6 The choice of technology

Spanish, Italian, British and US cotton mills compared, 1830–60

Joan Ramon Rosés

Introduction

Studies on the cotton industry proliferate. Remarkably, the cotton industry has figured in recent debates over the amplitude and significance of the British Industrial Revolution, the loss of British competitive advantage, and the wealth and the poverty of nations in the nineteenth and the early twentieth centuries. As research moves forward, it seems obvious that the comparative history of the European cotton industry in the period before the "cotton famine" has been grossly neglected. There have been several splendid books and articles on some national cases but the comparative perspective has barely been touched. In particular, to date no study has systematically analyzed the cotton textile industry in the Mediterranean basin during the early industrialization period. This chapter fills that gap by adopting a comparative perspective. More specifically, this chapter concentrates its energies on providing a careful analysis of the technological choices of four cotton industries: the two largest producers in the Mediterranean basin and the two largest producers in the world, from 1830 to 1860.

Before the arrival of the "cotton famine" in the 1860s, the most important settlements of the modern cotton industry in the Mediterranean basin were in Catalonia (Spain) and in the Kingdom of Piedmont-Sardinia.[1] Simultaneously, the world leadership in cotton textiles was in the hands of Lancashire (Britain), while New England (United States) occupied the second position. In these regions, the cotton industry represented the first large-scale application of modern technology and the factory system. However, these four cotton industries differed strongly. In the beginning, the new cotton mills followed the British model but within a few years each country had developed its own practices and adapted the British technology to its own needs. Therefore, it seems that there is a strong case for placing primary stress on the cotton industry as the first example of how technological choice is influenced by local conditions.

Few economic historians believed in the absolute tyranny of fixed factor proportions and fixed attribute bundles; that is, in the argument that the choice of technology is technologically determined. Hence, the majority recognized that there existed a fairly wide range of alternative technology choices. However, economic historians vary in the reasons they stress. For Habakkuk (1962) the choice of different technologies reflects differences in factor endowments. In particular, he argued that land abundance and labour scarcity in the United States led to high relative wages and the substitution of capital for labour. Instead, for North (1981) institutions had crucial importance for technological change since their historical development will decide the outcome of any economic activity in a community. Institutions should be seen in terms of cultural norms, written rules and unwritten codes of conduct that provide the framework within which economic agents function. Finally, David (1985) posits more emphasis on the path-dependence of technological choices. Divergence on technological choices has occurred, in this view, but not simply because of differences in factor endowments or institutions. Rather, the argument is that successive developments depend on prior events. Consequently, it seems that by focusing explicitly on technological choice, one can open the door to a deeper understanding of how prior history, institutions and factor prices could affect technological innovation and long-run growth.

The recent literature on the history of the cotton industry contains three broad perspectives as well. One maintains the unimportance of alternative technological choices in the cotton industry. In particular, Clark (1987) diminished the importance of alternative technology, thereby asserting that countries with different factor prices showed no evidence of any difference in cotton-spinning techniques at the beginning of the twentieth century. According to his view, the effort of workers was the major determinant of the performance of cotton industries. A second view stresses that patterns of adoption of technology are basically consistent with a rational response to prevailing factor costs. For Von Tunzelmann (1978) the technological choices of British, Belgian, and American manufacturers were constrained in the first place by the price they had to pay for energy. For example, he pointed out that in the United States the abundance of (cheap) water power was the incentive offered to develop a new, more power-intensive technology (the ring throstle). For Saxonhouse and Wright (1984), the choice of technology was driven by geographical factors and the capacity to innovate. In particular, they argued that the diffusion of ring-spinning was constrained by the availability of high-quality cotton and subsequently by ingenuity in devising alternatives like cotton-mixing. Instead, Harley (1992) considered implicitly a larger set of factors in his comparison between the British and American cotton industries in the mid-nineteenth century. Thus, he included the relative prices of raw cotton, energy, skills and labour as determinants of the technology. A third interpretation posits a more fundamental role in institutional factors. Lazonick (1990) claimed the importance of entrepreneurial failures for the choice of technology. In particular, he censured the British entrepreneurs for their alleged failure to choose the correct techniques in spinning and weaving during the late nineteenth and early twentieth centuries. According to his arguments, the fundamental error was retaining the British industry's horizontal specialization into spinning and weaving factories. Similarly, Fisher emphasized the reluctance of Swiss textile entrepreneurs to adopt the new spinning machinery. He argued that these entrepreneurs were more risk avoiders than profit maximizers (Fisher 1991: 151). Finally, for Otsuka *et al.* (1988) differential technological performance between the Japanese and Indian cotton industries emanated from differences in market structure and government intervention. They pointed out that in Japan the relative absence of market-intervention policies helped to both ensure an efficient choice of imported technology and to have it adapted in appropriate directions.

While I recognize the importance of institutional and cultural differentials across countries, my basic premise is that labour-force skills and factor endowments are of crucial significance to the choice of technology in cotton textiles. In the period before the "cotton famine", alternative technological choices were relatively important. However, these technology alternatives cannot be interpreted without consideration of the heterogeneity of cotton cloth. In other words, the production of different kinds of cotton cloth employed a particular amount of physical and human capital, labour, energy and raw cotton. Moreover, some types of machinery were more adept than others in the production of some kinds of cotton goods. For instance, the throstle employed more energy and less skilled labour, and was better at spinning coarse yarn than the mule. In consequence, one can argue that the choice of product and machinery was intimately connected with the availability of skilled labour and relative factor prices in this early period of the factory-based cotton industry.

The remainder of this chapter is organized as follows. In the next section, the main characteristics (size, quality-mix and export performance) of these four cotton industries are discussed. The third section provides an analysis of technological developments in cotton textiles during the period. The fourth section discusses the process of diffusion of the cotton-textile technology in Lancashire, New England, Catalonia and Piedmont. This is followed by a section which develops a framework for understanding how technological choices and quality-mix were interrelated and how quality choices were decided by factor endowments, especially workforce skills. The last section concludes and summarizes.

Main characteristics: size, quality-mix and export performance

For the sake of comparison, it is useful to know how large the cotton industries of Catalonia, New England, Britain and Piedmont were. To answer this question, I rely on the amount of cloth produced more than on the number of spindles or raw-cotton import figures. The number of spindles is not a good indicator of the size of the cotton industry because the productivity of

Table 6.1 Production of cotton cloth: Catalonia, New England, Britain and Piedmont, 1830–1860 (in thousands of m^2, average per year)

	Catalonia	*New England*	*Britain*	*Piedmont*
1830–40	21 291	229 440	680 614	9 690
1840–50	51 430	414 972	1 140 804	17 701
1850–60	109 132	612 815	1 852 892	34 165
1830–60	60 500	420 345	1 233 122	20 519

Notes and Sources:
Numbers subject to rounding errors.
New England's data is drawn from Davis and Stettler (1966: Table 4, 221).
The procedure to compute the Catalan and British figures was the following. First, according Huberman's (1996) method, a disaggregated yarn output series was constructed for Catalonia and Britain. Then, under the assumption that yarn exports and yarn inventories had the same distribution as yarn production, I derived the amount of yarn consumed in the weaving industry where the figures on British yarn exports are drawn from Ellison (1968: Table 2). That is, total yarn production minus exports of yarn, inventories, and wastage (5 per cent) during weaving. To arrive at output in m^2, I multiply the weight of the cloth consumed by a fixed coefficient. The coefficients are different for each quality also different for Catalonia and Britain. The Catalan coefficients are derived from Comisión Especial Arancelaria (1867) and the British coefficients from the figures on cotton fabrics from *The Economist* (1845). Then I sum across qualities to compute total estimates.
Piedmont's figures on raw cotton imports were drawn from Quazza (1961: 221). After deleting re-exports with coefficients furnished by Castronovo (1965: 282–283), these figures have been transformed into raw cotton consumption. Then, with quality figures of Table 6.3 and Catalan weights, I convert raw cotton consumption into m^2 of cotton.

spindles varies strongly with yarn quality (count). Similarly, the level of raw-cotton consumption does not furnish information on the real amount of production since, for example, wastage and the weight of the product vary according to yarn quality.[2] For the reasons above, my choice was to compare cloth produced in square metres (m^2). Table 6.1 shows the results.

This table immediately reveals that the British cotton industry was gigantic when compared with its rivals. In particular, on average, it was about three times as large as the second-largest cotton industry, New England. Moreover, in comparison with Britain or New England, both the Catalan and the Piedmont cotton industries were minuscule. Thus, by the 1850s, the British cotton industry was about seventeen times the size of the Catalan cotton industry and about fifty-four times the size of the Piedmont cotton industry. Finally, it should be noted that the cotton industry of New England did not progress in the same way as the cotton industry in Great Britain, Catalonia and Piedmont.

A common characteristic of these four regions was that they contained most of the cotton industry of their respective countries. By 1861, Catalonia produced about 75 per cent of Spanish cotton textiles.[3] However, some years earlier these indices of concentration were even higher when Catalonia

Table 6.2 Quality distribution of cloth production: Catalonia, Lombardy, New England and Britain, 1830–1860 (in average per cent per year)

Catalonia	*<20*	*20–40*	*40–60*	*60–80*	
1830–40	68.37	31.44	0.10	0.09	
1840–50	25.94	71.89	1.83	0.35	
1850–60	18.06	76.43	4.04	1.47	
1830–60	25.93	70.31	2.77	0.99	
Lombardy	*<20*	*20–40*	*40–60*	*60–80*	
1856	66.73	33.00	0.26	0.01	
New England	*<16*	*>18*			
1830–40	75.99	24.01			
1840–50	73.44	26.56			
1850–60	76.12	23.88			
1830–60	75.27	24.73			
Britain	*<20*	*20–40*	*40–60*	*60–80*	*>80*
1830–40	17.12	45.24	24.16	8.03	5.44
1840–50	14.82	48.66	27.87	4.44	4.21
1850–60	8.10	48.79	34.29	4.60	4.22
1830–60	11.76	48.12	30.55	5.17	4.40

Notes and Sources:
Numbers subject to rounding errors.
Spanish figures corresponded to Spanish counts and British, Lombardy's and New England's to English counts. Therefore, since the Spanish counts were slightly finer than the corresponding English counts, Spanish figures understated the quality of the Spanish production. When it has been possible, figures are computed as arithmetic averages to avoid cyclical variation in quality due to changes in the prices of raw cotton and short-term market adjustments.
New England data are drawn from Davis and Stettler (1966: Table A.2). Note that the New England figures are based on a sample of firms but in the entire population.
Lombardy's data are drawn from Zanelli (1967: Table 42).
For sources of the Catalan and British data see the previous Table 6.1.

enjoyed a *de facto* monopoly of the factory-based cotton industry in Spain. Thus, in the 1850s, new factory-based cotton industries emerged in the Province of Málaga (Andalusia) and the Basque country (Nadal 1974: 218–25). Due to the political fragmentation and the presence of important trade barriers, the Italian cotton industry was less concentrated than the Spanish. By the 1850s, Piedmont produced about 43 per cent of Italian cotton cloth but gradually lost its share of Italian production with the emergence of the cotton industry in other regions (Castronovo 1965: 284). Thus, other important settlements of cotton mills in Italy were in Lombardy, Liguria, Campania, Veneto and Tuscany (A'Hearn 1998: 736ff). In 1850, New England produced about 67 per cent of US cotton textiles (DeBow 1970: Table CXCVI, 180). It should be noted, however, that since the 1820s the development of the cotton industry in the southern and the mid-Atlantic regions had reduced New England's share in the US figures (Harley 1992). In 1856, about 68 per cent of British employment in cotton mills was in Lancashire. By sharp contrast with the other three regions, from 1822 to 1856, Lancashire increased its share in national output.[4]

It should be emphasized that the disparities in the quality of cloth among these countries were as notable as their differences in size. Table 6.2 shows that New England and Lombardy produced heavier fabrics than Catalonia and Britain.[5] For the period as a whole, the quality of the New England cloth did not change considerably because about 75 per cent of production was always of the coarsest quality.[6] Similarly, in Lombardy about two-thirds of the cotton cloth was of that quality. In a sharp contrast, Britain and Catalonia tended to concentrate their production in the medium range (counts from 20 to 60). By the 1850s more than three-quarters of their production was in these counts, thus abandoning the production of the heaviest qualities. In Catalonia sharp decreases in the production of coarse cloth took place in the 1840s, whereas in Britain this happened in the 1850s. Finally, it should also be noted that British industry reduced its share of the finest qualities (over 60 count) although Britain was the country with the largest share of that type of cloth.[7]

Differences in export performance were also important. The weakness of the international position of Spanish, Italian and American cotton textiles during this early period should be emphasized. The export of cotton textiles from Spain or Italy was practically negligible and British exports were about thirty times as great as American exports, though America was the world's second-largest cotton textile producer (Harley 1992: 576–9). On balance these three countries imported cotton textiles, mainly from Britain. By direct contrast, through the antebellum years, the British exported about two-thirds of what they produced. Nevertheless, as Sandberg previously noted, from 1845 Britain gradually lost its share of the world market, being replaced by the new European and US cotton industries (Ellison 1968: 97ff; Sandberg 1968).

Table 6.3 shows the evolution of cotton textiles exports from Britain to these three countries and the Mediterranean basin.

Overall cotton exports from Britain grew faster than cotton exports to the United States, Italy and Spain. From the 1820s to the 1850s, total figures for British cotton exports more than doubled whereas exports to the United States only increased by about 78 per cent, exports to Spain practically halved, and exports to Italy grew by a mere 32 per cent. The Spanish and Italian experience is also striking when compared with the rest of the Mediterranean basin, where British exports experienced a sudden increase. More specifically, in the early 1820s over 80 per cent of British cotton textiles exported to the Mediterranean basin were concentrated in the countries of the Iberian and Italian peninsulas, whereas by the end of 1850s this figure was only about 50 per cent.

Interestingly, Sandberg has proposed a quality-related explanation to the persistence of British exports in the countries with emerging cotton factory-

Table 6.3 British cotton textile exports, 1820–1858 (in thousands of £, average per year)

	World	*Mediterranean Basin*	*United States*	*Spain*	*Italy*
1820–29	16 948	3 544	1 825	808	1 422
1830–39	20 914	4 120	1 874	537	1 710
1840–49	24 361	5 207	1 359	584	1 537
1850–58	34 197	5 154	3 263	421	1 881

Notes and Sources:
Numbers subject to rounding errors.
Figures are in current values. The data are drawn from Mann (1968).
Spanish figures include smuggling which has been computed according to the procedures described in notes to Figure 6.1.

based industries. According to him, Britain continued to export high-quality goods to the American and western European markets while very cheap goods went to the rapidly expanding low-income markets (Sandberg 1968). Thus, the British cotton industry lost almost all of the markets for coarse and medium-quality cloth in Europe. Note that the evidence presented in Table 6.2 gives some support to Sandberg's arguments since the American, Spanish and Italian cotton industries produced coarser quality than Britain's. The evident questions are why European producers and the United States specialized in relatively low-quality and not in high-quality cloth? And why these important differences in quality-mix among Catalonia, Piedmont and New England?

Technology in cotton textiles

In this section I will show that in the pre-cotton famine period several alternative technologies were available to entrepreneurs in cotton textiles.[8] Some technologies required more power than others, some were suitable for domestic production and others simply not, some relied on a skilled workforce whereas others were suitable for unskilled labour. Equally important is the relation between machinery and the quality of goods because only a narrow range of machinery could be used to make each quality. Consequently, the range of "appropriate" technological options was more limited than the large list of machines might suggest.

Both spinning and weaving machines of the mid-nineteenth century were improvements on pioneering machines that dated from the Industrial Revolution. Power costs, and innovations in power sources, strategically affected these improvements (Von Tunzelmann 1978: 175–240). However, the phases of development in fine and coarse spinning showed important differences, both in comparison with weaving and between themselves.

The mid-nineteenth-century cotton-spinning machinery is clearly recognizable as the descendant of the two spinning machines invented in the 1760s. The jenny was invented by James Hargreaves and the water frame was developed by Richard Arkwright. Hargreaves' jenny spun intermittently whereas Arkwright's water frame was based on continuous methods of spinning. While the jennies were made of wood and their small size made them appropriate for use in domestic units, the water frames were used in large factories. However, these two primitive spinning machines proved to be complementary rather than competitive because of their wide differences. The water frame was at least five times as productive as the jenny but could not produce fine counts; therefore, it was used basically for the production of warps. On the other hand, yarn from the jenny was most suitable for wefts but this machine suffered a sharp decline in cost-efficiency when used for anything above quite coarse counts of yarn. In consequence, factory production of warp yarn on water frames also increased cottage production of weft yarn on jennies.

In the following decades, new intermittent spinning machines meant the demise of Hargreaves' jenny but not the ruin of continuous methods, which could produce coarse yarn faster and more cheaply than these new machines. Samuel Crompton invented the mule in 1779. This new spinning machine broke through the technical barrier to permit the economical spinning of fine yarns by machine methods. The first mules were made of wood and their small size made them suitable for use in domestic production. However, by 1790 new large mules made of metal and powered by waterwheels were being used in large factories which specialized in spinning fine yarns (Von Tunzelmann 1978: 224). By the 1830s, the mule was improved by Richard Roberts, who invented the self-acting mule. Until this new device appeared, a man's strength had been required for pushing the mule spindles back and forth on their carriage. When the self-actor removed this requirement, one spinner could now work up to 1,200 spindles, compared with about 300 on a traditional mule. Several constraints limited the universal use of the self-acting mule: it required more power, more repairs, more technicians, and was less flexible (since it had greater difficulty in changing quickly from one grade of yarn to another) than the hand-mule. In effect, until the 1850s, the self-acting mule could only spin yarn below the count number 50. Extremely fine yarn was spun on the older hand-mules into the 1880s.

The continuous method of spinning was also improved in the first half of the nineteenth century. In 1828, John Thorp and Charles Danforth developed independently the throstle, a variant of the water frame, in the United States.[9] This spinning machine automatically and continuously performed the drawing, twisting, and winding of yarn. The only intervention in the spinning process required from workers in throstles was to mend yarns when they broke and to replace bobbins. It should be noted that these tasks could be easily learned in a few days of training. In sharp contrast, the self-acting mule required specific skills and continuous attention from operatives.[10] By the 1850s, the Americans made other important improvements in continuous spinning. For example, the development of cap-spinning and ring-spinning allowed continuous spinning to achieve higher speeds than before. These primitive ring throstles required very great motive power and it was not possible to spin yarn of fine grades of sufficient quality on them. Because of these disabilities, the self-acting mule was not eclipsed by early ring throstles. For example, in the 1860s, only the American industry had almost as many ring throstles as mule spindles (Saxonhouse and Wright 1984: 274).

At the beginning, the diffusion of the new machinery in cotton spinning – which lowered the price of yarns – expanded handloom weaving. The first serious efforts to mechanize the operation of the handloom date back to the attempts of Edmund Cartwright in 1787. In 1803, Horrocks patented the first truly workable powerloom. But it was not until after 1815 that power-driven machinery (i.e. powerlooms) began to play more than an insignificant role in cotton weaving. As with the mule, the primitive powerloom technology was modified over many years, and it was not until the 1850s that weaving by machine triumphed over traditional handloom weaving in England. It took considerably longer in other countries and textile industries.[11]

Technological choices

During the first half of the nineteenth century, technological leadership remained in the hands of the British cotton industry. As shown above, a great part of the progress in cotton technology during the period was due to British engineers.[12] Though some European regions, and later New England, made many technological advances, Lancashire supplied all or most of the textile machinery to most factories in Europe. The first European cotton mills were completely British in design and equipment. Many skilled British workers, including women, performed important technical functions in the new factories. For example, they provided technical advice and guidance as well as supervision and management, and trained local workers in the new technology. According to Bruland (1989), British machinery suppliers provided foreign textile firms with a complete array of information, equipment, and labour. In other words, they provided the technological capability to new cotton factories. However, once they got this technological capability, non-British factories ran by themselves.

In Britain, at the very beginning of the nineteenth century, the fine-spinning branch was the most technologically advanced because, for example, it was the first to apply steam-power to the new textile machinery. These substantial improvements cheapened finer yarns, which had noticeable effects on both exports and cloth fashion. In particular, British firms produced cotton more cheaply than Indian ones (Von Tunzelmann 1978: 224). By the 1830s, however, technological leadership in cotton spinning moved to the production of coarse yarn (Von Tunzelmann 1978: 184ff). Robert's self-acting mule, along with cheaper steam-power and refinements in powerlooms in the following decade, greatly reduced prices of ordinary cloth. Therefore, by the mid-nineteenth century, the British cotton industry remained organized in two different branches: fine- and coarse-spinning mills (Gatrell 1977). Also, many coarse mills integrated vertical powerloom weaving (Gatrell 1977; Lyons 1985).

The first modern spinning machinery (i.e. Arkwright's water frames) appeared in the United States during the last years of the eighteenth century.[13] The embargo and the war with Great Britain had favoured the settlement of the cotton industry in the United States. But the first great expansion of the industry took place from the end of the War of 1812, when the industry was protected by high tariffs (Zevin 1971; Stettler 1977). In this early period, American cotton-textile mills, which were known as the Rhode Island type, were comparable to British coarse-spinning factories.

In a few years, American practices diverged from Britain's. American cotton mills preferred water-driven to power-driven machinery and worked their machines more quickly than the British (Montgomery 1840; Von Tunzelmann 1978: 266ff). As noted above, American engineers not only ran the same British machinery at faster speeds but also improved continuous methods of spinning, which required more installed power. Perhaps more interestingly, by the 1820s the Americans had introduced their own new type of cotton mill: the Waltham-type. They integrated power-spinning on throstles and powerlooms and a new form of organization of the workforce. According to Jeremy, these new mills succeeded in lowering the cost of production for the coarsest products (Jeremy 1981). However, until the American Civil War, both types of mills survived (Cohen 1990). Rhode Island-type mills and hand-weavers specialized in the segments of the market where fashion and flexibility were more important while the Waltham-type dominated the market for standardized products (Harley 1992).

The Catalan cotton industry was older than New England's. The first enterprises devoted to printing cotton cloth were established in Barcelona in the late 1720s.[14] These calicoes were sold in the protected markets of the Metropoly and the Spanish colonies in America.[15] Because for most of the eighteenth century all cotton yarn was imported (mainly from Malta), as well as a large part of the grey cloth consumed, cotton spinning and weaving were not important. It took about sixty years for Catalonia to develop cotton-spinning. In 1802, the new spinning industry was heavily protected since the import of foreign yarn and cloth was forbidden. Through the thirty years that followed the ban, domestic production and out-working were common practice in cotton-spinning. Thus, cotton-spinning tended to remain dispersed in the villages and small towns of the lower Pyrenees, where they could rely upon a good supply of cheap female and child labour, rather than becoming concentrated in the calico centre of Barcelona.[16] Initially, due to its unskilled workforce and the use of jennies and water frames, Catalan spinning concentrated on the low grades of yarn (below 20 count). During the same period, hand-weavers proliferated in the major Catalan manufacturing towns (Sánchez 1989). Catalan cotton cloth was also coarse due to the ban on cotton yarn imports. Nevertheless, skilled hand-weavers produced a wide range of qualities by using other textile fibres such as wool, linen and silk.[17] This development of the domestic industry was accompanied by the scattered adoption of the steam engine.

In 1832, the Bonaplata mill introduced the new forms of organization, the steam engine, and the most recent British machinery (e.g. the powerloom Nadal 1974: 198). In a few years, the new machinery was universally employed in cotton-spinning and dominated cotton-weaving. The Catalan industry was characterized during this period by the rapid adoption of mechanical innovations. For example, Catalan cotton mills made the transition from hand to self-acting mules in only a decade, so that by the 1850s more than 75 per cent of spindles were moved by self-actors (Ronquillo 1851–7; Maluquer de Motes 1976). The diffusion of the new machinery paralleled the increase in the quality of local production since the average count increased to 30 count from about 15 count (Figuerola 1968; Madoz 1846). Moreover, the vertically integrated cotton mills expanded rapidly and captured the market for coarse–medium cloth. However, well before the 1860s, some horizontal spinning mills and domestic hand-weaving survived by producing for more fashion-oriented segments of the market (Rosés 1998b: Ch. 8).

In the first phases of the adoption of the new machinery, during the 1830s and the early 1840s, British and French technicians and workers played a leading role but, by the 1840s, the foreign workers had been completely substituted in their tasks by local technicians. Therefore, after the initial period, the Catalans developed the capacity to maintain their own machinery, adopted the new technologies and, obviously, ran them without any foreign help. Through the post-adoption phase, Catalan firms incorporated a stream of incremental developments and modifications to improve and adapt foreign technology to local requirements (Rosés 1998a). For instance, like the Americans, they developed their own type of centralized, vertically integrated, water-driven cotton-spinning and weaving factory: the *colonia* (Carreras 1983; Nadal 1991).

The cotton industry in the Piedmont was less developed than in the other three regions that are considered in this study.[18] During the eighteenth century, several regulations and laws protecting the wool and silk industries prevented the expansion of cotton textiles. Up to the second decade of the nineteenth century, cotton textile firms had not adopted some modern spinning machinery (i.e. hand-mules). In this early period, the cotton industry was predominantly domestic and rural, employing an unskilled workforce. Moreover, capital for this early development came from foreign entrepreneurs, mainly Swiss and French. These foreign entrepreneurs also introduced the technology and production methods of their countries of origin.

Therefore, most of the Piedmont cotton mills bought almost all their machinery from Alsatian and Swiss engineering firms. It should be noted, however, that the machines did not differ from original British designs (Fisher 1991: 145ff). By the 1830s, economic policy increasingly benefitted cotton textiles since the government established high tariffs on cotton imports. As happened in Catalonia before 1832, these protective measures increased production but failed to stimulate the adoption of power-driven machinery.[19]

Certainly, the turning point in the history of the Piedmont cotton industry was in 1842. The government of Piedmont drastically reduced tariffs on cotton goods. Contrary to the most pessimistic observations, these free-trade measures did not ruin the industry but contributed to its modernization since they eased the substitution of factories for small units of production (Castronovo 1965: 24–5). In addition, by the same year, modern waterwheels and throstles were introduced in Piedmont. Only a few years later, by the 1850s, several spinning factories adopted self-acting mules. In a sharp contrast, cotton weaving did not show signs of modernization. This branch of cotton textiles did not experience any kind of mechanical breakout until the 1870s, when the first powerlooms were used by the new vertically integrated cotton-spinning and weaving factories. Therefore, up to the 1870s, cotton-spinning took place in factories whereas the domestic system and putting-out predominated in cotton-weaving (Castronovo 1965: 164).

Labour management in the very early factory period was similar in Catalonia, Piedmont, Lancashire and New England because all cotton factories combined two forms of factory management: subcontracting and foremanship.[20] More specifically, workers in the preparatory section and spinners on throstles were supervised by foremen, whereas spinners on mules were organized into autonomous, subcontracted work teams. In particular, these spinners had functional autonomy because the craft-oriented machinery ran intermittently. Thus, they decided the pace of their work, organized their own work teams, had the authority to hire and fire assistants, and were paid by piece.

However, by the 1850s, US practices moved towards a new system of production with a workforce mainly formed of women and children controlled by foremen (Cohen 1990). The adoption of powerlooms and self-acting mules in the United States went hand in hand with the transition from subcontracting to foremanship (Cohen 1990: especially Ch. 6). In Piedmont, where the division of labour had been less important (Castronovo 1965: 222ff), the adoption of throstles and self-acting mules signified the elimination of piece-rate payments among spinners. According to Castronovo, operatives in Lombardy's cotton factories were subject to rigid norms and only foreign technicians and foremen had any autonomy (Castronovo 1965: 224–6). By sharp contrast with the United States and Piedmont, the main consequence of the diffusion of the self-acting mule in Catalonia and Britain was the reduction of the number of helpers, but not the dislocation of craft control from the shop floor. Similarly, it seems that Catalan and Lancashire weavers managed to retain their autonomous position in production even if the introduction of the powerloom could have increased foremanship practices in some weaving factories.[21]

The difference in the technological development of the four cotton industries is indeed quite startling. We have seen that there are marked differences in the adoption of the factory system, labour management, the new machinery, and even in the type of machinery preferred. At first glance, the American, Spanish and Italian cotton industries employed during several decades machinery and techniques inferior to Britain's. However, by the 1850s, this technology gap had been practically cut by these followers. Then, the typical American, Spanish, or Italian cotton mill possessed the same machinery as the most modern British cotton mill. Energy costs were partly responsible for this delay in the adoption of new machinery, which was more power-intensive. Thus the invention of the high-pressure steam engine, which decreased coal costs, might ease the adoption of self-acting mules and powerlooms in Spain.[22] However, at this point, many readers can agree that it seems difficult to explain the choice of technology only in terms of technological gaps and energy costs.

Explaining technological choices

The discussion thus far suggests that the choice of technology and quality were closely connected in cotton textiles before the "cotton famine". For instance, American producers preferred throstles to hand-mules because they produced coarse fabrics. Meanwhile, fine-spinning mills in Britain never employed throstles and preferred hand-mules. Therefore, it can be argued that one can interpret technological choices by explaining the final determinants of quality-mix. It should be noted that several alternative explanations for quality choices have been advanced in the literature on cotton textiles.

Sandberg pointed out that it is possible that quality-mix was a consequence of the life-cycle of the cotton industry. Young cotton industries produce low-quality goods because they did not require skilled or experienced labour and there was a large domestic market for them (Sandberg 1968: 15). Instead, mature cotton industries were able to specialize in high-quality cloth as a consequence of their skilled labour. However, the same history of the New England cotton industry gives little support to this argument because the industry matured but was still producing coarse goods.

It is often maintained that the characteristics and sizes of markets shaped the product choice of the cotton industry. For example, Sandberg has argued that only a worldwide exporter such as Britain was likely to have a large market for high-quality goods (Sandberg 1968: 15). Therefore, according to this line of reasoning, all small countries should only develop the production of heavy cloth. The obvious counter-example is the small Swiss cotton industry that produced high-quality cotton goods and could successfully compete with Britain in some European markets for expensive cloth (Dudzik 1987). On the other hand, many authors have argued that the cotton mills in the USA were biased towards standard and cheap products because of the size and income of their home demand.[23] Following the same logic, one would expect Catalan cotton mills to produce cheap cotton goods since the Spanish home market for textiles was poorer and smaller than other European and American markets.[24] However, the Catalan cotton industry produced more medium-range than cheap goods. Therefore, it seems that the size of the home market does not by itself furnish a convincing explanation for the quality-mix of the cotton industries. It would be more appropriate, however, to relate the characteristics of home production to the preferences of the home consumers. According to this line of reasoning, consumers in the USA would be more prepared to buy standard products than European consumers. However, this argument cannot be verified quantitatively.

It is sometimes argued that barriers to free trade modify the quality of the local production and foreign imports.[25] During the nineteenth century, two types of tariffs were employed: *ad valorem* and fixed duties. The *ad valorem* duties have several relevant properties. First, *ad valorem* duties were higher on cheap than on expensive goods and, therefore, the level of protection was higher for the local production of heavy (low-quality) goods (Sandberg 1968: 15). Second, it is perfectly clear that, *ceteris paribus*, countries with higher *ad valorem* duties would exclude from their home markets finer goods than countries with lower barriers. Third, increases in *ad valorem* duties augmented the range of protected goods towards fine (expensive) qualities. Finally, the quality range of foreign production excluded from the home market rests on the price of local production and the amount of the duty. For the same reason, when local costs fell and the duty actually remained constant, both the level of protection and the range of goods protected rose. In fixed duties, instead, when local costs decreased and the duty was not modified, the level of protection grew but not necessarily the range of goods protected by the tariff.

Several studies have discussed the influence of tariffs on the development of the cotton industry in the USA.[26] Through the antebellum period, the US tariffs were in *ad valorem* terms. Duties on cotton textiles imports were established in 1789 and changed no less than twenty times up to the Civil War. The first tariff on cotton goods was relatively lower (5 per cent *ad valorem*) and comparable to tariffs on other manufactured products. In the period 1790–1811, the *ad valorem* duty grew in successive reforms up to 15 per cent. The first great reform happened in 1812 when duties were practically doubled (27.5 per cent) to finance the war. Moreover, in 1816, a law was passed by Congress that established the minimum valuation for all pieces of cloth imported into the United States. Note that the system of minimum values reinforced the fact that duties rested more on coarse than fine cloth. In 1832 the system of minimum values was dropped and rates were generally lowered although the *ad valorem* rate was still higher (25 per cent). From 1842 to 1846 there was another protective bubble and *ad valorem* rates were increased to 30 per cent. Finally in 1846 Congress lowered the tariff to 25 per cent and eliminated the minimum valuation.[27] The US tariff had disproportionate effects on the various cotton goods because it gave more protection to heavy than to light cotton cloth. However, Harley has recently shown that the level of protection of the industry in the USA, even after the reform of 1846, was enough to protect the production of coarse and medium-range cotton cloth (Harley 1992: Table 2, 562). Therefore, the level of protection was so high that it probably had negligible effects on the New England cotton mills' choice between coarse and medium products.

The Spanish cotton industry was protected from 1802 by the ban on cotton yarn and cloth imports (Nadal 1974). In theory, obviously, the level of protection in Spain was higher than in the United States. By the 1840s the scope of the ban was limited to yarn below 60 count and cloth produced with that type of yarn.[28] This modification of the structure of the tariff might not have directly affected Spanish production since the domestic industry produced very little yarn above 60 count. Therefore, the level of protection was so high that it probably had negligible effects on the Spanish cotton mills' choice between coarse and medium products. However, one must be aware that the ban on foreign imports was difficult to enforce during these years. As a consequence, smuggled British fabrics reached a large portion of the Spanish market (Prados 1984).

The obvious question is whether changes in the enforcement of the ban can explain changes in the choice of quality of the Catalan mills. Specifically, if the movement towards the medium-range fabrics in the 1840s was caused by an increase in the "real" level of protection (i.e. in the risk of smuggling due to an increase in the repression of the illegal trade). Note that the quantity of foreign goods illegally imported was a function of the margin received by smugglers, the premium risk obtained by consumers, and the risk involved in this illegal activity. For example, when the risk increases and the margin remains constant, smuggling decreases (i.e., the "real" level of protection and, therefore, the market for home industry increases). Moreover, if the risk of smuggling was little or unvaried over time, one could expect that, over the long run, the quantity of smuggled goods paralleled the margin received by smugglers and was independent of the risk incurred in illegal trade. Here, the hypothetical margin of smugglers is easy to compute since the premium risk received by consumers in Spain was negligible. The reason for this was that Spanish law punished only the smuggler and not the buyer, and the seizure of smuggled goods could only take place within the frontier zone. Thus, the margin of smugglers was equal to the domestic price of cotton goods minus transport costs and the foreign price of those goods. Figure 6.1 shows the relationship between the amount of smuggling and the margin of smugglers.

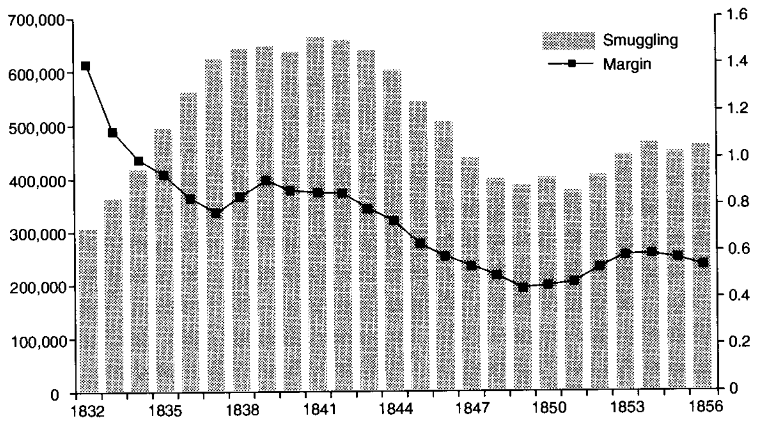

Figure 6.1 Smuggling of British goods in Spain (in £) and margin of smugglers (five-year averages).

Notes and sources:
The value of smuggling has been computed according to the formula proposed by Prados (1984). That is, British smuggling of cotton goods in Spain = 0.2 × exports to Portugal + 0.8 × exports to Gibraltar. The data on the value of exports to Gibraltar and Portugal is furnished by Mann (1968), table 25. The margin of smugglers is defined as the difference between the Spanish and British prices of printed cloth minus transport costs divided by British prices. For Spanish and British prices see Rosés (1998b), chapter 9.

If Figure 6.1 shows the true trend in smuggling and the smugglers' margin, one can reasonably infer that the quantity of smuggled cotton goods relies on the changes in the price gap between home and foreign goods. That is, the ban worked like an *ad valorem* tariff fixed at a (high) rate. In particular, the rapid decrease in the early 1840s of the quantity smuggled was due to the decrease in the price gap (margin), not to an increase in the repression of the illegal commerce. However, Figure 6.1 must be read and interpreted with caution since the data is highly imperfect. First, short-run variations cannot be captured by the formula that was used to compute the smuggling of British cotton goods because the formula was based on fixed coefficients. Second, the margin has been estimated as the difference between the prices of printed cloth in Spain and Britain. But it is possible that the difference between other types of Spanish and British cotton cloth did not evolve in unison with printed cloth. Third, Figure 6.1 cannot explain why smuggling increased faster during the 1830s. In any case, it seems implausible to link the movement of the Catalan cotton industry towards medium-range goods with a hypothetical increase in the repression of illegal trade. The level of protection grew due to the increase in the efficiency of the local production and, therefore, the local improvements were the main reason for the shift of production towards medium-range cotton fabrics.

In Piedmont, duties on cotton textile imports were first established in 1815 and were reformed several times up to 1860.[29] These tariffs were based on fixed duties for each kind of yarn or cloth. Early Piedmont tariff policy gave more protection to coarse than finer cotton goods and to weaving than spinning. The first important reform happened in 1830 when duties on coarse yarns (below 26 count) increased to 2 lire/kg, on medium yarns (from 26 to 49 count) to 1.50 lire/kg, and on fine yarns (up to 50 count) to 1 lire/kg. Similarly, duties on cotton cloth also grew and were fixed from a minimum of about 4 lire/kg on grey cloth to a maximum of 5–5.5 lire/kg on printed cloth. In 1842 the system of fixed duties was dropped and rates were generally lowered although the effective protection was still higher.[30] For instance, the common price of local yarns of the 8 count was about 2.5 lire/kg whereas the price of the imported British yarn, including duties, reached about 2.8 lire/kg (that is: 1.94 lire plus 0.9 lire of duty).[31] Finally in 1851 Cavour lowered the tariffs and signed a free-trade agreement with Belgium, a major producer of cotton textiles. Moreover, the structure of duties was modified, imposing higher duties on the fine qualities. After these reforms, duties on yarn were fixed from a minimum of 0.2 lire/kg in coarse yarn to a maximum of 0.6 lire/kg in fine yarn while duties on cloth were fixed from a minimum of 0.75 lire/kg on grey cloth to a maximum of 1.5 lire/kg on printed cloth. In spite of these reforms, the level of protection of the industry in Piedmont was enough to preserve the home production of coarse and medium-range cotton yarn.[32] Likewise, duties on cloth were so high that foreign cloth encountered many problems in Piedmont markets.[33] Consequently, the level of protection was so intense that it presumably had insignificant effects on the Piedmontese cotton firms' option between coarse and medium products.

It should also be considered that tariffs were endogenously, not exogenously, determined. In other words, the government did not establish duties independently of the pressure of local groups. Spain and Italy furnished many examples of duties influenced by local industrialists. In Spain, when the ban on foreign cotton imports was reformed in the 1840s, the employers' organization (the Junta de Fabricas de Cataluña) showed little opposition to reducing the ban to yarn up 60 count. The reason was that local spinners produced little yarn above 60 count and mixed-fabrics weavers needed this type of yarn (Comisión Especial Aranceleria 1867). Similarly, in Piedmont, Ligurian weavers specializing in fine cloth promoted lower tariffs on fine yarn because of the scarce local production of that good (Castronovo 1965: 302). Moreover, protection on cloth was higher than on yarn because the numerous hand-weavers could exert strong pressure on successive governments (Castronovo 1965: 305ff). Thus, one can argue that some cotton goods received more protection than others, simply because they were produced by the local industry. In consequence, duties were not established to modify the quality of home production.

The three interpretations traditionally advanced in the literature have to be rejected. Neither the life-cycle of the industry, nor home-market

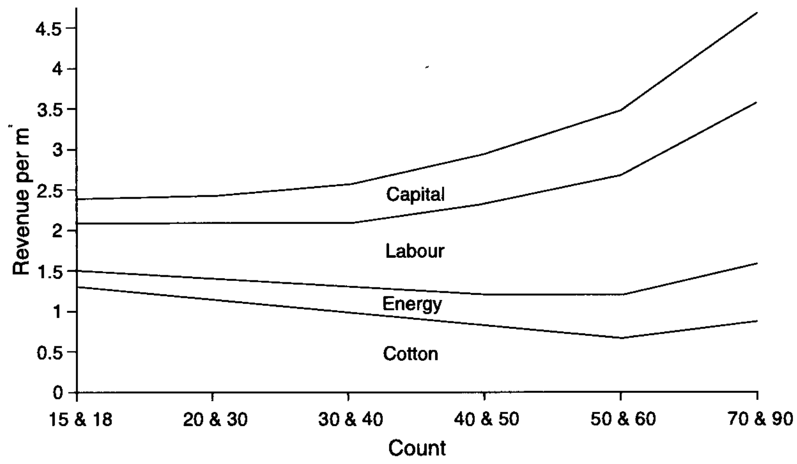

Figure 6.2 Producing costs of cotton cloth: Barcelona, 1860.

Notes and sources: Count refers to the count of yarn used in producing the cloth. The source is Comisión Especial Arancelaria (1867). The figures are drawn from the answer of the España Industrial S.A. The cost of the weaving in the quality 20&30 and 50&60 has been estimated. The cost of yarn in 15&18 counts is drawn from the answer of José Ferrer & Cía. This last figure has been modified to eliminate the transport costs of raw cotton and other materials from Barcelona to Vilanova, where the second firm was settled. Note that cotton comprises the wastage. Energy comprises not only coal for light and power but also other minor raw materials. Labour includes all labour cost even those outside the shop floor. Finally, capital costs comprise depreciation, profits and capital taxes.

Table 6.4 Share of inputs in total costs of cotton cloth: Barcelona, 1860 (per cent)

	Coarse	*Medium*		*Fine*		
Yarn count	*15 & 18*	*20 & 30*	*30 & 40*	*40 & 50*	*50 & 60*	*70 & 90*
Cotton	53.41	47.00	38.51	27.70	18.98	18.31
Energy	8.94	10.10	11.76	13.77	15.21	15.58
Labour	24.39	27.84	31.26	37.37	42.92	42.16
Capital	13.25	15.06	18.47	21.16	22.90	23.95

Notes and Sources: See Figure 6.2.

characteristics, nor barriers to free trade provide a sufficient explanation of the quality-mix of the three cotton industries summarized in Table 6.2.

Anyone who attempts to analyse the choice among different cloth qualities is immediately confronted with the fact that the combination of inputs changes through the quality range. As mentioned above, a different combination of energy, raw cotton, labour, and human and physical capital was employed to produce each quality of cloth. Therefore, it should be relatively straightforward to relate product-mix to factor endowments.

Figure 6.2 and Table 6.4 illustrate the costs of producing the different qualities of cotton cloth from the point of view of the Catalan manufacturers. Figure 6.2 practically covers the entire universe of Catalan production of cotton cloth and can be considered to be representative of the state of the industry at the end of the 1850s. A major objection, however, might be raised against this cost figure. It is impossible to assess the importance of labour-force skills and machinery alternatives in the production of the different qualities, since the two factories considered could produce the whole range of yarn and cloth.

Figure 6.2 shows that the production cost of cloth grew at different rates at each point; that is, the cost–quality relation was not a straight line.[34] Interestingly, the increase in total costs is more important in the transition from the medium to the finest qualities than in the transition from the coarsest to the medium qualities. For example, the cost of producing one square metre of coarse fabric (15 & 18 count) was about Rv 2.40. Whereas the cost of producing one square metre of medium-range fabric (30 & 40 count) was about Rv 2.56 (i.e. only about 6.6 per cent more). More specifically, raw cotton costs per square metre decreased throughout the spectrum of coarse–medium qualities, although wastage increases with count. In the fine qualities, particularly above 60 count, the raw cotton costs grew again due to the use of a large-staple and, therefore, expensive fibre. On the other hand, labour, capital and energy costs rose with count increases.

Table 6.4 displays the fact that the share of different inputs in total costs varied according to quality. Thus, the coarsest quality was the most raw-materials intensive and least labour-intensive, whereas the opposite holds for the finest qualities. Note that the two factories in the sample could produce the whole range of goods given their stocks of human and physical capital.[35] For that reason, the ratios of capital to labour and energy to labour are rather constant. However, they actually produced more medium-quality than other types of cloth (e.g. the share of medium-quality cloth in the production of España Industrial SA was about 80 per cent of the total). In other words, it seems that they were better prepared, given their stock of physical and human capital, to produce medium-range goods.

Figures for the whole Catalan cotton industry would probably diverge by some amount from the sample figures. Thus, firms specializing in the coarsest qualities used throstles instead of self-acting mules and, therefore operated with relatively more capital and energy per worker than the sample firms. Conversely, cotton mills specializing in the finest qualities used mule-jennies instead of self-acting mules and employed less capital and energy per worker.[36] In a few words, the figures presented above presumably overstate the share of labour in the cost of coarse qualities whereas the contrary holds for finest qualities.

Manufacturers in Catalonia were constrained by the price they had to pay for raw cotton and for coal, which was primarily influenced by geological and geographical factors.[37] The problem was alleviated by producing more fine cloth, which was less raw-materials intensive than coarse cloth. Thus, the efficient firm on the frontier of the local best-practice tried to produce cloth as fine as was possible with the level of skills of its workforce. The more skilled the workforce, the finer the production, and the high cost of raw materials was less important. In other words, cotton mills with less-skilled labour specialized in products in which the inferiority of their workforce had relatively little impact on the final price (i.e. in coarse cloth), whereas cotton mills with a highly skilled labour force did exactly the opposite. The constraint on this movement towards fine cloth in Catalonia was the efficiency of the local labour force, because the finest qualities were generally beyond the abilities of the Catalan workers.[38] However, it is not clear whether one should speak about the human capital constraint or the climatic constraint. The fact is that the thread breakages varied with the count level (high counts broke more often than coarse counts) and the dampness of the climate. Because Catalonia is less damp than Lancashire it is clear that thread tended to break more often in the former than the latter. For instance, during the summer, many spinning firms were at a standstill in Catalonia due to the low levels of dampness.[39]

Differences in the workforce skills facing the four countries at the time give strong support to the arguments advanced in the previous paragraph. During the first half of the nineteenth century, British and Catalonian workers were employed in different positions according to their skills. In hand and self-acting mules workers were skilled, whereas in throstles and preparatory machines workers were unskilled. Thus, in the production of coarse yarn workers were unskilled whereas the contrary holds for the finest qualities. Instead, the US and Piedmontese mills used self-acting mules and throstles, and an unskilled labour force to produce coarse cotton cloth. In particular, a contemporary described the situation of the cotton factories in Italy with the following words: "when a factory is unable to specialize in its working, then fewer, low-quality goods are produced, since it is forced to use what could be called *generic* machinery... and has *generic* workers as well".[40]

Conclusions

Despite the fact that the data reported on the previous pages have their limitations, one can argue that they provide an explanation for the technical choice and quality-mix of the Catalan cotton firms and, by extension, of the Piedmontese, British and US cotton mills. On average, Catalan cotton mills produced cloth that was in the middle of the extreme choices; the unskilled and raw-materials intensive production of the coarse-cloth New England mills, and the skills-intensive and raw-materials-saving choice of the fine-spinning Lancashire cotton mills. Therefore, one can argue that it is likely that Catalonia had a scarce supply of raw materials, but that its labour force was on average more skilled than those in the USA but less skilled than the British. Piedmontese cotton mills, with similar raw-materials restrictions to

Catalonia, produced slightly finer cloth than US cotton mills. However, these cotton mills could not produce so fine a cloth as Catalan or British cotton mills, due to their unskilled workforce. Thus, there is strong evidence that the efficiency of labour, which is mainly the result of prior human-capital accumulation, is important in determining the drift of best-practice technology in cotton textiles.

The other components of the quality choice must, however, be allowed their due. Plant and equipment costs were higher in Spain, Italy and the USA compared to Britain. This by itself lowered their optimal quality because it raised their relative operating speeds. Labour costs were higher in the USA and lower in Spain and Italy. In isolation this would have had the effects actually observed: lower quality in the former than in the latter. These aspects along with the particular characteristics of the consumers' choices are not perfectly disentangled.

Notes

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1 Specifically, in the regions of Piedmont and Liguria.
2 See, for example, Blaug (1961), Huberman (1996) or Comisión Especial Arancelaria (1867).
3 Gimenez Guited (1862) gives national figures on cotton industry production.
4 For example, its share in employment in cotton textiles grew from about 55 per cent to about 68 per cent. See Von Tunzelmann (1978: Table 7.18, 239).
5 Unfortunately, quality data for Piedmont are not yet available though Lombardy's figures can be considered similar to those of Piedmont. Particularly, many literary testimonies tend to support the view that all Italian regions produced low-quality cotton goods. See, for example, references given in Zamagni (1993: 89ff).
6 This result is similar to the evidence presented by Temin (1988) for the 1830s.
7 This sharp drop in the finest qualities can explain the drop in the quality index constructed by Sandberg (1968).
8 This section is based on Ellison (1968), Ure (1836) and Von Tunzelmann (1978).
9 The classical account of the American inventions in throstle and ring technology is Copeland (1912). See also Jeremy (1981).
10 See, for example, Cohen (1990) and Huberman (1996).
11 The extended co-existence between powerloom and handloom has led to an intense debate. For Von Tunzelmann (1978), some improvements in the application of power to cotton textiles production, particularly the adoption of high-pressure steam engines, reduced power costs substantially, significantly enhancing the profitability of power weaving. Moreover, the diffusion of the powerloom was partially interconnected with that of self-acting since this spinning machine produced regular yarn such as was required by primitive powerlooms. Instead, for Lyons (1987, 1989) the delay in the triumph of

mechanized weaving had a different explanation since powerlooms were more profitable than handlooms from about 1820. According to his view, handloom weavers adapted to the misfortunes of technological displacement because they moved to areas of rising economic opportunity, had their children earn higher incomes, and maintained family cohesion. In other words, to compete with more efficient powerlooms, handloom weavers squeezed their wages. Therefore, it seems that the triumph of powerlooms depended on the relative costs of energy and labour.

12 On the British advances during the period see, for example, Chapman (1987), Von Tunzelmann (1978), Ellison (1968), and Mann (1968).

13 On the early history of the US cotton industry see, among others, Cohen (1990), David (1970), Harley (1992), Jeremy (1981), Nickless (1979), Temin (1988) and Zevin (1971).

14 On the history of the cotton industry in Catalonia before 1830 see Thomson (1992), and Sánchez (1989).

15 There is a large debate on the role played by the colonial and home markets in the development of the Catalan cotton industry. See the review of the literature in Delgado (1995).

16 Gutiérrez (1834, 1837), Sánchez (1989) and Thomson (1992).

17 In Rosés (1998a), there is a full discussion of the skills differences between hand-spinning and hand-weaving.

18 This account of the Piedmont cotton industry is based on Quazza (1961) and Castronovo (1965).

19 Castronovo (1965) argued that, during this early period, coal costs made the adoption of steam power in cotton textiles uninteresting.

20 Cohen (1990) on the United States, Huberman (1996) and Clark (1994) on England, and Camps (1995) and Rosés (1998a) on Catalonia.

21 Cohen (1990: 73–4) gives inconclusive evidence on this aspect of the British cotton-weaving industry. By contrast, Catalan sources such as the Comisión Especial Arancelaria (1867) or Cerdá (1968) clearly stated that weavers were paid by piece during this period.

22 Von Tunzelmann (1978) relates the adoption of self-actors and powerlooms in England to the invention of high-pressure steam engines.

23 See criticism on this argument in Temin (1988).

24 On the Spanish home market for textiles see Sánchez-Albornoz (1981) and Prados (1983).

25 See, for example, Sandberg (1968) or Temin (1988).

26 David (1970), Stettler (1977), Temin (1988) and Harley (1992).

27 On tariff history in the cotton industry in the United States see Taussig (1931) and Stettler (1977: especially Ch.5).

28 Ronquillo (1851–7) and Gimenez Guited (1862).

29 On Piedmont's duties see Castronovo (1965: 305–12).

30 New duties were 0.9 lire/kg on coarse yarn, 2 lire/kg on grey cloth, 0.75 lire/kg on fine yarn, and 2.5–4 lire/kg on printed cloth.

31 These prices are drawn from Castronovo (1965: 249–50). British prices were prices at the Port of Genoa; thereby they comprised transport and insurance costs.

32 After 1852, the price of Piedmont yarn of 8 count was about 2 lire/kg whereas the price of the same British yarn, including duties, in Genoa was about 2.2 lire/kg. Similarly, the price of local yarn of 30 count was about 2.8 lire/kg while the price of the same British yarn, including duties, in Genoa was about 2.9 lire/kg. All prices are drawn from Castronovo (1965: 249–50), except for the price of the British yarn of 30 count which has been extrapolated from the data on Milan of Zanelli (1967: Table 15, 94).

33 For example, the duty represented about 30–40 per cent of the home price of grey cloth. The prices and duties are drawn from Castronovo (1965: 295–6 and 310).

34 This result invalidates the argument of Bils (1984) on the straight-line relation between costs and quality in cotton cloth.

35 They used steam-powered self-acting mules and powerlooms and organized their workforce into work-teams, as was typical in Catalan cotton firms.

36 Von Tunzelmann (1978: Table 7.3, 185) demonstrates this for Lancashire. See also Gattrell (1977).

37 In Rosés (1998b) costs differentials among Catalan, British and US cotton mills are fully discussed. On average, raw cotton prices in Barcelona were 47 per cent higher than in New York and 28 per cent higher than in Liverpool. Similarly, the price of coal in the Port of Barcelona was about 76 per cent higher than in Britain.

38 Contemporary and recent studies stressed the importance of human capital formation in determining the level of workers' efficiency in the early cotton industry. See, for example, Boot (1995) and Rosés (1998a).

39 See Farnie (1979) and the contemporary, Ferrer Vidal (1875).

40 Ellena cited by Zamagni (1993: 89).