Institutional barriers to technology adoption: the case of silk technology in colonial India*

Anirban Mukherjee†
Subhasree Sarkar‡

Abstract

This paper aims to bring out the complex nature of technological adoption in the colonial era by focusing on the British colonial power's attempt to bring in an Italian technology to Indian silk weaving industry and Indian weaver's reluctance to adopt it. In India (and also in China and Japan) silk was hand reeled making the thread uneven in quality and therefore, unsuitable for export to the European market. British realized that there was a great scope of trading if the problem of thread breakage could be solved. In order to solve the problem, in 1769 they imported a mechanized reeling technology known as filature from Italy – the then leader of the international silk market. However, this new technology was not well accepted by the Indian artisans and eventually, use of such technology was only limited to a few centers. It is noteworthy that similar technology was also tried in China and Japan in the nineteenth century and met with similar resistance in China. Japan not only successfully adopted the technology, within a hundred years they also captured the market for silk in Europe replacing Italy. Drawing on the Japanese experience, this paper focuses on the importance of micro-innovation in the successful adoption of a foreign blue print. Using a principal agent framework, we show that because of its dual status of the monopoly merchant and the political ruler, the East India Company could not credibly commit to an incentive scheme that could encourage micro-innovation.

*This is a preliminary draft

†University of Calcutta. Email: `anirban1976[at]gmail.com`
‡University of Calcutta.

1 Introduction

It is well observed in the literature that superior technologies are not always socially adopted leading to a loss in social surplus. The current project adds to the existing body of research that analyzes the factors that create barrier to the successful adoption of a superior technology. In this particular paper we look at the case of non-adoption of superior technology in the context of silk weaving industry of eighteenth century Bengal.

In the second part of the eighteenth century the East India company aimed to capture the European market for silk by importing it from Bengal. The major obstacle for out competing the Italians – the then leader in the world silk market – was the unevenness of Bengal silk. This quality issue was the result of the hand reeling method used by the Bengal weavers. The East India company tried to solve the problem by adopting the mechanized silk reeling known as the filature system. The Company, with the help of the Italian mechanics they hired and brought to India, built a few filatures across the silk producing centers of south Bengal. This endeavor however, could never yield the desired result for the Company as the Indian artisans by and large showed reluctance to use this technology. This dealt a blow to the Company's dream to take over the world silk market. Initially there was some increase in silk export from India but that was never sufficient to replace the Italians.

We locate the counterfactual of the Indian experience in the international context. In 1870, almost after a hundred years filature technology came to India, it made its way to Japan. Unlike their Indian counterpart, the Japanese artisans successfully adopted it. Not only did they adopt it, equipped with the new technology they rooted Italy out of the world silk market. The time series of the Japanese capture of the world silk market is given in table 1. (Reproduced from Federico (1997),p 31). It is noteworthy that in 1820 Italy had 65% of the export while India had 16.6%. At that time Japan was not even a significant player in the world market. A complete turn around could be seen by 1913 where Japan (41%) was way ahead of Italy (19%) and India was virtually non-existent in the market (0.7%). In this paper we compare the India and the Japanese case, and found that the key to Japanese success was their ability to come up with micro innovation on the blue print that helped them adopt the technology. We argue the lack of micro innovation in the Indian case as the reason behind the failure. We identify the institutional structure prevalent in India as the main barrier to successful micro innovation and eventual adoption of foreign technology. In India, East India company had the exclusive right to sell filature silk to Europe. Hence, the company had the opportunity to appropriate the economic rent arising from any micro-innovation. The company tried to open up the foreign market by allowing British nationals to have trade in their private account, but could not credibly commit to this policy.

The role of micro innovation in technology adoption is well discussed in the literature. An important section of the literature (Evenson and Westphal, 1995; Amsden, 1989; Odagiri and Goto, 1993; Saxonhouse and Wright, 2000; Hausmann and Rodrik, 2003; Lall, 2000) argue that technology is tacit, meaning that it cannot be easily codified into blueprints and hence cannot be easily applied. Accordingly, successful adoption of technology critically depends on several social and cultural factors which facilitate learning. In one of the country studies, Odagiri and Goto (1993)elaborated on this position using Japan's experience with steel. They showed how an "off-the-shelf" import of foreign technology so as to build a steel furnace in Japan failed to produce results until Japanese engineers were able to adapt production processes to local conditions. In similar lines, Amsden (1989) refers to the Korean shipbuilder Hyundai which could not replicate imported designs from a Scottish firm further arguing that there was more to the ship building technology than merely the blueprint. In their survey on technology transfer, Evenson and Westphal (1995) emphasizes that technical knowledge is tacit and not easily codifiable and transferable and thus domestic tinkering in the form of investments in learning is required for the technology's successful adoption. Saxonhouse and Wright (2000) observe heterogeneity in performance of countries despite access to identical technologies and states that for newly emerging industries to progress there has to be a mutual adaptation between machines and local conditions. Hausmann and Rodrik (2003) build their theory of trade protection and development on the premise that successful adoption of technology is culture specific and the blue print is not enough to learn about a technology. Therefore, entrepreneurs need to run production process to know the profitability of particular technology. Based on this premise, the authors argue in favour of optimal length of trade protection so that the entrepreneurs can experiment with the choice of appropriate technology.

Besides the general literature on technological adoption this paper is directly related to the body of works on the specific issue we intend to enquire in this paper – adoption of filature technology in Bengal. The colonial power in Bengal blamed the conservative mindset of the local artisans. Historians working on this issue rejected this view and proposed different reasons behind this failure ranging from changing production relation under new technology (Bhattacharya, 1966) to volatility of foreign demand and excessive control (Bhadra, 1991). Mukhopadhyaya (1996) on the other hand challenges the story of resistance by Indian artisans arguing that the so called reluctance to adopt filature was in fact the reluctance on part of the cocoon sellers to sell their product to the filature owners at the company determined prices. The details of these views are discussed below.

2 Historical Context

In 1765, the Dewani of Bengal was taken over by the East India Company and the Company became the sole authority on whom the power to levy taxes was vested. The Company obtained land revenue which was now financed for what came to be known as "investment" (meaning the activity of purchasing commodities such as textiles, silk, sugar, indigo, opium etc in Bengal). Thus the export of Bengal raw-silk to England increased rapidly. There was a large market for silk in Europe which was primarily captured by the Italians. In Asia, even though India was not as big as China and Japan, there was a large community of silk weavers in India who mostly supplied to the domestic consumers. In India (as also in China and Japan) silk was hand reeled making the thread uneven in width and quality Brown (1979); Bhadra (1991). The primary faults in Bengal raw-silk which was this unevenness and breakage. The Company thought that by introducing the Italian method of reeling and spinning in Bengal, popularly came to be known as filature, which allowed the production of raw silk of higher and more standardized quality and forcing artisans to work in the Company's filatures, which enabled better control of their work, it would solve all the problems that Bengali raw silk had met in Europe. British realized that there was a great scope of trading if the problem of thread breakage could be solved. The turn of events in mid-eigtheenth century gave them the opportunity. In order to solve the problem, in the eighteenth century they imported the Italian innovation of mechanized reeling known as filature. In 1769, the court of directors decided to introduce modern filature and send a team of Italian mechanics comprising J.Ruggeiro,Domenicus Poggio, C.F. Bricola and Augustus Della Casa to Rungpore for setting up filature and training Indian artisans Bhattacharya (1966). However, this new technology was not well accepted by the Indian artisans and eventually, use of such technology was only limited to a few centres. It is noteworthy that similar technology was also tried in China and Japan in the next century (i.e. nineteenth) and met with similar resistance in China. Only Japan successfully adopted the technology and by early twentieth century captured the market for silk in Europe which was earlier dominated by the Italians Federico (1997).

Although the court of directors introduced the modern filature machine in India in 1769, it took about fifty years for the Company to convert the whole of its achievements in silk into filature assortment (Mukhopadhyaya, 1996). Despite the technological superiority of the Italian technology, the artisans from Bengal by and large rejected it. Also, the upgrading process desired by the Company met with only partial success, for Bengali raw silk reeled with the new method never reached the highest standards of the Piedmontese raw silks (Davini, 2009). Thus there was a chasm between this blueprint of filature technology and the actual adoption of it in eighteenth century India. The East India company finally gave up on their attempts to produce and export filature silk to Europe in the mid nineteenth century when they sold their filature factories by auction to private sellers. The most productive Commercolly filature was bought by famous nineteenth century Bengali entrepreneur Dwarakanath Tagore(Ray, 2011).

3 The reasons behind failure – the existing explanations

The British observers such as the Governor General and his council and the Bengal Board of Trade held the culture of the artisans responsible for this. They held the view that the artisans's lack of openness towards new technology was mainly responsible for this rejection. However, historians, writing in the twentieth century largely discredited this colonial view.This colonial stereotype, which had been the predominant tone of many British writers, was later challenged by contemporary historians. In one of the early work on this issue,Bhattacharya (1966) discussed the case of resistance against new technology in silk industry along with two more cases viz. cotton spinning and smelting, where also adoption of European technology failed. In all these cases indigenous artisan community resisted the adoption of productivity enhancing foreign technologies. Bhattacharya (1966) however did not buy the colonial argument of technological conservativeness of Indian artisans . He instead conjectured that the new system would change the production relation hurting the vertical integration of cocoon production and silk weaving by the *chassars* (producers of cocoons). In his view the chassars could not afford to buy filatures and therefore with filatures entering the market, a new group of wholesale buyers (pykars) emerged who would mediate between filature owners and cocoon producers. This shifted the control from the hand of small producers to big players. This prompted the resistance on part of the *chassars*.

Bhadra (1991) on the other hand argues that unlike Bengal wound silk, filature wound silk did not have market within India. Hence, the producers of filature silk had to depend on demand coming from Europe which was very uncertain in nature. This was problematic because growing mullberry plants and rearing cocoons required time and investment which could sink in the recession periods. Hence market fluctuation is one of the major cause behind the reluctance of the chassars to supply to filature owners. Hence, there are three possible hypotheses explaining the reluctance of the artisans in adopting new technology: the colonial hypothesis citing cultural conservatism of the Indians, Bhattacharya's hypothesis of changing production relation and Bhadra's hypothesis emphasizing the role of uncertainly in international demand. The only article I came across that challenges the story of resistance by Indian artisans is by Mukhopadhyaya Mukhopadhyaya (1996). His position is that the reluctance to sell cocoons to filature owners should not be equated with reluctance to adopt filatures. He goes on showing that the low price of cocoons offered by the filature owners (rather than any cultural factor) was responsible for the reluctance on part of the cocoon owners to sell cocoons to the filature owners. In face of such resistance British officers required laws to force the chassars to sell their cocoons. Mukhopadhyay argues that to cover up the failure to procure cocoons the resident officers came up with the story of cultural resistance. But even if he rejects the hypotheses put forward by Bhattacharya and Bhadra, he could not deny that there were some forces which were restricting spread of filatures. His argument essentially says that there was some economic rent arising from the use of filatures. The contest to capture this rent restricted the growth of filatures. In some cases, such competition got reflected in the demand for higher prices of cocoons and higher wage, while in some other cases it got reflected in the attempts by the existing filature owners to restrict the number of filatures. The example of the second rent seeking mechanism was evident in the letter written by the resident of Bauleah (quoted in Mukhopadhyaya (1996))

> ...I would humbly suggest...the expediency of preventing more filatures being erected within certain limit of your factory by prohibiting the zamindars from granting land for that purpose.

Mukhia (1985) tried to explain this issue in terms of productivity and price differentials between the two labour process, that of the country-wound method (Putney) of reeling and spinning silk from cocoons and the filature method. Filature method required more labour and cocoon per unit of output than the indigeneous variety. To compensate for the higher input requirement the price of filature silk was higher, however according to Mukhia, this price differential was not high enough to compensate the productivity differential. Therefore he concluded that the chassars and merchants were better off by winding Putney, thus creating a resistance against filature silk. A contrary view is portrayed by Bhadra(1991) who points out factors completely different from that pointed out by Bhattacharya and Mukhia. According to Bhadra, the demand for filature silk was mostly from England as a substitute for the silk supplied from Italy, since filature wound silk didn't have market within India. However market in England was unknown to the artisans in Bengal and demand was erratic for filature silk from England and prone to competition from Italian silk. Also the demand for filature silk by the company was unstable as was observed during the American war of Independence. This uncertainty in demand was hindering growth of this technology due to two factors. Firstly, growing mulberry plants, for feeding the silk worms, and rearing of cocoons needed an investment and secondly, a sudden fall in demand for filature silk eat up the profits accruing from the supply of filature in the boom period. Thus while Bhattacharya and Mukhia looked into the supply-side factors responsible for slow diffusion of the filature technology, Bhadra observed the demand-side factors responsible for this.

However these conjectures were refuted by a more recent contribution by Mukhopadhyaya (1996). According to him, the price figures which Mukhia had cited to compute the price differential between the country wound and filature silk were contract prices, and that no inference could be made on the basis of those figures regarding the relative unprofitability of filature silk. Instead of being less profitable than Putney, European contractors made huge profits from selling filature silk to the Company. Also according to him the chassars who were to supply the cocoons to the Company's filatures would have been interested in the price which they had received for their cocoons, and the relative unprofitability of the filature silk in comparison to Putney was utterly irrelevant to them. On these terms, he hypothesised that the procurement price of cocoons (price at which pykars bought cocoons from the chassars so as to sell them to the filature owners) was possibly responsible for the resistance on the part of the chassars. This procurement price of cocoons was too low to encourage chassars to sell their cocoons. In fact according to Mukhopadhyay no silk was available to the Company except through debt bondage and coercion. In debt-bondage pykars forced arbitrary advances on the chassars and snatched away cocoons. The debt-bondage system by conferring upon the Company officials the legal right to prosecute the defaulting artisan in a court of law made it a punishable offence if the artisans were not able to deliver the goods in time. The Company's government passed the Regulation 31 of 1793 which led to achievement of the investment target of the Company for the first time. In addition the author recognised that the culprit behind the resistance to filature technology was not the bigoted chassar but the Company itself which restricted the spread of filatures since that would have increased the demand for cocoons and thus raising their prices. His argument essentially says that there was some economic rent arising from the use of filatures which restricted the dissemination of the filatures. (Davini, 2009) observes that the main economic reason for the peasants' resistance to selling their cocoons to the Company's filatures was simply the fact that, by producing putney and selling it to the agents of Asian and European merchants, they could obtain a higher price. This was because of the inability of the Company to restrict raw silk trade of the chassars with the private European and Asian merchants. The Company also had to face resistance from zamindars and talukdars, the local landed elites and collectors of the revenue. From the zamindar's point of view, the lowering of rents on lands that were traditionally rated by the state higher than lands cultivated with other crops and the protection that the state promised to peasants resulted in loss of both their economic profits and social control of their territory. This represented a good reason for the landed elites to favour the trade of Asian and private European merchants, in contrast to trade in products of the Company's filatures.

4 The story of success: Japan

The filature technology moved to China and Japan in the nineteenth century after meeting with rejection in India. A significant section of the literature in history discusses the development in China and Japan. Brown (1979) by examining the case of the Ewo filature, the first Western-style silk-reeling factory established in China, illustrated the manner in which technological, economic, and cultural elements intermingled to determine success in the transfer of technology. In particular, it underlines the importance of the social costs of adoption due to the displacement of existing techniques, values, and institutions. Since the filature was located in the port of Shanghai, where Western political and economic institutions shaped the environment, the venture's success was primarily determined by market forces which were favourable. However in activities such as the purchasing and drying of cocoons, the filature was forced to operate outside the treaty ports, where Chinese political and economic institutions were dominant, raising the price of cocoons to cause the filature to fail.

The western filature technology arrived in Japan during the mid nineteenth century through two different channels – the French technology was introduced by the Tomioka silk filature and the Italian technology was brought in by a domain-run factory in Maebashi and the Tsukiji Silk Filature owned by the Ono group. There was significant size difference among these factories – Tomioka plant equipped with 300 basins was much bigger than the Maebashi Silk Filature (12 reeling basins) and Tsukiji Silk Filature (60 basins) [p 29](Nakamura and Molteni, 1994). The diffusion of the foreign technology was rapid in the late nineteenth century Japan followed by a huge rise in the export of silk eventually capturing the market from Italy [p 36](Federico, 1997). The gradual increase in the market share of Japanese table is summerized in table (1)

Xu (2011) observed that while steam reeled raw silk (modern variety) played a leading role in China's industrialization from 1880-1930, estimates suggested that more than half of all raw silk production in China continued to be hand-reeled (indigenous variety) . Traditionally reeled silk persisted in China as the result of the combination of two key factors. At an initial stage, steam reeling was not superior to hand reeling at all levels. Modern, mechanized silk-reeling was particularly advantageous due to its superior uniformity and quality in the end product and not in any significant increases in productivity. Moreover, traditionally reeled silk had a greater demand from China's domestic market and a few peripheral markets where it was more suitable both in price and application. Ma (2005) on similar lines analysed the differential patterns of evolution in Chinese and Japanese silk reeling industries by linking it with patterns of technological borrowing and economy wide transaction costs. It shows that while Japan grew the fastest in the export of raw silk, the Guangdong region of China also expanded rapidly in the exports of machine-reeled silk, however the Lower Yangzi of China lagged behind in machine-reeling production in the latter half of the 19th century. This article argues that, to reap the full benefits of a growing foreign demand, both the economies had to overcome severe technological and organizational obstacles, which posed both barriers to learning and led to high transaction costs, negatively impacting the markets for capital, labour and other inputs. Thus, the contrasting performance in the two countries' silk exports was directly associated to the differential rates of decline in barriers to learning and transaction costs, which in turn were intimately linked with the diversified political and economic changes between these two countries in the late 19th and early 20th century.

The eventual success of Japan did not look very smooth in the early days of the introduction of the new technology which faced some early resistance. Despite these early stumbles, there was a sharp rise in the number of steam filatures established from the end of 1870s. But more than this quantitative change, what we find particularly impressive about the micro-innovation done by the Japanese artisans. This experience is consistent with the general literature on technology adoption which suggests that micro-innovations play an important role in technology adoption. We find that the Japanese silk weavers introduced some very important changes in the standard European blueprint of filature. In the first phase of technology adoption around 1870, Tomioka filature did the reeling in two stages which was done in one stage in Europe. But innovations were not restricted to big factories – smaller companies contributed significantly in the process of micro-innovation and the resulting adoption. Sometimes small companies were forced to come up innovations because of their capital constraint. Small enterprises such as Rokkusha filature which started its operation in 1874 took the Tomioka filature model but simplified the equipments considerably to cut on the set up cost. The most important innovation came out this period was done by Nakayamasha company in the early twentieth century. This is a company set up by nine small silk artisans led by Takei Dajiro. They blended both the French and Italian technology to come up with a proto type known as Suwa method .The Suwa method was characterized by some important points of departure from the Western blue print. Such differences could be spotted in different aspects of the production process –material used for the factory building, power source, shape of reeling basin, twisting devices etc [p 33-34](Nakamura and Molteni, 1994).

But even the Japanese artisans were not free from cultural resistance towards new technology. Tanaka Banuske – a technical trainee - was sent to France to learn sericulture in the late nineteenth century. He came back with devices for adding threads in four spooled reeling machines and did experiments for improvements and succeeded to some extent. But to his dismay he found that no one is ready to accept the new technology. He recalled (quoted from [p 35](Nakamura and Molteni, 1994))

> ...In 1889 I obtained a patent and then tried to spread its use in the industry. [However], at that time silk reelers were mostly satisfied with two-spool reeling machines and they did not like three or four-spool reeling machines. Thus they were extremely cold toward the new device...

In spite of this initial early aversion to new technology, I argue that Japan could overcome the resistance through proper incentive mechanism which a commercial concern such as East India Company could not commit to. Before looking into the archival data let us build a simple model for structuring our thoughts.

5 Model

5.1 Basic Principal Agent Model

The model is modeled after a basic, full information principal agent model. However, the commodity X may turn out to be of bad quality with a positive probability. If it's a good quality it is sold in the world market at price p. The model presented here assumes full information. This will be extended further for incomplete information.

The technology arrives in the form of blue print. If an agent blindly follows the blue print the probability of producing good quality is low and given by $\underline{\mu}$. Hence, if the agent follows the blueprint his effort is fully observable and hence, the blue print outcome is fully contractible. If the blue print is followed the principal gets

$$\pi_B = p\underline{\mu} - \kappa - w \tag{1}$$

where κ is the cost of production and transportation borne by the principal. Under the blur print solution The agent on the other hand gets

$$y_B = w - \eta \tag{2}$$

where w represents the wage payed to the agent and η represents the cost of exerting the contracted effort. However, the blueprint can improve if the agent does micro innovation. Micro innovation requires effort from the employees which cannot be directly observed by the principal. This effort is costly for the agent and therefore, he does not have any incentive to put high effort under the fixed wage contract. If the micro innovation takes place the probability of producing good quality goes up so that the following relation holds

$$\mu = \underline{\mu} + g(e) \tag{3}$$

The principal can elicit high effort from the agent by signing a profit sharing contract. Under the contract in stage 1, the agent is offered a share s of the profit and then in the stage 2, the agent decides to put effort e. We solve the game using backward induction. Under the sharing contract the payoff of the agent is

$$y_I = s[p\mu - \kappa] - \eta - e \tag{4}$$

The agent chooses e to maximize equation (4). The first order condition is given by

$$sp\frac{\partial g(e)}{\partial e} - 1 = 0 \tag{5}$$

For getting a closed form solution, let us assume that $g(e) = 2\sqrt{e}$. Hence, the first order condition looks like

$$spe^{-\frac{1}{2}} = 1 \tag{6}$$

This yields

$$e^* = (sp)^2 \tag{7}$$

Given agent's solution, principal's pay-off under micro-innovation is

$$\pi_I = (1 - s)p\mu(e^*) - \kappa \tag{8}$$

This after putting equilibrium values for e^* becomes

$$\pi_I = (1 - s)p(\underline{\mu} + 2sp) - \kappa \tag{9}$$

Hence, the principal chooses $s = s^*$ such that the following condition is satisfied

$$\frac{\partial \pi_I}{\partial s} = -p(\underline{\mu} + 2sp) + p(1 - s)2p^2 = 0 \tag{10}$$

Solving this we get the optimal value for s

$$s^* = \frac{1}{2} - \frac{\mu}{4p} \tag{11}$$

Hence, principal's equilibrium pay-off under the sharing contract becomes

$$\pi_I^* = (1 - s^*)p\mu(e^*) - \kappa \tag{12}$$

This becomes

$$\pi_I^* = p(1 - (\frac{1}{2} - \frac{\underline{\mu}}{4p})) \times (\underline{\mu} + 2p(\frac{1}{2} - \frac{\underline{\mu}}{4p})) - \kappa \tag{13}$$

This will be equal to

$$\pi_I^* = p(\frac{1}{2} + \frac{\underline{\mu}}{4p})(\underline{\mu} + p - \frac{\underline{\mu}}{2}) - \kappa = (\frac{p}{2} + \frac{\underline{\mu}}{4})(\frac{\underline{\mu}}{2} + p) - \kappa \tag{14}$$

The principal's net gain from sharing contract is given by

$$\pi_I - \pi_B = (\frac{\underline{\mu}p}{4} + \frac{p^2}{2} + \frac{\underline{\mu}^2}{8} + \frac{\underline{\mu}p}{4} - \kappa) - (\underline{\mu}p - \kappa - w) \qquad (15)$$

Hence, the principal will prefer sharing contract to fixed wage contract as long as the neto benefit from signing sharing contract

$$V = \pi_I - \pi_B = \frac{p^2}{2} + \frac{\underline{\mu}^2}{8} - \frac{\underline{\mu}p}{2} - w > 0 \qquad (16)$$

This can be rewritten as

$$V = \frac{1}{2}(p - \frac{\mu}{2})^2 - w \qquad (17)$$

Let us now calculate the effect of the success probability from the blue print ($\underline{\mu}$) and price of the product (p) on the net benefit. We find

$$\frac{\partial V}{\partial p} = p - \frac{\underline{\mu}}{2} \qquad (18)$$

We find that for $p > \frac{\mu}{2}$, $\frac{\partial V}{\partial p} > 0$

$$\frac{\partial V}{\partial \underline{\mu}} = \underline{\mu} - \frac{p}{2} \qquad (19)$$

This implies that $\frac{\partial V}{\partial \underline{\mu}} < 0$ for $p > 2\underline{\mu}$. From this we get our first proposition

Proposition 5.1 *For a sufficiently high price for the final product, the net benefit from micro innovation goes up for principal with a rise in the price of the final product (p) and a fall in the quality of the blue print ($\underline{\mu}$)*

5.2 Dynamic extension

Next, we extend the model to a dynamic step up. Suppose, principal can offer a multi period contract for T periods. In response, the agent exerts the effort at period 1 and once the effort is made, the knowledge generating from micro-innovation becomes public. Let us first find the effort level of the agent under this contract. Remember the agent only puts the effort in the first period and enjoys the benefit for T periods. The pay off for the agent is $y_I^1 = s[p\mu - \kappa] - \eta - e$ in period 1. For period 2 to T he gets $s[p\mu - \kappa] - \eta$ because for the period between 2 to (T-1) he does not have to spend the effort e anymore. If his discount factor is β, agent's lifetime income is

$$Y_T = \frac{1-\beta^T}{1-\beta}[s(p\mu - \kappa) - \eta] - e \tag{20}$$

The optimal choice of e for the agent is now

$$\frac{\partial Y_T}{\partial e} = \frac{1-\beta^T}{1-\beta} spe^{-\frac{1}{2}} - 1 = 0 \tag{21}$$

This yields that

$$e^*(T) = \Big[sp\Big(\frac{1-\beta^T}{1-\beta}\Big)\Big]^2 \tag{22}$$

From this we get our next proposition

Proposition 5.2 *The effort put by the agent for micro innovation goes up with the length of the contract period.*

Hence, the principal is always better off by committing to a long term contract as that would higher effort from the agent and increase the probability of success. However, the problem is that a principal such as the East India Company which had political power could not credibly commit to a T period contract as the improvement of technology becomes a public knowledge after one period. Hence, the principal (the East India Company in our case had every incentive to renege on the contract. Therefore, the level of micro innovation under the company rule could not reach the desired level.

In the previous case, the agent puts effort for micro innovation in one period. Hence, the principal does not have any incentive to commit to the sharing contract beyond one period. Now, we look at the case, where the agent can put effort even after the first period making the principal commit to a sharing contract for more than one period. Technology in this case is more like an investment – the probability of success in period t is given by

$$\mu_t = f(\mu_{t-1}, e_t) \tag{23}$$

This formulation shows that in period t, the agent works on the existing level of technology (μ_{t-1}) and puts his effort e_t to create a new technological quality μ_t. Under this scheme, the principal no longer has any incentive to renege at the end of first period. This is because by not reneging on the contract he can elicit more effort. However, the principal also does not have the incentive to continue with the sharing arrangements if the improvement of μ shows a diminishing return to effort. Because at period t, μ_{t-1} is a public knowledge which is available for the wage contract. If the marginal contribution of effort goes down with time it is possible to find an optimal T for which the principal will honor the sharing contract. The principal will prefer sharing contract if the following condition holds true

$$(1-s)\mu_t \geq p\mu_{t-1} - w \tag{24}$$

This can be re written as

$$p(\mu_t - \mu_{t-1}) \geq sp\mu_t - w \tag{25}$$

If we assume that $\mu_t = \mu_{t-1} + \phi(e_t)$, this condition (25) becomes

$$\phi(e_t) \geq s\mu_t - \frac{w}{p} \tag{26}$$

If we plot the above relation the left hand side represents a graph decreasing in t and the right hand side is increasing in t. Hence, we can solve for optimal T at the equality.

6 Innovations and incentives

In the last section we have discussed why a principal who has the political power to renege on a contract cannot credibly commit to a contract which can encourage micro innovation. In this section we detail, using the historical data, how East India company was switching between two types of contract and how was the company's attitude towards micro innovation. Before going into the details we present a time series data on the price differential in figure (1) between the local silk (commonly referred to as the Putney silk) and filature silk to get an idea of the economic rent associated with production of the filature silk. The calculation comes from Singh (2006). This representation shows that there was a continual decline in the price margin of the filature silk. Besides the price difference, the absolute price of both the filature and country silk took a dive during end eighteenth century. The details is presented in table (2. The calculation again comes from

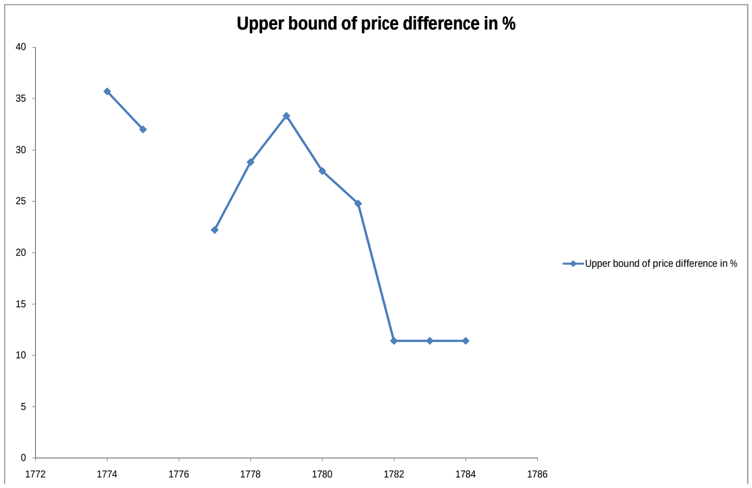

Figure 1: Upper bound of price difference between filature and country silk(%)

Singh (2006). Before analyzing the implication of such price movements for the nature of contract and subsequent micro innovation, let us elaborate on the type of contracts East India Company would offer. We can identify the production process to be a multi tier process. At the top there was the board of directors of East India company who would directly give instructions to the residents of different silk districts such as Commercolly, Bauleah, Maldah, Cossimbazar, Haripaul, Radnagore, Shantipore, Jungypore and Sonamukhi. There were supervisors and overseers in each factory who would supervise the work of the artisans. Besides the workers directly involved in the production of silk thread, there were *pykars* who would mediate between the cultivators (*chassars*) and the company.

In the first best scenario, we should look into the contract between the company and the artisans. However, we don't find any variation in the type of contracts that we find in case of the contract between English officers and the company. The East India Company had the monopoly right over silk trade. However, sometimes they would allow its officers to have trade in their private accounts. We identify this arrangement as the same as the sharing contract under which the officers would have incentive to undertake micro innovations. We find that the company suspended the trading privilege of its officers from time to time. In the next few paragraphs we trace the change in the regimes trade restriction. Any improvement in the quality of silk would generate some economic rent. The company could appropriate the rent if they had monopoly power while the rent would have been shared with the officers if they were allowed to export silk in their private account.

The filature technology was introduced in India around 1770s and in the early years the Company reserved the exclusive right of exporting Bengal silk to Europe. The Court of Directors in a letter in 1770 gave orders that all private traders and their gomostahs be prevented from interfering with the Company's purchases of silk where their investment was provided. No private trader was permitted to purchase silk of any kind or quality whatever at any aurung from where the Company's investment was supplied but that all such private traders were compelled to purchase silk from other aurungs. Ferret and three letterd Putney which were usually rejected by the Company were allowed to be purchased by the private traders. However Residents at Cassimbazar and Bauleah had stated during this time that "obstruction to private trade in silk must in the end prove detrimental to the Company's revenue which deserves at least equal attention with the investments and that the investment clashes with the collection of the revenues".the silk trade was opened for the first time 1781. (Letter by the Court of Directors)

> *The Bengal Government were directed to leave the trade free to all persons, either in the service of the Company in India, or enjoying their protection, and to permit them to export from Bengal to England any quantities of raw silk on their private account.*

It was further mentioned that,

> *The Company's buildings, filatures, and erections, used in the manufacture of raw silk were to be allowed to be*

> *rented by the private traders, and if they desired the assistance of the Italian superintendents and spinners, they might avail themselves of their services..*

However, it was also added that *"...the Company reserved the right of resuming the exclusive trade upon giving two years' notice"*. So clearly, the Company did not commit to the sharing contract for more than two years. (*p xviii-xxi, Report on Raw Silk, in Reports and Documents Connected with the proceedings of the East India Company in regard to culture and manufacture of cotton wool, raw silk and Indigo)*

The Company's resolutions for throwing open the trade could not be carried out immediately, however it was eventually done in 1783 whereby the Company's establishments constructed for the manufacture of filature silk were allowed to be rented to private traders. Also they were permitted to seek the services of Italian spinners and superintendents who were hired and brought by the Company to train the local artisans in Bengal. However at the same time the Company reserved the right of resuming its exclusive trade in Bengal raw silk upon giving two year's notice.

Open trade in Bengal raw silk did not last for long. These orders were given by the Court to the Bengal Government in 1785 under the presumption that their orders for giving up this branch to individuals had been carried into execution but it was found that the Bengal Government had adopted a mean between relinquishing the trade wholly from the company and giving it wholly to individuals by resolving to invest 15 lakhs in that article on the Company's account and permitting a participation in individuals to the like amount. The Court stated that by these orders it did not mean to establish a monopoly of the Company in the manufacture of raw silk in the Bengal provinces but merely to resume in proper time the Company's exclusive right of bringing it from Bengal to Britain and to revoke the privilege formerly given to them of sending that article to Europe on their own private account.

The Company's attempts to go back to the monopoly right of the silk trade with Europe provides evidence that the Company could not credibly commit to sharing the economic rent with the agents thereby withdrawing the incentive to do micro innovation. Company's reluctance to share economic rent with the agent can be further seen in their strategy of branding the silk. In a letter by the Court of Directors in 1779 it was directed that since the raw silk at different aurangs were represented by the names of the residents who were in charge of that aurang, the names/ marks on raw silk of same quality were frequently changed owing to the appointment of different residents in different aurangs at different points of time. Due to this frequent change of name/mark the weavers lost confidence on the raw silks produced, and in order to prevent such diffidence it was directed by the Court , that "all the silks be regularly and without variation, be marked or named in future according to the respective aurungs, or factories where they are spun".

It is easy to see that the change in the branding strategy has important implication for the economic rent. If the silk was branded in name of the residents any improvement in the silk could earn some reputation for the residents which could be translated into higher income stream. Branding the silk of the *aurangs* prevents this possibility as all the *aurang*s are owned by the East India company.

In spite of this lack of incentive schemes, we still observe some micro-innovation done by superintendents and overseers. One such superintendent Mr. Wiss is known to made some important improvement on the filature. Mr. Wiss, stationed in Commercolly made use of the brass cog wheels to spin a superior quality thread. It should be noted that Commercolly remained the best factory for the Company. However, Company's board in general had the view that conforming to the blue print imported from Italy could produce the best result. In a letter by Court of Directors to the Governor General written in 1780 it was written that

> "The reel on which the silk is wound must not form a skein longer nor shorter than 40 inches which is the same as 80 inches in circumference, in order to which, the outer edge of the four staves of the reel must be 20 inches distant from each other. The smallest size skeins that come from Italy are 36 inches in length which is the same as 72 inches in circumference and 18 inches distant from one stave to the other, which is the smallest size that can be wound off on the mills, but the size we direct is preferable on account of greater dispatch at the filature, and of drying faster."

The Company's adherence to the blue print is further revealed by a letter by Mr. Wiss (Letters to Court of Directors 1780, italics mine)

> "The Board of Trade gave their servants permission to use cog wheels made either of brass, iron or wood, *provided they should not be upon a different principle from the Piedmontize ones already in use*"

for a certain range of parameters, with fall in price, the Principal will favor the share contract over the sharing contract. In the data we find there was a fall in the price of filature silk around 1780 (Table 2). This is precisely the time when trade was made open to the private agents.

7 Revisiting the alternative hypothesis

In addition to the lack of microinnovation and the institutional structures prevalent in India responsible for the unsuccessful adoption of the filature technology we come up with other interesting facts. Supporting Bhadra's hypothesis of uncertainty in international demand for filature wound silk as the major cause behind the reluctance of the chassars to supply to filature owners we find the importations of raw silk to England have revealed quite an amount of fluctuation as we present in figure (2). The coefficient of variation of raw silk import has been calculated to be 0.497 for the period 1792-1833. Even though cotton has shown a higher amount of fluctuation, its coefficient of variation being 0.71 as compared to raw silk as we present in figure (3), we obtain less amount of variations for rice and sugar, their coefficeint of variations being 0.27 and 0.12 respectively. The price fluctuations in rice and sugar in Bengal during the above mentioned period is shown in figure(4). Also we present the price fluctuations for other commodities such as wheat, pulses, oil and butter in Chinsurah in the figure (5).Almost all the commodities other than cotton have shown less of fluctuations as compared to raw silk both in terms of quantities imported as well as in terms of prices during the period concerned. Viewing these results we are confronted with the question as to whether it was the intrinsic characteristics of raw silk that had led to fluctuations in its import to England or due to unstable demand for raw silk in England as hypothesised by Bhadra (1991).

8 Conclusion

In this paper we examine the institutional reasons for noon-adoption of a superior technology. In particular we focus on an Italian technology to India but could not get success. The technology however traveled to Japan where artisans successfully adopted it to become the world leader in the silk market. We argue that the lack of micro innovation in the Indian case was mainly responsible for the failure. We construct a theoretical model to show that contract arrangements play an important role in fostering micro-innovation and the East India Company being the ruler and business entity at a time, could not commit to a contract that could be optimal in fostering micro innovation. We support the model with archival evidence. We plan to extend this work with more archival data.

Primary Documents

- Reports and documents connected with the Proceedings of the East India Company in regard to the culture and manufacture of cotton, wool, silk and indigo in India, printed in London by the order of the East India Company(London,1836).
- Proceedings of the Controlling Committee of Commerce, Committee of Circuit, Board of Revenue (Miscellaneous), Board of Trade (Custom Commercial), West Bengal State Archives (WBSA), Kolkata.
- Parliamentary Papers, House of Commons, Ninth Parliamentary Report of the Select Committee,1783, Digest of the Evidence taken before the House of Commons? Report on the East India Affairs, 1830 and Select Committee on the Affairs of the East India Company (1831-?32),National Library.
- Fort William-Indian House Correspondence and other contemporary papers relating thereto, National Archives of India, Government of India.

References

Amsden, A. (1989). Asias next giant: South korea and late industrialization (oxford and new york: Oxford university press).

Bhadra, G. (1991). Silk filature and silk production: Technological development in the early colonial context 1768-1833. In Kumar, D., editor, *Science and Empire: Essays in Indian context, 1700-1947*. Anamika Prakashan.

Bhattacharya, S. (1966). cultural and social constraint on technological innovations and economic development: some case studies. *Indian Economic Social History Review*, 3(240):240–267.

Brown, S. (1979). The ewo filature: A study in the transfer of technology to china in the 19th century. *Technology and Culture*, 20(3):550–568.

Davini, R. (2009). Bengali raw silk, the east india company and the european global market, 1770–1833. *Journal of global history*, 4(01):57–79.

Evenson, R. E. and Westphal, L. (1995). Technological change and technological strategy. *Handbook of development economics*, 3(1):2209–99.

Federico, G. (1997). *An Economic History of the Silk Industry, 1830-1930*, page 37. first edition.

Hausmann, R. and Rodrik, D. (2003). Economic development as self-discovery. *Journal of development Economics*, 72(2):603–633.

Lall, S. (2000). Technological change and industrialization in the asian newly industrializing economies: achievements and challenges. *Technology, learning, & innovation: Experiences of newly industrializing economies*, pages 13–68.

Ma, D. (2005). Between cottage and factory: The evolution of chinese and japanese silk-reeling industries in the latter half of the nineteenth century. *Journal of The Asia Pacific Economy*, 10(2):195–213.

Mukhia, H. (1985). Social resistance to superior technology: the filature in eighteenth-century bengal. *Indian Historical Review*, 9:54–64.

Mukhopadhyaya, B. (1996). Orientalism, geneology and the writing of history: the idea of resistance to silk filature in eighteenth century bengal. *Studies in History*, 11(2):189–226.

Nakamura, M. and Molteni, C. (1994). Silk reeling technology and female labour. In Nakamura, M., editor, *Technology Change and Female Labour in Japan*. United Nations University Press.

Odagiri, H. and Goto, A. (1993). The japanese system of innovation: Past. *Present and Future'in Nelson*, pages 76–114.

Ray, I. (2011). *Bengal Industries and the British Industrial Revolution (1757-1857)*. Routledge.

Saxonhouse, G. R. and Wright, G. (2000). Technological evolution in cotton spinning, 1878–1933.

Singh, A. K. (2006). *Modern World System and Indian Proto-Industrialization: Bengal 1650-1800*, volume 1, page 191. Northern Book Centre, first edition.

Xu, Y. (2011). Industrialization and the chinese hand-reeled silk industry (1880-1930). *Penn History Review*, 19(1):26–46.

Table 1: Share of Total Export of Silk 1820-1913

	Italy	China	Japan	India
1820-24	65.7	11.9		16.6
1848-50	55.8	20.1		12.5
1859-61	26.5	50.6	6.7	8.6
1864-66	21.4	39.7	13.9	12.5
1873-75	30.9	53.1	8.3	3.7
1905-1907	32.8	33.9	27	1.5
1911-13	19.2	35.4	41.5	0.7

Table 2: Price difference between country and filature silk

Year	Country silk	Filature silk	% Difference
	(Rs-as-ps per seer)		
1774	9 to 10	14	35.71-28.57
1775	8-8-10-15	12-8 to 13-8	32-25.18
1776	8-8 to 10-10	NA	na
1777	8-8 to 10-8	10-8 to 13-8	19.04-22.22
1778	8 to 10-8	11-6 to 12	28.82-12.5
1779	8	11-10 to 12	31.15-33.33
1780	8-6 to 11-2	11-10 to 12	27.96
1781	8-12 to 11-2	11-10 to 12	24.78
1782	7-12	8-12	11.42
1783	7-12	8-12	11.42
1784	7-12	8-12	11.42

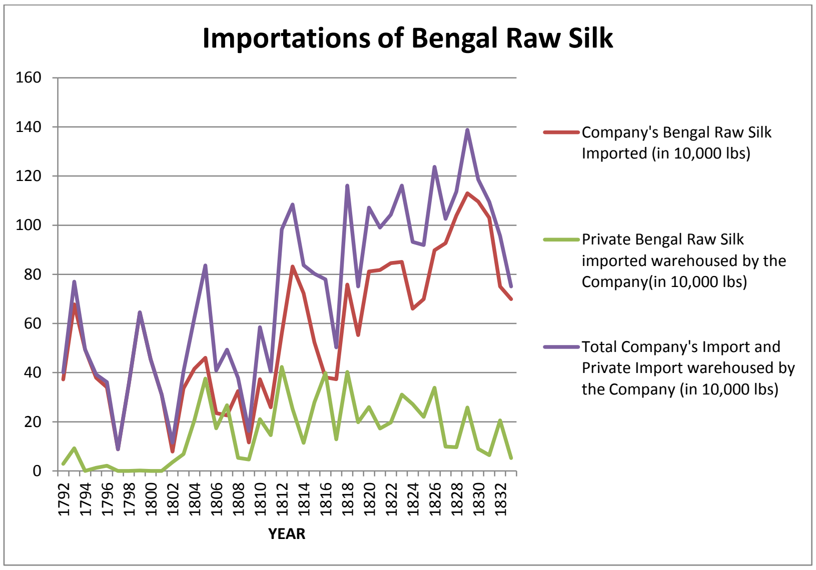

Figure 2: Importations of Bengal Raw Silk

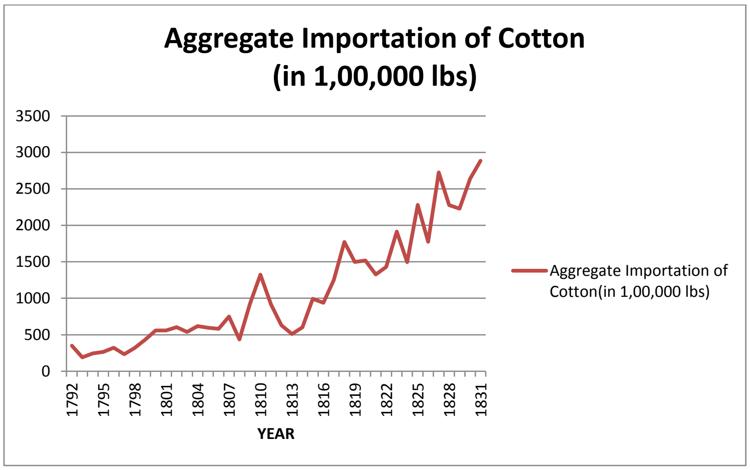

Figure 3: Aggregate Importation of Cotton

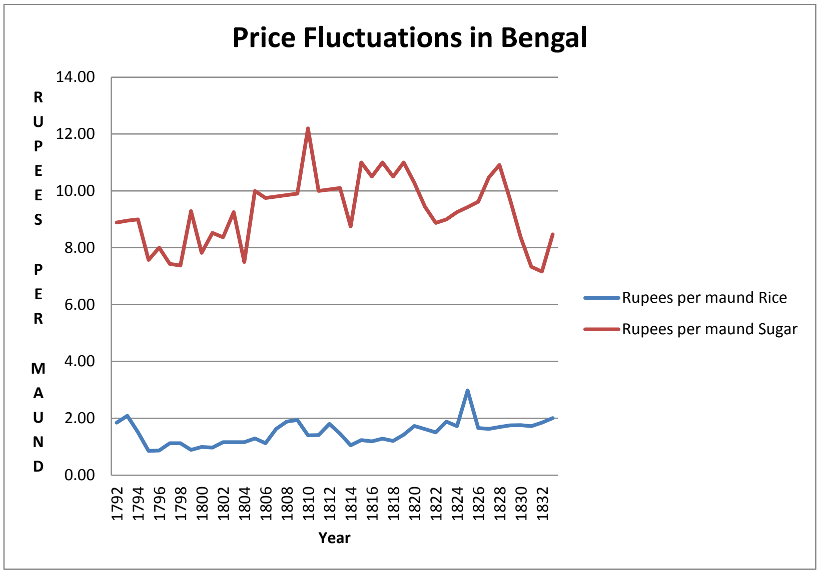

Figure 4: Price Fluctuations in Bengal

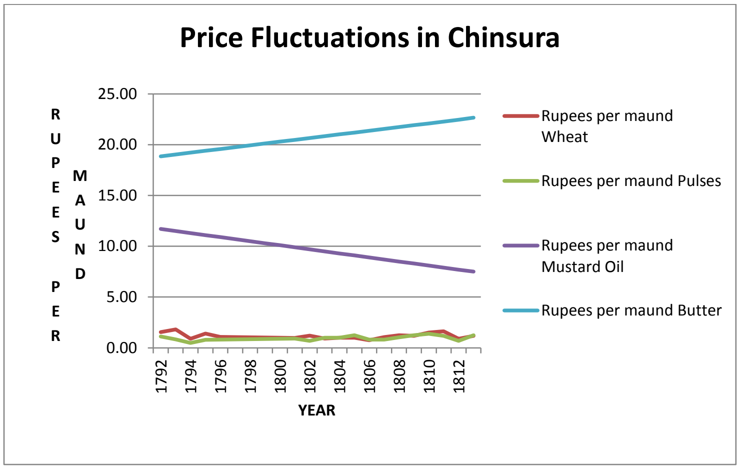

Figure 5: Price Fluctuations in Chinsurah