutually satisfactory it might help to settle our minds as to the building of an extra foundry. The only way we see to make a price for a long period would be to establish a price for the present that we thought fair between us and have a sliding scale, either up or down as prices of materials advanced or declined. Do you think such an arrangement could be made? We confess it hurts us not to be able to do all the work that is offering.[1]

Before the Broomells would expand their plant they wanted a long term, cost plus profit contract. In effect, they wanted to eliminate completely uncertainty instead of trying to handle it. When Lukens refused to enter into such a contract, the Broomells did not expand their foundry.

A second example of the Broomell's refusal to invest in new equipment is a gear cutter developed in 1905. Although gear sales rose sharply in 1900, they waited five years before building an automatic gear cutting machine. In other words, they refused to invest in new equipment until they were absolutely sure that the demand for gears would justify the investment.

The conclusion one reaches is that the firm's growth was severely limited by the Broomells' security motivation. In the twenty years between 1860 and 1880, capital invested in the firm increased five times, from $6,000 to $30,000. Yet, in the next thirty-five years, capital investment only doubled from $30,000 to $60,000.[2] Comparative data and information on decision-making for firms similar to Christiana are very limited. Some information has already been presented for S. Morgan Smith, York, Pennsylvania. This firm got a rather late start in the turbine industry. It started by manufacturing washing machines in 1871 and did not sell its first turbine until August, 1877.[3] Unlike most of the other firms in the industry, Smith concentrated on turbines for hydroelectricity and became a major firm in the industry in the twentieth century. By 1907, Smith had 500 employees as compared to Christiana's sixty.

Christiana's growth can be placed in some perspective if compared to aggregate data for the national economy. Although Christiana's capital investment doubled between 1879 and 1914, this increase is insignificant when compared to the increase of 831 per cent in iron and steel products; 4170 per cent in metal building materials; and 557 per cent in hardware and tools. Christiana's growth, measured by the increase in capital investment, was considerably below the aggregate increase for industries manufacturing iron, steel, and similar products.

The more security became a factor in decision-making, the lower the profits. Christiana averaged 19 per cent on investment between 1878 and 1883. While comparable data for the years af-

ter 1883 are not available, there is some indication that the firm was in financial trouble by 1915. The following letter to Christiana's "New York representative," describing a stormy meeting between the Broomells and the directors of the Christiana National Bank, indicates the nature of the trouble:

> As for notice sent you sometime since, a meeting of the Stockholders of our Company was held in our office yesterday. Five of the banks directors and their attorney were present. The first action taken was to force me to transfer all my stock on the stock register to the bank by asserting that a receiver would be asked for today if I did not comply.
>
> This being accomplished they proceeded to hold a stockholders meeting, and elected four directors, all bank directors including myself. After adjournment of this meeting, the directors elected for president M. P. Kent president of the bank for secretary Henry Broomell treasurer Samuel Carter General Manager E. G. Broomell. I asked them how this would affect our New York representative, they said you could continue to do business with us but could have no official management, nor could you do anything that would be of vital interest to the bank, without authority from the new officers, until such time as you could arrange to liquidate a considerable proportion of the claims of the bank say $6,000 to $8,000, or until we could do it. As soon as either of us arrange for this all of the collateral will be cheerfully surrendered.
>
> Now if you can arrange to raise this amount of money, and would buy that value of my stock I could turn the money over to the bank and C. M. Co. would owe me instead of the bank. This plan would not furnish any additional working capital but it would for the present relieve the situation. The suggestion made by me a few days since of creating a new mortgage would seem to be desirable but I do not know how difficult it would be to accomplish. I think the security would be more than ample.
>
> Now the question is, what are we going to do about it. There is no use whatever in trying to ignore the bank, and the quicker we act in some decisive manner the better.[4]

For the period 1915-1920 very little of the Company's records have survived but interviews with the firm's present management indicate that the Broomells must have been able to satisfy the bank. The present management maintains that the firm was purchased directly from the Broomells and not through the bank, as would have been the case if the firm were bankrupt. In fact, the Broomells were retained for several years in a managerial capacity. Nevertheless, the inability to pay off their bonded debt, when due, indicates that profits may have been limited in the latter part of the period under study. Thus it would seem that the desire for security kept the Broomells from performing the entrepreneur's major function in a free enterprise economy—maximizing profit.

Yet, the above discussion is not meant to suggest that the firm was unimportant. This study has dealt primarily with decisions involving technological change. Increased efficiency and reliability of Christiana's turbines, changes in power transmission equipment, and the development of machine tools were all part of the process of technological change. The first Burnham turbine sold in 1859 was quite an inferior machine compared to those made by Christi-

ana in 1895. Likewise, Christiana's power transmission equipment was undergoing constant improvements in quality to transmit greater amounts of horsepower. To be sure not all of the Broomells' technological changes were of much value, e.g., the Burnham automatic steam engine. Nevertheless, the technological changes associated with Christiana's turbines and power transmission equipment were solid technical accomplishments.

As an object of historical research, the Christiana Machine Company is important as an example of a typical firm in the turbine industry in the nineteenth century. Entrepreneurs as historical characters usually fall into two classifications: those men such as Carnegie and Ford who command economic events; and those men such as the Broomells who seemed to be commanded by economic change. The importance of Carnegie and Ford goes without saying, but the role of the other class of entrepreneurs in the industrialization process needs much greater study and clarification. Their accomplishments and rewards were considerably more limited than Carnegie and Ford. Nevertheless, they are important as examples of what was taking place in a rapidly industrializing, technologically changing America. By multiplying the activities of the Broomells in introducing technological change by thousands of other such entrepreneurs explains how America became an industrial society par excellence.

ABOUT THE AUTHOR

Ferdinand L. Molz was born July 27, 1940, at Lancaster, Pennsylvania, the son of Mary Beldermann Molz and Ferdinand Molz. He is a graduate of Lancaster Catholic High School. He received his B.S. degree from Rider College in 1963, his M.A. degree from the University of Maryland in 1964, and his Ph.D. from Catholic University of America in 1968. He is a member of the American Economics Association, the Economic History Association, and the Association of Evolutionary Economics. From 1968 to 1970 he was an Assistant Professor of Economics at York College. Since 1970 he has been an Associate Professor of Economics at Millersville State College. Dr. Molz is married to the former Diane Loiseau of Lancaster. They have four children and presently reside in Wrightsville, York County.

NOTES TO CHAPTER I

THE EARLY YEARS 1833 TO 1877

[1] H. M. J. Klein, *Lancaster County Pennsylvania: A History* (New York: Lewis Historical Publishing Company, Inc., 1924), pp. 47-48. The name of the hamlet was changed from McClarronville to Christiana after William Noble's first wife in 1847.
[2] *Christiana Ledger*, October 17, 1891, p. 1.
[3] Excerpts from "Fifty Years of Married Life," History read by Isaac Broomell at the Celebration of the Fiftieth Anniversary of the Marriage of Isaac Broomell and Rachel H. Wilkinson (In files of the company, n.d.), p. 1.
[4] *Ibid.*
[5] U. S., Bureau of the Census, Seventh Census of the United States: 1860. Original Marshall's Report, Schedule V, p. 1.
[6] Isaac Broomell, "Fifty Years of Married Life," p. 1.
[7] U. S., Bureau of the Census, Seventh Census of the United States: 1860. Original Marshall's Report, Schedule V. p. 1. Evidently the shop produced some type of sorghum mill before the Bromells purchased it but probably not the same kind made by them during the war or why else would they have had to purchase the manufacturing rights to another one from Samuel Lewis Denny?
[8] Isaac Broomell, "'Fifty Years of Married Life," p. 2.
[9] *Ibid.*
[10] Franklin Ellis and Samuel Evans, *History of Lancaster County, Pennsylvania* (Philadelphia: Everts and Peck, 1883), p. 1034.
[11] Isaac Broomell, "Fifty Years of Married Life," p. 2.
[12] *Ibid.*
[13] Deed from Isaac Broomell and wife, Rachel H. to Nathan F. Burnham, Record Book D (Recorder's Office of Lancaster County, January 14, 1878), pp. 492-493. Burnham probably invested an additional $500 above the purchase price of the real estate for tools and equipment. His total investment in 1878 was $6,000.
[14] *York Democratic Press*, December 26, 1890, p. 3.

CHAPTER II

NEW PRODUCT DEVELOPMENT, EXPANSION AND DESTRUCTION—1878 TO 1883

[1] Letter from E. G. Broomell to B. P. Kirk, Kenneth Square, Pennsylvania, Copy Book 2, February 2, 1880, p. 186.
[2] Christiana Machine Company, Order Book 1, pp. 254 and 517.
[3] Letter from E. G. Broomell to J. B. Alprice, Irwin, Pennsylvania, Copy Book 3, September 24, 1881, p. 866. In September of 1881, Christiana's productive capacity seems to have been pushed to the maximum. When approached by another turbine producer and good customer, Craig Ridgway & Son, Coatesville, Pennsylvania, about purchasing pulleys Edward wrote back:

> "We have about all the pulley patterns our list calls for but are at present poorly fixed for making castings for outsiders can't get our own out fast enough and have talked strongly of trying to buy some finished pulleys to help us through. We have 40 orders booked many of them large ones among them are thirty water wheels most of which are large ones from 66" down so we are as nearly stuck as we wish to be otherwise we would be glad to help you out."

Letter from E. G. Broomell to Craig Ridgway & Son, Coatesville, Pennsylvania, Copy Book 3, September 5, 1881, p. 810.
[4] Letter from E. G. Broomell to E. W. Mills, Ohio, Copy Book 2, April 23, 1880, p. 393. The key word here is "recently" if it goes back to 1879 then the six sold in that year may also have been of the "improved" style. There is no way of telling for sure but it is a distinct possibility. The above discussion will be based on this assumption.

[5] Letter from E. G. Broomell to T. H. Hart, Goldsboro, North Carolina, Copy Book 3, January 13, 1881, p. 249.
[6] Letter frm E. G. Broomell to Knapp Burrell & Co., Portland, Oregon, Copy Book 1, December 19, 1877, p. 26.
[7] Letter from E. G. Broomell to E. A. Betts, Wilmington, Delaware, Copy Book 1, September 7, 1878, p. 191.
[8] Letter from E. G. Broomell to A. G. Brooks, Philadelphia, Pennsylvania, Copy Book 1, September 12, 1878, p. 200.
[9] Letter from E. G. Broomell to Nathan F. Burnham, York, Pennsylvania, Copy Book 1, September 12, 1878, p. 203.
[10] The tool manufactured by Niles impressed them very much as they saw it in operation at Campbell & Rickards in Philadelphia.
[11] Letter from E. G. Broomell to Hilles & Jones, Wilmington, Delaware, Copy Book 1, September 28, 1878, p. 246.
[12] Letter from E. G. Broomell to Putman Machine Co., Fitchburg, Massachusetts, Copy Book 1, October 25, 1878, p. 284.
[13] Christiana Machine Company, "New Boring and Turning Mill," *American Machinist*, January 22, 1881, p. 1.
[14] Duncan M. McDougall, "Machine Tool Output, 1861-1910," *Output, Employment and Productivity in the United States After 1800* (New York: National Bureau of Economic Research, 1966), p. 501.
[15] Interview with Donald Werntz, foreman of the machine shop, Christiana Machine Company, July, 1967.
[16] Letter from E. G. Broomell to Stokes & Parrish, Philadelphia, Pennsylvania, Copy Book 4, November 11, 1881, p. 9.
[17] Letter from E. G. Broomell to E. P. Bullard, New York City, Copy Book 4, December 16, 1881, p. 121. One of the ironies of business history revolving around this incident was that Bullard evidently could not buy boring and turning mills at a price he thought reasonable. Thus he decided to produce his own and eventually became the leading producer of such machinery in the United States. It is interesting to speculate what might have happened to the Christiana Machine Company if it had actively pursued its machine tool trade.
[18] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 2, January 13, 1880, p. 148.
[19] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 2, February 24, 1880, pp. 243-244.
[20] At this point the decision seemed justified as Christiana had unfilled orders for twenty-five turbines, all large ones.
[21] Isaac Broomell, "Fifty Years of Married Life," p. 3.
[22] *Ibid.*
[23] Source for January 24, 1882: Letter from E. G. Broomell to N. F. Burnham York, Pennsylvania, Copy Book 4, January 24, 1882, p. 191; Source for other dates: Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania. Copy Book 4, March 31, 1884, p. 835. The $2,000 payment, dated January 15, 1884, to Burnham was equaled by a payment of $666.66 to each of the Broomells. If the insurance payment is considered a return on investment, assuming the plant's repairs after the fire were financed from current earning, then Burnham's profit was greater than the Broomells' figure of 25 per cent.
[24] Letter from Isaac, Edward and Henry Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 5, February 13, 1884, pp. 731-732.
[25] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania. Copy Book 5, January 31, 1884, p. 708. Edward arrived at a net profit by deducting from a gross profit of $6,338.24 the sum of $1,458.92. In turn the latter figure was arrived at by deducting $9,541.08 ($4,000 insurance payment divided among partners plus $5,541.08 building cost after fire) from $11,000 total amount of insurance payment for the fire. Why this was made a deduction instead of being treated as some sort of surplus is an open question. The most rational procedure would have been to set up a special account debiting the $1,458.92 to it and charging the cost of pattern replacement against it.
[26] Isaac Broomell, "Fifty Years of Married Life," p. 3.
[27] It was never absolutely proven that this was the cause of the fire but it

seems a good possibility as the town had a rash of fires including another one on October 10, 1883, at Hathaway's stable. The Broomells, along with other businessmen and property owners, organized a core of six night watchmen to patrol the town, but the individual responsible was never apprehended.

[28] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 5, October 5, 1883, p. 479.

[29] Isaac Broomell, "Fifty Years of Married Life," p. 4. As evidence of this note the following statement made by Edward to Burnham eleven days after the fire: "I know this—if our business could be just as good all the time as it has been this year we could make a quarterly dividend of $1,200 and make some little improvements all the while besides, which we think is about as good as any concern with the same capital does when they happen to have some patented article to sell as a specialty." Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 5, October 12, 1883, p. 494.

CHAPTER III

THE BURNHAM AUTOMATIC STEAM ENGINE

[1] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 5, September 15, 1883, p. 435.

[2] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 7, September 30, 1885, p. 331.

[3] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 7, September 21, 1885, pp. 307-308.

[4] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 7, October 26, 1885, p. 415.

[5] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 7, November 11, 1885, p. 478.

[6] Edward commented on the depression to a friend: "We have had what we call a dull season in business, and have made very little above a living, so you can console yourself that you are not alone in this matter. Indeed we feel very thankful to have been able to hold our own while so many have lost much and others have been entirely ruined." Letter from E. G. Broomell to E. S. Graves, Copy Book 7, n.d., p. 518.

[7] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 7, March 25, 1887, p. 738.

[8] Nathan F. Burnham, "Cut Off Mechanism for Steam Engines," Patent 274,559 (Original patent file in National Archives, March 27, 1883). Henry Broomell had been working on a similar device.

[9] Nathan F. Burnham, "Automatic Steam Engine," Patents 336,836; 336,837; 336,838 (Original patent files in National Archives, February 23, 1886).

[10] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 7, May 13, 1886, p. 830.

CHAPTER IV

THE BURNHAM TURBINE

[1] U. S., Bureau of the Census, Eighth Census of the United States: 1870. Original Marshall's Report, Schedule IV, p. 1.

[2] Nathan F. Burnham, "Improved Water-Wheel," Patent 23,011 (Original patent file in National Archives, February 22, 1859).

[3] Christiana Machine Company, *Hydraulic Turbines* (In files of Company, n.d.), p. 15.

[4] Performance here means "efficiency" or "useful effect," the terms are interchangeable and "denote the economy of a turbine in its use of water, or the number of gallons it will pump back into the pond for each one hundred gallons drawn therefrom to drive the wheel." James Emerson, *Treatise Relative to the Testing of Water Wheels and Machinery* (3d ed.; Springfield:

Weaver, Shipman & Company, 1881), p. 42. This is usually expressed as a percentage figure; and it can be taken to mean that if the pressure energy of the water contains one hundred horsepower and the turbine converts this into eighty horsepower of kinetic energy, it has an efficiency level of 80 per cent.

[5] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 2, March 8, 1880, pp. 280-281.

[6] Nathan F. Burnham, "Turbine Wheel," Patent 274,884 (Original patent file in National Archives, March 27, 1883).

[7] Burnham Bros., *Illustrated and Descriptive Catalogue of Burnham's New Improved Standard Turbine Water wheel* (In the files of Robert M. Vogel, Division of Mechanical and Civil Engineering, Museum of History and Technology, Smithsonian Institution, n.d.), p. 7.

[8] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 5, November 17, 1883, p. 557.

[9] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 6, January 1, 1885, pp. 682-683.

[10] Letter from E. G. Broomell to A. L. Sluder, Social Circle, Georgia, Copy Book 1, April 4, 1879, pp. 516-517. Burnham sold most of his turbines through local millwrights who would order either from him or directly from Christiana. The mill owners would be billed and the millwrights would not receive their commission (usually 10 per cent) until after the bill was paid. This system worked well enough when the turbine performed properly, but when it did not, Christiana had difficulty collecting the bill. Under this system both the millwrights and Burnham extended credit in order to make the sale, forcing Christiana to abide by the terms of the sale to get the order. If the mill owner refused to pay the bill, Christiana bore most of the loss. The mill owners had an incentive not to pay for anything until it was proved satisfactory. Emerson warned them: "The extreme variations in the results obtained from every kind tested, should convince purchasers that there is no certain way of procuring a good turbine otherwise than by testing, before acceptance, as they would do if purchasing a horse." Emerson, *Treatise Relative to the Testing of Water Wheels and Machinery*, p. 77.

[11] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 6, January 30, 1885, p. 714

[12] Letter from E. G. Broomell to J. J. Hardy, Lynchburg, Virginia, Copy Book 7, July 21, 1885, p. 164.

[13] Nathan F. Burnham, "Turbine Water Wheel," Patent 382,026 (Original patent file in National Archives, May 1, 1888).

[14] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 9, January 30, 1888, pp. 840-841.

[15] Letter from E. G. Broomell to Burnham Bros., York, Pennsylvania, Copy Book 13, February 3, 1891, p. 770. A year later the situation had still not changed except for Nathan's death, which meant that Frank and William had to use their own ingenuity to solve the problem.

[16] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 9, n.d., pp. 910-911.

[17] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 10, n.d., pp. 79-80.

[18] Letter from Isaac Broomell and Edward G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 10, September 12, 1888, p. 970.

[19] Letter from E. G. Broomell to the Bradstreet Company, Philadelphia, Pennsylvania, Copy Book 11, January 28, 1889, pp. 95-96.

[20] *Ibid.*

CHAPTER V

THE BALANCED GATE TURBINE

[1] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 6, January 27, 1885, p. 708.

[2] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 6, January 30, 1885, p. 714.

[3] Letter from E. G. Broomell to J. M. Odell Mfg. Co., Bynum's, North Carolina, Copy Book 11, January 20, 1889, p. 70.
[4] Henry Broomell, "Turbine Water-Wheel," Patent 410,487 (Original patent file in National Archives, September 3, 1889). Henry described the principle on which the mechanism worked as follows: "The principle upon which the gate of our wheel is moved, may be illustrated by supposing a deep ring of two or three feet in diameter to be provided with handles extending from its upper edge. To this is fitted either within or without, another ring of equal depth. Now, if a man should seize the handles—one in each hand—he will find there is much less friction, and the ring will turn much easier if he pulls with one hand and pushes with the other, with equal force than if he moves it by one hand only." Letter from Henry Broomell to E. G. Broomell, Copy Book 11, May, 1889, pp. 529-531.
[5] *Ibid.*
[6] Letter from E. G. Broomell to A. Coulten, Parkman, Ohio, Copy Book 12, April 11, 1890, pp. 783-784.
[7] Letter from E. G. Broomell to J. E. Ladd, Gardner, Maine, Copy Book 12, n.d., pp. 665-666.
[8] Letter from E. G. Broomell to C. T. Hanna, Pittsburgh, Pennsylvania, Copy Book 11, July 5, 1889, p. 741.
[9] Letter from E. G. Broomell to L. Grimm, Carthage, North Carolina, Copy Book 12, March 29, 1890, p. 74.
[10] Letter from E. G. Broomell to J. E. Ladd, Gardner, Maine, Copy Book 12, n.d., pp. 665-666.
[11] Letter from E. G. Broomell to D. G. Comings, Middletown, New York, Copy Book 12, October 21, 1889, p. 209.
[12] Letter from E. G. Broomell to J. J. Hardy, Lynchburg, Virginia, Copy Book 12, October 22, 1889, p. 211. Edward must have been very pleased with the turbine's early performance because he concluded the letter "we have several of those wheels at work and they are doing admirably."
[13] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 12, September 23, 1889, p. 113.
[14] Letter from E. G. Broomell to H. F. Farnsworth, Saltville, Virginia, Copy Book 11, March 15, 1889, pp. 264-265.
[15] Letter from E. G. Broomell to O. J. Seibert, Palmyra, Pennsylvania, Copy Book 12, October 12, 1889, p. 177.
[16] Emerson, *Treatise Relative to the Testing of Water Wheels and Machinery,* pp. 129-131.
[17] U. S., Bureau of Census, *Twelfth Census of the United States: 1900.* Manufactures, VII, p. cccvvi.
[18] "Turbines," *McGraw Hill Encyclopedia of Science and Technology,* XIV, 147-148.
[19] Letter from E. G. Broomell to Burnham Bros., York, Pennsylvania, Copy Book 15, May 16, 1892, p. 243.

CHAPTER VI

DISSEMINATION OF CHRISTIANA'S TURBINE INNOVATIONS

[1] Allen H. Fenichel, "Growth and Diffusion of Power in Manufacturing, 1838-1919," *Output, Employment and Productivity in the United States After 1800* (New York: National Bureau of Economic Research, 1966), p. 444.
[2] Letter from E. G. Broomell to Pennsylvania Railroad, Philadelphia, Pennsylvania, Copy Book 1, May 25, 1878, p. 120.
[3] U. S., Bureau of the Census, *Eleventh Census 1890. Manufacturers,* VI, 932, 940, 963.
[4] Allen H. Fenichel, "Growth and Diffusion of Power in Manufacturing, 1838-1919," pp. 456-457.
[5] Burnham Bros., *Illustrated and Descriptive Catalogue of Burnham's New Improved Standard Turbine Water Wheel,* p. 6.
[6] Nathan F. Burnham, Correspondence Between Nathan F. Burnham and Pat-

ent Office: Patent 23,011 (Original letters in Patent files of National Archives, February 2 and 7, 1859).

[7] Burnham Bros., *Illustrated and Descriptive Catalogue of Burnham's New Improved Standard Turbine Water Wheel*, p. 22.

[8] Charles Byran Kuhlmann, *The Development of the Flour-Milling Industry in the United States* (New York: Houghton Mifflin Company, 1929), pp. 46-47.

[9] *Ibid.*, p. 44.

[10] *Ibid.*, pp. 46-47.

[11] *Ibid.*, pp. 71-72.

[12] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 1, June 10, 1878, pp. 135-136.

[13] Letter from E. G. Broomell to H. Shaw, Shaw's Store, Pennsylvania, Copy Book 2, February 9, 1880, p. 204.

[14] Letter from E. G. Broomell to L. J. Smith, Reading, Pennsylvania, Copy Book 3, November 2, 1881, p. 989. Elsewhere he wrote: "We are under the impression that you have recently been handling the Victor [turbine], but do not know that fact need shut you out entirely from handling ours, as there are many cases where you can sell the one and not the other, our wheel being much lower in price." E. G. Broomell, Copy Book 12, October 12, 1889, p. 177.

[15] Letter from E. G. Broomell to J. M. Seibert, Palmyra, Pennsylvania, Copy Book 7, March 15, 1886, p. 739.

[16] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 7, May 18, 1886, pp. 839-840.

[17] Letter from E. G. Broomell to W. F. Ler, Blacks, South Carolina, Copy Book 9, August 19, 1887, p. 255.

[18] Letter from E. G. Broomell to D. J. Hyden, Lyndhurst, Virginia, Copy Book 11, January 31, 1889, pp. 109-110. Edward underlined the word "our" in the original letter.

[19] Letter from E. G. Broomell to John S. Butler, Copy Book 21, November 23, 1898, p. 691.

[20] Letter from E. G. Broomell to Bigges Machinery Co., Columbia, South Carolina, Copy Book 49, April 21, 1914, p. 915.

[21] Burnham Bros., *Illustrated and Descriptive Catalogue of Burnham's New Improved Standard Turbine Water Wheel*, p. 65.

[22] *Ibid.*, p. 62.

[23] U. S., Bureau of the Census, *Eleventh Census of the United States: 1890. Manufacturers*, VI, 940.

[24] *Ibid.*, p. 963.

[25] Peter Temin, "Steam and Water Power in the Early Nineteenth Century," *The Journal of Economic History*, XXVI (June, 1966), 203.

[26] U. S., Bureau of the Census, *Eleventh Census of the United States: 1890. Manufacturer*, VI, 932.

[27] Burnham Bros., *Illustrated and Descriptive Catalogue of Burnham's New Improved Standard Turbine Water Wheel*, p. 54.

[28] *Ibid.*, p. 57.

[29] Christiana Machine Company, Order Book 2, pp. 143-236. The Broomells never missed an opportunity to point out to prospective customers that the Lancaster wheel was "almost an exact copy of the old style Burnham, and has no advantages in way of arrangement for operating the gate easily." Letter from E. G. Broomell to L. Weise, Salunga, Pennsylvania, Copy Book 17, September 19, 1894, p. 412.

[30] Letter from E. G. Broomell to A. C. Kiser & Co., Kelly, Virginia, Copy Book 22, February 18, 1899, p. 145.

[31] Lancaster Turbine Wheel Co., *Improved Lancaster Turbine* (In the files of Robert M. Vogel, Division of Mechanical & Civil Engineering, Museum of History and Technology, Smithsonian Institution, 1894), pp. 57-70.

[32] Letter from E. G. Broomell to J. Culbuton, Cornsville, Virginia, Copy Book 7, March 12, 1886, p. 732. Edward did not delude himself about the strength of S. Morgan Smith as a business rival. The following statement indicates that Edward realized that price was the basis of competition between the two firms: "We are desirous to get you to try one of these [turbines] and have no objection to your doing the best you can under the circumstances.

Burnham's best prices on these wheels are $348 and $420, and we have added enough to make you 5% on them. We make both wheels and of course will be glad to furnish either. If these are not close enough to cut out S. Morgan Smith, he must be selling on a very close margin, and we would like if possible to know his bid." Letter from E. G. Broomell to J. Cartledge, Copy Book 12, February 3, 1890, p. 554.

[33] George R. Prowell, *History of York County, Pennsylvania* (Chicago: J. H. Beers & Co., 1907), I, 759.

[34] Letter from Henry Broomell to Carlos Mendizabal, Spain, Copy Book 27, May 20, 1901, p. 371. Mendizabal was "the general manager of a large steel company with works at Bilbao."

[35] Letter from Henry Broomell to Carlos Mendizabal, Spain, Copy Book 27, June 27, 1901, p. 997.

[36] Letter from Henry Broomell to Carlos Mendizabal, Spain, Copy Book 31, June 3, 1903, p. 99.

[37] Letter from Henry Broomell to Carlos Mendizabal, Spain, Copy Book 31, July 20, 1903, p. 287.

[38] *Ibid.*

[39] Burnham Bros., *Illustrated and Descriptive Catalogue of Burnham's New Improved Standard Turbine Water Wheel*, p. 7.

CHAPTER VII

THE SHIFT IN MARKET AND TYPE OF POWER TRANSMISSION EQUIPMENT 1887-1914

[1] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, n.d., pp. 387-388.

[2] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, November 14, 1886, pp. 322-323.

[3] Letter from E. G. Broomell to A. Insinger, Philadelphia, Pennsylvania, Copy Book 8, September 3, 1886, p. 107.

[4] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, December 1, 1886, pp. 356-357.

[5] Letter from E. G. Broomell to J. D. Petty Co., Philadelphia, Pennsylvania, Copy Book 8, December 13, 1886, p. 385.

[6] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, n.d., pp. 387-388.

[7] *Ibid.*

[8] Letter from E. G. Broomell to E. F. Landis, Lancaster, Pennsylvania, Copy Book 8, June 1, 1887, p. 962.

[9] Christiana Machine Company, Order Book 5, August 16, 1900, p. 314.

[10] Letter from E. G. Broomell to Philadelphia Office, Copy Book 8, February 2, 1887, pp. 574-575.

[11] Christiana Machine Company, *Hydraulic Turbines*, p. 35.

[12] Letter from E. G. Broomell, recipient unknown, Copy Book 26, March 5, 1901, p. 890; Letter from E. G. Broomell, recipient unknown, Copy Book 25, February 6, 1900, p. 363.

[13] Letter from E. G. Broomell to J. Yocum & Son, Philadelphia, Pennsylvania, Copy Book 15, n.d., p. 353.

[14] Letter from E. G. Broomell to Goyne Bros., Ashland, Pennsylvania, Copy Book 11, March 19, 1889, p. 285.

[15] U.S., Bureau of the Census, *Twelfth Census of the United States: 1900. Manufacturers*, IX, 1022.

[16] Christiana Machine Company, Order Book 4, March 20, 1897, p. 519.

[17] Letter from E. G. Broomell to Philadelphia Office, Copy Book 8, February 2, 1887, pp. 574-575.

[18] "The Machine Tool Industry," *American Machinist*, June 28, 1879, p. 8 The shift to specialized producers of machine tools was described as follows: "Machine tool-making as a distinct branch of industry is of recent date. A few years ago builders of steam engines and other kinds of machinery were accustomed to make for themselves such machine tools as

they required. Special tools for special work were usually crudely-designed and imperfect affairs. Tool making was then considered subordinate to other important operations—to work made for sale. Our engineering practice of today would be impossible without the improved modern machine tools, the perfection of which underlies the perfection of their own and all other machine making. Machine tool-making has come to be established as a distinct and important branch of industry, and the best talent is devoted to designing and constructing new tools for special purposes as well as in perfecting standard tools for more general use."

[19] Nathan Rosenberg, "Technological Change in the Machine Tool Industry," *The Journal of Economic History,* XXIII (December, 1963), 423.

[20] *Ibid.*

[21] Ross M. Robertson, "Changing Production of Metal Working Machinery, 1860-1920," *Output, Employment and Productivity in the United States After 1800* (New York: National Bureau of Economic Research, 1966), pp. 486-487.

[22] *Ibid.*, p. 487.

[23] *Ibid.*

[24] "The Machine Tool Industry," *American Machinist,* June 28, 1879, p. 8

[25] Ross M. Robertson, "Changing Production of Metal Working Machinery, 1860-1920," pp. 486-487.

[26] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, n.d., pp. 387-388.

[27] *Ibid.*

[28] Letter from E. G. Broomell to Putman Machine Company, Fitchburg, Massachusetts, Copy Book 4, December 27, 1881, p. 131.

[29] *Ibid.*

[30] Letter from E. G. Broomell to Putman Machine Company, Fitchburg, Massachusetts, Copy Book 4, January 6, 1882, p. 156.

[31] Letter from E. G. Broomell to Putman Machine Company, Fitchburg, Massachusetts, Copy Book 4, March 18, 1882, p. 360.

[32] Somehow the H. B. Smith Machine Co. of Philadelphia heard of this tool and wrote Christiana for prices. Edward replied: ". . . we are just now building first machine for our own use and are not prepared to quote prices on it." How Smith found out about this machine is a very good question, their inquiry even before it was finished or tested indicates the demand for such a tool. Christiana refused to duplicate this machine for outside firms which was a not uncommon practice. Brown and Sharpe, for example, refused to duplicate its machine tools for many years.

[33] Letter from E. G. Broomell to Craig Ridgway & Son, Coatesville, Pennsylvania, Copy Book 5, April 9, 1883, p. 82. The uses of the word "machinery" implying more than one machine is most interesting because Christiana seems to have made two machine tools to cut pulleys. Although there is only record of the one discussed above, a second tool is listed in a fire insurance application as follows: "1–40 inch special pulley lathe $625.00" and the other tool as "1–40 inch boring machine $600.00." Most probably the Broomells developed both tools after the one purchased from Putman proved inadequate. A pulley drill ($100) and a key-seating machine ($50) are also listed: it is an open question whether or not the Broomells also made these tools. Christiana Machine Company, Copy Book 5, January 17, 1884, p. 683.

In submitting a list of patterns destroyed by the fire Edward mentions. in addition to the tools discussed above, patterns for a large radial drill, a double press drill, and a small pattern lathe. None of these tools were patented, and only the boring and turning mill was ever sold to an outside firm. Christiana Machine Company, Copy Book 5, n.d., p. 477.

[34] Letter from E. G. Broomell to Carey Machine & Supply Co., Baltimore, Maryland, Copy Book 33, March 31, 1905, p. 929.

[35] Interview with Donald Werntz, Foreman of Machine Shop, Christiana Machine Company, July 1967.

[36] Henry Broomell and Joseph Powrall, "Animal Trap," Patent 188,753 (Original patent file in National Archives, March 27, 1877); Henry Broomell, "Pencil Sharpener," Patent 466,734 (Original patent file in National Ar-

chives, January 5, 1892); Henry Broomell, "Street Sweeper," Patent 550,014 (Original patent file in National Archives, November 19, 1895).

[37] John Joseph Murphy, "Entrepreneurship in the Establishment of the American Clock Industry," *The Journal of Economic History,* XXVI (June, 1966), 176.

[38] Letter from E. G. Broomell to Philadelphia Office, Copy Book 8, January 31, 1887, pp. 567-568.

[39] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, January 31, 1887, pp. 567-568.

[40] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, March 15, 1887, pp. 701-702.

[41] Letters from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, April 23 and 26, 1887, pp. 825-837.

[42] Letter from E. G. Broomell to John Seibert, Philadelphia, Pennsylvania, Copy Book 8, April 16, 1887, pp. 798-799.

[43] Letter from E. G. Broomell to N. F. Burnham, York, Pennsylvania, Copy Book 8, May 24, 1887, p. 929.

[44] Letter from E. G. Broomell, recipient unknown, Copy Book 24, May 10, 1900, p. 41. This system could be modified to meet the needs of the firm, for example, sometimes an apprentice "would be required to go first into our core department for about six months and then would go in the regular moulding." Letter from E. G. Broomell, recipient unknown, Copy Book 28, December 7, 1901, p. 574.

[45] Incorporating Charter Christiana Machine Company, Charter Book 1 (Recorder's Office of Lancaster County, January 14, 1887), pp. 347-348. Edward was also Secretary and Burnham, President.

[46] Interview with Louis Bond, Manager of the Christiana Machine Company, July, 1967.

CHAPTER VIII

CONCLUSIONS

[1] Letter from E. G. Broomell to Lukens Iron and Steel Co., Coatesville, Pennsylvania, Copy Book 27, June 18, 1901, p. 575.

[2] Letter from E. G. Broomell to H. M. Behre, New York City, Copy Book 49, April 13, 1914, p. 873.

[3] Grant H. Voaden, "First Turbine Installation by S. Morgan Smith at Jacobs Mill," *Turbine Topics* (In files of Allis-Chalmers, November, 1946), p. 2.

[4] Letter from E. G. Broomell to H. M. Behre, New York City, Copy Book 51, February 6, 1915, pp. 995-996.