A CAPITAL INTENSIVE INNOVATION IN A CAPITAL-SCARCE WORLD: STEAM-THRESHING IN NINETEENTH CENTURY ITALY

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ABSTRACT

The Italian agriculture in the 19th century enjoyed a quite poor reputation among historians, for its innovative record. This article deals with a possible counterexample, the wide diffusion of steam threshing since the 1870s. It was a highly capital-intensive machine, and thus its success seems to contrast with the scarcity of capital, which plagued the Italian agriculture. Indeed, the pattern of diffusion in time and space was influenced by the cost of capital, but the constraint was eased by outsourcing. Steam-threshers were owned by specialised entrepreneurs and rented to farmers and landowners. This successful institutional arrangement casts a lot of doubt on the negative effects of the alleged institutional rigidity on technical change.

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1. INTRODUCTION: THE MECHANISATION OF ITALIAN AGRICULTURE

Agriculture does enjoy a poor reputation among historians of Italian development (Cohen & Federico, 2001). According to the available (and highly controversial) figures, the rate of growth of agricultural output from the Unification of the country in 1861 to 1938 was a paltry 0.7% p.a. (Ercolani, 1969). This poor performance dragged down the growth of the whole economy. Historians blame the failure to exploit the available opportunities of technical progress – i.e. to imitate the "best" (British) practice. High-farming was adopted only in the Po Valley, and mechanisation was very slow. On the eve of World War I, there were only 12,500 horse-driven reapers in the whole country, almost one century after their first appearance in the USA, and tractors spread only after World War II (UMA, 1968). The blame rests squarely on the "institutions" – i.e. on the power of the ignorant, lazy and risk-avert landlords who exploited ruthlessly the poor peasants, and feared that any innovation could endanger their social status.

This conventional wisdom has been challenged of late by several scholars. They have pointed out that many innovations: they were not suited to the Italian environment and factor endowment (Galassi, 1986, 1993; Corona & Masullo, 1989). The British varieties of grass could not stand long, dry summers, and were unsuited to soil in most of the peninsula. The hilly terrain, and the ubiquitous presence of vines, mulberries, olive and other fruit trees made the use of machines designed for the Midwest plains very difficult. Furthermore, as reminded many years ago by Dowring (1965), labour saving, capital-intensive techniques were unsuited to labour-abundant countries, such as Italy. Suitable innovations, such as fertilisers did spread quite fast since the end of the 19th century (Pezzati, 1993). So far, however, the debate has relied mainly on experts' statements and other anecdotal evidence. The data are admittedly scarce, but not totally absent.

This article deals with the adoption of a specific innovation, the steam thresher. The case is especially interesting because the machine was apparently wholly unsuited to the Italian conditions. It used steam in a country without coal (Bardini, 1998). It was a bulky and expensive piece of equipment, subject to substantial scale economies, while farms in Italy were rather small and allegedly starved of capital. Last but not least the steam thresher competed with other, simpler and cheaper, machines. Yet it was a success-story, as the Inchiesta Jacini, the great survey of the conditions of Italian agriculture in the 1870s and 1880s shows. For instance the volume for in Emilia remarks that "the adoption of tools and machinery is quite limited . . ., but for the steam threshers, which have been introduced not without troubles at the beginning but now quite successfully".[1] How is possible to explain this success? Why did peasants and landowners opt for mechanising threshing well before harvesting or any other operation? And why did they choose steam instead of horse power?

The paper begins with a description of the available techniques, including some evidence on their costs (Section 2). The following section deals with the situation in the late 1880s, on the basis of a very detailed official source, the *Statistica delle Caldaie a vapore* (henceforth Statistica, 1890). Section 4 frames that snapshot in the long-term growth of mechanical threshing in Italy, with some comparison with other countries. Section 5 tests a simple econometric model of diffusion in time and space. Section 6 puts forward an "institutional" explanation of the success of steam threshing. Finally, Section 7 sums up the results and sketches out the implications for the broader issues of technical progress and rationality in Italian agriculture.

2. THRESHING: A SHORT TECHNICAL OVERVIEW

Threshing is the final stage of the production of wheat and other cereals. The grains are separated from husk and straw, before being sent to milling (or otherwise utilised). This operation can be performed almost any time, provided that the wheat is dry. In humid climates with a late harvest, as in North Europe and USA, the cereals were stored in barns and threshed during the slack season. In the Mediterranean countries, wheat was harvested in June, early July and threshed immediately after. The risk of heavy rainfall, which could spoil the grain, was small, even if not negligible, while the system saved substantial amount of capital. Storing grains instead of the whole wheat shocks reduced the needed size of the barns by almost two thirds, the proportion of husk and straw out of the total weight of the crop.

For centuries, cereals had been threshed by hand or by animal (Giacomelli, 1864; Herve-Mangon, 1875; Cencelli-Lotrionte, 1919; Cei, 1913; Niccoli-Fanti, 1924; Rogin, 1931). Men either slammed the stocks on a table ("al banco") or beat them with a flail ("correggiato") when lying on the ground. Horses or oxen threshed the cereals either by treading over them or pulling heavy rolls, stones etc. Then the grains were tossed into the air in windy days to winnow them. These traditional methods were very physically demanding, for men and animals, and so there was a strong incentive to mechanise them (Daumas, 1968; Wik, 1953; Rogin, 1931; MacDonald, 1975; MacClelland, 1997). After several attempts, the first working machine was invented in 1786 by a Scotsman, Meikle. It consisted of "a drumlike beater revolving inside a set of concaves to knock out the grain from the heads" (Wik, 1953, p. 16). The first threshers were fixed and powered by horses. In the following years, the size of the machine was reduced to make it movable (portable) and/or powered by men (with a crank or pedals).

Steam was first introduced in the 1830s, in fixed plants.[2] The first portable steam thresher was built in 1841 by "Ransomes", a British firm which was to became a major supplier of machines all over the world. The original ("simple") machines only threshed, and sometimes winnowed, the wheat. They thus needed a large crew to feed the machine, take away and bind the straw, clean the wheat from impurities etc. Since then, the steam thresher was substantially improved: the most advanced models of the late 19th century were entirely mechanised, and produced clean grain, which had only to be stored away.

In the 1910s, steam began to be substituted by the internal combustion engine, further reducing the size of the machine. It was thus possible to build combined harvesters – which reaped and threshed at the same time.[3] There had been several experiments with steam-powered harvesters, but with little practical success, perhaps because the machines were deemed too dangerous. The sparks from the engine would have set fire to the whole field. Actually, steam threshing itself was quite an hazardous task. The boiler and the threshing machine were usually kept apart, but in spite of this precaution, fires were common and sometimes claimed lives (Wik, 1953, pp. 138–139; Isern, 1981; Adelman, 1994, p. 128).

The evolution of threshing technology attracted much attention in Italy in the 19th century, and the costs and benefits of alternative techniques were discussed at length. Table 1 reports three of the most reliable examples of this literature.[4] These figures must be considered with a lot of caution. The productivity depended on the cereal to be threshed (wheat, barley etc.), on the way in which it was cut (with sickle or scythe, with short or long straw etc.), on the skill and strength of the workers and on the state of the machinery. The wages and the cost of horses varied very much in time and space and the fixed costs of machinery were inversely proportional to the amount of work. The wide differences between the figures in panels (a) and (b), the work of a knowledgeable university professor, show how tricky these computations were. The evidence on actual threshing costs (Table 2) is unfortunately quite scarce and, at least in one case (the Conti, 1887), somewhat suspicious. That source reports the results of a survey among landowners about the returns to wheat growing during the agricultural crisis of the early 1880s. The authors might have exaggerated the costs in order to support their claims for protection.

Tentative as they are, the data highlight two important points.

First, steam-threshing was a capital-intensive-labour saving innovation. In the 1880s in Italy, a fully operational machine cost about 1,500 lit pr HP, and

Table 1. The Cost of Alternative Threshing Technologies: Technical Sources.

Panel (a)

	Productivity (quintals/hour/men)	Cost (lit./q.le).
Hand with flail	0.08	2.18
Horse treading	0.11	1.75
Men-powered threshers	0.12	1.37
Horse-powered threshers	0.11	1.10
Steam thresher	0.47	1.53

Panel (b)

	Productivity	Cost
Hand with flail		1.67
Horse treading		2.01
Men-powered threshers*	0.16–0.28	O.65–1.21
Horse-powered threshers *	0.23–0.31	0.44–0.58
Steam thresher		1.33

Panel (c)

,	Productivity		Cost	
Handthreshing "al banco"	0.05	0.07	1.5	1.9
Hand threshing with flail	0.07	0.08	1.35	
Horse treading	0.08		1.15	1.3
Horse with rolls	0.10		0.95	1.10
Men-powered threshers	0.15	0.20	1	1.35
Horse-powered threshers	0.19	0.25	0.8	1.15
Steam thresher #	0.33	0.55	1.0	1.1

* different types; # 6–8 HP.
Sources: (a) Caruso, 1873; (b) Caruso, 1875; (c) Niccoli-Fanti, 1924 pp. 321–326.

10,000 overall (as much as 5,000–6,000 days of pay of a day labourer), ten times as much as a horse-powered thresher.[5] The productivity of labour was correspondingly higher. Clark (1989, Table 2) reports a wide range of data on labour productivity for threshing with flail – ranging from 0.04 quintals/hour in Moravia in 1838 to 0.23 in the North United States in 1820–1850, with an average of 0.11 quintals. The labour productivity of man and horse-powered machinery was about 0.2–0.3 quintals per hour/worker.[6] Second, steam threshing was indeed cheaper than the traditional methods, but apparently no more so

Table 2. The Cost of Altemative Threshing Technologies: Other Sources.

	Year	Cases	Cost	Source
"Traditional"				
Flail	Early 1880s	3	2.25	Conti, 1887
Horses	1882–1887	1	1.37	Galassi, 1986, n.37°
	Early 1880s	11	2.29	Conti, 1887
Not specified	Late 1870s	4	1.34	Inchiesta Jacini*
Steam				
	1882–1887	1	0.80	Galassi, 1986, n. 37
	1872–1893	1	1.15	Galassi, 1993, Tables 1 and 2
	Late-1870s	4	1.15	inchiesta Jacini
	Early-1880s	12	1.44	Conti, 1887
	Mid-1880s	12	1.17	Risultati, 1885–1888

* treading or with rolls ° actual data from a Tuscan farm.

than other types of mechanised processing.[7] Actually, the horse-powered machinery might have been the cheapest system at least until the 1870s.

3. STEAM-THRESHING IN ITALY IN THE LATE 1880s

The early diffusion of steam-threshing in Italy is exceptionally well documented. In the mid-1880s the government decided that steam boilers were a health hazard which had to be monitored closely. As a first step, in October 1886 the Ministero di Agricoltura, Industria e Commercio began a detailed census of the existing boilers. The operation lasted four years, but the results were highly rewarding, at least from the historian's point of view.[8] The Statistica 1890 has a separate entry for each of boiler, which reports the location, type, material, power, steam pressure, fuel, date of installation, provenance and sector of utilisation. This paper singles out all the boilers labelled as in use for threshing (either full or part-time), and in "agriculture" without further detail, provided they worked for less than 60 days per year, and were portable ("locomobili"). Some of these latter might not have been used for threshing, but whatever overestimation of the data was compensated by the omission of other boilers.[9] If any, the source understates the total stock.

The Statistica lists 3074 boilers for threshing (including the part-time and the "likely" ones), with a combined power of about 21,000 HP. They accounted for about a third of all Italian boilers (9,984) and for 13% of total power (157,390 HP), but, as shown by the data of Table 3, differed from the rest of the stock.

Most of these differences can be easily explained. Firewood was surely cheaper than coal in the countryside, even if it is difficult to estimate the extent of savings. The machines had to be portable because it was cheaper to move a thresher then the cereals. Most of the fixed machines were used for rice (Loria, 1961). And the smaller the machines, the easier it was moving them around. Finally, more foreign-built boilers were used for threshing than for other activities.[10] Bardini (1997) has shown that Italy imported boilers that were usually more technically advanced than Italian ones. Boilers for threshing need not be really sophisticated. The really complex machine was the thresher itself, and apparently, the Italian firms were not really good at building them. Only in Veneto, domestic firms succeeded in gaining a substantial market share – up to a half of all boilers for threshing (Lazzarini, 1992; Bigatti, 1988). Thus, the region accounted for about half of all the Italian-produced boilers. The reasons of this (relatively) brilliant performance are unclear, as the region was not specially known for its engineering industry. The competitiveness of domestic

Table 3. Boilers for Threshing and All Other Boilers.

	Threshing			Others°		
	n.	HP	%*	n.	HP	%*
Fuel						
Coal	434	3074	14.7	5281	115675	84.8
Wood	1822	11976	57.3	422	4754	3.5
Coal + wood	807	5773	27.6	610	6979	5.1
Other (incl. gas)	11	80	0.4	597	9081	6.7
Average power		6.8			19.3	
Mobility						
Portable	304	20601	98.6	609	5103	3.7
Fixed	34	302	1.4	6301	131385	96.3
Provenance						
Domestic	868	5624	26.9	4244	76313	55.9
Unknown	12	936	4.5	174	1890	1.4
Import	2086	14343	68.6	2492	58285	42.7

* on HP

° including agricultural uses other than threshing.

Source: Statistica, 1890.

producers was to improve later, but much less than in other industries: as late as 1935, after half a century of industrial growth and some years of high protection to engineering industry, foreign threshers still accounted for at least half the total stock.[11]

The diffusion of steam-threshing did entail a massive investment of capital. In the late 1880s, steam-threshers accounted for about a fifth of total capital in machines and tools of Italian agriculture.[12] Actually, and quite surprisingly, cereal-growing was quite a steam-intensive activity: the share of threshing on total stock of boilers did exceed by far that of cereal growing on Italian Value Added, some 8% in 1911 (Federico & O'Rourke, 2000).

Last but not least, the development of steam threshing was heavily concentrated in a relatively small area. Three quarters of boilers for threshing were located in the North, a fifth in the Centre (including Latium) and a meagre 6% in the South. There were no boilers to that purpose in 18 provinces out of 69 (a province is roughly the size of an American county) and more than 80% of the total power clustered in twenty provinces alone (Table 7, Col. a) – all but five in the Po Valley. Viceversa, many Northern provinces (including the whole Liguria) had no steam-threshers at all, and the threshing power in the whole Piedmont barely exceeded half of that of the province of Bologna. Indeed, also wheat growing was unevenly distributed among provinces, but the differences in the output to be processed were much smaller.

4. THE DIFFUSION OF STEAM-THRESHING IN ITALY

Steam-threshing was imported quite early in Italy. The oldest registered machine in the *Statistica* dates back to 1843, only two years after the first commercial sale in the United Kingdom. However, after this promising start, the new technique spread only very slowly. The source registers only 120 machines installed before 1865 – admittedly a lower bound as some of the early threshers may have been scrapped in the meanwhile. Anyway, the number of new machines remained rather low until the late 1860s. The number began to grow in the early 1870s, and soared towards the end of the decade. Almost half of the total stock registered by the Statistica was installed from 1877 to 1882. Then the boom petered out, and in 1883–1885 the number of new machines shrank to the early 1870s level.

The late 1880s were only the dawn of the era of the steam-thresher. The number and power of these machines went on growing quite fast until the 1920s (Table 4).

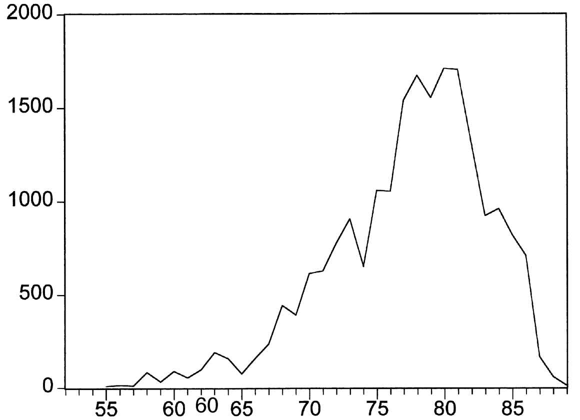

Fig. 1. New Installation Per Year (HP).

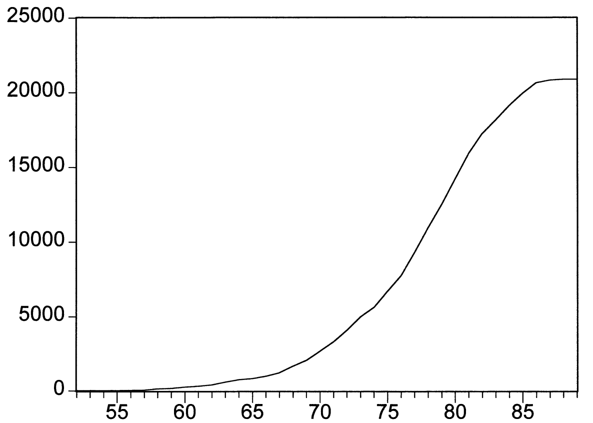

Fig. 2. Stock of Threshers (HP).

The growth in average power reflects the increasing use of more powerful and sophisticated "complete" machines, even if the leap between 1899 and 1904 is partly spurious.[13] Part of the increase after 1904 may have been caused by the substitution of steam by the internal combustion engine. In 1935 the internal combustion engines accounted for about three fifths of the total, steam for a

Table 4. Number and Power of Steam Threshers.*

	Threshers		Growth rates		HP/	% total
	Number	HP	Number	HP	Thresher	agriculture
1865	117	830			7.1	57.4
1875	907	6,705	20.4	20.9	7.4	59.3
1880	2,002	14,233	15.8	15.1	7.1	61.1
1887	3,074	20,903	6.1	5.5	6.8	65.0
1894	5,620	43,987	8.6	10.6	7.8	61.7
1899	6,050	43,950	1.2	–	7.3	48.5
1904	10,302	123,701	8.9	20.7	12.0	77.1
1928	21,499		3.1			
1935	26,176	403,385	2.8	3.8	15.4	n.a.
1947	29,745		1.1			

* current boundaries.
Sources: 1865–1887 Statistica, 1890[30]; 1894 and 1899 Statistica, 1899; 1904 Statistica, 1904; 1928 ASI, 1929; 1935 Indagine, 1935; 1947 Costo, 1949.

mere quarter (probably almost all installed before 1915), and the rest was powered by gas or electricity (Indagine, 1935, prosp. 5).

The number of boilers or their power is not really a revealing piece of information for the uninitiated. The key parameter is the proportion of total crop they could process. The figure can be computed (for any given year or province) as:

$$\% = (HP^* \alpha^* \beta^* \gamma)/P$$

where HP is the total number of HP, α the average number of working days, β the average length of the work day, γ the "productivity" (quantity of cereals threshed) per HP/hour and P the total output to be processed. The details of estimation of these parameters are reported in Appendix A, and the results are reported in Table 5. It is then possible to trace the increase of the percentage of cereals threshed by steam (Table 6). Until the mid-1880s, the percentage shadowed quite well the growth in equipment – up to a fifth of the crop. Afterwards, the share of threshed output did not grow as much as the total power. A (nearly) four-fold increase in total power from 1904 to 1935 brought about only few additional points in the share. In those years, the output (the denominator) increased by almost half, while the productivity per HP/day and the number of days fell by 15% and 35% respectively. The decline in the

Table 5. Productivity of Steam Threshers.

			γ (quintals/HP/hour)			Total (quintals/year)		
	α	β	Min	Best	Max	Min	Best	Max
1887	42	10	1.0	1.20	1.50	2900	3500	4300
1894	40	10	0.95	1.14	1.42	2950	3550	4400
1899	37	10	0.98	1.17	1.46	2600	3150	3900
1904	34	10	0.73	0.88	1.10	3000	3600	4500
1935	22	10		0.70		2450	2450	2450

Source: Appendix A.

Table 6. Percentages of Steam Threshing: Change in Time.

	Lower	Best	Upper
1866–1868	1.2	1.4	1.8
1869–1871	2.4	2.9	3.7
1872–1874	4.5	5.4	6.8
1875–1878	8.4	10.0	12.6
1879–1881	12.9	15.5	19.3
1882–1884	15.2	18.2	22.8
1885–1888	19.6	22.9	28.6
1894	30.3	36.3	45.4
1899	29.4	35.3	44.1
1904	52.3	62.8	74.4
1935		69.7	

Source: 1866–1868/1904 Appendix A, 1935 Indagine, 1935.[31]

number of days can be tentatively attributed to the growing competition among threshers (Vitali, 1939; Potenza, 1947). The "productivity" was falling as capital was substituting labour, and more and more operations were mechanised. The modern machines of the 1930s used only half their total power for threshing proper (Carena, 1942 p. 49). It can be computed that, had these two coefficients remained constant at their 1880s level, the total threshing capacity would have exceeded the output by a third. Actually it would have exceeded the production even if the number of days only had remained constant and productivity had fallen.

A look at the share by province in the 1880s (Table 7 col. b) confirms the geographical concentration of steam threshing. In 10 provinces it processed almost the whole crop, but already at the twentieth place in the rank the share was down to a third.[14] The list (Table 7, col. b) coincides almost perfectly with that of the twenty provinces with the highest threshing power – but the ranking is quite different.

In the following decades, steam-threshing spread outside the "core" areas of the Po Valley, but the lack of data before the 1930s prevents to outline the process with any precision. In 1935 mechanised threshing was almost universal in the North and Centre, while in the South about 80% of cereals were still threshed by traditional methods (down from almost 99% fifty years before). These latter still were in use as late as 1949, albeit for "modest" quantities (Costo, 1949 p. 23).

The discussion so far has focused on steam threshing: what about the other "modern" technologies, the man and horse-powered machines? They were surely

Table 7. Share of Steam Threshing, by Province.

(a)		(b)	
Bologna	6.3	Venezia	136.4
Vicenza	6.1	Ferrara	121.6
Ferrara	5.9	Vicenza	114.4
Padova	5.7	Verona	106.6
Roma	5.5	Modena	99.2
Rovino	5.4	Reggio Emilia	92.9
Verona	5.3	Rovigo	87.5
Mantova	5.0	Grosseto	83.8
Modena	3.8	Mantova	82.5
Milano	3.7	Milano	78.4
Grosseto	3.7	Piacenza	65.7
Venezia	3.7	Cremona	60.8
Reggio Emilia	3.4	Brescia	58.0
Cremona	3.3	Bologna	56.6
Parrna	2.5	Padova	55.1
Perugia	2.5	Treviso	50.6
Siena	2.4	Parma	46.8
Foggia	2.4	Siena	44.8
Ravenna	2.4	Roma	41.6
Piacenza	2.2	Ravenna	37.5

(a) share of each province on the total threshing power; (b) proportion of steam-threshed cereals (computed with the "best guess" productivity estimate of Table 4) out of total output.
Source: see text.

known, but the evidence on their use is mixed, to say the least. The only data are provided by survey of sales of agricultural machinery by a sample of 27 engineering firms in 1875–1879 (Notizie, 1878–1879, Vol 3, p. 88). In these four years, they sold 1,856 thresher (of any kind), while the Statistica registers only 897 new boilers for threshing: at least 959 must have been man and horse-powered machines (and the number was probably higher, as the sample did not include all the firms selling steam threshers). Official sources, such as the Inchiesta Jacini or other enquiries do quote the use of man-powered machines and, much less frequently, of horse-powered ones.[15] Unfortunately, these quotations are quite scattered and apparently casual, and a missing reference is somewhat hard to interpret. But the small number of references to horse-powered threshers seems to rule out a widespread use of them. The case may have been different for men-powered threshers. The 1935 survey (Indagine, 1935) listed still 1878 active machines, three quarters of which in Liguria, Trentino and Venezia-Giulia (these two last regions still belonging to the Austrian Empire in the 1880s). These were hilly areas of small family farms, which appeared to be particularly suited to the small men-powered machines. There were many similar areas all around the country – including most of Piedmont and Northern Lombardy, where in the 1930s mechanised threshing prevailed. Had these areas adopted men-powered threshing – say – in the 1850s–1860s, and switched later to steam-threshing or simply jumped from the flail to the modern machines? It is impossible to tell.

How did Italy fare in comparison with other countries? Was it so backward as assumed by the conventional wisdom? Answering to these questions is far from easy. The diffusion of steam-threshers has not attracted the attention of foreign statistical offices as much as of the Italian one. There are few data, and some of them are hardly useful. For instance the often-quoted figures by Dowring (1965, Table 58) do not distinguish steam from horse or man-powered threshers. If they referred to steam threshers alone, the productive capacity would have exceeded by far the total output to be processed. Nor really useful are the Van Zanden's data on the number of farms employing threshing machines (of any sort) in the early 1900s, without data on the distribution of cereal output by size of farm.[16] There is however some scattered evidence, which suggests that the pattern of diffusion of steam threshers depended to a remarkable extent on the previous trends.

In the advanced countries, steam-threshing replaced horse-powered threshing, which had spread in the first half of the 19th century. In the United States (Bidwell-Falconer, 1925; Rogin, 1931; Wik, 1953; Danhof, 1962; MacClelland, 1997), the United Kingdom (Collins, 1972; Fox, 1978; Macdonald, 1978) and Australia (Raby, 1996) the process started in earnest in the 1850s and 1860s.

In the United States, steam dominated in the core wheat-growing areas already by the early 1880s, even if the traditional techniques and horse-powered machines survived in the fringes, such as the New England until the end of the 19th century. In North-Western Europe, steam-threshing was much less successful. In France, it began to spread in the late 1840s, early 1850s.[17] An agricultural survey in 1852 registered some 400–500 steam-threshers and about 60,000 horse-powered ones, while thirty years later, the numbers had risen to 9,000 (with 42,000 HP) and 200,000 respectively. The share of steam on total threshing power may not have exceeded a 20% – i.e. the same level of the Italian one.[18] In Germany, in 1907, steam was used only by a third of the farms which used mechanised threshing, i.e. by about 10% of the total (Van Zanden, 1991, p. 233). In Belgium, steam-threshers accounted for 15% of total threshing power in 1910 and a 25% in 1929 (Blomme, 1993, p. 184), and in the Netherlands for a mere 4% in 1905 (Van Zanden, 1991, p. 233). Also in Canada and Argentina the horse-powered machinery remained the standard until quite late in time, and it enjoyed a sort of revival in Canada on the eve of World War I (Adelman, 1994, pp. 227–228, 244–245).

"Peripheral" European countries, such as Italy, seem to have jumped from traditional methods directly to steam threshing. The timing of the process differed quite markedly. In the wheat-growing plains of Russia, Hungary and Southern Turkey, around Adana) steam-threshing developed impressively.[19] On the contrary, the Mediterranean countries (other than Italy) lagged behind. In the 1880s, the whole of Spain, there were only 52 steam-threshers (Simpson, 1996), in Portugal less than 10 (Reis, 1992, Table 15).

Summing up the (admittedly scarce) evidence available suggests that Italy was not as backward, at least from this point of view, as argued by the conventional wisdom. It could not compete with the USA or the United Kingdom, but was roughly at a par or even preceded other "advanced" Northern European countries. This was surely not the case for other machines, and this peculiarity has to be understood.

5. THE DIFFUSION OF STEAM-THRESHING: AN ECONOMETRIC ANALYSIS

The selection of a technique (steam threshing in the case at hand) depended on the unit costs relative to the alternative ones. The key parameters were thus the productivity and the expected prices of relevant inputs – i.e. labour, capital and fuel for steam threshing, labour and the price of horses for the alternative techniques. It is likely that the would-be investors formed their expectations averaging out several years of the relevant variables, albeit the length of the period cannot be ascertained a priori. They could be take into account other variables as well. For instance, they might want to consider the conditions of the labour market. It was easier to gather the large teams necessary for steam-threshing where there were many day-labourers for hire than in areas of household farming, where each household may have had its own ideas on how to allocate its time. On the other hand, the appeal of a labour-saving innovation such as steam-threshing was the larger the more militant the day-labourers were. Another potentially important variable was the probability of rainfall, as there were no barns to store the wheat before threshing. *Ceteris paribus*, steam-threshing was quicker than any other method.[20]

Last but surely not least, the decision was influenced by the expectation about the amount of product to be processed. The steam-thresher was more profitable than the competing techniques only if its output exceeded a minimum, some 450–500 quintals if the alternative was the flail and 1200–1500 quintals if it was the horse-powered machine (cf. Appendix B). This fact affected the diffusion of steam-threshers in three different ways. First, as argued by David (1971) in a well-known article about reapers, the innovation might not be adopted simply because the farm was too small to produce enough cereals. The minimum amounts of wheat quoted above were produced on average (nation-wide) in 50–60 and 135–170 hectares respectively, but the size of the farm had to be substantially greater. Second, either one had to gather the cereals in one location, or to move around the thresher: in both cases, the task was easier if the terrain was level and the rural roads were good. The conditions in late 19th century Italy were so bad as to prompt the government to set up two prize competitions among builders specifically aimed at small machines (Concorso, 1880; Concorso, 1885).[21] Third the decision whether to adopt steam-threshing or not depended on the likelihood that in future the production stayed above the threshold, and the assessment of that probability was likely to depend on past trends in prices.

Summing up, the adoption of steam-threshing was positively related to the productivity growth, wages, the cost of horse power, the productivity of threshers, the share of farms exceeding a minimum size, the amount of rainfall, the percentage of day labourers on the totall agricultural workforce, their degree of militancy, the production and prices of cereals, the conditions of rural roads and the share of plains on total acreage. It was negatively related to the cost of capital, the cost of threshers and the cost of fuel. Most of these variables could explain both the changes in time and the differences among provinces. There are however some exceptions. The amount of rainfall did not change through time, while all price variables could account for differences in the spatial distribution of threshing only if the relevant markets were not integrated. Furthermore, the available data seriously constraint the analysis (cf. Appendix D for details). There are simply no data on variables such as the conditions of rural roads, the degree of militancy and the cost of threshers – and thus they have to be dropped.[22] Many other variables have to be proxied. Following a common practice, productivity growth is proxied by a time trend. The wages in the time-series regression are proxied by a series for urban unskilled wages – assuming that the labour market worked efficiently enough. The unavailable data on wages and the cost of horses by province in those years are substituted by the number of male labourers and of (rural) horses per hectare.

The dependent variable in the cross section is the number of HP per wheat acre by province. The dependent variable is truncated and thus the equations are estimated both with a standard OLS regression (with a White correction for heteroskedasticity) and with a Tobit regression model. Many variables are not significant, so Table 8 presents the results of the estimation also of a reduced model, with only the significant ones.[23]

The Tobit and OLS regressions yield very similar results, and a Wald test fails to find any significant difference among the estimated coefficients. The statistical results are good, even if the poor results of the RESET test points out to the omission of some potentially important variables. Four variables only, the interest rate, the labour endowment, the dummy and the share of plains are significant. The latter variable might capture also the effect of a greater diffusion of wheat-growing in plains.

The coefficients of Table 8 are difficult to interpret. A simple method to assess the importance of each variable is to estimate how large (small) the total threshing power would have been if that variable had been in the whole country at either extreme of the actual range of values by province (Table 9).

The first row shows how sensitive the stock of threshers was to the interest rates. A relatively small variation in these latter would have changed the (counterfactual) stock of threshers very much. It capital had cost throughout the whole country as little as in Cremona the threshing power would have been (almost) three times as large; if, on the contrary, interest rates had been as high as in Bari, there would have been no steam thresher at all in Italy. The effect of the labour/land ratio and of the share of plains is somewhat smaller, especially if compared with the wider range of the explicative variables, but still quite substantial.

The time series regression (Table 10) is estimated in log-linear form. The dependent variable is the number of new HP installed each year from 1863 to 1885. Some of the explicative variables are not available for the years before 1861, and anyway the data for the 1850s are likely to be biased, as some of

Table 8. Econometric Analysis: Cross Section by Province.

	Full model		Reduced	
	OLS	Tobit	OLS	Tobit
Constant	0.412	0.541	0.415	0.591
	(4.84)***	(5.15)***	(5.41)	(6.14)***
% Farms > 100 ha.	–0.055	–0.079		
	(0.98)	(1.50)		
Interest rate	–0.054	–0.069	–0.052	–0.075
	(4.80)***	(4.86)***	(5.13)***	(5.93)***
Labour/land ratio	–0.083	–0.178	–0.091	–0.166
	(3.16)***	(3.82)***	(3.25)***	(3.99)***
% plains	0.061	0.054	0.088	0.089
	(1.64)*	(1.88)**	(4.54)***	(4.06)***
Total rainfall	0.00	0.00		
	(0.11)	(0.45)		
% Labourers	0.00	0.00		
	(1.16)	(0.92)		
Horses per ha	0.28	0.54		
	(0.93)	(1.57)		
Dummy Cagliari	–0.19	–0.23	–0.195	–0.247
	(4.76)***	(3.63)***	(3.77)***	(4.21)***
Adj-R^2	0.535	0.577	0.542	0.587
RESET (2)	8.00		5.48	
	(0.00)		(0.006)	
F	10.79		21.15	
	(0.00)		(0.00)	
Log likelihood°		66.30		62.50
		(0.00)		(0.00)

Between parenthesis *t* statistics in OLS regression and *z*-statistics in Tobit model (significant at * 10%, ** 5% *** 1 %).
° Null hypothesis that all variables were zero.

the boilers installed in those years could have been scrapped in the meanwhile. The explicative variables are three-year backward-moving averages: this specification yields the best results in a repeated test with different lag lengths. As for cross section, Table 10 reports the full model (panel a) and a restricted one with the significant variables – both in levels (panel b) and in first differences (panel c).[24]

The results of the first-difference equation (panel c) are rather disappointing: its R^2 is quite low, and only the interest rate is significant. Clearly such a simple

Table 9. Counterfactual Estimates of the Total Threshing Power.

	Actual data		Maximum stock		Minimum stock	
	Variable*	HP	Variable	HP	Variable	HP
Interest	6.8	20,900	5.8a	57,200	8.1b	0°
Lab/land	0.4	20,900	0.1c	35,900	1.3d	0°
% plains	27	20,900	100	59,950	0	10,600

Coefficients from the reduced OLS estimate (Table 8).
* unweighted average for the 69 provinces; ° negative number.
(a) Cremona; (b) Bari; (c) Leghorn (d) Massa-Carrara.

Table 10. Econometric Analysis: Time Series.

	(a)	(b)	(c)
Constant	–5.352	–8.43	–0.122
	(0.30)	(1.29)	(1.15)
Time	0.064	0.062	
	(3.78) ***	(3.92)***	
Interest rate	–3.628	–3.602	–6.207
	(2.34)**	(3.00)***	(2.48)**
Wheat prices	5.711	4.288	–0.837
	(1.77)*	(4.07)***	(0.26)
Fuel prices	0.894		
	(0.72)		
Real wages	1.488		
	(0.50)		
Output cereals	–0.957		
	(0.59)		
Adj-R^2	0.92	0.92	0.15
RESET (2)	1.06	1 25	1.26
	(0.373)	(0.31)	(0.30)
F	40.97	90.91	3.22
	(0.00)	(0.00)	(0.06)
DW	2.12	2.02	1.62
LM(2)	0.13	0.21	11.27
	(0.88)	(0.81)	(0.00)
UROOT°	–3.62	3.30	
	(3.01°)	(3.01°)	

(a) full model; (b) reduced model, level specification; (c) reduced model, first differences. Between parenthesis *t* statistics (significant at * 10%, ** 5% *** 1%) ° critical value of the MacKinnon test for stationarity of the residuals at 5%.

model cannot capture the short-term adjustment process. On the contrary, the level specification yields good statistical results. Neither wages nor the fuel price is significant, possibly because the available series refer to prices in the cities throughout the whole year, and thus are not really representative of the costs in the countryside during the threshing period. The elasticities to wheat prices and to interest rates are quite high. A decrease of one point in the interest rate (which amounted to a fall by 20% at the sample mean) increased the new installation by a 70%. Also technical progress was rather fast: it alone would have caused the total threshing power to grow more than five times from the 1860s to 1885.

A good test of the power of a model is its predictive power. It is possible to estimate the implicit number of HP at any date by simply cumulating a yearly extrapolation of new equipment added net of (an estimate of) the scrapped boilers. Table 11 compares the results of the exercise (based on the coefficients of the reduced model) with the actual stock.

Prima facie, the results are quite poor: the extrapolated stock (col. b) is close to the real one only in 1899, and is about a half in both 1894 and 1904. However, these figures do not take into account the long-run decline in "productivity" (i.e. quantity of cereals threshed) per HP. New functions beyond the simple threshing were being added, and thus more power was necessary to process the same quantity of cereals. This effect can be taken into account by computing a "constant 1885 HP stock" (col. c) as the (estimated) stock in 1894, 1899 and 1904 times the ratio of "productivity" in 1885 to the "productivity" in that year. This estimate is indeed quite close to the actual stock in 1904, but neither in 1894 nor in 1899. The model first underestimates the growth of the stock, and later overestimates it. These differences are arguably accounted for by changes in expectations brought about by changes in trade policy. In 1887, Italy adopted for the first time a duty on wheat, which was repeatedly increased in the following seven years. The increase reassured farmers that the government would not have let prices of wheat fall too much, and this may have stimulated

Table 11. Threshing Power in Italy, 1894–1904 (HP).

	Actual	Predicted		
	(a)	(b)	(c)	(c)/(a)
1894	43,987	28,291	33,265	0.76
1899	43,950	43,907	52,721	1.20
1904	123,701	63,676	115,862	0.94

Source: Col. (a) Table 4; others see text.

the adoption of steam-threshing "ahead of schedule" in the late-1880s early-1890s. The very boom may have slowed down the adoption in the second half of the decade.

6. THE DIFFUSION OF STEAM-THRESHING: AN INTERPRETATION OF THE RESULTS

In spite of some puzzling or disappointing result (partly due to the shortcomings in the available data), the econometric analysis does succeed in explaining the diffusion of steam-threshing in 19th century Italy. The geographical diffusion depended on the endowment of labour and on the environment, while the time profile of innovation was deeply affected by the grain prices. In both cases, the key factor was the availability of capital: steam-threshing spread whenever and wherever the interest rates fell. This conclusion is not exactly startling, nor really new (Galassi, 1993). And it does not tell the whole story. It does not explain why farmers did not buy men or horse-powered machines if they felt the need to modernise threshing, nor why did they not use that "cheap" capital to purchase other type of machinery (reapers etc.).

Why did alternative "modern" techniques not spread? The men-powered thresher had some serious disadvantages in "normal" conditions. Their unit costs were similar to or higher than those of steam-powered machines (Table 2), and their use was extremely tiring. In the word of a textbook, "threshing with these machine cost as much as horse-trampling, with the difference that in this case the men, not the animals, are worked to death" (Niccoli & Fanti, 1924, p. 323; cf. also Cencelli & Lotrionte, 1919, p. 641; Notizie, 1877, p. 857). Threshing by hand might be convenient if the quantity of cereals to be processed was very small and the terrain and the conditions of country roads made the movements of steam-threshers difficult – i.e. in the mountains. As said before, there is some evidence of their diffusion in these cases.

Horse-powered threshers had many advantages, and a serious defect: they needed a lot of horses – at least three per machine (two to pull and a replacement). But in Italy the traditional draught animal was the ox and not the horse (Segre, 1998), and hence the stock of rural horses was quite small. In the mid-1870s there were about 625000 animals in the whole country, cities included (MAIC, 1876) – i.e. about as many as in Ireland, where the arable acreage was ten times smaller.[25] In fact only in Sardinia (the provinces of Cagliari and Sassari), the number of animal exceeded that of farms (Censimento, 1930), and in six other provinces (Grosseto, Cremona, Foggia, Sondrio, Pisa and Ferrara) there was more than one horse every two farms. Even in these areas, horse-powered threshing would have required the pooling of horses of several farms, and this would have entailed substantial transaction costs, as speed of processing was such a prominent concern. Elsewhere the density was even lower, down to a horse every ten farms or less in 13 provinces.

In theory, the shortage of horses could have been solved in three different ways. The farmers could have used oxen, or could have rented the horses, or a commercial firm could have owned and hired a horse-powered threshing machine and the animals to pull it. None of these solutions was feasible. The threshers had to be adapted to be pulled by oxen (Caruso, 1875, p. 281), and the results were anyway poor. In fact the oxen were too slow and hardly capable to move in narrow circles, and thus they were unsuited to power modern threshers (Notizie, 1878–1879, Vol. III, p. 6). Nor was renting horses feasible, at least in the short run. Each farmer faced a monopoly or oligopoly of the few local horse-owners who could extract as rents the profits of horse-powered machines. Of course, in the long-run, a strong demand of horses for threshing would have stimulated the competition among horse-owners, as there were clearly no barriers to entry. Yet no demand, and hence no competition, materialised: one has to infer that the differential profits from horse-powered threshing were too small to overcome the possible losses from the unemployment of horses during the rest of the year. Finally, there is no evidence whatsoever of horse-powered threshing enterprises in the sources. The risk of unemployment was clearly too great. Threshing lasted at most a month, and the possibility of employing the animals in other activities (e.g. in transportation) during the rest of the year must have been really uncertain.

In a nutshell, horse-powered threshing could have developed only with a radical change in the draught power, which its additional profits alone were too small to foster. The lack of horses hampered the diffusion of horse-powered machine also in Spain (Simpson, 1996, p. 158) and, maybe, in Portugal (Reis, 1992, p. 140). Of course, one could ask why the ox and not the horse had became the standard draught animal in Italy, but this is a different, and more complex, issue (Galassi-Kauffman, 1997; Fenoaltea, 1999, p. 11).

The lack of horses may explain the failed adoption of horse-powered threshing, but not the popularity of steam-powered alternative. Why did Italian landowners invest in a highly capital-intensive piece of equipment instead of sticking to traditional threshing methods and use their scarce capital in some other way?

The simple answer is that they did not, either individually or pooling their resources. Less than a third of steam-threshers was registered as property of landowners, in the 1935 survey (Indagine, 1935, p. 271). There are no comparable data for previous period, but the anecdotal evidence suggests that the share of threshers owned by landlords was, if any, lower. The majority of Italian machines belonged to threshing firms, which rented them to landowners. The firm provided the machine, and the skilled workforce (the engineer and an assistant), and was paid with a share of the output – usually a 3–4% of the crop.[26] The landowner had to supply the fuel and oil for the machine, the rest of the crew (to feed the machine, carry away the grain and the straw etc.) and the food for all the workers. Yet there is not doubt that he could rely upon traditional methods.

On the other hand, setting up a threshing firm may have been quite a profitable enterprise. The implicit rate of return always exceeded the interest rate on the (best) short-time commercial bills, and the premium, still below 10% in the 1860s, jumped up to 15% in the second half of the 1870s, to fall to about 5% in the 1880s. These figures are computed as a lower bound, under very conservative assumptions – a 3% rent, and the lowest "productivity" coefficient of Table 5. The changes in time of the estimated premium tallies quite well with the timing of the diffusion of steam-threshers: they would perform very well as independent variable in the time-series regression, if one could trust the estimate enough to use it. Of course, these profits had to be balanced with the risk of having the machine left idle for lack of customers. The risk may have been high for the pioneers, as landowners were still not familiar with the new technique. It was bound to fall as steam threshing was spreading.

Fig. 3. Rate of Return to Steam-Threshing: Premium Over Discount Rate.

The prevalence of custom-work can explain the poor results of the firm-size variable in the cross-section (Table 8), and also the much better performance of prices than of output as an explicative variable in the time regression (Table 10b). In fact the profits of the threshing firms were proportional to wheat prices as long as their share on the product remained constant. Of course, in the long run the share was not likely to remain constant, as any substantial extra-profit would attract new competitors in the business. However, in the short run, especially for small price changes, the rate seems to have been fairly sticky, may-be because the transaction costs of changing it were high enough to overcome the benefits of adjustment.

7. CONCLUSIONS

The results so far can be summed up in three points:

- Italy was quite advanced in the adoption of steam-threshing, even if *prima facie* that technology did not suit the country's "environment" and factor endowment.
- the diffusion depended on the cost of capital and on the features of the agriculture in each area. The process started in the Po Valley, where the conditions were more favourable and then spread in the whole country. The boom of the late-1870s early-1880s was made possible by the fall in interest rates and fuelled by sanguine expectations on the prospects of wheat-growing. These predictions proved to be wrong in the short term, but the growth of steam threshing resumed after the imposition of the duty on wheat.
- threshing was usually outsourced to specialised firms, which were quite profitable.

This latter point seems especially interesting in a wider perspective. Custom-work eased the constraint from the size of farms. Italian sources quote it very seldom, if at all, as a obstacle to the diffusion of steam threshing.[27] Indeed, custom work was the rule for threshing in the United States (Wik, 1953; Isern, 1981), England (Collins, 1972), Australia (Raby, 1996) Argentina (Adelman, 1994) and was widespread in Canada as well (Adelman, 1994). On the contrary, custom-work was uncommon in Spain (Simpson, 1996) and in Portugal (Reis, 1992), where farm size is said to have been a major obstacle to the development of steam-threshing. In Spain, steam threshing developed only quite late, in the 1900s, as a co-operative undertaking. Arguably this solution was less efficient than the custom work. In fact the co-operative entailed sizeable transaction costs in the allocation of threshing time among members, given the advantages of having his own wheat threshed first.

To be sure, the development of an efficient institution to circumvent a technical constraint should not surprise an economist. However, this “achievement” may come to a surprise for most Italian historians, who usually assume that institutions could not adapt to changing circumstances, and attribute to this rigidity the alleged failure of the Italian agriculture.

NOTES

1. Inchiesta Jacini II p. 106; Similar statements on the diffusion of steam threshing from the same source in Lombardy (VI.1, pp. 343, 506; VI.2, pp. 58, 459, 617, 827, 925), Campania (VII, p.117). Piedmont (VIII.1, p. 270; VIII.2, p. 64), Calabria (IX.1, p. 17), Latium (XI.1, p. 321), Marches (XI.2, pp. 430, 886). Cf. also Relazione, 1870–1874, pp. 609, 614 (Veneto), 615 (Emilia), Condizioni 1884 (Rome) and the historical works by Varni, 1988 and Corona Massullo, 1989.

2. An account of agricultural activities by J. Wilkinson (Chaloner, 1957, p. 51) mentions a steam-powered thresher as early as 1798. The machine was however “of a cumbersome and expensive construction”, and this may explain the lack of imitators.

3. Some horse-driven combined harvesters were used in California (Olmstead-Rhode 1993) but they were really unwieldy (e.g. they had to be pulled by 50 horses).

4. It is assumed that an hectolitre weighted 0.75 quintals and a “sacca” (a Tuscan unit) 0.55 quintals. Cf. other examples in Carega, 1859, Salvagnoli, 1852 and Rapporto, 1853 and also the data reported by Simpson (1996, pp. 156–158) and Reis (1992, p. 123), which cast some doubts about the advantages of steam threshing over horse trampling.

5. Cf. the extensive evidence on prices in Concorso, 1880 (an average of 1700 lit/HP) and Concorso, 1885 (1400 lit/HP), Carega, 1859; Salvagnoli, 1852; Cuppari, 1870, p. 202; Muzi, 1882, pp. 96–97; Relazione, 1870–1874, Vol. II, p. 52; and Galassi, 1993 (who quotes an actual purchase price). In the late 1890s, the price per HP was down to 1100 lit. (Niccoli, 1898 p.191), but the average power was greater as well, so the unit cost of a machine had not changed so much. The cost of horse-powered threshers is from Cuppari, 1870, p. 202; Niccoli, 1898, p. 191.

6. Cf. for men-powered machines Notizie, 1878–1879, Vol. III, pp. 63–64; Notizie, 1876, p. 276; Notizie, 1877, p. 857; Inchiesta Jacini, VI.1, p. 461; Cencelli and Lotrionte, 1919; and Niccoli and Fanti, 1924; for horse-powered ones Notizie, 1877, p. 857; Coupan, 1913; Herve-Mangon, 1875; Salvagnoli, 1852; Niccoli and Fanti, 1924; Collins, 1972, p. 21; and Rogin, 1931, pp. 182 ff. for the United States. The computation assumes that a horse was equivalent to six man in Italy and to three in the United States (according to the relative cost).

7. In theory, steam threshing had an additional advantage: it eliminated the losses of product, a rather serious problem with traditional methods (Giacomelli, 1864; Herve & Mangon, 1875; Niccoli & Fanti, 1924; Collins, 1972). The reality might have been different: Vitali, 1939 complains that the poor maintenance of the machines and a too hasty work caused high losses.

8. Statistica, 1890. Twelve provinces out of 69 were surveyed in 1886, 34 in 1887, 20 in 1888, one in 1889 and the two last ones in 1890.

9. The "likely" threshers accounted for less than 10% of the total stock (some 500 machines with 4700 HP), but their share was quite substantial in some provinces such as Venice (41%) and Milan (93%). There is evidence of omissions in the Po delta (Lazzarini, 1995, pp. 312–313), in the province of Pavia (Inchiesta Jacini, VI.2, pp. 58 and 154) in Tuscany (Galassi, 1997) and in Sardinia (Notizie, 1878–1879, III, p. 65 and Inchiesta Jacini, XIV, p. 344).

10. The figures may even understate the real share of imported machinery, if, as likely, the number of Italian boilers powering foreign threshers exceeded that of foreign boilers powering Italian machines.

11. Indagine, 1935; out of the 26,176 threshers then existing in the country, 9,214 had been produced in Italy and 13,298 imported (the provenance of the other 3,664 is unknown).

12. The total value of the stock amounted to some 30 millions lire at replacement cost and maybe somewhat less than half that sum at the actual value – assuming a 25-years productive life as suggested by Bardini (1997, Table 7). According to the available series, the net value of "agricultural implements and machinery" in 1889 was about 75 millions at current prices (Ercolani, 1969, Table, XII.3.5).

13. The owner of the boiler provided data on the heating surface, which were converted in power (HP) by the statistical central bureau. In 1894 and 1899 (following a suggestion of Statistica, 1890), it assumed that a square meter of surface produced 0.83 HP in any type of boiler. In 1904, it raised the coefficient to 0.91 for fixed boilers and to 1.33 for the portable boilers (Statistica, 1904). The power per square meter was indeed growing, as the efficiency of boiler was improving (Colombo, 1920, p. 344), but the posited increase seems too abrupt.

14. A figure in excess of 100 is not necessarily an error: the equipment could have been used to thresh the wheat in neighbouring provinces.

15. Men-powered machines were in use in Piedmont (Inchiesta Jacini, VIII.1, p. 270), in the provinces of Vicenza (V.1, p. 362), Bergamo, Brescia and Cremona in Lombardy (VI.2, pp. 617, 712 and 925 respectively), Genova and ("few") Massa in Liguria (X, pp. 456 and 729), in Tuscany (III, p. 170, "few"), in Ascoli Piceno, Macerata ("few") and Pesaro in the Marche (XI.2, pp. 889, 900) and ("a handful") in Sicily (XIII.1.3, p. 325). Cf. also the Relazione, 1870–1874, II, p. 603 (Piedmont) and 609 (Veneto), Notizie, 1877, pp. 857–860 (provinces of Novara, Udine, Avellino and Cagliari), and Notizie 1878–1879, III, p. 60–61 (Chieti). On the contrary, horse powered machines are quoted by the Inchiesta Jacini only three times, in Mantova (VI.2, p. 827), Potenza and Catanzaro in Calabria (IX.1, pp. 17, 148). A textbook (Giacomelli, 1864, p. 306) states that this type of machine was "the most diffused", but without any detail.

16. Mechanised threshing was used by a third of German farms, a quarter of Danish, a fifth of Swiss and a mere tenth of Austrian ones (Van Zanden, 1991 p. 233). Van Zanden reports also some data on the share of farms, which *owned* a thresher in France, the Netherlands, Belgium and Hungary (all ranging between 4% and 6% of the total). They surely underestimate the actual use of threshing machines, which were often shared or rented.

17. Cf. Agulhon, Desert and Specklin, 1976; Laurent, 1976, p. 681; and Demonet, 1985, pp. 79–81. The mechanisation contributed substantially to the increase in labour productivity in wheat cultivation (Grantham, 1991, Tables 13.8–13.9).

18. France produced about 14.5 millions of tons of threshable cereals (Mitchell, 1976, Table D.2), while horse-powered machines could process up to 1500–2000 quintals in a season and steam-powered ones up to 3500–4000 (cf. Table 5). Both figures are computed assuming 40 days of work, which are probably too many.

19. In Russia there were 20,000 threshers in 1911 (Reis, 1992, p. 99) i.e. roughly two times more than in Italy, but the Russian grain output was 10 times the Italian one (cf. also Kahk, 1988 for Estony). In Hungary the first steam-thresher was imported in 1854, and the number rose to some 230 in 1863 (Komlos, 1983, p. 67), to 2,400 in 1872 and to 8,920 in 1895 – plus some 46,800 horse driven machines (Voros, 1980, pp. 68–69). By then, traditional methods were in use only in the mountains. Cf. for the Adana area Quataert, 1981, p. 78.

20. Speed is frequently quoted as one of the advantages of steam threshing (cf. Giacomelli, 1864, p. 301; Carega, 1859, p. 97; Caruso, 1875, p. 281; Inchiesta Jacini, XI.2, p. 909; and also the discussion in Reis, 1992, p. 135). Hobsbwam-Rudè (1969, p. 369) argue that speed was sought after as market prices of wheat fell markedly in the weeks after the harvest. The first farmers to bring their product to the market enjoyed a substantial advantage.

21. In 22 provinces out of 60, there were no plains at all, while only four (Cremona, Ferrara, Rovigo and Venice) were totally level. They accounted for 18% of total Italian threshing power.

22. Reis (1991) provides a series of thresher prices, which however is almost flat, apart from a hike in the early 1870s.

23. The dummy refers to the province of Cagliari (Sardegna). The source reports an unrealistically low figure for the interest rate in that province – about half the national average.

24. All series are I(1), except the real wages, which are a I(2). Both the full and restricted form (Table 10a and b) of the level specification model pass the Johansen cointegration test for the variables at 1% and show no sign of serial correlation (LM test) or of omission of variables (RESET). On the contrary, the first difference specification (Table 10 c) pass none of these tests.

25. Turner, 1996 table 2.4; however in Italy there were five times more mules and asses – 293000 and 674000 respectively, against a cumulated total in Ireland of about 200000.

26. Cf. Relazione, 1870–1874, II, p. 608 (Cremona) and 614 (Padova), Inchiesta Jacini, II, pp. 106 and 187 (Emilia), V.1, p. 97 (Verona), VI.2, p. 154 (Pavia) and 925 (Cremona), VIII.1, p. 270 (Piemonte), XI.2, p. 915 (Pesono), Risultati, 1885–1888, p. 67 (Pavia) and 146 (Udine), Conti, 1887, p. 9 (Alessandria), p. 83 (Parma) p. 125 (Perugia), Niccoli, 1898, p. 191. The percentage was higher in few cases, up to 6% in the surroundings of Alba, in Piedmont (Inchiesta Jacini, VIII.2, p. 252). A source of the 1920s suggests a wider range, from 2.5% to 7% (Pagliani & Vitali, 1929, p. 443), while after World War II the cost (a nation-wide average) amounted to 2.27% of the value of the crop in 1946, 2.51% in 1947 and 3.04% in 1948 (Costo, 1949 prosp.8). A 3–4% share of the product was customary in the United States in the 1870s (Wik, 1953, p. 46).

27. Exceptions are Notizie, 1878–1879, Vol. III, p. 62 (Campania) Inchiesta Jacini, X, p. 729 (Liguria) and XI.2, p. 889, Conti, 1887, pp. 173–174 (Apulia). One could

remark that all these notations refer to regions where steam threshing had not developed.

28. Cf. Niccoli, 1898, p. 191; Caruso, 1875, p. 277; Irianni, 1933, p. 420; Costo, 1949, p. 77. Caruso, 1873 and Conti, 1887, pp. 173–174 suggest a longer workday, of 11 and 12 hours respectively. If they were right, the share of threshed wheat on total output would be undervalued.

29. In 1935 the total productive capacity was about 275000 quintals/hour – (cf. footnote 32). Thus, it needed 194 hours, or 19 days, for threshing 53.4 mil. quintals of wheat (Indagine, 1935, prosp.1). The source does not quote the threshing of other cereals – and thus the figure is augmented by 10% – the ratio of the combined output of barley, oats, rice and rye to the output of wheat (Sommario, 1958).

30. The figures for 1865, 1875 and 1880 are simply the cumulated total of new installations until that date. To compute it, the 217 boilers (1723 HP) without a date are distributed by year assuming the same proportion as the registered ones.

31. The original figure refers to the processing of wheat only, which was then subject to regulation. It is assumed to hold true for all cereals. Any resulting bias could not be substantial because wheat accounted for about 90% of the output to be threshed. A later official source (Costo, 1949, p. 77) argues that the figures are underestimated because of tax elusion.

32. Costo, 1949, p. 77 estimates the hourly productivity of threshers according to the length of their awner – a total of 320000 quintals for 29745 machines. Using the same coefficients, the 26176 machines in 1935 would have had a threshing capacity about 275000 quintals/hour or 0.7 quintals/hour/HP.

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APPENDIX A

The Estimate of the Share of Steam-Threshing

The estimate of the share of steam-threshed output needs data on the total production to be threshed (P), the number of days (α) and hours of work (β) and the hourly productivity per HP (γ), for the period 1865–1886, and the years 1894, 1899 and 1904.

The data on output to be threshed (P) are obtained from the official statistics, with a suitable upward revision to take into account the undervaluation of the data (Federico, 1982, and 2000). The figures for 1894, 1899 and 1904 are three-year moving averages. The output by province is the average of the official data in 1879–1883 (MAIC, 1891) and 1890–1894 (MAIC, 1894) increased by 10% and 25% respectively.

It is assumed that each days of work lasted ten hours, as reported by most sources.[28] The data on the number of workdays in the 1880s is computed as a simple average of the data by boiler (Statistica, 1890), while the figure for 1935 is estimated from the information from Indagine 1935.[29] The figures for 1894, 1899 and 1899 are obtained as linear interpolation, while the number of workdays is assumed to have remained constant in the 1860s and 1870s. This last assumption may cause the share of threshed cereals in those years to be undervalued if the downward trend had begun earlier.

The really thorny issue is anyway the productivity per HP/hour. Some evidence is available from textbooks, proceedings of competitions for the best machine and the catalogues of producing firms (cf. Table A.1).

The figures for the period up to the 1880s are quite consistent, with few outliers, but they are likely to be an upper bound of the actual productivity. In fact most of them were measured in competitions among threshing machines or were declared by the engineering firms. In both cases, they refer to brand-new, state-of-the-art machinery in ideal working conditions. In the real world, a sizeable part of the stock consisted in worn-out, old machines (the average age according to the Statistica was about 10 years), and some time was lost for repairs, small accidents etc. – thus reducing the actual productivity. It seems thus prudent to assume a lower figure – a best guess of 1.2 quintals/hour HP, within a 1.0–1.5 range, for the standard 7 HP boiler.

Unfortunately the evidence on the levels of "productivity" in the 1890s–1900s is too scarce to put forward an estimate. A linear interpolation (as for the number of days) may yield biased results. In fact, as the right-hand column in Table A.1 shows, the productivity per HP was inversely related to the power of the boiler, and, as said in the text, this latter was rising fast in the early 1900s. It

Table A.1. Productivity of Steam-Threshing (quintals wheat/hour/HP).

	Year	Num.	Productivity		Power (HP)		Coef. Cor.#
			Range	Avg.	Range	Avg.	
(a)	1852			7.42		2	
(b)	1850s			1.5		6	
(c)	1859	2	1.8–2.2	2	4–7	5.5	
(d)	1864	3	0.95–1.7	1.4	4–7.5	8.75	
(e)	1873	11	0.7–2.6	1.25	2.1–11.5	7.2	–0.42
(f)	1870s	2	2.0–2.1	2.05	6–10	8	
(g)	1870s			3.8		26	
(h)	1878			1.5		3	
(i)	1880	6	1.2–1.5	1.4	7–13	10.7	–0.79
(j)	1880	11	0.8–2.85	1.63	2.5–5.6	3.5	–0.28
(k)	1883		1.25	1.25		8	
(l)	1885	15	1.05–2.25	1.85	2–5.5	4.2	–0.10
(m)	1887			1.4		7	
(n)	1888	3	2.33–6	3.66	3–6	4.3	
(o)	1898		1.25–1.66			6–8	
(p)	1901	7	1.19–2.22	1.69	4–11.5	6.5	–0.26
(q)	1907		1.33–2.25			Ns	
(r)	1913	5	0.77–0.85	0.8	12–30	20.1	0.08
(s)	1913	4	0.8–1.6	1.12	5–12	8.2	–0.88
(t)	1926		0.71			Ns	
(u)	1925	7	0.6–1.1	0.8	4.5–34	17.6	–0.83
(v)	1933		0.5			30	
(w)	1935		0.7				

between (average) productivity and (average) power.

Sources: (a) Salvagnoli, 1852; (b) Collins, 1972; (c) Carega, 1859; (d) Giacomelli, 1864, p. 316; (e) Herve-Mangon, 1875, p. 766; (f) Wik, 1953; (g) Rogin, 1931; (h) Notizie, 1878–1879, III, p. 60; (i) Concorso, 1880; (j) Coupan, 1913, pp. 328–335 (the results of a competition in Joinville, sponsored by the Société des Agriculteurs de France); (k) Inchiesta Jacini, VI.1, p. 268; (l) Concorso, 1885; (m) Conti, 1887, p. 173–174; (n) Ringelmann, 1888, II, p. 64; (o) Niccoli, 1898, p. 191; (p) Niccoli and Fanti, 1924, pp. 319 and 325; (q) Bordiga, 1907, p. 376; (r) Cei, 1913, p. 348 (threshers built by "Marshall and sons"); (s) Cei, 1913, p. 351 (threshers built by the "Società Italo-Svizzera"); (t) Pagliani and Vitali, 1929, p. 441 (results of a test in Munich); (u) Pagliani and Vitali, 1929, p. 441 (threshers built by "Breda"); (v) Irianni, 1933, p .419–420; (w) Estimate for the whole country from Indagine, 1935 and Costo, 1949.[32]

is thus likely that in those years the hourly productivity per HP has been falling. This effect can be captured by an elasticity productivity/power, which can be obtained by the estimated the regression:

$$\text{Log Productivity} = a + b_1 \log HP + c_1 \ldots c_n\ D$$

from a pool of "representative" sources – i.e. those of Table A.1 which reports data on more than one thresher (i.e. the rows e, i, j, l, p, r and s). The set of dummies D refer to the source, to the time period (the 1880s, the 1900s and the 1920s), and to the nature of the data (firms' catalogues versus all other types). Only this latter variable is significant (cf. Table A.2).

Table A.2. Productivity/Average Power.*

Lproductivity = 0.92	– 0.32 LHP	– 0.27 Dummyfirms	
(8.17)	(5.31)	(2.73)	
adj-R^2 = 0.49 F 33.98 (0.00) RESET(2) 2.75 (0.07)			

t-statistics between brackets.
* White-heteroskedasticity consistent data.

Thus productivity per HP in 1894, 1899 and 1904 is computed assuming that a 1% increase in average power (Table 5) caused it to decrease by 0.3%.

APPENDIX B.

An Estimate of the "Threshold" Farm Size

The threshold can be computed (David, 1974, p. 221) as:

$$T = [(d + 0.5i)/Ls]^{*}\ (C/w),$$

where d is the coefficient of depreciation i the interest rate, w daily wage and Ls and C the differences between each pair of two competing techniques respectively in labour use (man-day per unit of acreage) and in total cost of the equipment. The relevant data are reported in Table B.1.

Steam saved about nine days versus the flail and three versus the horse-powered machine, but a steam machine cost 9000 lire more than a horse-powered one (the cost of the flail was negligible). The threshold varies between 45 and 56 hectares (according to the wages) if steam is compared with the flail, and between 130 and 165 if it is compared with the horse-powered machine. These figures are substantially lower those quoted by the literature, some 200–220 hectares in Italy (Niccoli & Fanti, 1924, p. 326) and more than 300 Portugal (Reis, 1992, p. 124). The difference between Italy and Portugal can be accounted for, at least in part, by lower wages.

Table B.1. Data for the Estimatuion of the Threshold.

	Flail	Horse-powered	Steam
Labour use (quintals/man/day)	0.8	0.17	0.40
Yield per ha	9	9	9
Days/ha	11.25	5.3	2.25
Cost (C)	0	1000	10000
Interest (i)	0.055	0.055	0.055
Depreciation (d)	0.033	0.033	0.033
Wages	1.2–1.5	1.2–1.5	1.2–1.5

Sources labour use Table 1; yield from MAIC 1894 increased by 20%; wages Niccoli, 1898.

APPENDIX C

The Estimate of Rate of Return in Commercial Steam-Threshing

The revenues of the threshing firm are computed as 3% of the value of the crop, assuming that each machine processed 2800–3000 quintals of cereals per season (cf. Table 5), and multiplying the quantity by the market price of soft wheat from Sommario (1958). The operating costs included a flat 0.5 lit/day for maintenance and repair (Niccoli, 1898, p. 191) and the wages for the engineer and his assistant. These latter were 6 and 4 lit/day respectively in the 1880s (Conti, 1887; Risultati, 1885–1888), and are retropolated to the 1860s with the unskilled labour wage index of Fenoaltea (1985). The depreciation is computed assuming the simplest straight line model, with an average life of 30 years and a cost of 1500 lit/HP (corresponding to 60 lit/season/HP). The interest rate is the official discount rate (De Mattia, 1967). As such, it may understate the cost of capital to a would-be threshing entrepreneur was probably somewhat higher, especially if he borrowed from the machine-builder and had no land to mortgage.

APPENDIX D.

Sources of Variables for the Econometric Analysis

This Appendix details the sources of the variables employed in the estimation of regressions of Tables 8 and 10, and sketches out the outcome of using alternative sets of data.

Dependent variables

(a) cross-section: number of HP (Statistica, 1890) per hectare of cereal land. This latter is computed by summing the acreage in wheat, barley, rye and oats – as the average of the data for 1879–1883 (MAIC, 1891, Table 1) and 1890–1894 (MAIC, 1894). This variable has been preferred to the (theoretically more appropriate) share on output by province, which takes into account the differences among provinces in yields and in the number of workdays, because the computation of this latter (cf. Table 6) is too much fraught with questionable assumptions to be reliable. Anyway, the coefficient of correlation of the two variables is as high as 0.94.

(b) time series: the new HP installed each year (Statistica, 1890). Using the number of threshers instead of the power yields slightly worse results, while the cumulated stock performs very poorly. (no variable is significant).

Explicative variables

(a) Cross-section

- size of farms. The percentage of farms beyond several different thresholds is taken from the census of agriculture of 1930 (Censimento, 1930), taking into account the changes in the provincial boundaries. The regression in Table 8 adopts 100 ha. as a threshold, but the use of different sizes (e.g. 50 or 500 ha.) does not improve the results.
- the cost of capital is proxied by the discount rate on loans by local saving banks in 1890, the earliest available date (Cotula & Raganelli, 1996).
- the labour/land ratio is computed as the number of gainfully employed males in agriculture (Censimento, 1881) divided the total agricultural land (arable land, permanent meadows and specialised fruit-tree acreage) from the Catasto 1929. The use of these figures implies a small bias, as they include the land reclaimed from the 1880s to the 1920s. Unfortunately, there is no alternative: the available wage series by province (Arcari, 1936) start in 1905, when the great emigration wave had already begun to raise wages in the South.

- share of plains: the percentage of plain on total acreage by province according to the Catasto 1929 adjusted for boundary changes.
- amount of rainfall computed: the cumulated sum of rainfall in July and August as the averages of data from 211 observatories for the period 1938–1957 (ASM 1959 Appendice II). Other specifications (such as the number of days of rain in the same period, or the total rainfall and the number of days in each month separately) yield poor results as well.
- share of labourers on total agricultural workforce from Censimento 1881.
- stock of horses per hectare of acreage. The number of rural horses is obtained as a residual, deducting from the total stock in 1876 (MAIC, 1876) an estimate of urban animals. This latter is computed as the population of cities above 10000 inhabitants according to the 1881 Census (Censimento, 1881) times the average number of horses per inhabitant in a sample of 150 cities in 1908 (Giusti, 1911). The total acreage is taken from the Catasto 1929.

(b) Time series

- the cost of capital is proxied by the discount rate on "cambiali" (short-term bills) computed as the average monthly rates of the Banca d'Italia (De Mattia, 1967 tav.20).
- the price of (soft) wheat is taken from the Sommario 1958, and is deflated with the wholesale price index.
- the cost of labour is proxied by the index of (urban) unskilled construction workers by Fenoaltea (1985) deflated by the consumer price index from Sommario 1958.
- price of fuel is the price of firewood (Sommario, 1958). Tests with the prices of coal at import (Sommario) or in the harbour of Genua (Felloni, 1957) yield similarly poor results.
- the output of cereals is taken from an estimate by the author (details available on request).