

# WATER WHEELS IN THE PREINDUSTRIAL ECONOMY OF JAPAN†

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In previous book and articles we have examined the use of mechanical power in manufacturing in Japan after the 1880s.<sup>1</sup> We argued that the rapid development of modern sources of power, steam and electricity, played a significant role in the rapid industrialization of Japan. In this paper we examine the utilization of the water wheel, a traditional source of mechanical power, in Japanese manufacturing prior to industrialization.

Water wheels were the primary source of mechanical power in preindustrial Japan. In fact, before the end of the Edo period (1603–1867), the water wheel was the only widely used source of power other than human power. Unlike in the West, animal and wind power were rarely utilized.<sup>2</sup> Steam engines were first introduced to Japan during the late Edo period, but water power remained dominant over steam power until the 1880s.<sup>3</sup> As late as 1884–86 water wheels comprised 56.1% of total horsepower compared with the 43.9%

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<sup>1</sup> Ryōshin Minami, *Dōryoku Kakumei to Gijutsu Shinpo: Senzen-Ki Seizō-Gyō no Bunseki* (Power revolution and technological progress: A study of prewar manufacturing) (Tokyo, 1976); "The Introduction of Electric Power and Its Impact on the Manufacturing Industries: With Special Reference to Smaller Scale Plants," in Hugh T. Patrick, ed., *Japanese Industrialization and Its Social Consequences* (Berkeley, Calif., 1976); "Mechanical Power in the Industrialization of Japan," *Journal of Economic History*, 37 (Dec. 1977); and "Mechanical Power and Printing Technology in Pre-W.W. II Japan," *Technology and Culture*, forthcoming.

It is generally agreed that the industrialization of Japan began in the mid-1880s. The modern cotton-spinning industry, the first modern industry, started with the establishment of Ōsaka Spinning Mill in 1883 and other large mills in 1887. Output of cotton yarn increased rapidly thereafter, and by the end of the 1880s domestic production exceeded imports. This demarcation is consistent with the claim of Ohkawa and Rosovsky that the period 1886–1905 marks the beginning phase of modern economic growth according to the Kuznets paradigm. Kazushi Ohkawa and Henry Rosovsky "A Century of Japanese Economic Growth," in William W. Lockwood, ed., *The State and Economic Enterprise in Japan* (Princeton, N.J., 1965), p. 66. Indeed, industrialization and modern economic growth can be considered to be a single phenomenon.

<sup>2</sup> Animal power in Japanese industry was limited to sugar manufacturing. The Pre-Meiji Japan History of Science Association, ed., *Meiji-Zen Nippon Kikai Gijutsu-Shi* (History of mechanical engineering in pre-Meiji Japan) (Tokyo, 1973), pp. 17, 88–90. Cows were used from the late eighteenth century in the Ryūkyū Islands and Kagoshima Prefecture to turn the *sakusha*, a rotary cylinder used to crush sugar cane. In 1883 at Amami Ōshima in Kagoshima Prefecture there were 6,574 cow-operated *sakusha* compared with only 552 water-powered machines. Kagoshima Prefecture, *Kagoshima Ken Dai 4-Kai Kangyō Nenpō* (The fourth annual report on the industries of Kagoshima Prefecture) (Kagoshima, 1883), pp. 17–42. It was only after 1902 with an invention of Shikakichi Okuyama that hullers and threshers were operated by animals in some regions, especially Okayama Prefecture, Kyūshū, and Shikoku. The Pre-Meiji Japan History of Science Association, ed., *History*, p. 17. Non-utilization of animal power in Japan is partly attributable to the existence of an abundant labor force and the incapability of Japanese agriculture to raise sufficient livestock because of scarce land and dense population. Wind power was used for irrigation and rice cleaning only in very limited areas because Japan is frequently hit by typhoons. *Ibid.*, pp. 15–17.

<sup>3</sup> Minami, "Mechanical Power," n. 6.

share of steam engines. However, in 1887, with the onset of industrialization, steam overtook water to become the most prevalent source of power for manufacturing.<sup>4</sup>

In Japan, as well as in most other countries, water power was initially employed to process grain, and eventually water wheels became quite widely used for this activity. The introduction of water power to pure manufacturing uses developed from the earlier application of water wheels in processing grain. Although grain processing is conventionally classified as an agricultural activity, it is in fact rather similar to manufacturing. The "manufacturing activities" which are covered in this study, therefore, are broadly defined to include grain processing.

The first two sections of this paper take up the use of the water wheel in rice polishing and milling and in pure manufacturing activities. The third section examines the technology of the water wheel. The last section summarizes the conclusions and the implications to be drawn from this analysis. The most important implication concerns what light this study sheds on the degree of development of manufacturing and the level of technology of machinery production before industrialization. In other words, this paper helps to describe the initial conditions of industrialization in Japan.

## I. *Water Wheels for Processing Grain*

### Water Wheels before Meiji

Before the Meiji era, the main use of water wheels in Japan, outside of irrigation, was for processing grain, primarily for cleaning or polishing rice and to a lesser extent for milling wheat. Japanese farmers' widespread use of water for irrigation purposes, however, had several significant effects on the diffusion of water power to these manufacturing activities.

Rice processing was the first manufacturing use of water wheels in Japan and dates back to the seventh century. *Nippon Shoki*, one of the earliest Japanese historical records, tells that in 610 the priest Don Chō from Korea constructed a *mizu-usu*, a quern operated by a water wheel.<sup>5</sup> A second reference to the water-powered quern is found in *Yōryō Ritsuryō*, a legal code promulgated in 718. Among the laws laid down in this document is the stipulation that the water-powered quern may be used only when it does not disturb public and private irrigation.<sup>6</sup> Water wheels for rice processing, however, were not widely used and disappeared sometime after the early eighth century. This fact can be explained by the dietary preferences of the times. The general taste was for unpolished rice, and the demand for rice cleaning was small.<sup>7</sup>

<sup>4</sup> This conclusion depends on my estimates from the *Nōshōmu Tōkei Hyō* (Statistical tables of agriculture and commerce, henceforth STAC). In my estimates I have adjusted for the underenumeration of horsepower of the water wheel in STAC. Without this adjustment steam power exceeded water power by 1884. It should be noted also that small factories those with less than 10 workers, were not surveyed in STAC. If these factories, where the water wheel was the only source of mechanical power were included, the predominance of water over steam power would be more persistent.

<sup>5</sup> Iwanami Shoten, ed., *Nippon Koten Bungaku Taikei* (Series on Japanese classical literature), vol. 68 (Tokyo, 1965), p. 194.

<sup>6</sup> Katsumi Kuroita, ed., *Shintei Zōho Kokushi Taikei* (New enlarged edition, series on national history), part 2, vol. 2 (Tokyo, 1951), p. 335.

<sup>7</sup> The Agricultural History Research Association, ed., *Nippon Nōgyō Hattatsu-Shi: Meiji Ikō ni okeru* (History of agriculture in Japan since Meiji), vol. 2 (Tokyo, 1954), p. 93.

The water-powered quern appeared again early in the Edo era. Historical records show that one such quern was operated at Yamada near the Aikawa Mine on Sado Island during the Genroku period (1688–1703) and that another was erected at Takasaki Shuku in Kōzuke around the beginning of the eighteenth century.<sup>8</sup> There are two hypotheses to explain the revival of the water-powered quern. The first claims that use of the water wheel for irrigation eventually led to the reapplication of water power for rice cleaning. This hypothesis has been developed from references to the fact that in 1726 Ichirōemon erected a water-powered quern at Sano in Shimotsuke.<sup>9</sup> Ichirōemon used the *Yodo no suisha*, a water wheel employed to draw irrigation water from the Yodo River, as a model for this quern. The second hypothesis is that the water-powered quern was reintroduced from abroad. It is argued that the technology either came directly from China and Korea or was developed in Japan relying on Chinese agricultural textbooks such as *Tenkō Kaibutsu* (1637) and *Nōsei Zensho* (1639).<sup>10</sup>

During the Edo era the water-powered quern gradually came to replace the foot-powered quern which had become popular in the early seventeenth century.<sup>11</sup> But at the time of its reintroduction the demand for water power in rice processing was still quite small. Outside of the court and the aristocracy, people ate nonpolished or at most semipolished rice,<sup>12</sup> and semipolishing could be accomplished easily with human power.<sup>13</sup> However, the increasing popularity of polished rice among the common people after the eighteenth century stimulated the spread of the water-powered quern.<sup>14</sup>

Milling grain was the only other manufacturing use of the water wheel in Japan before the Meiji era. But, unlike in the West, water wheels were only rarely used for milling wheat and other grains. This was true in spite of the fact that milling requires much greater energy than rice cleaning. In order to separate and remove the hard skin of wheat, the grain must be ground into a fine powder. The difference in diet and the greater difficulty of wheat processing account for the wider utilization of water power for milling in the West.<sup>15</sup> However, even in Japan, water power was used for this purpose in some parts of the double-cropping area. For instance, in the Edo era *sōmen* (vermicelli) manufacturers in Hyōgo Prefecture drew water from the Kako River to power water wheels used for grinding wheat.<sup>16</sup>

The fact that Japanese agriculture depended heavily on water had two opposing impacts on the diffusion of water wheels for grain processing. On the negative side, the water concession of farmers restricted water power utilization for manufacturing activities. The clause from the *Yōryō Ritsuryō* cited earlier suggests that the conflict between agricultural and manufacturing uses of water existed as far back as eighth century.

This conflict continued to much more recent times. For example, in 1744 permission was given to install a water wheel at a mill in the Minami Kōchi District of Osaka Prefecture

<sup>8</sup> Eitarō Tamura, *Nippon Kōgyō Bunka-Shi* (History of industry and culture in Japan) (Tokyo, 1943), p. 731.

<sup>9</sup> *Ibid.*, p. 731.

<sup>10</sup> The Pre-Meiji Japan History of Science Association, ed., *History*, p. 3.

<sup>11</sup> The Agricultural History Research Association, ed., *History*, vol. 2, pp. 93–96.

<sup>12</sup> *Ibid.*, p. 93.

<sup>13</sup> Mitsukuni Yoshida, *Kikai* (Machinery) (Tokyo, 1974), pp. 10–11.

<sup>14</sup> The Agricultural History Research Association, ed., *History*, vol. 2, p. 93.

<sup>15</sup> Shigeo Miwa, *Ishi-Usu no Nazo: Sangyō Kōko-Gaku e no Michi* (Puzzles on stone mills: An approach to industrial archaeology) (Tokyo, 1975), p. 226.

<sup>16</sup> Yoshida, *Machinery*, p. 11.

only on the condition that the mill be closed during the growing season, from spring to autumn. Struggles between millers and farmers in this district became more serious with the construction of another four water wheels between 1751 and 1763. In 1764 the millers finally had to agree to remove the water wheels within the subsequent five years. Throughout Japan during the Edo period millers were restricted from operating water wheels during the rainy season from spring to summer. And in winter, when they were allowed to operate, sufficient water was not available. This competition with agricultural interests for access to water disturbed the development of water-powered grain processing as a business independent of agriculture.<sup>17</sup>

On the other hand, in addition to the restrictions it imposed, the importance of water in Japanese agriculture also created a situation favorable to the diffusion of water power for these manufacturing activities. The highly developed irrigation system, which extended to most of the arable land, made it possible to install water wheels throughout the country. In other words, grain processors were not limited to locating near principle rivers or streams. This positive impact is largely neglected in appraising the early development of Japanese manufacturing.<sup>18</sup>

### Water Wheels in the Meiji Era

During the Meiji period (1868–1911) the importance of water wheels for grain processing gradually diminished as new sources of power became available.<sup>19</sup> It is possible to trace this trend in some detail because quantitative statistics on water wheels are available for the Meiji period.

Nationwide statistics on water wheels used for rice cleaning for the year 1822 to 1910 are available from the *Chōhatsu Bukken Ichiran Hyō* (Tables for goods and resources for provision).<sup>20</sup> This survey was conducted by the Rikugun Shō (Ministry of War) to determine the national capability to provide goods and resources in time of emergency. It records the number of water-powered rice-cleaning mills in operation, a figure which can also be taken as an estimate of the number of water wheels employed for this activity. Column 1 of Table 1, which is taken from this survey, shows that a great number of water wheels were in operation and their number was rather stable for the period. (The decline between 1896 and 1900 is attributable to a change in the coverage of the survey.)

The significance of water power in rice cleaning during the Meiji period can be judged further by comparing the capacity of water-powered mills with total rice production. Columns 2 and 3 of Table 1 present estimates of rice-cleaning capacity under the assumptions

<sup>17</sup> *Ibid.*, pp. 9–10.

<sup>18</sup> I am indebted to Professor Hiroshi Shinpo of Kobe University for making this point.

<sup>19</sup> In spite of the diminishing importance of water wheels in rice cleaning, an interesting innovation appeared in this field. It was rice cleaning in a boat on the Tenryū River, which commenced in 1893–94 and became most developed during the late 1910s. Six to twelve (usually eight) querns were run by water wheels installed on both sides of a boat. Tamura, *History*, pp. 735–736. This technique calls to mind the “floating mill” which was widely seen in Europe. T. K. Derry and Trevor I. Williams, *A Short History of Technology: From the Earliest Times to A.D. 1900* (Oxford, 1960), p. 252.

<sup>20</sup> The earlier version of this survey by the Rikugun Shō, the *Kyōbu Sei Hyō*, also contains statistics on the number of water powered rice-cleaning mills. There were 9,200 in 1878; 9,516 in 1879; and 10,010 in 1880. The average number of water wheels in these three years, 9,575, was only about one seventh of the number recorded in the *Chōhatsu Bukken Ichiran Hyō* for 1882 (Table 1, column 1). One of the reasons for this underenumeration in the former survey is that this survey covers only towns and cities with 100 or more inhabitants.

TABLE 1 NUMBER OF WATER WHEELS FOR RICE-CLEANING  
AND THEIR CAPACITY COMPARED WITH RICE PRODUCTION: 1882-1910

Year	Number of Water Powered Mills	Capacity for Rice Cleaning		Rice Production	Ratio	
		a	b		(2)/(4)	(3)/(4)
	(1)	(2)	(3)	(4)	(5)	(6)
		(1,000 <i>koku</i> )		(1,000 <i>koku</i> )	(%)	
1882	62,879	8,803	13,205			
1883	56,507	7,911	11,866	27,481	28.7	43.2
1884	55,692	7,797	11,695	23,583	33.1	49.6
1885	59,264	8,297	12,445	25,673	32.3	48.5
1886	47,048	6,587	9,880	35,797	18.4	27.6
1887	48,649	6,811	10,216			
1889	52,924	7,409	11,114	30,121	24.6	36.9
1890	47,776	6,689	10,033	41,082	16.3	24.4
1891	52,130	7,298	10,947	39,656	18.4	27.6
1896	52,710	7,379	11,069	38,261	19.3	28.9
1900	38,983 <sup>e</sup>	5,458	8,186	41,441	13.2	19.8
1902	42,823 <sup>e</sup>	5,995	8,993	37,278	16.1	24.1
1904	43,047 <sup>e</sup>	6,027	9,040	49,773	12.1	18.2
1906	44,100 <sup>e</sup>	6,174	9,261	46,231	13.4	20.0
1908	43,705 <sup>e</sup>	6,119	9,178	51,322	11.9	17.9
1910	43,876 <sup>e</sup>	6,143	9,213	46,316	13.3	19.9

a Estimation under the assumption that the rice-cleaning capacity of a water wheel is 140 *koku*.

b Estimation under the assumption it is 210 *koku*.

c Water mills processing one *koku* and more a day.

Source: See Text.

that a water wheel can process 140 or 210 *koku* of rice.<sup>21</sup> Total rice production is shown in column 4, and the ratio of capacity to production is indicated in column 5 or 6 depending on the capacity assumption. Two important observations can be made from these statistics. The first is the overall low level of dependence on water power in rice cleaning in the Meiji period. As shown in columns 5 and 6, only 30-50% of total rice production in 1883-85 was cleaned by water power. In other words, since other sources of mechanical power were negligible, 50-70% of the rice produced in Japan at this time was polished by human power.<sup>22</sup> This surprisingly low level of mechanization in rice cleaning can be explained by the lingering influence of two factors important in the Edo era: the small power requirements of the rice-polishing process and the restrictions imposed by the water concession of farmers. In addition, low wages may also have discouraged mechanization of rice polishing.

The second observation to be made from these statistics is the decreasing dependence on water wheels for rice cleaning over the Meiji period. The percentage of total rice production cleaned in water-powered mills fell to between 13 and 20% by 1910. This trend is attributable to the substitution of other sources of power—steam engines, internal com-

<sup>21</sup> One *koku* is equivalent to 180 liters. Yoshiyuki Sueo made similar estimates of rice cleaning capacity for Nara Prefecture. His estimates were derived from the number of water wheels in the *Suisha Shirabe* (Survey on water wheels) in 1881. Our assumptions about processing capacity of a water wheel employed in Table 1 are taken from his estimates. *Suiryoku Kaihatsu Riyō no Rekishi Chiri* (History and geography of development and utilization of water power) (Tokyo, 1980), p. 94.

<sup>22</sup> According to Sueo only one-sixth of rice produced in Nara Prefecture was cleaned by the water wheel. *Ibid.*, p. 94.

TABLE 2 WHEAT FLOUR CONSUMPTION BY SOURCE: 1878-1912

Year	Imports	Processed by:	
		Water Wheels	Other Engines
1878	1	97	2
1884	1	97	2
1896	7	89	4
1897	6	89	5
1898	6	88	6
1899	7	87	6
1900	16	78	5
1901	12	79	9
1902	16	76	8
1903	35	56	9
1904	33	57	10
1905	32	56	12
1906	29	59	12
1907	20	47	33
1908	10	41	49
1909	5	37	58
1910	5	41	54
1911	5	43	52
1912	4	36	60

Sources: The Japan Engineering Association, *Meiji Kōgyō-Shi* (History of manufactures in Meiji) *Kikai Hen* (Volume on machinery) (Tokyo, 1930), pp. 199-200, 222-223.

bustion engines, and electric motors—for the water wheel in rice cleaning.<sup>23</sup> This substitution was closely associated with the development of rice cleaning as a commercial activity in urban areas.

It is more difficult to examine the utilization of the water wheel for milling because there is no nationwide statistical data. Nevertheless, some indication of the importance of water-powered milling in the early Meiji period can be gained from the *Suisha Shirabe* in Nara Prefecture in 1881. According to this survey, of the 556 water wheels operating in Nara Prefecture in 1881 only 38 (6.8%) were employed for milling wheat compared with the 296 (53.2%) in use in rice cleaning establishments.<sup>24</sup> Although relative use of water wheels for milling and rice cleaning certainly differed among prefectures, it would be safe to conclude that throughout Japan milling wheels were far outnumbered by rice-cleaning wheels during the Meiji period, just as they had been during the Edo period.<sup>25</sup>

Not only was flour milling a relatively insignificant activity, but also, the dependence on water power in milling decreased over the Meiji period with the establishment of large-scale mills employing steam engines. As shown in Table 2, the percentage of total flour consumption processed by water wheels fell rapidly from its 97% share in 1878. By 1912 water wheels processed only 36% of wheat flour compared with the 60% processed by other engines.

During the Meiji period grain processing came to rely less and less on the water wheel

<sup>23</sup> Although there is no nationwide data on the number of water wheels after 1910, it is believed that it decreased rapidly since the 1920s depending on the substitution by internal combustion engines and electric motors. Toshiro Kuroda, Masami Tamaoki and Kiyoshi Maeda, *Nippon no Suisha* (Water wheels in Japan) (Tokyo, 1980), p. 150.

<sup>24</sup> Sueno, *History*, p. 89.

<sup>25</sup> *Ibid.*, p. 115.

as a source of power. This trend was seen in both rice polishing and in wheat milling. The declining importance of water wheels is believed to have continued in the post Meiji years and can be inferred from the spread of other power sources to this traditional, rural-based manufacturing activities. For example, the total number of rice-cleaning machines powered by internal combustion and electric engines almost tripled from 25,153 in 1927 to 72,597 in 1939.<sup>26</sup> In addition, milling machines powered by 1–2.5 hp engines became popular during the 1920s.<sup>27</sup> There were 3,264 such machines in 1927 and four times as many in 1939.<sup>28</sup> The increasing availability of these machines, coupled with the development of large-scale millers, sounded the death knell for the water wheel in grain processing.

## II. *Water Wheels for Industrial Use*

### History before Late Edo Era

Water power has been applied to various manufacturing uses outside of grain processing, dating back to the eighteenth century. Until the late Edo period, water wheels were, with few exceptions, found only in lower levels of manufacturing processes. But the benefits which mechanization by water power offered were in a range of industries.

Sake brewing was a typical industry which early benefited from the introduction of water wheels. Sake brewing consists of two processes, rice cleaning and brewing itself. Although brewing, which required technical skill and long experience, could not be mechanized, labor-saving mechanical devices could be applied to rice cleaning, which was a very simple process. Brewers in Nadagō were the first to successfully employ water wheels for rice-cleaning at the beginning of the eighteenth century. Nadame, a section of Nadagō, situated on the so-called fall-line starting at the Rokkō Dislocation, was in a particularly favorable location for water power utilization. The number of water wheels employed by sake brewers increased from 4 in 1718 to 40 in 1788 and to 66 in 1810.

Introducing water power had considerable positive impacts for sake brewers. Not only did labor costs decrease and output increase, but also output quality improved remarkably. Tarōzaemon Yamamuro utilized water wheels to produce a special brand of sake from rice cleaned continuously for 72 hours. Incessant cleaning for such a long time with constant speed and power had been impossible with human power. As a result of this innovation and the quality improvement, the sake of Nada won high reputation and overwhelmed all other brands sold in Edo (Tokyo).<sup>29</sup>

There are numerous other examples of the advantages of water power to manufacturing coming from the early Edo period. In the eighteenth century oil manufactures in Settsu, Kōchi, and Izumi introduced water wheels to grain toasted rape and cotton seeds. *Seiyū Roku* (Record of oil manufactures) written by Nagatsune Ōkura in 1836 documents that grinding efficiency doubled with this innovation. Ground seeds were then pressed by the

<sup>26</sup> The Agricultural History Association, ed., *History*, vol. 6 (Tokyo, 1955), Table 15 of ch. 3, pt. 3.

<sup>27</sup> Yasuto Hashimoto, *Komugi Seifun to Seimen* (Wheat milling and noodle making) (Tokyo, 1937), pp. 41–46.

<sup>28</sup> See n. 26.

<sup>29</sup> Sei-ichi Kawamura, "Shuzō Manufacture to Suisha" (Sake brewing manufacture and water wheels), *Kobe Gaidai Ronsō* (Review of Kobe Foreign Language University), 2 (Feb. 1952), pp. 23–36.

*sa* (wedge press) and *nakagi* (lever press) to release their oil. However no animal or mechanical power was utilized in this latter process.<sup>30</sup>

Technical progress occurred in sugar cane processing first with the introduction of animal power but then also with the use of water power.<sup>31</sup> Substitution of cows for men to operate the *sakusha* (crushing machine) increased the amount of sugar cane processed from 135–136 *kan* to 250–1,000 *kan*.<sup>32</sup> Then, in 1717 Sabuni Tabata in Amami Ōshima introduced a water wheel, and output of raw sugar, which had been 1 *chō* per day by animal power, doubled to 2 *chō*.<sup>33</sup>

Ceramic manufactures and ore processors also realized the advantages of water power for crushing materials. It is known, for example, that a water wheel installed on a boat on the Nishiki River at Iwakuni was being used to crush potter's clay as early as the beginning of the nineteenth century. And at Arita and Seto, the centers of porcelain production in the Edo period, water wheels were being used to crush subsoil at least since the late eighteenth century.<sup>34</sup> During the Bunka period (1804–1817), a gold mine in Sado employed a water wheel with nine pounders to crush ore into much finer powder than was possible by human power using iron hammers.<sup>35</sup>

The industrial uses to which water power was put during the early Edo period all showed the characteristics that they were at the primary level of manufacturing. As the previous example show, utilization of water power was most common in activities which involved processing or crushing materials (rice, wheat, rape seeds, sugar cane, soil, and ore). Water wheels were used only rarely at higher levels of production processes. One example of the more advanced application of water wheels occurred in yarn production. Water power had been used in twisting silk yarn at Ashikaga from about 1800. And Shige-ichirō Numaga at Fujitsuka Village in the Usui District ran several sets of *zakuri* (sedentary reeling machine) by water power. This unique structure was washed away by a flood in 1861.<sup>36</sup>

In spite of the advantages of water wheels, water power was not widely applied to industrial activities until the end of the Edo period. The water concession of farmers, which was discussed earlier as a restriction on the application of water wheels to grain processing, may have been a factor limiting the use of water power in other manufacturing activities as well. But it does not seem to have been the decisive factor, because it does not explain the expansion of water power utilization to industrial uses which occurred from the end of the Edo era. It is our hypothesis that the demand for mechanical power played a significant role in the diffusion of water power. That is, before the end of Edo, manufacturing industries had not been developed enough to utilize mechanical power.

### History in Late Edo and Early Meiji

Over the latter part of the Edo and early Meiji periods water power was increasingly applied to a number of more sophisticated manufacturing processes. The spread of water

<sup>30</sup> The Pre-Meiji Japan History of Science Association, ed., *History*, pp. 9–11.

<sup>31</sup> *Ibid.*, pp. 84–92 and the Japan Engineering Association, ed., *History of manufacture, Kagaku Kōgyō Hen* (Volume on the chemical industry) (Tokyo, 1925), pp. 777–78.

<sup>32</sup> One *kan* is equivalent to 3.76 kg.

<sup>33</sup> A *chō* is a measure of a barrel of sugar, the size of which is unknown.

<sup>34</sup> Yoshida, *Machinery*, pp. 18–20.

<sup>35</sup> *Ibid.*, p. 16.

<sup>36</sup> The Pre-Meiji Japan History of Science Association, ed., *History*, pp. 12–13.



power to these industrial activities occurred both with the introduction of Western technology and with the wider use of the traditional Japanese water wheel.

Modern technology imported from the West in the late Edo offered advantages to a number of industries. The Saga Clan, installed a water wheel in 1852 and used it to bore a cannon in the next year. By this innovation they saved on labor inputs and increased the accuracy of the cannon. In 1853 the Satsuma Clan made the same innovation.<sup>37</sup> Water power was also used to operate bellows at the Kamaishi Iron Mine in 1857, and in the middle 1850s the Tokugawa Shogunate established several gun powder plants powered by water wheels.<sup>38</sup> A notable example of water power utilization was the *Suisha Kan* (water-powered factory) at Tagami Village of Satsuma Clan. Here imported weaving machines were run by water power for about ten years starting in 1857.<sup>39</sup>

Water wheels became a substantial source of power for manufacturing in the early Meiji period. The energy policy of the government to encourage water power utilization in place of steam power was somewhat responsible for the spread of water wheels. A government report on the International Exhibition in Vienna in 1873, was a declaration of the policy. The report emphasized the advantages of water power over steam power in Japan a country with abundant water resources. The government encouraged the use of the Western water wheel and water-powered turbine. These engines were widely adopted in modern industries like spinning, weaving, paper manufacturing, and so forth.<sup>40</sup>

However, substantial growth in water power utilization also occurred with the application of the traditional Japanese water wheel in traditional industries.<sup>41</sup> The textile industry is the foremost example of this phenomenon. The traditional water wheel was the primary source of power in the silk-reeling industry, which developed in Nagano Prefecture during the early Meiji period (1877–1886). This technique gradually spread to silk-reeling establishments in other regions.<sup>42</sup> Water power was also used in connection with traditional technology in cotton spinning. For example *gara*-spinners, a development of the older hand spinners, were run by water wheels from the second decade of the Meiji.<sup>43</sup>

The significance of the application of water power to the traditional textile industry can be understood by comparing power capacity in this industry with that of other manufacturing industries in the early Meiji period. Table 3 shows the mean horsepower of water wheels and water turbines in various manufacturing industries for 1884–90. (These machines were largely of the Japanese type and turbines were not yet widely used.) A very great proportion of total water power in all manufacturing was used in textiles (87.6%), especially in silk reeling (73.9%). Silk reeling was the foremost user of water power in Japan during the 1880s. Spinning employed a much smaller, though comparatively quite large, share of total water power (13.1%), because spinning was accomplished to a large extent in modern

<sup>37</sup> *Ibid.*, pp. 8–9, 14.

<sup>38</sup> *Ibid.*, p. 9.

<sup>39</sup> *Ibid.*, pp. 13–14 and Hirone Saigusa, *Saigusa Hirone Chosaku-Shū* (Collected papers of Hirone Saigusa), vol. 10 (Tokyo, 1973), pp. 106–108.

<sup>40</sup> Yoshida, *Machinery*, pp. 28–29.

<sup>41</sup> *Ibid.*, p. 23 and the History of Modern Japanese Industries Research Group, ed., *Gendai Nippon Sangyō Hattatsu-Shi* (History of the development of modern Japanese industry), vol. 29, *Sōron, Jyō* (General considerations, Part 1) (Tokyo, 1967), p. 114.

<sup>42</sup> Minami, "Mechanical Power," pp. 947–48.

<sup>43</sup> *Ibid.*, pp. 949–50.

TABLE 3 HORSEPOWER OF WATER WHEELS AND WATER TURBINES  
IN MANUFACTURING

Industry	Horsepower of Water Wheels & Turbines <sup>a</sup>	Share of Total (%)
All Manufacturing	2,447 <sup>b</sup>	100.0
Textiles	2,144	87.6
Silk Reeling	1,809	73.9
Spinning	320	13.1
Others	15	0.6
Metals & Metal Products	131	5.4
Machinery	2	0.1
Ceramics	21	0.9
Chemicals	73	3.0
Wood & Wood Products	54 <sup>c</sup>	2.2
Printing & Binding	0 <sup>c</sup>	0.0
Food	22	0.8
Miscellaneous	0 <sup>c</sup>	0.0

Figures for private establishments with 10 or more production workers.

a. Mean of horsepower in seven years, 1884-90.

b. Total of the nine industry groups.

c. Mean of horsepower in five years, 1886-90.

Sources: Estimation based on STAC.

TABLE 4 HORSEPOWER OF WATER WHEELS AND TURBINES AND SHARE OF  
WATER POWER IN TOTAL HORSEPOWER IN ALL MANUFACTURING AND  
TEXTILES: 1884-90

	All Manufacturing			Textiles		
	All Engines <sup>a</sup>	Horsepower of Water Wheels & Turbines	Share of Water Power (%)	All Engines <sup>a</sup>	Horsepower of Water Wheels & Turbines	Share of Water Power (%)
1884	2,064	1,274	61.7	1,437	1,088	75.7
1885	2,026	1,020	50.3	1,408	906	64.3
1886	4,796	2,519	52.5	3,624	2,421	66.8
1887	8,915	2,793	31.3	6,407	2,642	41.2
1888	13,414	3,176	23.7	9,515	2,910	30.6
1889	25,072	2,515	10.0	17,738	2,025	11.4
1890	29,948	3,425	11.4	21,795	3,015	13.8

a. Water wheels and turbines and steam engines and turbines.

Sources: Same as Table 3.

factories which were powered by steam engines. Among industries other than textiles, metals and metal products, chemicals, and wood and wood products were the most important users of water power, though their share of total water power capacity was quite small.

Not only was total water power capacity concentrated in the textile industry, but also water was a more important source of power to textile production than to other manufacturing activities. Table 4 provides a comparison between the share of water power out of total power capacity (water and steam) in textiles and in all manufacturing. In 1884 water power comprised 61.7% of total power capacity in all manufacturing compared with its 75.7% share in textiles. In other words, during the early Meiji period, textile production

was much more dependent on water power than other industries, which relied more heavily on steam power.

Table 4 also documents the declining importance of water power and the rise of steam power. In 1877, water power's share of total power capacity had fallen below 50% both in all manufacturing combined and in textiles alone.<sup>44</sup> Thus, the place of water power in all manufacturing fell dramatically as the textile industry, the predominant industrial user of water power capacity, switched over to steam power. That is, because the textile industry had been the only manufacturing activity to rely heavily on water power, the transition from water to steam power in Japan was confined largely to the textile industry.<sup>45</sup>

### III. *Technology of Water Wheels*

#### **Traditional Technology**

Technology of water wheels remained almost unchanged until the late Edo period and its level was much lower than in Europe. We will examine the design of the water wheel and the mechanism of transmission in Japan in comparison with Europe.

The only water wheel used in Japan appears to have been the vertical type.<sup>46</sup> Although the horizontal water wheel (Greek or Norse mill) was also used in Europe and China, there are no historical records which refer to this type wheel having been used in Japan. Vertical water wheels are of two designs, undershot and overshot. The overshot wheel, more efficient than the undershot, was limited to the areas with abundant falls.

Until the late Tokugawa period, all water wheels in Japan were wooden, and they were made by *kuruma daiku* (wheel carpenters). Relying on instructions passed on from their masters and on their own experience, and considering the size and speed of the stream, these craftsmen determined the diameter of the wheel and the number of paddles so that the wheel would rotate ten to fifteen times a minute. This method of production continued unaltered down through the Edo period.<sup>47</sup>

In the middle of the eighteenth century several experiments in Europe revealed the greater efficiency of the overshot against the undershot type. For instance, John Smeaton of England contributed a paper to the Royal Society in 1759 showing the superiority of the overshot water wheel.<sup>48</sup> However, such scientific investigations into the efficiency of the

<sup>44</sup> See n. 4.

<sup>45</sup> In small establishments, which are not covered in Table 3, tools and machines were operated by both human and water power. Human and water power were replaced by electric motor in the 1920s. There was no age of steam power. Minami, "Electric Power," pp. 303-306 and "Mechanical Power," pp. 951-52. Therefore, inclusion of these establishments does not alter our conclusion in the text that the transition from water to steam power was generally limited to the textile industry.

<sup>46</sup> This fact seems to be attributable to a technical condition. The horizontal wheel with vertical shaft was easily used for operating wheat mills because the shaft of the mill is also vertical. But rice cleaning, which was more important than milling in Japan, depends on the up-and-down movement of pounders, and this motion was not easily achieved with a horizontal wheel. With the vertical wheel, on the other hand, rotation of the horizontal wheel shaft was converted to up-and-down movement simply by placing lugs on the shaft.

<sup>47</sup> Kiyoyasu Maruyama, "Nōson Suisha no Gijutsu-Shi: Kita-Kantō ni okeru (History of rural water wheels in Northern Kantō), *Kagaku-Shi Kenkyū* (Studies on the history of science), 37 (Jan. and March, 1956), p. 6.

<sup>48</sup> Richard L. Hills, *Power in the Industrial Revolution* (Manchester, 1970), p. 98.

water wheel were never conducted in Japan. This was one of the reasons for the stagnancy in the level of technology of water wheels.

The application of the water wheel to manufacturing depends not only on the design of the wheel itself, but also on the mechanism by which power is transmitted to accomplish the final task. In this respect, too, Japanese technology lagged behind that in Europe. Rice cleaning, ore crushing, and other typical uses of the water wheel in Japan depended on the up-and-down movement of pounders. Power was transmitted to the pounders by lugs attached to the rotating wheel shaft. In addition a gear system which converted the rotation of the shaft to vertical movement was employed to run the rotary quern used for milling wheat and rape seeds and the *sakusha* used for crushing sugar cane. Both of these mechanisms which were widely used in Japan, are rather simple to construct.

A more complicated transmission mechanism is necessary to employ the water wheel for general, higher level, industrial activities. For example, a combination of two gears of different sizes or two pulleys of different sizes connected by belts is necessary in order to change the speed of rotation and transmit power from the wheel shaft to a parallel shaft which runs machinery. In Europe cutlery grinding machines and lathes employing this mechanism were operated by water wheels from the thirteenth or fourteenth century.<sup>49</sup> But this type of apparatus was rarely seen in Japan before Meiji. The Japanese had developed a primitive machine tool, the *rokuro*, which had two pulleys of different sizes connected by belts. However, the *rokuro* was operated by human power until about 1887 when an attempt was made to connect the machine to a water wheel.<sup>50</sup>

A crank and cum transmission system converts the rotating motion of the water wheel to reciprocating motion. In Europe bellows and sawing machines equipped with such a system were developed in the eleventh and thirteenth centuries respectively. In Japan, however, water power was never employed for sawing. And blowing in the *tatara*, the traditional iron manufacturing technique, sometimes depended on human power.<sup>51</sup> In Izumo, one of the representative places for *tatara* production, for instance, it was not until the third decade of the Meiji era (1887–96) that water-powered bellows were first employed.<sup>52</sup> In some places, however, water-powered bellows were utilized. The *tatara* in Nejime in Kagoshima Prefecture built between 1851 and 1861 was one of examples.<sup>53</sup>

### Influences of Western Technology

Western technology relating to the water wheel was not introduced in Japan until the end of the Edo period. The wooden water wheel with wooden gears operating in the *Suisha Kan* in 1857 is believed to have been brought from the Netherlands.<sup>54</sup> In addition, modern water wheels were imported from the West in the Meiji period. For instance, an iron water wheel from England was installed at the Kashima Spinning Mill in 1872.<sup>55</sup> The modern

<sup>49</sup> Information on transmission technology in Europe comes from Samuel Lilley, *Men, Machines and History*, rev-and enl-ed. (New York, 1965), p. 46.

<sup>50</sup> The Pre-Meiji Japan History of Science Association, ed., *History*, p. 269.

<sup>51</sup> Saigusa, *Collected papers*, p. 212.

<sup>52</sup> Shōji Okumura, *Koban Ki-ito Watetsu: Zoku, Edo Jidai Gijutsu-Shi* (Gold coin, silk, and iron: Tokugawa history of technology, continued) (Tokyo, 1973), p. 138.

<sup>53</sup> Toshirō Kuroiwa and Masami Tamaoki, *Sangyō Kōkōgaku Nyūmon* (Introduction to industrial archaeology) (Tokyo, 1978), pp. 102–109.

<sup>54</sup> The Pre-Meiji Japan History of Science Association, ed., *History*, p. 14.

<sup>55</sup> The History of Modern Japanese Industries Research Group, ed., *History*, vol. 29, p. 117.

technology also motivated an improvement in the traditional water wheel, which still comprised the majority of the water wheels in use during the Meiji era.<sup>56</sup> Masataka Tazawa and Keijirō Kishi of Dengyō Company produced small-capacity, iron water wheels from 1910 until about 1917. These machines were about twice as efficient as the wooden wheels which were still being produced in the rural areas by traditional techniques.<sup>57</sup>

#### IV. *Conclusion and Their Implications*

In Japan, as in the West, water wheels found their initial manufacturing application in grain processing. The peculiar requirements of grain processing in Japan shaped the diffusion of water power and the development of manufacturing technology for more than a millennium, from 610 to the Edo period. The developments surrounding the water wheel in the preindustrial economy have implications for modern industrialization.

The application of water wheels to manufacturing uses in Japan centered on rice polishing. Even so, water wheels were not widely used for this purpose until the eighteenth century when polished, rather than unpolished, rice became popular among the ordinary people. The water wheel was never as widely utilized for grain processing in Japan as it was in Europe. Even in the Meiji period, more than half of all the rice consumed in Japan was polished by human power. The minimal power requirements of rice cleaning compared with wheat milling, coupled with the characteristic that flour products were only of secondary importance in the Japanese diet, may have discouraged the diffusion of water power. In addition, rice cleaning required only relatively simple mechanisms to transmit power from the water wheel. Thus, the fact that technology related to water-power utilization was virtually stagnant in Japan until the late Tokugawa may also be laid to the principle application of the water wheel for rice cleaning.

The pure manufacturing use of water wheels in Japan also developed in connection with rice polishing. The introduction of the water wheel to the initial rice-cleaning step in brewing sake resulted in increased efficiency in this industry. Other later manufacturing applications of the water wheel were similarly limited to simple production processes, like crushing materials, until the late Edo. The failure to develop more advanced transmission systems may account for the fact that water power was not widely adopted for more sophisticated manufacturing activities.

Industrial water-power utilization became more widespread in the late Edo period. The spread of water wheels was motivated in part by the introduction of Western technology in the mid-nineteenth century. The statistics show, however, that the diffusion of the water wheel to manufacturing was eventually confined to the textile industry, especially to the traditional activities of silk reeling and cotton spinning. Dependence on water power in other manufacturing industries was very low by the 1880s. Mechanization of these industries was primarily accomplished by modern engines—steam engines and electric motors. Thus, the great transition from the water wheel to the steam engine, which characterized the

<sup>56</sup> The Pre-Meiji Japan History of Science Association, ed., *History*, p. 15.

<sup>57</sup> Eitarō Tamura, *Nippon Denki Gijutsu-Sha Den* (Biography of electric engineers in Japan) (Tokyo, 1943), pp. 286–88 and Dengyō Company, *Dengyō Sha Gendōki Seizō-Jo 45-Nen-Shi* (45 year history of Prime Mover Factory, Dengyō Company) (Tokyo, 1955), pp. 7–13.

inception of the Industrial Revolution in England, was seen in Japan only in the textile industry.

This examination of water wheels and the unique characteristics of the diffusion of water power in the preindustrial economy of Japan has at least three implications relating to the preconditions for modern economic growth. First, the introduction of mechanical power to manufacturing activities has as a prerequisite a certain level of development of these activities themselves. The limited application of water wheels to industrial uses in Japan before the Edo period indicates that manufacturing had not yet generated a significant demand for mechanical power. Had the need for power existed, water wheels, which had been available long before steam engines, would have been more widely exploited. In fact, it was the growth of the textile industry in the early Meiji period which led to the heavy reliance of this industry on the water wheel, the only accessible source of power.

Second, Japan's experience indicates the role of the availability of technology along with mechanical power in determining the shape of the transition to modern industrial production. In Japan, the classic transition from traditional water wheels to modern steam engines occurred almost solely in the textile industry. Western-type water wheels had been used by some modern industrial factories during the early Meiji period on the advice of the government. But utilization of the water wheel in such modern plants was not widespread because the steam engine was much more powerful. Even in the textile industry, the first successful introduction of modern cotton-spinning technology at the Osaka Spinning Mill depended on steam power. Because modern technology became available simultaneously with the steam engine most industries never relied on water power. More generally, as a late-comer to industrialization, Japan had the advantage of introducing highly advanced technology at a very early stage of development, and thus, her modern industries virtually bypassed traditional technology and traditional sources of power.<sup>58</sup>

The final implication of this analysis relates to the role of the level of development of machine technology as a condition for modern industrialization. On the one hand, the large number of wheel carpenters dispersed in the rural areas of Japan and the development of clock making before Meiji were of some significance in the successful application of modern machinery technology.<sup>59</sup> It may be important to examine the availability of such skilled crafts in order to appraise the initial conditions of Japanese industrialization compared with present developing countries.

On the other hand, by and large the technology of machine production in Japan on the verge of modern industrialization was at a low level. Clock making had suffered during the closing of Japan in the Edo period. The long prohibition on ocean navigation limited the need for accurate time keeping.<sup>60</sup> In addition, the scarcity of livestock and the poor road system meant that vehicles, especially animal-powered ones, were rarely used.<sup>61</sup> These

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<sup>58</sup> We arrived at this conclusion originally through a study on the printing industry. "Printing Technology."

<sup>59</sup> For instance, Hisashige Tanaka, the most prominent clockmaker in the Tokugawa, became an electric engineer. In 1875 he established the Tanaka Factory, the first electric machinery producer in Japan and the forerunner of the present-day Tokyo Shibaura Electric Company. Kenji Imazu, *Kindai Gijutsu no Senku-Sha: Tōshiba Sōritsu-Sha Tanaka Hisashige no Shōgai* (Pioneer of modern technology: Life of Hisashige Tanaka, the founder of Tokyo Shibaura Company) (Tokyo, 1964).

<sup>60</sup> Imazu, *Pioneer*, p. 45.

<sup>61</sup> See n. 2.

two factors were unfavorable to the development of a machinery industry.<sup>62</sup>

Outside of clocks and vehicles, the water wheel was the major mechanical apparatus developed in the preindustrial economy. But the facts that a large percentage of rice was polished by human power and that water power was rarely applied to milling and manufacturing indicate that both the capacity and the number of water wheels in Japan was far below that in the West. Furthermore, before the late Edo, the technology of the water wheel had been stagnant, and the means had not been developed to adapt water power to the advanced transmission needs of manufacturing. Thus, it is safe to say that the use of the water wheel had not contributed significantly to the domestic development of adequate machine technology, as it had in the West prior to the Industrial Revolution.

Overall, then, the level of technology of machine production inherited from the preindustrial economy in Japan was quite underdeveloped. The deficiency in machine technology may account for the slow progress of the machine industry in Japan during the early stage of industrialization up to World War I.<sup>63</sup>

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<sup>62</sup> In Europe, in contrast, the production of water wheels, clocks, and vehicles led to the development of a machinery industry prior to industrialization. The machinery industry became the basis for the modern engineering which characterized industrialization in the West. According to Samuel Lilley, "modern engineering is the child of a marriage between the clock-makers' skill in fine workmanship and the techniques of heavy engineering that were used by the millwrights and builders of other power-driven machinery." Lilley, *Men*, p. 56.

<sup>63</sup> Hiromi Arisawa, ed., *Gendai Nippon Sangyō Kōza* (Lectures on modern Japanese industries), vol. 5, *Kikai Kōgyō* (Machinery industry), 1 (Tokyo, 1965), pp. 11–22.