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Transfer of European Technologies and Their Adaptations: The Case of the Bengal Silk Industry in the Late Eighteenth Century

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Abstract

This article investigates the adaptations of the Italian silk technologies to the environment in Bengal. The case is particularly interesting as the English East India Company invested considerable effort into making the technologies operational in the new climatic and socio-economic context. The article highlights the unequal focus on technical adaptations, although it points out that commercial and economic, and social adaptations were not completely neglected. It concludes that the key obstacle for the commercial success of the transferred technologies was the lack of attention to institutional adaptations. Institutional problems that arose were the result of lack of leadership and managerial innovations on the part of the Company rather than the technology itself.

Keywords: Adaptations, technology transfer, Bengal silk industry, English East India Company, entrepreneurship and managerial innovations

Adaptations are commonly seen key to the successful transfer of technology: technologies need to be adapted to the local circumstances. The literature on technology transfers argues that adaptations are decisive for making the transferred technology operational and its application in the new environment commercially viable.[1] Such adaptations range from alterations to the machinery and the institutional framework of production and the development of infrastructure.

This article considers the technical, commercial and economic, social, and institutional adaptations of the silk technologies transferred from Europe to Bengal in the late eighteenth century. The article points to the necessity to implement not only technical but also commercial and economic, social and institutional adaptations of transferred technologies in order to secure their economic success.[2] It explores a venture of the English East India Company (EEIC) into manufacturing raw silk for export markets in Bengal in which transfer of technologies and their adaptations played a central role. The article draws attention to the lack of institutional adaptations and attributes this to the lack of leadership and managerial innovations on the part of the EEIC. This article concludes that the EEIC was successful in implementing technical adaptions of the silk technologies transferred to Bengal. The EEIC also took positive steps towards implementing economic and commercial adaptations. The implementation of such adaptations was however also negatively affected by the lack of entrepreneurship on the part of the EEIC.

Literature focusing on the eighteenth-century transfer of European silk technologies to Bengal ascribed problems with the adoption of the technology in the new environment to incompatibilities between the socio-economic environment in Bengal and the requirements of the transferred technology.[3] This article instead looks at the transfer from the point of the EEIC and assesses whether the Company did all the steps necessary for successful innovations of the processes of silk production. In this way the article differs from the literature that studied technology transfers from the point of compatibility or incompatibility of factor endowments between a country importing and exporting particular technology.[4] My research focuses on the potential of companies to mitigate issues affecting technology transfers through the implementation of adaptations. Since businesses need to flexibly respond to the various challenges accompanying technology transfers entrepreneurship plays key role.

The first part of the article summarizes main approaches to adaptations and technology transfers, it shortly describes the successful adaptation of European cotton and silk technologies in Japan in order to draw comparisons with the Bengal case. Part two examines technical adaptation, part three commercial, economic and social adaptations in the Bengal raw silk production. Part four focuses on the lack of institutional adaptations.

Adaptations, Technology Transfers and Bengal

Growth in silk weaving in North-western Europe in the eighteenth century increased demand for raw silk, especially in Britain where demand could not be met domestically because the climate was unsuitable for sericulture.[5] Consequently, this strengthened the interest of the EEIC to import Bengal raw silk to Britain. However, the quality of the Bengal raw silk was low and not suitable for weaving.[6] The Bengalese technologies of sericulture (mulberry cultivation and silkworms rearing) and silk reeling (process of making silk thread from silk cocoons) lagged behind that of China and Italy – the leaders in the eighteenth-century world market. Therefore, in order to improve the quality of the raw silk produced in Bengal, the Company decided to adopt Piedmontese silk reeling technologies – the most advanced technologies of reeling silk in Europe.[7] The Piedmontese technologies required centralization of production as the Piedmontese reeling machine represented a considerable capital investment. Moreover, supervision was necessary to secure production of high-quality silk thread.[8]

Overall, the implementation of the Piedmontese technologies necessitated a host of changes: setting up silk filatures; training the Bengalese workforce in the new method; changes in the organization of labour in silk reeling; and changes in procurement. The process of technology transfer was accompanied by a series of adaptations as the technologies needed to fit the new climatic, social and economic environment. All the changes were implemented by the Company with the aim to significantly increase the quality of Bengal raw silk and substitute the importation of raw silk from Italy, Turkey and Mediterranean Europe into Britain with Bengal raw silk and to widen the Company's silk trade.[9] However, in spite of all the efforts by the EEIC, the quality of the Bengal raw silk did not improve as much as expected. This article considers whether the technology transfer failed to result in quality improvement because of lack of adaptations to the technology.

The development of Bengal silk industry was studied by handful of authors who largely explain the problems with the adoption of the new silk technologies in Bengal from the point of view of clash of the local practices and socio-economic environment in Bengal with the requirements of the transferred technology. The work of Gautam Bhadra emphasised the role of the EEIC in making of the British Empire in Bengal, it portrays the Company as a power determining the development of Bengal silk production. Bhadra stressed resistance on the part of the winders, middleman and peasants rearing cocoons and argued that the EEIC had the power of coercion and the diffusion of filatures resulted in 'subjection to strict control' of primary producers.[10] Indrajit Ray argued that the initial resistance to the new technology and system of organisation subsided by 1790s and the Company managed to diffuse European know-how.[11] Yet, the process of technological and organisation innovation was not continuous. Ray argued that the nineteenth-century decline of the industry was caused by the inability of the Bengal silk industry to catch up with the technological innovations of the sector at global scale.[12] Sabyasachi Bhattacharya emphasised that social and cultural constraints initially slowed down the diffusion of the filature system. The author argued that the new system weakened the position of peasants vis a vis the middlemen and the Company.[13] Roberto Davini, in contrast to the other authors, argued that the EEIC was largely unable to control the Bengal economy and this factor negatively affected the progress of the filature system.[14] Most importantly according to Davini the Company lacked power to reform the system of sericulture and the low quality of cocoons was the key obstacle to quality improvement of Bengal raw silk.[15]

Not denying the difficulties that the Company faced i.e. when recruiting reelers to its filatures, procuring cocoons from peasants and dealing with intermediary merchants, my research points to a different conclusion. In spite of all the difficulties the Company succeeded in exporting ample quantities of raw silk to Britain – on average over 40 percent of raw silk imported to Britain during the period 1773-89 came from Bengal. The most significant issue that marred the success of the EEIC's venture was the quality of the filature silk which often did not answer the demand in Britain. This article focuses on the issue from the point of the Company and the steps it undertook in Bengal. Businesses often face adversary conditions when implementing product and process innovations, especially so in new markets, similarly as the EEIC did in Bengal. Successful businesses are able to overcome these conditions through innovative approaches and adaptations. Focusing on the ability of the EEIC to adapt the transferred technologies permits me to assess whether the Company managed the venture into silk industry adequately and encountered problems with the quality of the filature silk due to a clash between the local socio-economic environment that could not be mitigated. This article differs from the previous research also by focusing on a shorter time period – 1760s-1810s – that is before the 1830s when the EEIC was forced to sell its silk filatures and cease all its trading activities.

The literature shows that transfers of technologies from areas with widely differing factor endowments often fail. A handful of studies have emphasised that ready access to necessary inputs and to output markets are essential for any successful technology transfer.[16] These arguments draw on factor price theory. As valuable as these insights are, differing factor endowments were not the reason why the transfer of the Piedmontese technologies to Bengal failed to have the intended effect on the quality of the raw silk.[17] Moreover, as Shannon R. Brown observed, most studies pay only little attention to other factors influencing the success of technological borrowing such as institutions, values, etc. in the importing country.[18]

The concept of adaptation came to the fore in debates about technology transfers in the 1970s, when it became clear that mere technical assistance to developing countries was not producing the results hoped for. Literature on the international diffusion of technologies argues that transferred technologies must often be adapted if they are to meet the needs of the recipient country.[19] Differences in the size of the market, in the price of inputs, the cost, quality and capability of infrastructure, differences in taste and in climate are some of the key aspects that make adaptations necessary.[20] Edwin Mansfield and his colleagues focused their research on transfers of technology especially at a firm level and they pointed to the fact that well-managed firms have better prospects to successfully implement technologies in a new environment.[21] Such firms, they argued, focus on commercial and economic aspects of technology transfer rather than solely on technological solutions.[22]

The case of the transfer of the Piedmontese technologies to Bengal supports the conclusion that a pure focus on technical aspects of transfers undermines the possibility of commercial success. Furthermore, this article underlines that institutional adaptations are as important as commercial, economic and technical adaptations because institutions are necessary for creating an environment conducive to technological adoption. The article points to the fact that entrepreneurship and managerial innovations play key role in institutional development.

Technology can be defined as set of techniques and rules governing the production of goods and services.[23] Rosenberg has argued that technological change is the process of adaptations and modifications and that the capacity of an economy to adapt technologies is key for its ‘technical vitality’.[24] Similarly, Robert Evenson in his study of technological transfers in agriculture calls the introduction of new technology ‘adaptive invention’. His argument is based on the understanding that factor prices, soil and climate conditions or new agricultural inventions induce changes to adopted technologies.[25]

Although adaptations are crucial, they are the final phase of technology transfer and the most difficult to achieve. The most elementary phase of technology transfer is 'material transfer' – the export of new products or materials to a recipient country. Design transfer denotes the transfer of designs and blueprints and marks the phase of adoption of the new technology. At the end of this phase recipient countries have the ability to manufacture new products. The final phase is 'capacity transfer' – that is the building of the capacity to adapt new technologies to local circumstances.[26]

Rosenberg's analysis of technological adaptations shows that changes can be radical because technologies are often transferred not only from one place to another but also from one industry to another.[27] However, even when a technology is transferred within one industry, changes inevitably are far-reaching.[28] In such a context, the difference between macro- and micro-inventions is useful in explaining the process of adaptation. We can consider the original transfer of technology as a macro-invention. The process of re-tooling and updating of the context in which the technology is utilised, can be seen as that of the realm of micro-invention. Joel Mokyr argues that 'during the implementation stages, inventions were usually improved, debugged, and modified in ways that qualify the smaller changes themselves as inventions'. He further points out that the process of adaptations often resulted in 'productivity gains as a result of learning by doing'. [29] Such micro-inventions are therefore decisive to the successful adoption of a technology.[30]

The theoretical findings of Mokyr, Rosenberg and Mansfield about the role of adaptations have been reiterated in several case studies which show that adaptations were necessary especially when technologies spread to new regions, countries and continents. Rosenberg illustrated the key role of the institutional, managerial, technical and organizational adaptations in several industries after they spread from Britain to the US in the nineteenth century.[31] Lilliane Hilaire-Pèrez and Catherine Verna reached similar conclusions for early modern technology transfers as did Michael Pearson in his studies of adaptations of European technologies to the environmental and social conditions of Australia.[32] Warwick Pearson, relying on his study of transfer of the watermill technology from Britain to Australia in nineteenth century has drawn several conclusions about the extent of necessary adaptations of imported technologies. He found that the extent of adaptations depended on differences between the economic and environmental contexts. Moreover, technologies and the materials necessary for the construction of the 'hardware' of the technologies – machinery and equipment – were often transformed under the influence of adaptive pressures from the existing system of manufacturing. Socio-cultural variables also played an important role in creating an environment either facilitating or opposing transfers.[33]

Although the majority of studies on technology transfers emphasise the importance of economic factors, several of them nonetheless claim that transfers of technologies often necessitate adaptation to the social environment. Janet Hunter, for instance, illustrates how the required attributes of employees and social perception of gender influenced the gender division of labour in postal and telephone communication services in Meiji Japan.[34] Another factor that should not be overlooked is the local political-economy context as resistance to transferred technologies can impair efforts to adapt them. Brown has demonstrated that the adoption of the Western technology of soybean crushing to China in the nineteenth century failed not because of the incompatibility of the technology with the Chinese factor endowments or environmental conditions, but because of the opposition of merchant guilds and government officials.[35]

Similarly, the evidence for the silk industry shows that in the case of successful transfers, a series of micro-inventions which altered the technology to make it suitable to the new environment followed.[36] Most of the research on technology transfers in the silk industry has focused on transfers of silk twisting technologies.[37] Comparatively less research is concerned with silk reeling technologies.[38] From the point of view of adaptations, the most interesting case was the transfer of reeling technologies to Japan. Comparing this case with the transfer of the Piedmonese reeling technologies to Bengal can shed light on some of the shortcomings that technological adaptation encountered in the Subcontinent.

For the purposes of this article it is effective to compare the transfer of the European silk reeling technology to Bengal with the transfers of European silk reeling technologies to Japan and also with the transfer of European cotton spinning technologies to Japan. Such a comparison allows to relate the successes and failures of the EEIC in adapting new technologies to the Bengal environment with the experience of successful adaptations in Japan. The comparison illustrates the essential role of entrepreneurship and managerial innovations in the success of the Japanese cotton spinning and silk reeling sectors. Such comparison is effective in spite of the fact that the technological differences between silk reeling and cotton spinning and the fact that the transfer of the Piedmontese silk technologies to Bengal took place half a century before the transfer of the European cotton technologies to Japan. The unifying factor lies in the fact that both the late eighteenth-century Piedmontese silk technologies and the late nineteenth-century British technologies reached a technological frontier.[39] Adaptation of the technologies to the socio-economic environment of Bengal and Japan, respectively, relied on the ability of entrepreneurs to flexibly innovate the technology and management to make the technology fit the new environment. European technologies of cotton spinning and silk reeling were transferred to Japan in the nineteenth century, their successful adaptation to the local socio-economic conditions was the key factor that enabled Japan to become one of the largest exporters of textile products in late nineteenth and early twentieth century. Both of these sectors initially experienced technical difficulties. Scholars of Japanese industrialization have pointed to the fact that entrepreneurial management was key in facilitating technology and knowledge transfers and overcoming difficulties.[40] The new technologies necessitated innovative managerial decisions about the allocation of business resources.

Motoshige Itoh and Masayuki Tanimoto showed that Japanese cotton merchant-entrepreneurs relied on a mix of traditional and innovative approaches in the production and distribution of cottons.[41] Cotton spinning was the sector of cotton production that in particular relied on entrepreneurship. Japanese cotton spinning – section of cotton industry that produced yarn for export and for cotton weaving sector – was on the forefront of adopting and adapting European technologies. Eugene Choi stressed that the competitiveness of the infant industry and international trading of Japanese-made cotton yarn was facilitated by the entrepreneurial leadership of the Osaka Spinning Company and the Mitsui Trading Company under the direction of Takeo Yamanobe and Senjiro Watanabe, respectively. The co-operation between the companies and their leaders decreased the costs of information about the technical and commercial trends and therefore reduced the costs of business decisions. It provided entrepreneurial vision to Meiji spinners who lacked knowledge of advanced technologies as well as the knowledge and practice of international trade.[42]

Transfer of European technologies was essential also for the development of Japanese silk weaving industry and similarly as in the case of cotton industry adaptations were the key to success. The process of technology transfer went far beyond simple transplantation of the new techniques. The requirements of the new technologies on skill and knowledge made investment into technical education necessary. As pointed out by Tomoko Hashino it was not only the government that facilitated this investment, trade associations set up in Meiji silk weaving districts were at the forefront of the efforts – establishing regional educational institutes.[43] The key importance of investment into specific human capital lays in the fact that it enhances the capacity to absorb new technologies and knowledge. Moreover, the profitability of silk weaving in Japan was shaped by continuous processes of adaptation of the technologies in response to changes in prices of labour and capital, labour productivity, requirements on quality of product etc..[44] Entrepreneurial capacities were essential for successful adaptation. Tomoko Hashino and Keijiro Otsuka, in their study of changes in the early twentieth century weaving in the Japanese district of Kyriu, emphasised that the successful product, process and organisational innovations relied on managerial capacity to carry them out.[45]

The best opportunity to draw comparisons between the Bengalese and Japanese experience with adaptations is to look at the transfer of European silk reeling technologies to Japan. Successful transfers of silk reeling technology were carried out in Japan in the nineteenth century and a century later in East Asian countries.[46] In both cases, adaptations of foreign technology were key to their successful adoption. The first phase of the transfer of European technologies of raw silk production to Japan was not dissimilar to that of Bengal. In the late nineteenth century the Meiji government decided to implement a European system of filature reeling.[47] Similarly to the case of Bengal, the process was managed by foreign silk specialists and machinery was imported from Europe. The first Japanese filature, the Tomioka filature, followed the European system of filature production in its entirety. However, as it soon turned out, the filature suffered losses.[48] This initial failure was followed by the implementation of a series of adaptations to suit the local conditions. The filature switched from a 'quality-first' (that is a focus on the production of small quantities of very high-quality thread) to 'quantity-first principle' (with a focus on the production of large quantities of medium-quality thread). Production thus concentrated on thicker silk. Alterations of labour management (such as the introduction of gang-production system) were implemented and a system of quality control was also introduced.[49]

The technical principles according to which new filatures were built were altered as well. In the decade following the setting up of the Tomioka filature, the new filatures that were erected were smaller than their predecessor and did not use steam-power. They also had smaller production capacity, used less advanced machinery and were more labour intensive.[50] These adaptations of the filature system were supported by institutional and social adaptations and by the development of sericulture.[51] Debin Ma observed how the expansion of the production of raw silk was supported by the development of social and physical infrastructure – such as legal system, public education, research, modern monetary and banking systems, new transportation and communication systems – during the Meiji period.[52] The new infrastructure helped the transportation of cocoons to filatures and of silk thread for export and created the human capital necessary for research and innovations in sericulture. Domestic innovations in sericulture played an important role in the expansion of silk production in nineteenth-century Japan.[53]

Several differences emerge when we compare the Japanese experience with silk reeling with the one from Bengal a century earlier. First, in Bengal technical adaptations were given comparatively more attention than economic and commercial adaptations. Second, in spite of similar preferences for the production of thicker thread, it took the EEIC several years before it favoured a 'quantity-first principle'. Third, since the adaptations in Bengal were designed by silk specialists they narrowly focused on technical and commercial problems and did not pay enough attention to the institutional framework of silk reeling. And finally in the case of Bengal the development of sericulture was not sufficiently promoted.

Furthermore, when we compare the Japanese experience in both cotton spinning and silk reeling with the case of Bengal silk reeling, it becomes clear that entrepreneurial leadership was the factor that was lacking in the Bengal venture. The EEIC was unable to innovate the system of management in silk manufacturing in ways that would facilitate the development of an efficient institutional framework of production. The Company relied for adaptations solely on its silk specialists who had no experience with managing business ventures. The Court in London – the principal managerial body of the EEIC – had a good access to information on the development of demand for raw silk in Britain, however, the coordination between the Court and the Board of Trade – the principal managerial body in Bengal – was highly unsatisfactory. The Board of Trade often did not send reliable and up-to-date information to the Court in London and it did not implement the instructions it received from London. The lack of information sharing enhanced the costs of business decisions and undermined commercial and economic adaptations.

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Adaptations of the Reeling Technology

The Company focused in its efforts to improve the quality of the Bengal raw silk exclusively on the phase of reeling and paid attention also to the adaptations of the transferred technology. Claudio Zanier has observed that the Piedmontese innovations to reeling would not be successful if they were not built on organisational, professional, and technical improvements.[54] The EEIC focused above all on technical adaptations. Such technical innovations implemented in Bengal were crucial for making the Piedmontese technology operational in the new context. The technical adaptations were thorough and efficient in addressing the technical issues, however their implementation was not without problems.

The Company directed its attention to adapting the reeling machinery to the Bengal environment. Considering that little attention was paid to adaptations of the institutional structure and to adaptations of sericulture, it is important to note that the Company spared no effort to solve the technical problems with reeling machinery. Two points need to be made in this respect: first, the Company only implemented innovations necessary to make the reeling machinery operational in the Bengal climate. The overall productive capacity or any other aspect of the technology were not altered. Second, the EEIC depended on the knowledge and advice of James Wiss, one of the silk specialists in the Company's services, for designing the adaptions of the machinery.

James Wiss planned most of the adaptations of the reeling machinery.[55] Wiss's guidance was also essential for the correct assembling of the reeling machines. He set precise guidelines about the distances between the different parts of the reeling machine.[56] Such detailed instructions were indispensable for making the machine operational as well as for producing raw silk of appropriate dimensions. For instance, keeping the appropriate distances between the staves of the reel was of primary importance as otherwise the resulting skein of silk would not answer the requirements of the European market.[57] Wiss also advised the Court to send more silk specialists to Bengal and on several occasions suggested suitable candidates.[58]

The climate of Bengal necessitated two types of adaptations: adaptations of the machinery and of its maintenance.[59] Most pressing were the problems with the wheels used in the reeling machines. In Piedmont, cog wheels were made of wood, however the weather in Bengal was detrimental to the use of wood. Wiss pointed out the problems arising from the use of wooden cog wheels and instigated the change of wooden cog wheels for brass ones.[60] The Court in London observed that: 'one capital defect attending filature Silk has arisen from the bad condition of the Cog Wheels, which by the heat of the Sun and damp of the night frequently become cracked and damaged'.[61] Thus, it was decided that the wooden wheels would be substituted with brass ones and later that the axis of reels be made of hardened steel. The Court had the cog wheels and reels made in Britain and sent to Bengal. The number of the wheels and other components sent in 1780s was sufficient to equip all the filatures.

Change to the material of cog wheels required changes in the whole construction of the reeling and double crossing machines. Although such changes were small, they still caused confusion among the Company's servants and the reelers. The Court had to repeatedly send guidelines on how the brass cog wheels were to be used and how the reeling machine was to be altered. To avoid problems, models showing how the wheels were to be put onto frames to construct the reeling machine were sent from London. [62] The models were to be copied in Calcutta so that every filature could receive two models.[63]

The climate had a negative impact on the lifespan of the equipment used in the filatures and it became necessary to implement specific rules for the maintenance of the machinery. This applied also to the brass cog wheels and to the new reels partly made of steel. The Court was well aware of the importance of maintenance and the orders sent to Bengal were very precise in this respect:

> In regard to the quality of this Brass Cog Wheels we are persuaded if they are kept properly oiled and cleaned (neither of which we fear has been the case) they would last many years. The Steel Axis should be oiled every day or as often as wanted and the Wheels should be covered from dust and cleaned as often as experience might shew they require.[64]

The Company had to wrestle not only with the effects of the weather on the machinery but also with the resistance of its servants and reelers to adaptations. The Court, for instance, had to persuade the servants in Bengal about the usefulness of the new materials. In 1782, the Court wrote to Board of Trade in Bengal:

> We were convinced of the efficacy of those Implements before we sent them out, and we are surprised at the doubts and difficulties that started to impede their effect, for we did not send the Brass Cog wheels to perform different variations, from the wooden ones, as both are acting perfectly the same after the Piedmontese principle, which is the only one we can permit to be made use of, let the Instrument be constructed of wood, Brass or Iron.[65]

Although the models sent to Bengal helped to overcome such resistance, adaptations of the machinery were not implemented as smoothly as the Court expected.

All of this shows that the Company spared no effort to make alterations to the machinery that would remedy the technical problems and make the machinery more suitable to the conditions of Bengal. The Court in London even evaluated the impact of the innovations as can be understood from a letter to the Board of Trade in Bengal: ‘we also direct that a few of the Reels that are worn out may be carefully packed and sent home to us by some of the returning Ships, noting how long they were in use, in order that by an inspection of their defects, it may be discovered whether any and what means may be adopted to remedy the same'.[66] The Court was very keen to receive feedback. Apart from evaluating the used machinery, it also demanded that 'after sufficient trial", the Board would send a report on the merits of the innovations.[67] The feedback that the Court received shaped further efforts and practical problems in putting the altered machinery into use:

> The wheels are thicker, the axis much stronger and the bearings are 3 or 4 times as broad besides which one of them is made of hardened Brass and the other hard cast Iron and they have holes through them to admit clean oil.[68]

Moreover, plentiful attention was being paid to making the altered machinery easy to maintain:

> These Reels are not to be screwed down horizontally upon the wood frame but must be fixed vertically with the wood pegs uppermost which pegs must be taken out to put oil in them and then put in their places again to keep out dust and dirt.[69]

Thanks to the silk specialists, the Company had very precise knowledge of the practical problems with maintenance of the machinery. Overall, the Company was successful in adapting the reeling machinery to the Bengal environment.

Commercial, Economic and Social Adaptations in the Bengal Raw Silk Production

Commercial and economic adaptations are part of the final phase of technology transfers. They are integral to building the capacity to adapt production processes in order to manufacture products that answer the specific demand of the markets. [70] For instance, in the Japanese case, one of such adaptations was the switch to the production of coarser silk. When studying the transfer of the Piedmontese technologies to Bengal, it is useful to focus on commercial and economic adaptations because these were essential not only to make the technology useful in Bengal but also to produce raw silk satisfying the demand in London.

It cannot certainly be said that the transfer failed due to a lack of attention to the adaptation of Bengal raw silk to the needs of the British market. The Court had up-to-date knowledge about the demand in Britain and the EEIC embraced several commercial adaptations. The first adaptation the EEIC adopted was that of quality differentiation. In the 1780s the EEIC started to differentiate the thickness of the Bengal reeled silk into sorts A, B, and C.[71] The Company became aware that the principle of distinguishing quality according to the number of cocoons that were used in the production of the thread was inadequate. The Court complained about the old system: 'We deem this a very indefinite Mode of Expression, as the Cocoons of Italy may differ from those of India or China so much that a given Number of each may for a Thread of a very different Size'.[72] The Court was very attentive to the issue of creating standards of fineness of silk. In 1796 it started distinguishing sort A into No 1, 2 and 3, with No 1 being the finest. It was even specified that 'the Letter A No 1, 2 and 3 should be drawn from the best Cocoons of the Filatures of Cossimbuzar, Radnagore, Gonatea, and Commercolly, in preference but not to the exclusion of the other Filature, as those threads seem to be cleaner, and more like the Italian Fabricks'.[73] All these efforts of the Court to set up standards of fineness of thread and the sending of samples of these different sorts to the filatures shows the determination of the Court to create standards of thickness which would make it easier for buyers in Britain to choose the exact silk they wanted. It shows that no efforts were spared in analysing the demand in London, or in transmitting the information to Bengal and in setting precise guidelines about the thickness of raw silk to be sent back to Britain.

The second adaptation was the preference given to production of thicker thread. The initial aim of the EEIC was to produce high-quality silk of the fineness of the Italian silk in Bengal. The Company was confident that the improvement of the quality of the raw silk would enable it to outcompete its rivals: '[we] entertain no doubt but that in a short time the Quality of our Merchandize Imported [raw silk] will obtain for us a decided preference over the Importations of any other Country'.[74] At first, the focus on the production of thicker thread was driven by the technical difficulties of producing the finest quality thread in the rainy season. This task was nearly impossible because cocoons were more prone to get mouldy and silk threads never dried properly in the rainy season. Therefore the Court directed that in June, July and August silk was 'to be spun of 7 to 8, 9 to 10, and 10 to 12 Cocoons' instead of producing coarser silk.[75] The Company still supported the production of the finest sorts of silk but only outside the rainy season and in limited quantity. For instance, in 1785 the Court ordered that:

> 1/5 of the 360,000 small lbs. of Filature Silk abovementioned be wound of equally in quality and size (neither coarser nor finer) than the sample A, 2/5 of the said 360,000 small lbs. equal in size but not coarser than the sample B and the remaining equal in size to the letter C, if however these assortment should be reeled a little coarser it will not prejudice the sale provided the Silk is wound off perpetually even, round and clean.[76]

Until the late 1780s and early 1790s the preference given to finer thread meant that the production of thicker thread was insufficient to satisfy the demand in Britain. The EEIC preferred the production of finer thread notwithstanding the high demand for thicker thread on the British market. Only in 1793 the Court deemed that 'the coarse Sort has been the most productive', from the point of view of sales, and ordered that 1/9 of the quantity demanded to be reeled of sort A, 4/9 of sort B, and 4/9 of sort C.[77] The Company favoured the thicker sorts of silk threads as these more readily found market in Britain.

It should be assumed that the Court was successful in adapting the filature system to the social environment of Bengal, especially in adapting the gender-division of labour to the local norms. Although the gender division of labour was not addressed directly by the Company, it is apparent that the changes to the Piedmontese system were far-reaching. In 1788 women represented approximately 72 percent of the workforce employed in filatures in Piedmont.[78] Women were employed as master-reelers, as apprentice-reelers and young girls were assigned the task of watching over the fire under the basins. The reason for employing women as reelers was that they were considered to have more skilful fingers for the task of reeling.[79] In Bengal reeling outside the household was done by Cuttanies – male reelers travelling from village to village.[80] The Company seemed well-aware of the gender division of labour in silk reeling and relied on male workforce in filatures.[81]

The reason why the EEIC was successful in planning adaptations was that it relied on silk specialists for diffusion of the reeling technologies. Several studies recognise the role of skilled individuals such as craftsmen, technicians, engineers, and mechanics in transferring foreign technologies.[82] Rosenberg has argued that the role of practitioners is key because not all technical knowledge can be codified or learnt from the technical literature.[83] However, the dependence on silk specialists for transmission of new technologies also had its drawbacks. The EEIC relied on the specialists for technical and commercial changes and even for adapting the system to the social environment in Bengal. However, it could not expect the silk specialists to reform the institutional framework of filature production. The adaptations that the specialists suggested had a technical character; the Company did not employ any personnel with managerial skills to adapt the institutional framework to the conditions of Bengal. In this way the adaptations significantly differed from the economic adaptations of the reeling system in Japan a century later when managerial rather than technical rationales were invoked in changing the system of production.[84] As a consequence, the EEIC faced problems with the implementation of these adaptations. For instance, the silk it obtained quite often did not answer the system of thickness of A, B and C as the thread sent to London was often finer or coarser than what was demanded.[85]

Institutional Adaptations in Bengal Silk Production

Institutional adaptations also belong to the final phase of adaptations and are key for efficient organisation of production. Besides the system of organisation of labour, it is frequently also necessary to innovate the systems of contracts with suppliers and systems of marketing. In the case of Bengal silk production, institutional adaptations were neglected by the EEIC. The Company did not innovate the system of management of its servants involved in silk reeling in Bengal and it was unable to put in place a system of contracts with peasants rearing silkworms that would secure it a supply of high quality cocoons. This had serious effects on the quality of reeled silk.

Gautam Bhadra and Sabyasachi Bhattacharya mentioned resistance of local actors – peasants, intermediary merchants, and reelers – to the filature system as the most significant obstacle for achieving the demanded quality and quantity of silk. They found that the Residents – senior English officer – and superintendents of filatures often complained of difficulties with contracting reelers and the fact that reelers did not stay in the Company's employment for long periods of time.[86] Pykars – intermediary merchants procuring cocoons for the Company – often paid peasants very low prices for their cocoons and sold them to the Company for significantly higher prices.[87] Peasants thus preferred to reel their cocoons and sell raw silk on the local market rather than to sell them to the EEIC.[88] In some rearing seasons, especially when the harvest was smaller, the Company had problems to procure the demanded quantity of cocoons. However, the want of cocoons was never as serious as to halt Company's production altogether. The above grievances were legitimated and had to negatively affect the filature production, however the quality of the filature silk suffered principally due to the management practices of the Company's own employees. Moreover, the EEIC even suffered losses due to mismanagement.

Several papers studied the internal management of early modern trading companies such as the EEIC, Royal African Society, Hudson Bay Company and Russian Company and the ways in which the Companies dealt with opportunism of its employees.[89] This literature found private trade to be the major source of opportunism of employees of trading Companies. The only exception was the EEIC as Santhi Hejeebu found that access to private trade motivated the Company's employees to fulfil orders from London as private trade was their major source of income and they would lose access to it upon dismissal.[90] Rachel E. Kranton and Annand V. Swamy focused on the EEIC's management of its contractual relations with producers. They found that in the procurement of cotton textiles the Company was unable to overcome opportunism on the part of its contractors and employees involved in enforcement of contracts with weavers due to geographical distance and poor management. Since weaving villages were far from the Company's factories the EEIC needed to rely on intermediaries in textile procurement. The Company was unable to strike balance between the power it gave to its employees and intermediaries whose role was to enforce contracts with weavers. In the early eighteenth century the weavers were oppressed by intermediaries. In the late eighteenth century too much power shifted to weavers with the outcome that they often did not fulfil their contracts and took advance from the EEIC but sold their production locally. The authors argued that vertical integration would have been too expensive as weavers were scattered on large area, moreover, it would bring new agency problems.[91] The Company's silk venture proved this conclusion to be right as vertical integration did not curb opportunism. Moreover, in the case of filature silk production the EEIC had to deal with opportunism of both its employees and the intermediary merchants and peasants from whom it procured cocoons.

The example of the Agency System implemented by the EEIC and later the British Crown in opium production shows that innovations in the systems of management could mitigate opportunism. The Opium Agency secured the EEIC a monopoly on cultivation and sale of opium. According to Kranton and Swamy the key reason why Opium Agency mitigated opportunism was its market power and the fact that the EEIC built an institutional framework that enabled it to control its agents. The monitoring system consisted of two Opium Agencies, 27 sub-agencies each linked to three to four sub-divisional offices. Moreover, the officials in the agencies went through special training.[92]

In the case of silk production in Bengal the Court in London focused solely on implementing the technical aspects of the Piedmontese technologies and paid little attention to the system of quality enforcement and management of its employees. This negatively affected both the quality of cocoons and quality of reeling.

The seventeenth- and eighteenth-century Piedmontese superiority in the production of raw silk was underpinned not only by technical innovations but also by important institutional changes in production. Such changes – Claudio Zanier notes – 'also reverberated back to the agricultural phase in compelling producers to raise cocoon quality'.[93] The case of nineteenth-century Japan also point to the importance of adapting sericultural practices. The development and technological upgrading of sericulture aided the success of Japan in becoming a major exporter of raw silk.[94] The EEIC, on the other hand, made no serious attempt to alter sericulture in Bengal. It must be said that the silk specialists sent to Bengal by the Company pointed to the fact that sericulture was no less problematic than the practices of silk reeling. Thus, by neglecting to address these issues and by focusing solely on silk reeling, the Company undermined its attempts to improve the quality of Bengal raw silk.

The quality of reeled silk is determined by the quality of cocoons and by the quality of reeling. The quality of cocoons depends on the practices of sericulture and on their storing and handling. In contrast to silk reeling, the EEIC did not attempt to adapt the practices of sericulture. The highest management bodies of the Company – Court of Directors in London and Board of Trade in Bengal – were aware that it would be very expensive to directly supervise silk worms rearing and mulberry cultivation because these activities were labour intensive and scattered over the expanse of Bengal. The Company had to rely instead on intermediaries and face the problems with the quality of the procured cocoons. The Company would have to innovate its contractual and management practices if it wanted to further increase the quality of the silk thread. Under the contemporary system of contracts the Company did not have the means to compel peasants to implement practices that would increase the quality of cocoons and deliver cocoons of demanded quality.

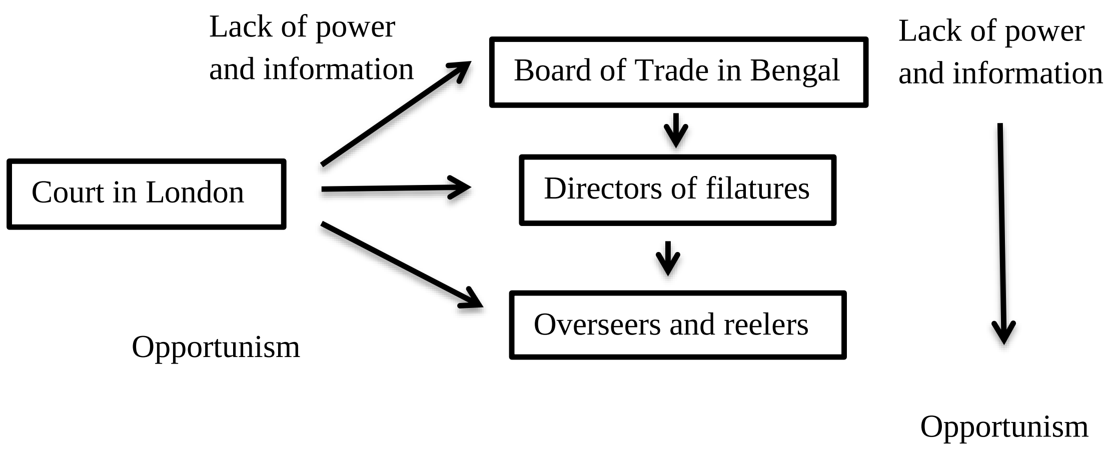
Due to the lack of control over peasants – peasants could sell their cocoons on the local markets – the EEIC could impose no practical measures of quality improvement. Rearing silkworms under the Company's direct control would have been very expensive. Altering the system of sericulture would be exceedingly difficult.[95] Rearing silkworms remained a household activity at least until the late nineteenth century in all silk producing regions of the world. Coercing whole families to become involved in sericulture under the EEIC's management and control would require more political power than the Company had.[96] Moreover, direct supervision of the rearing activities would be very expensive. Giovanni Federico has argued that the principal reasons for sericulture to remain a household activity were its labour intensity and the high costs of supervision that centralization of sericultural production would elicit.[97]

In Japan the problems with the quality of cocoons were solved through innovations in the system of contracts rather than through vertical integration. Japanese silk reeling factories secured supply of adequate quantity and quality of cocoons by implementing sub-contractual direct purchase system. The system established long-term exchange between reelers and peasants. Under this system reeling factories provided peasants with scientifically bred silkworm eggs and technical guidance and gained monitoring capacity. Peasants secured a long-term contract for their output.[98]

In the Bengal case, innovating solely the system of contracting for cocoons would not achieve the desired effect on quality, unless the Company also managed to control its servants better and prompted them to pay attention to the quality of production. The second problem the EEIC faced was the decline in the quality of the cocoons due to inappropriate handling by the Company's employees. Only by implementing changes to the institutional framework of production the EEIC could incentivise its Bengal employees to pay attention to the storing of cocoons which would have significantly improved the final quality of silk thread. As one of the European silk specialists employed by the EEIC contended, attaining perfect cocoons was central to improving the quality of raw silk since 'notwithstanding the ability of workmen perfect silk cannot be reeled from bad cocoons'.[99] Many issues with the quality of cocoons could have been avoided if the cocoons were stored in better conditions, however, the Company was unable to enforce such practice.

The lack of improvement of the quality of the cocoons represented an impediment to the improvement of the quality of the silk thread. Opportunistic behaviour and lack of attention to quality was common in cocoons handling and silk reeling. The key issue was that the geographical distance did not allow the Court of Directors to fully benefit from hierarchical organization of filature reeling. Whereas in Piedmont the merchant-entrepreneurs strengthened their control over the process of reeling, the Court had to delegate its control to the Board of Trade in Bengal which had to delegate the control further due the distance among the filatures (figure 1). The outcome was lack of control over the reelers and the Company's employees involved in silk production. None of the actors involved in silk production – Board of Trade, directors of filatures and reelers – were rewarded for producing high-quality silk and it was exceedingly difficult to punish them as it was almost impossible to ascertain direct responsibility for faults in quality and because the Company's employees working in silk production changed frequently.[100] Thus, it should not be surprising that cocoons were often handled and stored in inappropriate way which led to their fermentation.

Figure 1. System of hierarchy in filature silk production in Bengal, 1770s-1810s



The Court showed concern over the way cocoons were being stored. Inappropriate modes of storing cocoons were known to have a negative impact on the quantity of silk reeled from cocoons, on the colour of the silk, and consequently on the Company's profits:

> Supposing a quantity of Cocoons, this taken care of produce lb 1000 of good Silk; the same quantity, and of the same kind, not carefully placed, not frequently turned, will probably not produce 950 lb., perhaps not near so much, of inferior Silk, indifferent in quality, and defective in colour; for Cocoons neglected will grow mouldy, and from this will originate all the evils above specified respecting Silk spun from damaged Cocoons. It will not be in the power of the Spinners to prevent Silk made from such Cocoons from being discoloured; the Contractors will get nothing by it; and the Company will loose the profit, which they would otherwise gain, upon Silk made from good Cocoons.[101]

In order to prevent these problems the Court ordered that all 'bad' cocoons were to be separated from the good ones upon arrival at the filatures. The Court sent to Bengal a very detailed explanation of the necessity to rigorously implement such a step: 'every Cocoon that is bruised, or in which the Worm has been squashed, will spot as many good Cocoons as come in contact with it; and all such Cocoons will grow mouldy, foul the water in the Pan exceedingly; and infallibly cause the Silk to be of bad Colour'.[102] Unfortunately, these rules were often not complied with which had negative consequences for the quality of silk thread. British silk manufacturers frequently complained about the colour of the silk and the difficulties to dye such silk.[103] Moreover, reeling mouldy cocoons had a negative effect also on the strength of the silk thread as mouldy cocoons had their gummy substance – which makes silk thread strong and flexible – weakened. Also the use of unclean water in reeling weakened the flexibility of the thread. Consequently, Bengal silk threads frequently broke, especially during throwing into silk yarn in British mills.[104]

In filature reeling inadequate system of monitoring of employees led to opportunism and lack of commitment to the goal of producing high-quality silk. First, many of the superintendents of the filatures lacked sufficient knowledge of silk production and/or paid little attention to quality control. One of the consequences was that good quality silk was mixed with deficient quality silk in one bale. This had negative effect on the prices of the raw silk, especially as good silk was placed on the top of the bale and inferior was inside it, since buyers had no way to ascertain the quality of the silk within the bale, the demand dwindled. This was, for instance, the case of a filature directed by Mr Burges that sent to Britain good quality silk reeled over coarse silk. The Company believed that this was due to Burges being deceived by reelers as he lacked sufficient knowledge of reeling, yet in spite of this finding the EEIC made to no attempt to formally educate its employees in the principles of silk manufacturing.[105] The Court ordered that its employees involved in silk trade should 'improve themselves in the knowledge' and sent guidelines on the 'best practices' of silk production but took no further step.[106]

Second, due to the geographical distance the Court in London was dependent on the

Board of Trade in Bengal and the Residents for information considering both quality and purchasing prices of cocoons and raw silk. Not having a mechanism to check this information made the Company vulnerable to opportunistic behaviour. Asymmetry of information between the Board of Trade in Bengal and the Court in London became a major source of opportunistic behaviour in the production and procurement of filature silk, especially at times when the EEIC was procuring silk from private filatures with the aim to increase exports to Britain. For example, during the period 1774-86 the Board of Trade was buying silk from private filatures for prices significantly higher than costs of production and its members were making profit at the expense of the EEIC (table 1).

Table 1. Contract prices of silk from private filatures, 1774-1784 (in Sicca Rupees/Seer)

Year	Country-wound silk (in Rupees)	Filature silk	Costs of production of filature silk in EEIC's filatures
1774	9 to 10	14	
1775	8.5 to 10.9	12.5 to 13.5	
1776	8.5 to 10.9	-	
1777	8.5 to 10.5	10.5 to 13.5	
1778	8 to 10.5	11.4 to 12 or 13	6 Rupees 3 Annas 5 Pice
1779	8	11.6 to 12	(or 6.2 Rupees or 13s. 5d.)
1780	8.4 to 11.1	11.6 to 12	
1781	8.8 to 11.1	11.6 to 12	
1782	7.8	8.8	
1783	7.8	8.8	
1784	7.8	8.8	

Sources: IOR/E/4/630, 12 April 1786, p. 389; TNA C 12/175/27, 24 March 1789 to 11 November 1789. The costs of production of filature silk in the Company's filatures, stated in the third column, were not cited for any specific year and should be considered as an average for the period.

All figures in the first two columns are in Rupees. Under the eighteenth-century monetary system in Bengal 16 Annas were equivalent to 1 Rupee and 12 Pice were equivalent to 1 Anna.

It took the Court in London several years to uncover this practice. The reasons why the Company was unable to detect this fraud sooner was the time-lag in communication and the lack of access to precise information.[107] In 1783 the Court demanded information about the breakdown of the costs of filature silk production but did not receive such information from the Board.[108] A year later, in 1784 the Court turned to James Frushard – at the time the owner of a private silk filature in Bengal – for information about the breakdown of the costs of production.[109] The information the Court received confirmed that the price the Company was paying for filature silk was exorbitant. As table 1 shows, the prices for which the Company bought raw silk from private filatures (the EEIC bought both country-wound and filature silk) was considerably higher than the cost of reeling silk in the Company's filatures.

A significant difference between the Japanese and Bengal case of transfer of reeling technologies was the lack of changes in Bengalese sericulture and lack of institutional adaptations. When adapting the Piedmontese system of reeling to the Bengal environment, the EEIC paid special attention to the technical adaptations of the reeling technology and to commercial adaptations. In contrast, the EEIC's attempts to adapt sericulture never got beyond the stage of experimentation. The EEIC did not develop a system of contracting for cocoons that would secure it a sufficient supply of good quality cocoons as the Japanese filatures managed. Most importantly, the Company did not develop a system to monitor its employees and enforce contracts. This negatively affected the venture into silk manufacturing, especially as quality control is essential for producing uniform quality raw silk.

Conclusion

The case presented here shows that technical, commercial and economic, social, and institutional adaptations all play an important role for economic success of technology transfers. The technical adaptations play key role because without them the new technology cannot be used in the new environment. Social adaptations are necessary, especially for attracting workforce as foreign technologies often do not adhere to social norms. Economic and commercial adaptations guarantee the production of goods answering the specific demand of markets. Finally, institutional adaptations are indispensable to make organisation of production efficient. The Bengal case shows that the institutional adaptations might be the most difficult to adopt, especially if adaptations are designed by specialists who rely solely on technical knowledge.

Overall the adaptations of the Piedmontese technology were far from minimal, especially in the case of the technical adaptations necessary to make the technology reliable in Bengal. The EEIC was not oblivious to the need to adapt the Piedmontese reeling technologies to the Bengal context. However, the innovations the Company implemented addressed only the most pressing issues. First, in order to make the Piedmontese technology suitable to the climatic conditions of Bengal, technical alterations were put in place. For this reason brass wheels were substituted for wooden ones and reels started to be made partly of iron. Second, besides technical innovations the Court focused on commercial adaptations such as the regulation of the thickness of the thread and setting-up of a new standard of thickness. Third, the Company attempted to innovate the way in which cocoons were stored. Last, the EEIC was swift in adapting to the gender-division of labour in silk reeling in Bengal.

The alterations to the Piedmontese technology cannot be considered as thorough as the ones implemented in the Japanese silk reeling and cotton spinning industry in the following century. The fact that the Company did not alter the system of organization of production or did not innovate the system of quality control derived from the technical input of the silk specialists. The engagement of silk specialists had its obvious advantages as they built on their very detailed knowledge of silk reeling and were thus able to propose suitable alterations. On the other hand, the knowledge of these specialists did not stretch beyond the technical aspects of silk reeling. This is the key difference between the transfers of European technologies to Bengal and to Japan. In Japan thanks to entrepreneurial capacities adaptations were more far-reaching. Business strategies of such companies as Osaka Spinning Company and the Mitsui Trading Company in cotton spinning provided entrepreneurial vision for the whole sector and decreased the costs of business decision through better access to information about technologies and far-away markets. The EEIC was unable to attain a position of entrepreneurial leadership due to the inefficient system of sharing information between London and Bengal and vice versa and inefficient system of managing its employees in Bengal.

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Notes

[1] Rosenberg, "Economic Development and the Transfer of Technology", 550-75; Hilaire-Pèrez and Verna, "Dissemination of Technological Knowledge". 535-59; Mansfield, "International Technology Transfer", 372-76.

[2] Mansfield has pointed to the fact that in order for a technology to achieve economic success in a new environment, "it is very important that a proper mating occurs between the technological considerations, on the one hand, and the more purely economic considerations, on the other". Mansfield, „International Technology Transfer", 373.

[3] Bhattacharya, "Cultural and Social Constraints", 243-246; Ray, "Silk Industry", 349 -73.

[4] See for instance: Hayami and Rutan, "Factor Prices and Technical Change in Agricultural Development",1135-136; Broadberry and Gupta, 'Lancashire, India', pp. 282-302.

[5] Sericulture consists of mulberry cultivation and silkworm rearing.

[6] Goldsmiths' Library [G.L.], 1796 fol. 16654, *Considerations,* 21; Goldsmiths' Library [G.L.], 1795 fol. 16280, *Reports of the Committee of Warehouses,* 13; Chaudhuri, *The Trading World of Asia,* 346.

[7] Silk reeling is the process of making silk thread from silk cocoons.

[8] IOR/E/4/625, 9 April 1777, 219.

[9] IOR/E/1/65 ff. 440-441v: “Letter 270 James Wiss in London to the Court Recommending, 20 December 1779”, 440-41; Goldsmiths’ Library [G.L.], 1795 fol. 16280, *Reports of the Committee of Warehouses,* 1; IOR/E/1/61 ff. 486-487v: “Letter 240 James Wiss in London to the Court, 18 November 1777”, 487.

[10] Bhadra, ‘Role of Pykars”, 17-18, 34-35; Bhadra, “Silk Filature”, 75-77, 82.

[11] Ray, “Silk Industry”, 349.

[12] Ibid., 371-373.

[13] Bhattacharya, “Cultural and Social Constraints”, 243-246.

[14] Davini, “Bengali Raw Silk”, 62.

[15] Davini, “History of Bengali Raw Silk”, 9-10.

[16] There is wealth of studies focusing on the transfer of technologies to the USA explaining the success or failure of these transfers by differences in factor endowments. Other studies look at the role of the changes in output markets. See for instance: Jeremy, “British Textile Technology and Transmission to the United States”, 46-52; Temin, “A New Look at Hunter’s Hypothesis about the Antebellum Iron Industry, 345-51; Coleman, “An Innovation and Its Diffusion: The ‘New Draperies’”, 420-29; Hayami and Rutan, “Factor Prices and Technical Change in Agricultural Development”,1135-136.

[17] Considering factor prices in Bengal silk industry, these were favourable for adoption of the Piedmontese silk technologies. The returns on investment into silk filatures were positive and the investment was profitable. Moreover, the study of transfer of dairy technology from Sweden to Uruguay shows that technology can adapt to the local factor endowment. After being adopted in Uruguay the technology became more labour intensive than it was in Sweden. Sterner and Tansini, “Transfer and Adaptation of Technology”,116-19.

[18] Brown, “Cakes and Oil: Technology Transfer and Chinese Soybean Processing”, 449-50.

[19] Rosenberg mentions that technologies need to be adapted not only to economic but also to environmental conditions – to climate, geography and geology. Rosenberg, “Economic Development”, 571-73. See also: Mansfield, “International Technology Transfer”, 373.

[20] Mansfield, “International Technology Transfer”, 373.

[21] Mansfield and Wagner, “Organizational and Strategic Factors Associated with Probabilities of Success in Industrial R&D”, 187. Edwin Mansfield is among the pioneers of the study of technology transfer and diffusion of innovations. Teece, “Technology and Technology Transfer: Mansfieldian Inspirations”, 17-33. Writing with various co-authors, Mansfield focused on several aspects of technology transfers, especially on the firm level.

See for instance: Mansfield and Romeo, “Technology Transfer to Overseas Subsidiaries by U.S.-Based Firms”, 737-50; Mansfield, “Intellectual Property Protection, Direct Investment, and Technology Transfer”; Id., “The Speed and Cost of Industrial Innovation in Japan and the United States”, 1157-68.

[22] Mansfield and Wagner, “Organizational and Strategic Factors”, 188.

[23] Evenson, “International Diffusion of Agrarian Technology”, 51.

[24] Rosenberg, “Economic Development”, 569.

[25] Evenson, “International Diffusion”, 55.

[26] Mansfield, “International Technology Transfer”, 373.

[27] Rosenberg, “Economic Development”, 552-54.

[28] This shows that even if a technology is not necessarily labelled as a ‘macro-invention’, it cannot be successfully adopted without large-scale alterations.

[29] Mokyr, *Lever of Riches,* 10.

[30] Joel Mokyr defines macro-inventions as ‘inventions in which a radical new idea, without clear precedent emerges more or less ab nihilo’. The distinction between macro- and micro-inventions was first made by Mokyr. He defined micro-inventions as ‘small, incremental steps that improve, adapt, and streamline existing techniques already in use, reducing energy and raw material requirements’. Such a definition of micro-inventions fits well the definition of changes that accompanied successful technology transfers. Mokyr argued that micro-inventions occur more frequently than macro-inventions and that they account for most of the gains in productivity. Moreover, macro-inventions are not feasible without micro-inventions. Although Mokyr did not dispute the vital contribution of the key ‘macro-inventions’ of the industrial revolution such as Arkwright’s water-frame, or in the instance of steam engine, he decisively shifted the attention to micro-inventions. What he emphasized was the fact that it took time for these macro-inventions to find wide usage and that adaptations were often indispensable. Mokyr, *Lever of Riches*, 13.

[31] Rosenberg, “Economic Development”, 552-73.

[32] Hilaire-Perèz and Verna, “Dissemination of Technological Knowledge”, 535-59. His research focused particularly on the whaling and lime industries. Pearson, “Technology of Whaling in Australian Waters”, 40-54; Pearson, “Lime Industry in Australia”, 28-35.

[33] Warwick Pearson argues that in colonial context ‘sociocultural values of tradition will quickly give way to those of innovation, and even long-established traditional technologies will not survive transfer’. Pearson, “Water Power in a Dry Continent”, 58-59.

[34] The gender division of labour in Japan was not dissimilar to Western industrial economies. Yet, adaptations were necessary if the new technologies were to comply with Japanese social norms. Hunter, "Technology Transfer and the Gendering of Communications Work", 1, 5 and 9-18.

[35] Brown, "Cakes and Oil", 454-61 and 463.

[36] For silk industry, see: Ma, "Why Japan, Not China", 369-94; Kiyokawa, "Transplantation of the European Factory System and Adaptations in Japan", 27-39.

[37] See for instance: Cordeiro, "Technology Transfer in Portugal's Late Eighteenth Century", 177-88; Endrei, "Italian Contribution to the Development of Sericulture in Hungary", 301-13; Chicco, *La Seta in Piemonte,* 247-94.

[38] Transfer of Piedmontese technologies is briefly mentioned by Chicco, *La Seta in Piemonte*, 288-94.

[39] Piedmontese silk reeling technologies were very advanced in terms of organisation and technology – they relied on centralisation, factory discipline and advanced machinery – the system of production relied on constant innovations of both technology and organisation. Zanier, "Pre-Modern European Silk Technology and East Asia", 131-39;

[40] See for instance: Itoh and Tanimoto, "Rural Entrepreneurs", 61-63; Choi, "Entrepreneurial Leadership", 930-32; Kawagoe, "Technical and Institutional Innovations in Rice Marketing in Japan", 37-43, Yonekawa, "University Graduates and Large Japanese Enterprises", 193-218.

[41] Itoh and Tanimoto, "Rural Entrepreneurs", 61-63.

[42] Choi, "Entrepreneurial Leadership", 930-32.

[43] Hashino, "Institutionalising Technical Education", 25-27.

[44] Hashino and Otsuka, "Expansion and Transformation of the Export-Oriented Silk Weaving District", 24-26.

[45] Hashino and Otsuka, "Hand Looms, Power Looms and Changing Production Organizations", 801-802.

[46] Kiyokawa, "Transplantation of the European Factory System", 27-39; Furuta, "Silk-Reeling in Modern East Asia", 191-221.

[47] Kiyokawa, "Transplantation of the European Factory System", 27.

[48] It has been argued by Kiyokawa that the modern factory system and social conditions in the filature were too 'idealistic for the pre-industrial society of Japan'. Kiyokawa, "Transplantation of the European Factory System', 27-8 and 30.

[49] Ibid., 31-34.

[50] Steam was substituted for water, Ibid., 34.

[51] For instance, the government and entrepreneurs made efforts to remove prejudice against Western culture as part of their efforts to promote Western technology and create a favourable environment for the development of silk reeling. Kiyokawa, "Transplantation of the European Factory System", p. 34; Ma, "Why Japan, Not China", p. 375-76.

[52] Ma, "Why Japan, Not China", 374-6 and 383. The efforts to develop social and physical infrastructure falls in the category of „capacity building". Capacity building has been mentioned by the opponents of pure laissez-faire approach to technology development in developing countries as essential for successful technology borrowing. See, for instance: Lall, "Technology Capabilities and Industrialization", 181.

[53] Ma, "Why Japan, Not China", 374-76 and 383.

[54] Zanier, "Pre-Modern European Silk Technology", 133.

[55] IOR/E/1/63 ff. 158-160v : "Letter 70 and James Wiss in London to the Court, 28 October 1778"; IOR/E/4/625, 14 July 1779, 484-86.

[56] IOR/E/1/66 ff. 422-424v : "Letters 212-213 James Wiss in London to Peter Michell, 10 May 1780", 424; IOR/E/4/638, 30 May 1792, 624.

[57] The skein was to be 40 inches in length and 80 inches in circumference, IOR/E/1/66 ff. 422-424v, 424.

[58] IOR/E/1/63 ff. 19-20v: Letter 8 Report of James Wiss to the Committee of Correspondence, London 14 July 1778", p. 21; IOR/E/1/65 ff. 440-441v : "Letter 270 James Wiss in London to the Court, 20 Dec 1779", 441.

[59] Also buildings had to be adapted to the weather conditions. Resilient materials such as bricks and wood had to be used in the building of the filatures. Moreover, filatures had to be closed rather than semi-open because of the rainy weather. However, this created the problem of how to dispose of the fumes created by the furnaces. Davini, "Una Conquista Incerta", 230-32.

[60] IOR/E/4/625, 14 July 1779, 484-86.

[61] Ibid., 484.

[62] IOR/E/4/625, 14 July 1779, 485; IOR/E/4/626, 12 May 1780, 107.

[63] IOR/E/4/625, 14 July 1779, 486.

[64] IOR/E/4/628, 11 April 1785, 560-61.

[65] IOR/E/4/627, 12 July 1782, 350.

[66] IOR/E/4/628, 11 April 1785, 561.

[67] IOR/E/4/629, 8 July 1785, 90.

[68] Ibid.

[69] Ibid.

[70] Mansfield, "International Technology Transfer", 373.

[71] It is not clear of how many cocoons were used in the reeling of the sorts A, B and C respectively. The filatures were simply ordered to use the samples sent from London without any further specification. It can only be said that A was the finest sort of these three but it was hardly the finest sort that could possibly be made.

[72] The differentiation of silk according to fineness into sorts A, B, and C first appeared in the letters to Bengal in 1785 and rapidly became prevalent. IOR/E/4/640, 25 June 1793, 517; IOR/E/4/628, 11 April 1785, 552.

[73] IOR/E/4/645A, 27 July 1796, 340.

[74] IOR/E/4/628, 16 March 1784, 261.

[75] The coarser sorts of silk could not be spun in the rainy season as the silk would be impossible to dry the silk and it would grow mouldy. 'If it be made of 5 or 6 Cocoons, it will occasion a prodigious waste in winding off at the Mill, owing to the Bars of the Reel being too hard for so slender a thread, which cannot be loosened therefrom without breaking; and should it be made of 18 to 20 Cocoons the Silk will be black and musty, for want of time to dry it on the Reel, and occasion a Considerable difference in the price in England'. IOR/E/4/625, 9 April 1777, 201-3.

[76] IOR/E/4/628, 11 April 1785, 552.

[77] IOR/E/4/640, 25 June 1793, 517.

[78] Chicco, *La Seta in Piemonte*, 213.

[79] Only in Calabria reeling was done by men. Cinzia Capalbo, "Mercato Esterno e Tradizione di Mestiere, 73-96; Zanier, "Pre-Modern European Silk Technology and East Asia", 131; Chicco, *La Seta in Piemonte*, 212-13.

[80] Goldsmiths' Library [G.L.], 1775 fol.: Williamson, *Proposals*, 17-18.

[81] The issue of employing female reelers was never discussed by the Company. Other sources reveal that all the reelers employed by the EEIC in Bengal were men.

[82] The role of the movement of journeymen and other skilled artisans in the transfer in the transfer of technologies has been underlined, for instance, by Hilaire-Pérez and Verna. Hilaire-Perez and Verna, "Dissemination of Technological Knowledge", 544-48, 554-57 and 562. The fact that the transfer of the Piedmontese reeling technologies to Bengal was driven by the EEIC, made it more coordinated and controlled than most early-modern technology transfers. For instance, the silk specialists were employed directly by the Company rather than being given privileges. Also it was the EEIC who retained ownership of the technology,

not the specialists. For this reason, it is helpful to compare the silk specialists sent to Bengal with the skilled personnel employed in transfer of technologies in nineteenth century. For the discussion of the role of skilled individuals in diffusion of steam power in Europe and North America see: Robinson, "The Early Diffusion of Steam Power", 91-107.

[83] David J. Jeremy called practitioners 'the most efficient agent(s) of international diffusion'. Jeremy, *Transatlantic Industrial Revolution,* 162.

[84] Kiyokawa, "Transplantation of the European Factory System", 33

[85] 'We are concerned to observe, that in our last Sale there was some deficiency in this respect. There were complaints of inferiority and particularly of its being generally too coarse. In some case the Sorts, denominated A were not finer than the B should have been, and the same of the B and C. There were also some instances of frauds in package, which ought particularly to be attended to, for preserving the reputation of our Sales. What We allude to, is the making the Coating on outside a Skain of the Letter A when the inside is only B, or perhaps C. The Silk of Collinsons was faulty in this respect, as was also some from Rungpore, a specimen of which is forwarded for your inspection.' IOR/E/4/645A, 27 July 1796, 355. It should be observed that this problem with the labelling of silk continued from the period before 1770s.

[86] Bhadra, 'Role of Pykars", 25-27; Bhattacharya, "Cultural and Social Constraints", 243-244; Davini, "Una Conquista Incerta", 129-135.

[87] IOR/E/4/630, 21 July, 1786, p. 548.

[88] Davini, "Una Conquista Incerta", 47.

[89] Chaudhuri, *Trading World,* 208-213, 298-300 and 325; Hejeebu, "Contract Enforcement", 498-500; Davies, *Royal African Company*, 163-165; Wilson, *England´s Apprenticeship* 174-176; MacKay, *Honourable Company,* 66-67; Willan, *Early History*, 258-267.

[90] Hejeebu, "Contract Enforcement", 498-500.

[91] Kranton and Swamy, "Contracts, Hold-up, and Exports", 977.

[92] Ibid., 981-983.

[93] Zanier, "Pre-Modern European Silk Technology and East Asia", 139.

[94] Ma, "Why Japan, Not China", 370.

[95] LSE Archives, W7204, East India Company, *Reports and Documents,* p. xxxiv. 'That mulberry plantations can be established on account of the Company, so as in time to render the public investment in a considerable degree independent of the other sources of supply of cocoons, is not, we conceive, to be expected, considering

that, for the accomplishment of such an ends, lands to so great an extent must be cultivated, and servants so numerous must be employed, as well as buildings be erected for rearing of cocoons comprehending altogether such a field of care and superintendence, as no Resident could be competent to, in addition to the minute and constant attention requisite to the peculiar and important duty of manufacturing silk. Such a plan, even if it were found to be practicable, should, in all probability, from the greatness of the expense attending it, prove decidedly objectionable.' LSE Archives, W7204, East India Company, *Reports and Documents,* p. 63.

[96] In Bengal peasants owned their product throughout the production process which was a significant difference to the putting-out system practiced in Europe and it gave the artisans more freedom. For the Company it meant that many silk producers did not abide to the contracts. Riello, *Cotton,* 62-64; Gupta, "Competition and Control", 292-97.

[97] In many regions sericulture remained a household activity even in the twentieth century and entrepreneurs gained control over the production process by creating dependence. Ma, "Why Japan, not China", 381. Federico, *Economic History of Silk Industry,* 16. In Japan the problems with quality of cocoons were overcome under the household system of production thanks to institutional innovations. A new system of contracts called „sub-contractual long direct purchase system" emerged and institutionalised a long-term system of purchase contracts between farmers and filatures. Ma, "Why Japan, Not China", 379.

[98] Ma, "Why Japan, Not China", 379.

[99] IOR, Bombay (Misc. Public Documents, etc.)., 1793.m.17: "Letter from Giuseppe Mutti to John Bell Esquire on 20 October 1838", India Office Records and Private Papers.

[100] IOR/E/4/625, 9 April 1777, 225-26; IOR/E/4/626, 5 July 1780, 219.

[101] Ibid., 182-84.

[102]Ibid., 172-74.

[103] IOR/E/4/625, 9 April 1777, 176-84.

[104] IOR/E/4/627, 12 July 1782, 351; IOR/E/4/625, 9 April 1777, 175.

[105] IOR/E/1/66 ff. 422-424v: 'Letters 212-213', 10 May 1780, p. 422.

[106] IOR/E/4/623, 24 December 1776, p. 281.

[107] Carlos and Nicholas, "Agency Problems", 856; Hejeebu, "Contract Enforcement", 497.

[108] IOR/E/4/630, 21 July 1786, pp. 538-42.

[109] IOR/E/4/630, 12 April 1786, p. 390; IOR/E/4/630, 21 July, 1786, pp. 538-42.

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