AN EMPIRE LOST: SPANISH INDUSTRY AND THE EFFECT OF COLONIAL MARKETS AND TRADE ON INNOVATION

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Job Market Paper

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Abstract. This paper studies how changes in access to international markets affect the direction of technical change. I use two historical trade shocks that transformed markets for the Spanish textile industry at the end of the 19th century, along with newly digitized data on textile patents and production in Spain. First, after Spain effectively forced its colonies to buy manufactured cotton goods in 1891, I document an increase in cotton textile innovation relative to other fabrics. Second, after the Spanish-American war and the unexpected loss of these captive markets, I find that innovation in cotton textiles changed towards new weaving patents relative to other parts of the cotton textile production process such as threading. After 1898, cotton industrialists entered and competed in international markets where more sophisticated fabrics were in demand. Using novel archive data from a big cotton firm, I provide price and quantity-based evidence of the strength of each type of technical change. Finally, I show that these new incentives to innovation translated directly into adopting new mechanized tools in the sector. I find evidence of an expansion in industrial technology due to an increase in mechanized cotton looms used in Spain after 1900. Together, these results provide some of the first causal evidence on how international trade shapes the direction of the technical change. Although each shock meant access to new markets for Spanish cotton textiles, their effect on innovation varied because the composition of textile demand was different.

JEL Codes: F15, F63, L16, N73, O24, O32

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"***Opening a new and inexhaustible market*** to all the commodities in Europe, it gave occasion to new division of labour and ***improvements of art***, which, in the narrow circle of the ancient commerce, could never have taken place for want of a market to take off the greater part of their product" - Adam Smith (1776), *An Inquiry into the Nature and Causes of the Wealth of Nations*

1. Introduction

The effects of international trade on growth (Smith, 1776; Marshall, 1890), relative prices, and the distribution of income have been long-standing concerns among economists. An important channel through which international trade fuels economic growth is via innovation and technological change. However, there is little research on how trade can also alter the direction of technical change by altering the demand patterns that producers face. My paper fills this gap using historical patents and newly collected price data together with large changes in international markets affecting the 19th century Spanish textile production.

International trade might not only affect the rate of technological change (see Rivera-Batiz and Romer, 1991; Grossman and Helpman, 1991) but also the type of technology that innovators choose to develop (see Acemoglu, 2002; Gancia and Zilibotti, 2009; Gancia and Bonfiglioli, 2008). In this paper, I document how access to different types of markets shapes the direction of technological progress. Previous empirical work by Hanlon (e.g. 2015) showed that shocks to inputs prices can affect the direction of technical change. Here I provide evidence that the composition of the demand in output can have similar effects. New markets affect the inventors' incentives. Out of several possibilities these agents choose the most profitable sectors to introduce new machines, and, with sector differential access to new markets, those decisions might change. To provide this evidence, I exploit two unique historical experiments that vastly transformed international trade patterns in the Spanish textile industry at the end of the 19th century during the Spanish colonial period. First, I study the extensive market integration between Spain and its colonies, and second, I analyze the American-Spanish war shock. While the former policy effectively forced the colonies to buy cotton textiles mainly from Spain, the latter incident ended with these captive

Spanish markets and led cotton producers to enter new markets with different and more sophisticated tastes. Although both shocks affected Spanish cotton textiles' access to new markets, their nature was different, and so were their implications for the adopted technology.

These two market shocks meant different incentives to inventors. In 1891, the market size for Spanish cotton goods increased when the Spanish authorities introduced an imperial protective tariff. In practice, cotton producers in Spain witnessed an increase in their benefits after the tariff system forced colonies to buy most cotton manufactured goods from them. Consequently, this market expansion implied more incentives to develop cotton augmenting technology in contrast with other sectors. However, said conditions lasted only a few years. With a significant installed production capacity and without a strong internal market, industrialists needed to find new external markets after the colonies' independence in 1898. New international consumers that Spain found mainly in Argentina tended to be more willing to pay for product quality than Spanish consumers (Markusen, 1986; Flam and Helpman, 1987; Hallak, 2006; Verhoogen, 2008), and Spain responded by raising exported fabric quality to reach those wealthier markets. Yet these more sophisticated fabrics came with a cost. They required a more effective use of weavers. Ultimately, this change in production characteristics meant higher weaving costs and a shift in innovation incentives towards the cotton-weaving production section.

I find evidence in the patent data that supports the previous points: the two trade shocks affected inventors' incentives. First, I find that the colonial trade induced innovation in technologies used to produce cotton goods along all production stages. Second, after Spain lost its colonies, I find a shift towards weaving technologies with a rise in cotton patents designed for this production stage.

Finally, using novel archive price data from a big cotton firm (*La España Industrial*), I document price changes induced by the shocks in the textile industry. This exercise helps me to illustrate the strength of each induced technological change. Following the forced colonial integration, I document a temporary rise in cotton-finished textile prices relative to textiles made with other fibers. This evidence is consistent with a strong directed technical change and substitutability between cotton and other fibers. I also show that the 1898 shock led to an increase in design-intensive cotton goods, and, in particular, I find that the prices of unfinished cotton fabrics increased relative to cotton threads in the wake of the shock. Lastly, I show how relative wages inside the cotton industry changed in the presence of this biased technology upgrading. I document a positive trend in the payments to weavers but not to spinners after 1903.

This is consistent with a weak directed technical change and complementarities between weaving and other cotton textile labor.

One caveat is necessary when interpreting these results. Spanish regulation allowed two types of patents. A patent for the invention that protected new ideas and procedures, and patents for introduction which protected ideas never implemented in the country despite being developed and used in other countries. This system was not exceptional, and many peripheral countries adopted it during the 19th century, as they sought to facilitate technological transfers (see Saíz, 2014). I use this feature to show that real innovation drives my results. They are not just copying foreign technology effects. The effects that I find hold for innovation patents as well as all patents. Therefore, I conclude that changes produced by trade structures indeed affected incentives to create new production structures and ideas.

My findings relate to the literature on directed technical change, in particular, the empirical works that document the behavior of innovation under different shock types (Popp, 2002; Hanlon, 2015; Aghion et al., 2016). I follow the previous literature, using a clean historical experiment to isolate causal effects. I take advantage of exogenous and surprising shocks generated by the increase in tariffs and the war on Spanish industry. However, my paper differentiates from the previous literature in two ways. I study two shocks on the output market. While this literature has extensively documented the effect of input shocks on innovation, the type of shocks I study has not been evaluated empirically. Even though the shocks are analyzed under the same theoretical lens, their nature and implications are not the same. Also, I analyze the industry behavior when sectors whose technology could expand are not substitutes. In this paper, contrary to all previous empirical literature, I study innovation in sectors that are complements. I show that this feature plays a big role when defining the bias of technological improvements.

Also, to my knowledge, this is the first paper showing how the presence of imperial possessions influenced technical direction. I review how Spain responded to exogenous changes in trade relations with its colonies. I draw on the extensive literature on Western European colonialism that searches for the effects of this policy on both the colonized territories and the societies that did the colonizing. In particular, I build on the previous literature that questions how the Europeans obtained benefits from their colonial empires (e.g. O'Brien and Escosura, 1998; Findlay, 1990; Butel and Crouzet, 1998). Previous literature has argued that both slave trade profits (Williams, 1944) and the expansion of colonial trade (Inikori, 2002) are two main drivers of colonial benefits. However, and despite the interest in the relation between North Atlantic trade and growth (Davis, 1973), there has been little empirical evidence of the actual impact of trade on the economic development in western societies. Following Davis and Huttenback (1982, 1986), I show that the benefits of the imperial enterprise did not distribute equally across all economic sectors. I provide formal empirical support of a channel that literature has not studied before: the effects of trade on innovation incentives. According to this literature, commerce created a unique price and wage structure that modified incentives and allowed the technological breakthroughs of the 18th century in Britain (Allen, 2009, 2011). I contribute to this literature by studying the related mechanisms and broadening the analysis beyond the British empire. I look at the effects of trade and innovation on the technological periphery. In this work, I suggest that even in the presence of an institutional environment that was far from the best (Acemoglu, Johnson, and Robinson, 2005), colonial trade was able to induce growth in some economic sectors.

These results relate to many works on trade and development that analyze the behavior of exporting firms. Although I cannot document heterogeneous effects in firms after they access new markets, I can provide evidence that supports the idea that trade affects aggregate levels of technological upgrading, particularly the adoption of technology. Using local tax data, I find an increase in the number of cotton weaving machines compared with other textile industries after Spain lost its colonial captive markets. I hypothesize that this change also derives from the demand shock that accounts for weaving innovation observed during the same period. Previous literature has documented positive effects on the adoption of new technologies as a result of trade agreements (Bustos, 2011; Lileeva and Trefler, 2010) or temporary trade protection (Juhász, 2018). I complement this literature suggesting that general trade competition also produced a change in industrial machinery. I suggest that trade induced improvements in another dimension beyond the mere product and quality upgrading as reported by anecdotal evidence. There was also an increase in the scope of the technology used to produce goods parallel to enlargements of the products varieties' set and the quality of goods.

Finally, this paper is related to quality improvements literature. It is a well-established fact that firms will produce higher-quality goods to appeal to wealthier foreign consumers. Since Verhoogen (2008) formalized the fact that quality upgrading is a firm decision to compete in global markets, a growing literature has supported this empirical fact in very different contexts. However, there is still a debate about the mechanism that explains this change. Literature has not answered if a scale effect or a quality choice motivate quality improvements in trade (Verhoogen, 2021). In this paper, I provide supporting evidence for the latter since the quality adjustment stems from a change in demand features rather than export volumes. There is a strong correlation between trade and quality production, either when looking at a direct measure of qualities (in Egypt (Atkin, Khandelwal, and Osman, 2017) or France (Crozet, Head, and Mayer, 2011)) or when drawing inferences from prices and other indirect measures (in Portugal (Bastos and Silva, 2010; Bastos, Silva, and Verhoogen, 2018), China (Manova and Yu, 2017), France (Martin, 2012), or Hungary (Görg, Halpern, and Muraközy, 2017)). Nonetheless, there is no evidence of how quality upgrading also motivates other upgrading mechanisms such as learning or specialization patterns. In this paper, I study this mechanism, arguing that the need to produce high-quality goods was the main driver of an increase in innovation.

2. Background

2.1. **Spanish cotton industry.** Cotton has been one of the most important industries in the world. Indeed, during the 18th century, European empires used cotton as a platform to create new industries, that is, it was a launching pad for the Industrial Revolution (Beckert, 2015, pp.xiv). Spain was not the exception, and the cotton textile industry was one of the few modern industries with relative success in the country. During the second part of the 19th century, it was one of the first industrialized sectors in a period characterized by industrial productivity growth following the incorporation of new ideas and technologies (Carreras, 2006). Textile industry represented 1.7%[1] of the entire country's tax value (compared with 4% of industrial values) and the cotton textile employment was around 4% of total employment (29% of total employment in the main industries)[2].

After the shock on raw input global markets produced by the American Civil War, the Spanish cotton industry displayed several distinct features. First, the sector relied completely on raw material imports[3]. Second, despite its presence in different areas, the industry was concentrated in Catalonia due to geographic advantages and historical

[1]Based on the payments of industrial taxes Nadal (1987) in 1856. This value was not bigger than any other individual industry. Comparable industries were just a half of the value.

[2]Based on the Giménez y Guited (1862)'s study of the main industries in Spain in the most relevant provinces in 1860. The whole textile employment represented more than a half of industrial employment, including wool industry (14% employment), silk industry (4.8%), and linen industry (3.5%).

[3]There was some minimal experience in raw cotton production, such as in Motril (Granada). Still, they were unable to meet the industry demand, and disappeared during the second half of the century (Martín, 2018).

changes one century before[4]. Third, most of the production was carried out in vertically integrated firms in which both spinning and weaving mills were under the control of the same firm[5]. Fourth, although the market was dominated by large firms[6], relatively to other countries in Europe, the size of the industry was small. Finally, firms used piece payment on both spinning and weaving production. Like in technological leaders such as England or the North American, those payments remained unchanged during the last part of the 19th century. When facing external shocks, firms adjusted their output, hours of work, or employment (Domenech, 2008).

Those characteristics derived directly from the internal market characteristics the industry faced. The heavily protected agricultural output sustained internal demand, and, therefore, it was small and volatile. Unable to support more prominent firms and more considerable savings through the economies of scale, the cost structure remained high in comparison to global market leaders (Nadal and Sudrià, 1993). To survive, firms followed a different strategy: protecting the internal market and capturing external markets.

2.2. **Colonial markets, tariffs and the war.** After losing all continental possessions in America during the first half of the 19th century, Spain managed, albeit with hardship, to maintain some territories such as Cuba, the Philippines, and Puerto Rico (in addition to some other small possessions in Africa and the Pacific). After the first Cuban independence war (1868-1878), there was a renewed need to formulate the relation between the metropolis and the colonies. There was a tension between the Cuban sugar entrepreneurs' need for free trade and Catalan cotton industrialists' need for colonial market protection. The solution was a in the middle. Although the textile lobbies did not achieve a high protective tariff, they reached a change in the trade policy towards the colonies[7]: the Antillean colonial markets and the metropolis started to be considered as a single market. The *Ley de Relaciones Comerciales con las Antillas* in 1882 established a gradual yearly reduction of tariffs between the colonies and Spain

[4]An agrarian crisis in Catalonia between 1770-1775 forced capital to move into the production of cotton textiles due to the increase in agricultural wages and reduction of rents. Moreover, the presence of rivers and mountains provided industrialists with a valuable power source to move mills without relying on other external sources such as coal (Nadal, 1975).

[5]According to Rosés (2009), in 1860, 60% of spinning production and 69% of weaving production came from integrated firms.

[6]Rosés (2009) estimated that in 1860 both spinning and weaving were dominant in over 60% of firms that produced more than 100 output tons per year.

[7]The tariff system did not include a protective tariff to industrial products. The system was a result of negotiation with other European powers in exchange for low tariffs to Spanish agricultural output such as wine and flour (Nadal and Sudrià, 1993).

over the course of ten years that would end with the complete elimination of trade barriers between the two territories[8]. Albeit imperfect, after this change, Spanish textiles found a market to overcome the internal market limitations.

The real protection and market capture came in 1891 with the rise of a protectionist tariff (known as *Canovas Tariff).* Although a starting point in future negations to reduce French tariffs to Spanish wine, tariffs for industrial products remained high when negotiations failed (Sabeté-Sort, 1995). In practice, there was an effective market integration with both the reduction of the barriers between the colonies and extremely high tariffs after 1891. In this system, colonies were forced to buy overpriced metropolis' products (Nadal and Sudrià, 1993)[9]. However, the benefit did not last much. In 1895 Cuban independence movement gained strength after a widespread disappointment with Spanish policies (Zanetti, 2013)[10]. This movement ended in 1898, with the loss of the colonies and therefore the loss of protected markets for Spanish cotton textiles[11].

Figure 1 shows the tariff evolution of basic textiles in Spain between 1878 and 1910. I include two of the fibers that, due to their characteristics, can fit the colonial market's necessities: cotton and linen[12]. Cotton textiles, throughout the period, had greater protection than linen textiles. Before the introduction of the protective tariff in 1891, there was a downward trend in textile tariffs[13]. However, this pattern changed when the new protective tariff system came into force. Cotton tariff doubled in the period and remained around 60% while the linen tariff increased by a half and remained around

[8]The law established a yearly 5% reduction in the original tariffs during the first three years, then a 10% decrease in the next four years, followed by a 15% in the remaining three years until 1891.

[9]This is not a distinctive feature of the Spanish colonial policy. Beckert (2015) reports several cases in which the industrial policy implied using the colonies as a captured market for textile industrial outputs. For instance, England used this strategy to displace Indian textiles from global markets during the late 17th century. Belgium observed a boost in the industry during the Great Netherlands period thanks to the access of Dutch colonial markets in the Pacific.

[10]For instance, trade policy was not reciprocal. The Spanish exported a considerable amount of products to the colonies, while the colonies' main market was not the metropolis. According to Zanetti (1998) in 1978, the United States represented 82.5% of Cuba's exports destination

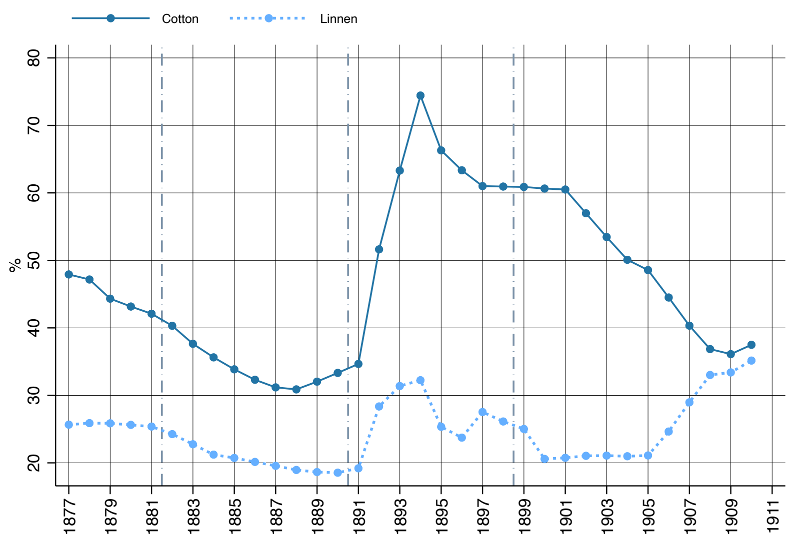
[11]Despite some proposals of autonomy (which found opposition among the textile sector), after the United States quick intervention, Spain lost its last colonial possession in America and the Pacific. See Heraclides and Dialla (2017) for a detailed explanation of the United States intervention in the Cuban and Philippine independence movement.

[12]The to the tropical location of the colonies, generated the need is for breathable summer fabrics. Other fabrics like those made of wool and silk fail to fulfill this requirement completely. For instance, in 1895, Cuba imported a minimal amount of wool and silk manufactures. In that year, Cuba received 11,796 tons of linen textiles and 4,932 tons of cotton textiles, 312 tons of wool textiles, and 19 tons of silk textiles (Dirección General de Hacienda, 1894-1895).

[13]This is in line with the literature that emphasized that the goal in this period was to protect the agricultural sector.

30%[14]. I exploit this fact in my analysis, and I use linen and other fibers as a "control" group to get a sense of the behavior of textiles without an extensive market capture.

FIGURE 1. **Textile tariffs**



Source: Dirección General de Aduanas (1876-1898, 1899-1911)
Notes: Tariff measure as the fraction of total tariff revenues on import value. Cotton tariff is measured as a weighted average on tariff on plain-woven and twilled woven fabrics either unbleached, bleached, or dyed on 2 different quality grades. After 1906 the cotton categories also include different fabric weights, and I have ten other quality groups. Linen tariff was measured as a weighted average on tariffs on plain-woven and twilled weave fabrics on three different quality grades (4 after 1906). Imports' weight in each category is used to assess the importance of each category when constructing the series. In both cases, I show the two years moving average of the raw numbers.

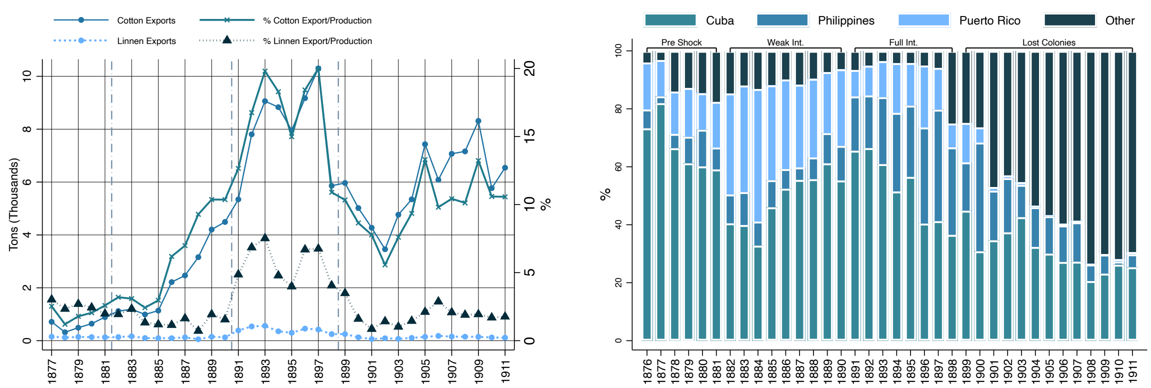
Figure 2 shows how the tariff regimen was reflected in exports' volume and destinations. Cotton production and exports were very similar to their linen counterparts prior to 1982. Cotton production and the share destined to exports started to grow similarly after the reduction in trade barriers during that year. With the protective system in 1891, the share of production destined for exports in both sectors significantly increased. For cotton, it reached a maximum of 20%, while for linen, this value was around 8%. However, the behavior of exports was different between the two types of fibers. In the case of cotton, the exports growth had a similar pattern to the share of exports. It shows an increasing capture of the colonial market with new production[15].

[14]This is even less than the cotton protection before 1891.

[15]Contrary to linen exports that did not increase in the same proportion, showing relative constant production levels and a replacement of the internal market. Even more, in 1895, according to Dirección

In terms of destination, even before 1891 (and 1882), colonial markets represented more than 90% of total exports markets (Figure 2 Panel B)[16]. This market got lost, and exports to those markets decreased dramatically. In 1898 they represented more than 90% while ten years later those values fell to around 20%[17]. This confirms my decision to use other textiles industries as control groups since they were not highly affected by the trade policies in comparison to cotton[18].

Figure 2. **Cotton textiles export**



A. Cotton textile production and exports **B.** Cotton textile destination

Source: Same as figure 1 and Ministerio de Agricultura, Pesca y Alimentación (1929-1935)
Notes: In Panel A, I estimate available raw materials' weight adding average yearly cultivation yields between 1929 and 1935 to total raw imports weights for each year. I estimate textile production based on this raw material weight following Sudrià (1983). I calculate available raw material two years average and assume a 25% weight reduction during all production stages. I show the two years moving average of the raw numbers. Panel B shows the destination market share, highlighting the share of main colonies. Figure D.2 in the appendix, Panel A shows detailed desegregation of cotton textile export destinations besides Caribbean and Pacific colonies.

2.3. **Market lost.** Colonies gained back the trade freedom they lost to the metropolis, and the Spanish industry had to compensate for this loss. According to Nadal and

General de Hacienda (1894-1895) the cotton imports in Cuba from Spain represented around 70% of the total imports weight while the linen imports from Spain amount to only 31% of the total imports' weight.

[16]The only change that the 1891 tariff reform represented was a change in internal compositions. After 1891 there was an increase in exports to the Philippines.

[17]This is contrary to linen textile markets. The market share of colonial markets returned to the previous values at around 40% (See. Panel B appendix figure D.1).

[18]Actually, figure D.1 (Panel A) shows that none of the other textiles sectors were comparable with any cotton product type when analyzing exports to colonial markets. Colonial trade of silk, wool, or linen was minimal in value, and they were far below any category of cotton textiles.

Sudrià (1993) some characteristics were the constants of the industry during the first decade of the century: the significant presence of female and child labor and the wide variety of produced fabrics. Both were the strategies to reduce costs and to gain access to new markets. First, women and children were a cheaper labor source, and, according to Smith (1991), it was a deliberate strategy across the weaving sections to reduce costs. Second, the wide range of fabrics types allowed the firms to reach a greater amount of buyers despite the cost on productivity that it represented[19].

The final strategy adopted in Spain was the increased protection of the internal market, although it came late in 1906. This tariff system extended the classification categories, which according to (Sabeté-Sort, 1995), in practice, led to a relative increase in the tariff for high-quality textiles against low-quality textiles. Figure 1 shows this pattern. After the 1898 war, cotton textile protection decreased while linen protection increased. Nonetheless, this only policy cannot explain the industry recovery that started prior to this tariff system change. This is the argument of this work; an insertion in global markets, which requires new technologies to produce new fabric types, explains the industry's recovery.

Jointly with this internal work, firms began to fight for international markets to replace the ones lost after the war. Figure 2 shows that, despite a slight reduction in exports during the first years after the war[20] this variable grew and it remained around the general values after 1891. Two facts explained this behavior. First, the search for alternative markets that resulted in good replacement market for cotton textile products in the American republics (Pane A appendix figure D.2) and other European powers (to a lesser degree). Second, the change in the quality of exported fabrics. Spain completely stopped the exports of white textiles. It increased the production and exports of more valued-added fabrics[21] like dyed, printed, double fabrics and knitted fabrics[22] (Pane B appendix figure D.2). That is, even on a small scale, Spanish industrialists looked to compete in the global market with more specialized products[23].

[19]Without specialization, large economies of scale were impossible. Moreover, the constant change in machines and techniques required a greater number of loom workers (Nadal and Sudrià, 1993).

[20]This despite the fact that the peseta's value decreased after the instability caused by the war.

[21]Appendix D.1 also showed that imports to colonial markets did not disappear completely. Export values of sophisticated fabrics remained high, at the same level observed prior to the market integration periods.

[22]In 1895, most of cotton textiles entering Cuba were low-quality textiles (around 50%). This included textiles with a low number of threads and without any additional processing.

[23]This was not a unique Spanish feature. Beckert (2015) account recorded evidence in several countries with similar experiences. For instance, the Ottoman industry took advantage of cheap input products and catered highly differentiated weaving output markets (p. 331 Beckert, 2015).

3. Theoretical Framework

When technical change is endogenous, trade and international markets affect the direction in which innovators develop new technology. Several authors have built theories of international trade and the effects on innovation (see Acemoglu, 2002; Gancia and Zilibotti, 2009; Gancia and Bonfiglioli, 2008). These are some of the critical features of the theory (see appendix section A for a complete review of the theory). The theory focuses on two sectors (they can represent cotton textiles and other fiber textiles, for instance). Intermediate goods and machines, combined, produced each one of the textiles, and both machines and intermediate goods are specific to each sector. Each sector uses raw fiber (cotton (Z) or other fibers (X)) endowments to produce intermediate goods depending on a unique sector cost structure. Ultimately, I am interested in the number of machines since they represent the available technology in each sector. A number of them (A_i for the numbers of machines in the sector i) measures each sector's innovation degree. Machine developers hold an infinite patent on machines and sell them in a monopolistic market to textile makers after producing them at a marginal cost. Developers must pay a fixed cost to enter the market and decide then in which sector to invest. Because each sector's market structure and demand for their machines affect investors' profits, those characteristics are essential to determine in which sector a new machine should be introduced. Consequently, I will analyze how each trade shock affects first the market structure and the profits innovators can make in each sector and then the incentives to expand the sector machinery.

The Spanish patent law allowed the introduction of innovations already patented in other countries. That is, it allowed the imitation of foreign ideas. Under this framework, developers must consider the overseas technology.Gancia and Bonfiglioli (2008) show that even in this case, local conditions determine the technological levels adopted in the non-technological leader country. Having this in mind, I argue that the conclusions in this section apply. First, there was no perfect replication of foreign technology in Spain. Second, even when there were no total barriers to overseas technological adoption, the Spanish markets' conditions were still affecting the decision of local innovators when they determined the type of innovation to develop.

In the case of the market integration shock, I assume that the change in innovation incentives is through the prices of intermediate goods. When Spain forced its colonies to buy cotton textiles, the prices of these manufactured goods increased after the production left the country to the colonies[24]. Since innovators were selling their machines in a monopolistic market, the increase in prices in the cotton sector also translated into an growth in the profits they can make selling the machines to this sector. This leaves the following prediction

Prediction **1.** *With fixed technology, cotton textile relative price increased after the protective tax and the market integration. Due to this rise in cotton textile relative prices, there was an increase in patented machines to process cotton (A_z) relative to the machines to process other fibers (A_x).*

The case of Spanish textiles' entrance into competitive global markets is more complicated. There are two sectors inside the cotton industry, producing intermediate goods and using two different types of labor: weavers (L) and other types of workers (H). In this case, innovators choose between introducing machines into the weaving sector (that uses weavers) or other production sectors. With the new markets' needs and tastes, weavers' costs increased. In the context of new conditions the demand, firms needed to expand their variety range, and it represented an increase in the cost to use a weaver that has to work on more sophisticated fabrics[25]. Ultimately, the shock translated into a rise in fabrics prices, and, therefore, in more incentives to innovators to develop weaving machinery. However, since weavers are costly to use, producers of these goods were now less willing to produce in this sector, or, what is the same, there was less space for innovators to develop these technologies. Two contradictory forces acted over innovation incentives producing ambiguous conclusions regarding the expected technology direction. However, these two sectors are complements in the production of a single product (cotton textiles). The willingness to produce machinery is, therefore, not a big concern. The rise in prices' positive effect on innovation incentives remained. This leaves the following prediction

Prediction **2.** *After entering a new market where tastes were different, with fixed technology, weavers got relatively scarcer and the fabrics' price increased. Since weaving and other production stages are complements, the increase in the fabric relative prices motivated innovators to introduce machines for weaving. Then, there was an increase*

[24]In terms of endowments, it meant that raw cotton relative to other fibers was scarcer in the integrated market as compared to Spain.

[25]When producing more varieties, weavers cannot specialize. Workers must use the same machine to produce several types of fabrics. This requires more time to prepare the loom, and more production stops, required to change the arrangements when producing each different fabric.

in patented machines for weaving (A_l) relative to machines needed in other sectors (A_h).

4. Data

4.1. ***Patents.*** I use patent data to analyze the central concept I want to study in this paper: innovation. The patent data I use comes from the work by Saíz et al. (2008). These authors worked directly with the original documents containing historical patent applications[26]. The source is the government office in charge of patent historical archives, Oficina Española de Patentes y Marcas (or OEPM, for its Spanish acronym). I work with all patents registered in Spain[27] in the period between 1878 and 1911[28]. I scraped the OEPM website to get access to the basic characteristics of the patents: application date[29], patent description, applicant's name, place of residence and occupation, patent duration and patent type[30] and information whether the applicant implemented patented idea.

This dataset classifies patents according to the International Patent Classification (IPC). This hierarchical classification allows me to identify to some degree the technology behind each patent. The table in appendix E.1 presents the technology classification of textile patents, showing all technological subcategories in which there was at least one application between 1878 and 1911[31]. In the main analysis, I use two patent features. The first characteristic I exploit is the ability to use the patent on the production of cotton textiles. I reviewed all registered patents and divided the patents'

[26]In some cases, these authors only worked with administrative records since some inventors used to retire more detail descriptive documents at the expiration period of their patents.

[27]I exclude from my analysis any addition made to previously registered patents.

[28]During this period, there were no significant changes in patent legislation. Actually, the Spanish patent system changed significantly in 1878. A law in this year modified the 1826 law. It introduced, among other things: a new payment system based on progressive quotas, the possibility of patents protection extended to foreign inventors that have already patented the invention overseas, and a more rigorous procedure to verify that the protected idea was implemented. Besides some complementary laws orientated to regulated specific matters, there was a new significant law in 1902. However, this law did not change significantly the previous regulation spirit, and it only modified minor issues to adjust the system according to new realities. See Saíz (1995) for a detailed history of the Spanish patent system.

[29]I follow (Hanlon, 2015) using the applications date since, as highlighted by this author, it allows me to focus on patents at the early stage of patenting and without any concern for differential speed during the granting process.

[30]That is if the patent was a patent of invention or a patent of introduction

[31]Since the classification was created in 1970, some patents do not fit in a single category or concept in the classification. I assigned the patent as a textile patent to solve this problem if one of these classifications was related to textile production. In the case of a textile patent categorized with several divisions, I assigned it to the classification of the patent's primary purpose after reading the patent's description.

categories into those machines and ideas applicable to cotton and those that are only applicable to other materials. I label a patent as cotton-related if the patent description mentions as its main purpose the process of either general fibers and fabrics or cotton and fabrics made with this fiber. A non-cotton-related patent is a patent designed for different fibers and fabrics made exclusively with those fibers. The second characteristic I exploit is the use of the patent at the weaving production stage. For that, I use three subcategories under the "Weave" IPC classification, adding the knitting subcategory[32]. In my analysis, I compare the behavior of cotton patents in these four categories against the remaining 27 categories. Therefore, I use 62 technology-material categories to compare the number of cotton-related textile patents against textile patents related to other materials besides cotton in the market integration period against the pre- and post- periods.

4.2. ***Textile wages and prices.*** I evaluate the effect of innovation on relative wages and textile prices using data I collected from a big cotton textile firm located in Barcelona: *La España Industrial*. I gathered price information from inventory ledgers. I included different industrial products such as thread, unfinished fabrics (output after being woven), as well as finished fabrics. The firm produced several different fabrics and threads, so I recorded information on several types of qualities that the firm constantly produced for a long time. I gathered the information for three types of threads: warp thread without size, warp thread with size, and weft thread. For each of these cotton thread varieties, I recorded the price for the different product qualities available in the inventories. Also, I gathered information for two types of unfinished fabrics: *molesquin* and *madras*. As in the thread case, I recorded the price for all products' qualities of these two fabric types available in the inventory. I chose these two types of fabrics since those were the only ones that the firm constantly kept on the inventories during my period of interest (1880-1910). Finally, I gathered the information for a single type of finished fabric: *percalina superior lisa*. I needed comparable information across the years, and this type of cloth offered me the longest available series since the firm kept them on the inventories between 1877 and 1907. For wages, I used information from payroll ledgers. I collected data from weekly payments in spinning and weaving mills between 1880 and 1910 for four weeks in the year (weeks 1, 14, 27 and 40)[33]. The information includes, besides the total amount of wages paid during the

[32]I included knitted fabrics since those represented a significant proportion of textile export after 1898 representing the shift towards high quality-value textiles I want to study.

[33]When the information was not available because the firm stopped production during that week, I extracted information from the closest available week that has production information.

week, the total number of workers in each section and the total number of pieces (for fabrics) or kilograms (for threads) produced. It is important to note that I do not have information on spinning mills during 1888-1890 since the firm completely stopped thread production during those dates.

4.3. ***Machines.*** I also look at the impact of innovation on mechanization and machines acquisition using data I gathered from industry and business tax reports payments (see Dirección General de Contribuciones, 1879, 1893-1894, 1895-1896, 1900-1909). I expect that the change in innovation to be reflected in shifts of mechanization patterns in different Spanish regions. Although imperfect, this is the best available measure of machines used in several textile industries. First, the reports do not entirely cover my period of interest, and sometimes they cover two years of contributions. I recovered information for the following years: 1879, 1893-94, 1895-96, and yearly from 1900 to 1909. Second, tax evasion and fraud were an extended problem in Spain during the 19th and 20th centuries. Therefore, the number of machines and taxes paid on them represent only a fraction of the real capital employed in those industries[34]. Hence, the analysis using this data is only a lower bound of the real effect, and it is valid if there were no differential changes in evasion across industries. From this source, I collect information about different machines (such as mechanical and manual looms and spindles) used in three different textile industries: cotton, wool, and linen (hemp) industry[35]. In my analysis, I compare the patterns of mechanization across 45 provinces[36] between different fiber industries and in a different stages of production. While in 1879 most of provinces had the presence of linen and wool industries (only three did not report any machine working with these fibers), cotton machines were located in 20 provinces and most of them on the coast (see appendix figure D.3)[37]. This situation changed, and the industry grew beyond these natural borders. Many

[34]Moreno Lázaro (2015) identified an extended fraud in flour mills. He estimates, on average, revenue losses around 40% to 60%. See Comín (2018) for detailed information about this practice in Spain.

[35]I do not include information about machines used for mixed-material fabrics and stages in which it is not possible to identify the type of textile such as textile bleaching.

[36]*Provincia* is an administrative division of Spain's territory. The system had its origins in 1833, and it did not have any significant change during the analysis period. The tax payment reports did not cover some territorial regions, such as the provinces belonging to the Basque Country (Vizcaya, Álava and Guipúzcoa) and Navarra that were under a different tax system during my period of interest. Also, I do not include Canary Islands' regions since they never reported a machine on textile industries during these years.

[37]A strong international orientation of cotton textiles and lack of good communication roads help to explain this location decision close to ports.

provinces recorded the presence of cotton machinery after 1900 (only three provinces did not report the presence of cotton machines).

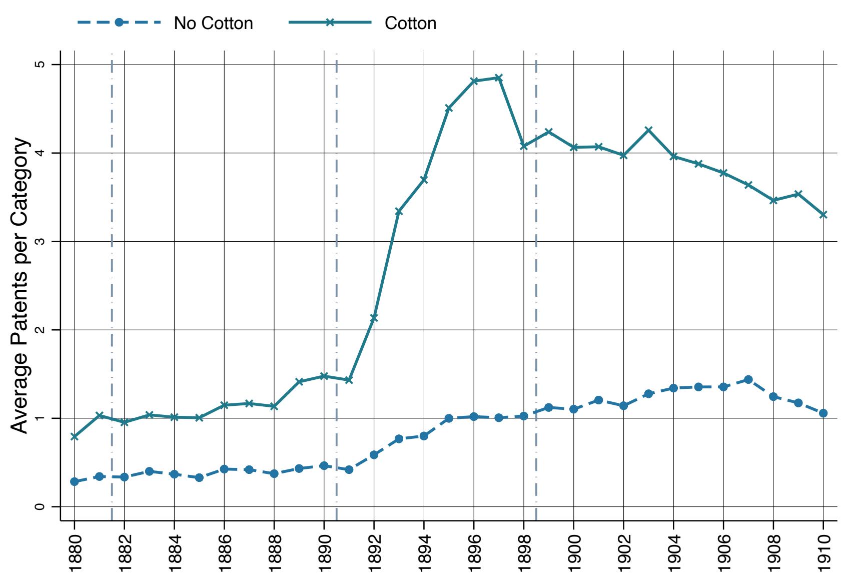
4.4. ***Other data.*** I complement this data with a large dataset on provincial demographic characteristics recovered from the 1877 census (Dirección General del Instituto Geográfico y Estadístico, 1877). I use the information on population, the number of men, the number of regular residents, the number of single and married individuals, the number of people identified as catholic, the number of illiterate people, the number of the population born in the same province, and the number of regular residents in the same municipality. The goal of this data is to control for characteristics that might affect the development of textile industries. Table E.2 in the appendix shows that the presence of the cotton industry in 1879 was not related with most of the province characteristics except with a lower proportion of the illiterate population.

5. Technical Change

5.1. ***Empirical Strategy.*** The first main idea I investigate in the empirical work is the effects of colonial-metropolis market integration on the cotton industry innovation. I exploit two variation dimensions: the existence of textile industries that colonial market integration did not affect and the timing in which the integration took place between 1891 and 1898. My strategy is then based on a *difference-in-differences* approach. I use data on patents in 31 technology categories in all textile production stages and two material categories (i.e., whether the patent is related to cotton or not).

Figure 3 shows the average number for both cotton and non-cotton-related patents per technology category in all production stages between 1878 and 1911. During this period, there were more cotton-related patents registered in Spain compared with non-cotton-related patents. Before market integration between Spain and its colonies in 1891, both patent categories had similar behaviors, and both counts did not increase significantly. However, cotton-related categories had a sharp after 1891. This increase was constant, and in 1897 the number of cotton-related patents reached a value five times higher than in the period before the market integration. After the American-Spanish war and the loss of the colonial markets, this patent count began to decrease, although it never reached previous market integration levels. This is consistent with theory predictions since it shows that there was a change towards technologies related to cotton textile production during the market integration period.

FIGURE 3. **Cotton related and no-cotton related textile patents**



Notes: This graph shows the evolution of textile patents for both cotton and non-cotton-related patents. In both cases, I show the two years moving average of the raw numbers.

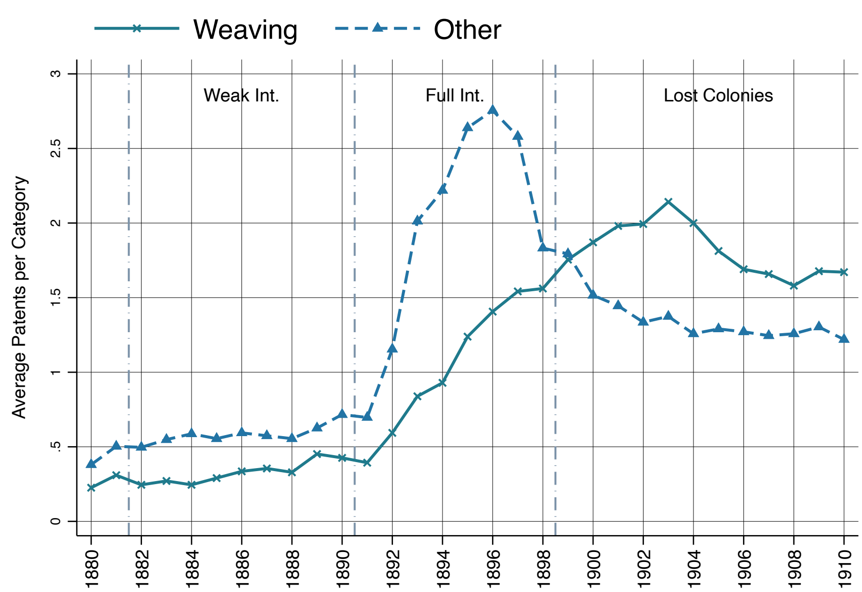
Formally, I estimated the following equation after aggregating the data into eight periods of four years each[38], where subindex j denotes technology-material category and subindex t denotes period.

$$Pat_{jt} = \sum_{k \neq [1879-82]} \beta_k (\text{Period}_k \times \text{Cotton}_j) + \alpha_t + \alpha_j + \varepsilon_{jt} \tag{5.1}$$

[38]To analyze the data formally, I have a panel of 32 years for 62 technology-material categories. However, this panel structure presentsseveral challenges when applying standard econometric methods (see Hanlon, 2015, :83 for more details on these issues). Then following this author, I use a similar aggregation strategy. With this strategy, I deal with truncation problems in some technology series that show zero patents in different years (although I am not able to eliminate all zero counts) and serial correlation errors that generate bias on the standard errors estimation (Bertrand, Duflo, and Mullainathan, 2004). Actually, according to the table in appendix E.3 panel B, there is evidence of serial correlation presence in the data that is partially solved when using this strategy. When applying a Q-stat Born and Breitung (2016) biased corrected test to a yearly model similar to equation 5.1 (column 1), I can reject the null hypothesis of no serial correlation of order 1 or 2. In contrast, I cannot reject the hypothesis using the 4-year aggregated data (column 2). However, the evidence is ambiguous. Using the LM portmanteau test for serial correlation developed by Inoue and Solon (2006) there is some evidence of serial correlation in my model. With four years of aggregated data, I can eliminate some zeros in the series yet preserve time structure that I can use to test dynamics effects.

where Pat_{jt} is the count of patents and Cotton_j is a dummy that takes the value of one for technology categories related to cotton. α_t and α_j are time and technology-material fixed effects that capture any time-invariant category characteristics and any aggregate time shock, and ε_{jt} is the error term. The key coefficients are β_k that capture the differential change between each period k[39] and the baseline period (1879-82) in the number of cotton related patents relative to the change in non-cotton related patents. The identification assumption is that the number of cotton-related patents would have behaved similarly to the number of non-cotton-related patents in the absence of market integration. I provide evidence that this assumption is plausible using the comparison with weak integration periods. I expect a zero effect since there was a gradual reduction in tariffs between the colonies and metropolis but not an effective integration because colonies were still allowed to trade with other foreign powers.

FIGURE 4. **Cotton textile patents per category by stage production**



Notes: This graph shows the evolution of cotton related textile patents for weaving and other production stages: thread, spinning and yarn treatments and textile finishing. I show the 2 years moving average of the raw numbers for each series.

The inference is an additional challenge when conducting this analysis. Due to the small number of observations and panel units, I cannot rely on standard inference approaches that use asymptotic and model assumptions. I use a randomized test to

[39]The periods are weak integration (1883-86) and (1887-90); full integration (1891-94) and (1895-98); and lost colonies (1899-1902), (1903-06) and (1907-10).

derive significant conclusions. First, I randomly take one group in each technology category pair and treat it as a cotton-related technology. Second, I randomly shuffle the periods and treat them as the period assigned. I use 20,000 different realization combinations of these randomizations and estimated placebo coefficients. Under the null distribution of no effect on cotton-related pattern and same time effect on both material categories, it does not mater how treatment and time are assigned. Any of these randomization assignments would not change the observed outcomes [40]. I construct both p-values and confidence intervals to derive conclusions. To calculate confidence intervals, I follow Garthwaite (1996) using an efficient search algorithm[41].

The second main idea I investigate is the effect of lost colonial markets and further competition in international markets on cotton industry innovation at the weaving stage. In this case, I exploit three variation dimensions: the existence of textile industries that colonial market integration did not affect, the timing in which competition in international markets started after 1899, and the presence of 4 out of 31 technology categories classified as weaving and looms. The approach is then a triple difference model in which, besides the previous comparison, I exploit in the *difference-in-differences* approach; I compare the additional effect on cotton-related textile patents at the weaving stage with other cotton-related patents at different stages.

Figure 4 shows the average number of cotton-related patents per technology category disaggregated by textile production stage between 1878 and 1911. The number of patents in each one of the production stages remained relatively unchanged before the market integration period, and the patents in all the categories started to grow after 1891. However, after the colony lost in the 1898 war, the number of patents began to decrease in all production stages except for weaving. After the loss, patents at this stage continued growing, and the numbers never dropped below the level reached during the

[40]This is a similar approach used by Hanlon (2015). However, I also randomized over the period. This allowed me to test the hypothesis that differences in the pre-shock periods do not drive the estimated effects.

[41]Randomization tests have the advantage of relying on few distributional assumptions, however finding CI is computationally costly. In theory, the calculation involves searching over a grid of possible treatment effects using randomization distributions to calculate a p-value under the null hypothesis that the treatment is equal to each value in the grid. Then the calculation involves choosing the lowest and highest value in the grid with a p-value of 0.05. Garthwaite (1996) proposed an efficient search process independently for each endpoint of the confidence interval. This procedure reduces the search dimensionality. Instead of using the whole randomization distribution for every single possible effect, the algorithm uses a single randomization in each search step. I follow the author's suggestions regarding the starting point and the length of the search.

market integration period[42]. This is again consistent with theory predictions. It shows that the effect observed during the market integration period on cotton-related patents is exclusive to this period. During the lost colonies period, competition positively affected international markets in cotton patents at the weaving stage.

I follow the same strategy as in the *difference-in-differences* model and aggregate the data in 8 periods of 4 years[43], and I estimate the following equation:

$$\begin{aligned} Pat_{jt} = &\sum_{k\neq[1879-82]} \gamma_k^1(\text{Period}_k \times \text{Cotton}_j) + \sum_{k\neq[1879-82]} \gamma_k^2(\text{Period}_k \times \text{Weave}_j) \\ &+ \sum_{k\neq[1879-82]} \gamma_k^3(\text{Period}_k \times \text{Weave}_j \times \text{Cotton}_j) + \alpha_t + \alpha_j + \varepsilon_{jt} \end{aligned} \tag{5.2}$$

Weave_j is a dummy that takes the value of one for technology categories at the weaving stage of production. In this case, the key coefficients are γ_k^1 that capture the same effect as β_k^1 in equation 5.1 and γ_k^3 that capture the differential change between period k and the baseline period in the cotton related patents at the weaving production stage in comparison with other cotton production stages. The identification assumption is that without the insertion of Spanish fabrics in international markets after the American-Spanish war, the difference between cotton patents and non-cotton patents for weaving would have behaved in a similar way to the patents at different stages[44]. I evaluate the plausibility of this assumption by looking at the coefficients for triple difference in the periods prior to 1998. I expect that without competition in the international market motivated by the loss of colonial markets, there is no effect on cotton patents used in weaving technologies. Finally, for inference, I use the same approach as in the previous model estimation. However, I add a third randomization. I randomly chose four technology groups out of the 31 technology groups and treated them as weaving technologies. Under the null distribution of no differential effect on weaving

[42]Figure D.4 shows this same disaggregation for non-cotton related patents. The behavior in these industries is different. The number of patents did not decrease after the American-Spanish war, and they remained at the same level after the colonies' independence.

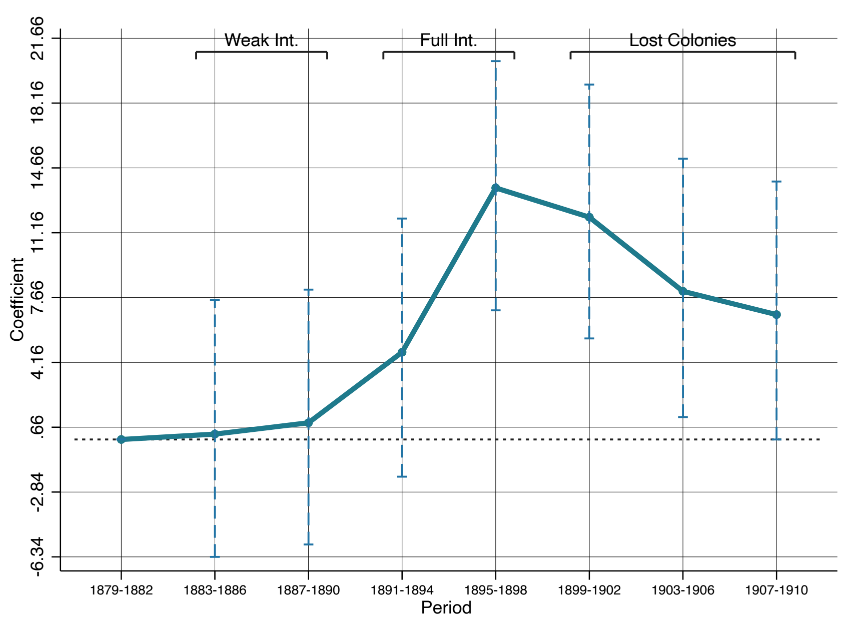
[43]Table E.4 shows that this aggregation seems to solve serial correlation found in the yearly model. When applying a Q-stat Born and Breitung (2016) biased corrected test to an annual model similar to equation 5.2 (column 1), I can reject the null hypothesis of no serial correlation of order 1 or 2. In contrast, I cannot reject at the 95% of confidence the hypothesis using the 4-year aggregated data (column 2). Using the LM portmanteau test for serial correlation developed by Inoue and Solon (2006) I achieve the same conclusion. I cannot reject at any level the hypothesis of no serial correlation.

[44]Olden and Møen (2020) formalized the identification assumption for triple differences model and showed that only one parallel trend assumption must hold to have a causal interpretation of the coefficients.

technologies, the assignation of these placebo categories is not relevant to the observed outcome.

5.2. ***Results.*** I present equation 5.1 estimation in Figure 5. The results confirm the observation in figure 3, in that there was an increase in the number of cotton patents during the market integration period in comparison with patents related to other fibers. During the period of incomplete market integration, before the protectionist tariff, point estimates move very close around zero. This result is in line with the theory where only under the complete integration there are enough incentives to change the direction of the employed technology towards more expensive cotton textiles. The results are significant at the 95% confidence after the second half of the market integration period[45]. According to these results, during the 1895-1898 period, there were on average 13.5 more cotton-related patents per technology category when compared with non-cotton-related patents. The effect begins to fade, yet it remains significant during the three periods after the American-Spanish war and the colonies' loss[46].

FIGURE 5. **Event study: Effect market integration on cotton patents**



Notes: This figure shows coefficients β_k from regression 5.1. 95% Confidence Intervals using randomized inference. I followed the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Total number of observations 496.

[45]Figure D.5 in the appendix shows the convergence path for the confidence interval estimation and the distribution of placebo coefficients for each one of the coefficients plotted in Figure 3.

[46]This pattern would evidence the path dependence on innovation (like the one theorized in Acemoglu et al. (2012)) however, in the next section, I am going to evaluate this theory against the presence of an additional effect due to the insertion of Spanish textiles in international markets.

Figure 6 shows equation 5.2 estimation. Panel A shows the difference between cotton and non-cotton-related patents. This estimated difference is similar to the one observed in the previous results. Before the full integration period, the estimated difference is very close to zero and is nonsignificant. During the market integration period, there is an increase in the number of cotton related patents, and it is significant at the 95%[47]. Actually, this point estimate is similar to the one found before. During the 1895-1898 period, there were, on average, 11 more cotton-related patents per technology category when compared with non-cotton-related patents. However, contrary to the previous results, differences after the war are not significant and are approaching zero. These results are against the theory of a strong path dependence on cotton textile innovation, at least in this setting.

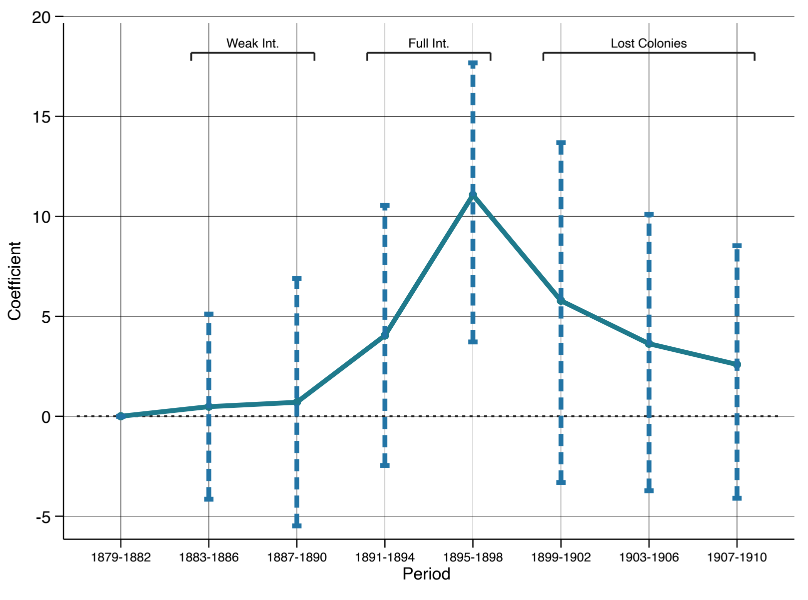
Panel B shows an additional difference in cotton-related patents between patents at weaving production and other stages. The results confirm the observation in Figure 4: The number of cotton patents designed for the weaving production stage increased after the war. Even more, there is no evidence of significant differences in cotton weaving patents prior to 1898. The coefficients are close to zero and are nonsignificant (although in period 1896-1898 the magnituede is considerable yet it is not significant). Four years after the 1898 crisis, there were, on average, 48 more patents used in the cotton weaving process. In the next period, the effect persisted around the same level (additional 33 patents), and it was significant. The protection of local markets for high-quality textiles cannot explain this behavior since the policy was introduced much later. My argument is that the insertion in international markets explains these results. With the entry into new markets, skilled weavers got scarcer, and firms needed to adopt technologies in the weaving sector.

5.3. **Robustness.** The previous results use a 4-year aggregation. However, my results are not driven by this specific estimation. I estimate a yearly panel from 1878 to 1911 of the equation 5.2 in appendix figure D.7. In this case, due to the number of years i estimate a more restrictive form including differential trends by technology category[48]. Finally due to the presence of serial correlation I a calculate Newey–West standard errors with a lag length of 3, based on Greene's rule-of-thumb lag length of $T^{1/4}$ rounded upwards. Also, because of the presence of cross-sectional dependence I

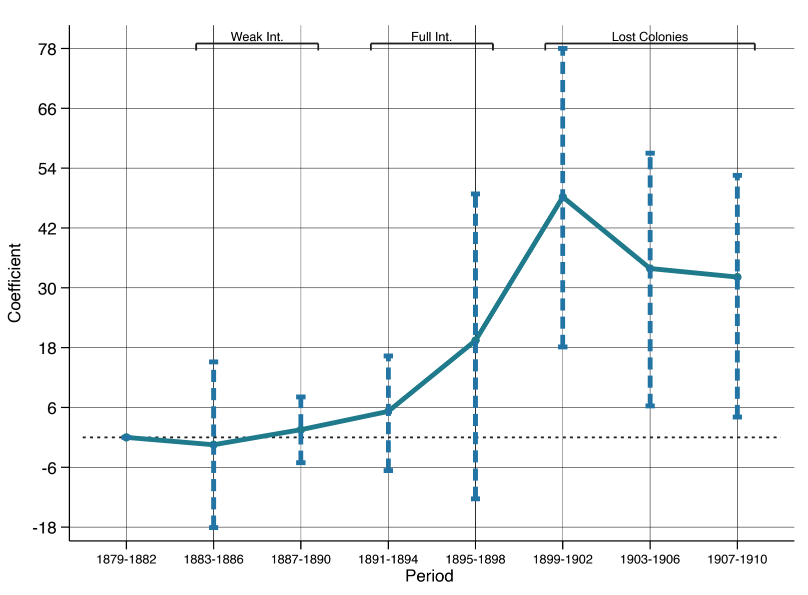
[47]See figure D.6 in the appendix for the detail of the placebo coefficients distribution and the convergence path of the confidence intervals estimation.

[48]Exactly I estimate the following equation: $Pat_{jt} = \sum_{k\neq[1881]} \gamma_k^{01}(\text{Year}_k \times \text{Cotton}_j) + \sum_{k\neq[1881]} \gamma_k^{02}(\text{Year}_k \times \text{Weave}_j) + \sum_{k\neq[1881]} \gamma_k^{03}(\text{Year}_k \times \text{Weave} \times \text{Cotton}_j) + \sum_{g\in\text{Tech}} \alpha_g \times t + \alpha_t + \alpha_j + \varepsilon_{jt}$ where $\alpha_g \times t$ are the technology group differential trends

FIGURE 6. **Event study: Effect market integration and colonies lost on cotton and weaving patents**



A. Cotton x ....



B. Cotton x Weaving x ....

Notes: This figure presents the regression results from equation 5.2. Panel A shows γ_k^1 coefficients and panel B shows γ_k^3 coefficients 95% Confidence Intervals using randomized inference. I followed the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Total number of observations 496.

include an estimation with double cluster standard errors at group and year levels[49].

Results do not change significantly. The estimated difference between cotton and non-cotton patents is very close to zero before 1891. After this period, there was a significant increase in the estimated difference until 1898, when the difference started to decrease. However, the difference remained significant during some years after the colonial markets lost. This is evidence of some small path dependence in innovation. When analyzing an additional effect on weaving patents, the estimated difference moves around to zero before 1895. After that year, the number of weaving cotton patents increased. This points to some anticipation effects, perhaps due to disruptions in Cuba with the reactivation of the independence movement. This is consistent with the historical evidence that accounts for growing concerns in Spain about the possible US intervention, and the view of a possible lost of the colonies (Heraclides and Dialla, 2017). Overall, this is reassuring on the previous analysis conclusions. First, the market integration motivated greater innovation in all cotton patents due to the change towards a price determined in the integrated market. Second, the insertion in global markets (forced by the colonial markets that have lost) motivated an increase in weaving innovation to face the relative cost of the use of weavers.

The previous results might not capture the changes that the industry faced due to the market integration between Spain and the colonies or the entrance of Spanish cotton manufacturers into the international markets. In particular, the effects captured after 1898 might be related to external forces in the international markets. First, the changes could be related to shocks on external innovating countries that tried to allocate production outside their national frontiers. To rule out this type of offshoring shock (theorized by Acemoglu, Gancia, and Zilibotti (2015)) I evaluate my results using patents registered only by Spanish residents (i.e., leaving out all patents registered by foreign residents). Spanish patent law allowed ideas protection of non-resident individuals if they plan to insert the technology in the country. Figure in appendix D.10 shows the results when I estimate equation 5.2 using the patents originated in Spanish as a dependent variable. The graphs show that any type of shock that motivated capital reallocation does not drive my main results since this new estimation does not change the conclusions I arrived at before. Second, it might be the case that my results capture the forces of new countries demanding new textiles after 1898. Indeed, during this same period, Argentina experienced an economic boom that translated into a bigger demand

[49]Table E.4 shows the presence of some cross-sectional dependence between units. Pesaran's test with a statistic of 5.3 and p-value of 0.

for industrial goods[50]. To formally rule out the possibility that Argentina's conditions explain my results, I estimate equation 5.2 controlling by Argentinian exports. I include a new set of variables that make the material-technology fixed effects interact with the total yearly import values in Argentina[51]. Appendix figure D.9 shows the results of this exercise. Again, the results' behavior is the same as that of the original results. There is a positive increase in cotton weaving innovation that is significant during all the periods after 1898. Then, I conclude that there are a few possibilities that some external shocks that occurred during the periods of the market integration or after the colonial loss are contaminating my results.

Finally, no patent quality differences are driving my results. I use two approaches to control for the differential quality of the patent application. First, the Spanish law required an inspection to corroborate that the applicant actually used the patent innovation during the first two years after the application process. Figure D.11 in the appendix shows the results when I use only the counts of these high-quality patents, that is, patents that were used in the production of new goods. During the market integration period (especially during 1895-1898), high-quality cotton patents increased compared to non-cotton patents. However, the change in high-quality patents destined for cotton weaving started before the entry to global markets during the Cuban independence war (1895-1898). The difference remained stable around the same value in the following periods: on average, nine more patents per technology category. Again, it seems that these are some of the anticipation effects. Even before the Spanish cotton fabrics entered a global market competition, there was an increase in high-quality patents directed to cotton fabric production. Second, the Spanish law allowed the introduction of innovation and ideas already used in other countries but not in Spain. Appendix figure D.10 shows the results when I exclude these types of patents, that is, using only new ideas or innovations. New patents in cotton weaving also increased after 1898, showing that the implemented innovation was not just a copy of foreign

[50]Argentina became one of the most important markets for Spanish cotton fabrics. Between 1905 and 1910 the Argentinean market represented 15% of total cotton exports far above other important markets such as France (6.9%), Turkey (4.9%), Uruguay (4.7%) and Colombia (4%). However, economic conditions in Argentina started to improve several years before the American-Spanish war. By 1895 the railroad system was already developed, and it connected several inland cities, and the imports values were high (see Fajgelbaum and Redding, 2021). That means that the Argentinean market was already available to Spanish producers by the end of the 19th century. Still, they did not actively look to enter into the new market before the loss of colonial protected markets.

[51]I estimate this new equation $Pat_{jt} = \sum_{k \neq [1879-82]} \gamma_k^1(\text{Period}_k \times \text{Cotton}_j) + \sum_{k \neq [1879-82]} \gamma_k^2(\text{Period}_k \times \text{Weave}_j) + \sum_{k \neq [1879-82]} \gamma_k^3(\text{Period}_k \times \text{Weave}_j \times \text{Cotton}_j) + \alpha_t + \alpha_j + \alpha_j \times \ln(\text{Arg Imp}_t) + \varepsilon_{jt}$, where $\ln(\text{Arg Imp}_t)$ is the natural logarithm of import values in Argentina measured in constant Argentine *peso moneda nacional* (source Dirección General de la Estadística de la Nación, 1916)

inventions. Overall, I can conclude that my main results are robust to different specifications and account for high quality improvements in cotton textiles in all production stages (between 1891 and 1898) and only in cotton fabrics after 1898.

6. Intermediate products prices

6.1. **Finished textile prices after market integration:** My argument is that the full market integration between Spain and its colonial markets affected the relation between the price of finished cotton and other fiber fabrics. This is the mechanism that explains the increase in innovation in the cotton sector. Once Spain exported its cotton manufactures production to their colonies, the price of this product increased in the internal market and then the incentives on innovators to develop new mechanisms for cotton textiles production also grew. To evaluate this hypothesis, I compare the behavior of the price of a cotton finished fabric[52] to the finished manufactures of linen and wool prices[53]. Formally I estimate the following model:

$$\ln(P^F_{jt}) = \left[\sum_{k=1889}^{1898} \gamma^F_k \times \text{Years}_k \times \text{Cotton}_j\right] + \gamma^F_{99-10} \times \text{Colonies Lost}_t \times \text{Cotton}_j + \alpha_j \times t + \alpha_t + \alpha_j + \varepsilon_{jt} \tag{6.1}$$

Where P^F_{jt} is the textile price of material j at time t. Years_k are dummy indicators for each year, and Colonies Lost_t is an indicator for the years after the Spanish-American war. Cotton_j is a dummy indicator if the material of the textile is made from cotton. I include a differential time trend in the regression since the prices of each material fabric presented different trends before the market integration. I am interested in coefficients γ^F_k that captured changes in the cotton prices relative to other textiles, while comparing the market integration years with the years before this shock[54]. I expect an increase in cotton fabric prices after the integration period. However, with the adjustment of the innovation, I expect these values to resume to pre-shock levels. Appendix figure D.12 shows some evidence of this behavior, especially when comparing with wool prices.

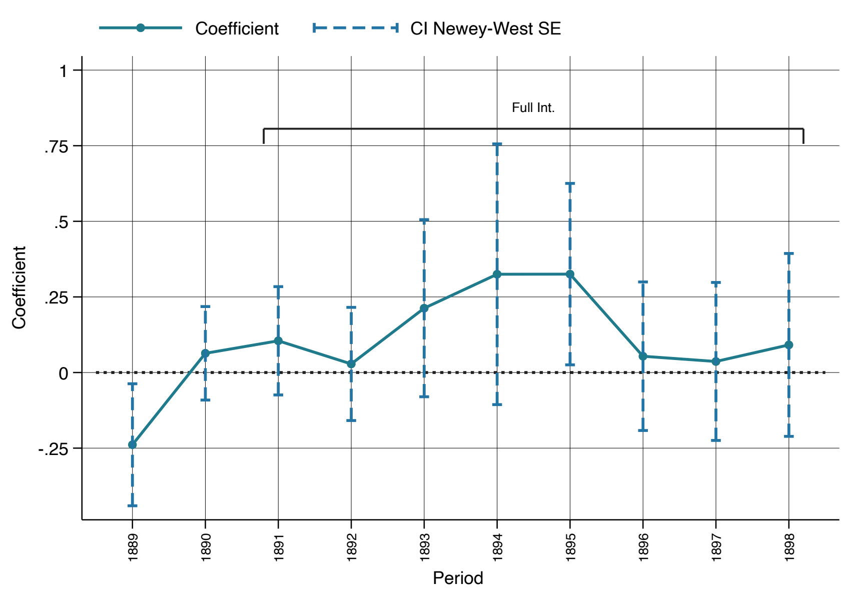
[52] I use *Percalina Lisa Superior* price. The source of this information is the inventory ledgers of *La Espanña Industrial*. This is the only fabric that the firm constantly produced between 1878 and 1907, and, therefore, when analyzing this price variety, I have fewer concerns about possible changes in textile quality.

[53] Price is the average manufactures price for imported goods from England to Spain. The data was gathered by Nadal Ferreras (1978) in pounds and converted to pesetas using historical exchange series provided by Rodney Edvinsson. All prices are measured as constant pesetas per meter.

[54] Including that the colonies lost dummy allows me to isolate the effect from the change coming to the insertion of Spain in international markets.

After 1891 both cotton and wool fabric prices decreased. However, the drop in prices is more pronounced for the wool finished textile price. Moreover, the reduction trend reverted for wool fabrics, suggesting that the price of cotton fabrics became relatively cheaper after 1895.

FIGURE 7. **Behavior of textile prices**



Notes: This figure shows the coefficients γ_k^F from regression 6.1 for each year starting from 1889 to 1898. 95% confidence intervals using Newey-West standard errors with three lags. Annually data from 1877 to 1907. Total number of observations 99.

Figure 7 shows an increase in the relative cotton finished textile price that started in 1893 and remained high for three years. Also, this graph shows that after 1895 this increasing trend reverted, and the price ratio experienced a fall. It returned to pre-shock levels. This suggests that the initial trigger that motivated the cotton innovation was the increase in cotton relative price. This is consistent with the theory that predicts that adjustments in innovation would revert this tendency and would push the price ratio to the levels before the initial shock. Finally, estimated coefficients allow me to sense the elasticity of substitution between cotton fabrics and other fiber products. Suppose I assume that the prices changes observed in 1895 have not absorbed any adjustment on technologies yet. In that case, 1895's point estimate will imply an elasticity of substitution between cotton textiles and other textiles ($\epsilon^{z,x}$) of 1.07[55].

[55]See appendix section A for more details. If prices do not yet reflect innovation adjustments γ_{1895}^F is equal to $1/\epsilon^{z,x} \ln \lambda$. I can estimate λ using the observed ratio increase in patents in each sector. Before 1891 the cotton-other fibers patent ratio was 3.18, and in 1895 this ratio was 4.51. These

6.2. **Cotton products prices after colonies lost:** Following the insertion in the international market motivated by the loss of protected markets, my argument is that the change in effective weavers to spinners due to an increase in the use cost of weavers affected the price relation of fabrics over threads in the cotton industry. Therefore, the price change is the initial trigger that explains the increase in incentives to innovate in the weaving sector. To evaluate this hypothesis, that is, if there is a change in the cotton fabric prices and not in the cotton thread prices, I compare fabric prices[56] with thread prices behavior before and after 1898. Formally I estimate the following model:

$$\begin{aligned} \ln(P_{jgt}) =& \gamma^P_{1891-95} \times \text{Integration}_t \times \text{Fabric}_j + \left[\sum_{k=1896}^{1910} \gamma^P_k \times \text{Years}_k \times \text{Fabric}_j \right] \\ & + q_j + \alpha_g \times t + \alpha_t + \alpha_g + \varepsilon_{jgt} \end{aligned} \tag{6.2}$$

where P_{jgt} is the price of product j of variety-type g[57] at time time t. Years$_k$ are dummy indicators for each year, and Integration$_t$ is an indicator for the first years in the full integration period (1891-1895). Fabric$_j$ is a dummy indicator if the product is a fabric (i.e., not a thread). I am interested in coefficients γ^P_k that capture the differential change of fabric prices between each year of the colonies' loss period and the years before the full market integration compared to the change in cotton thread prices.

This specification has some challenges. Mainly, the basket of products available for each variety type is different in each period, and therefore the average quality of the product may change over time. Then, changes in product prices might capture changes

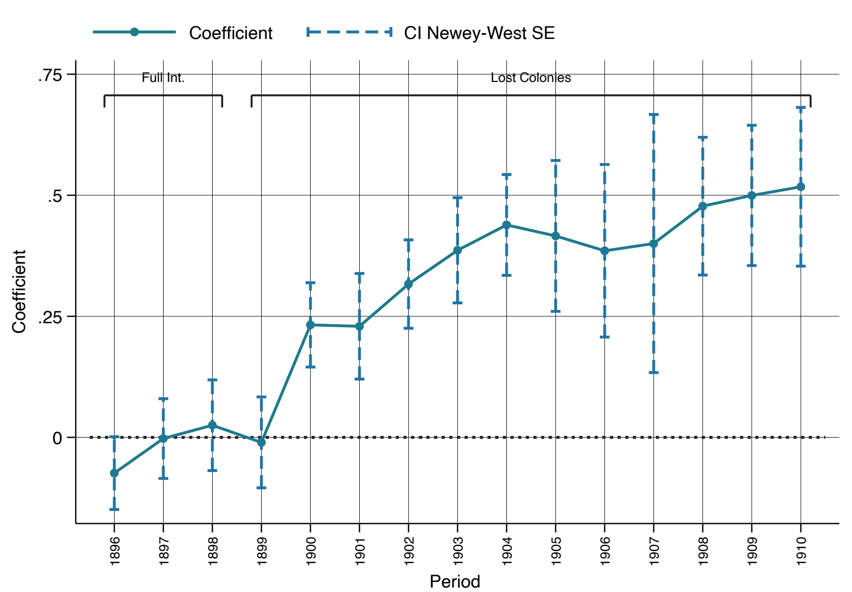
numbers imply that λ is equal to 1.4. Finally, and given that γ^F_{1895} is 0.33, I estimate an elasticity of substitution of 1.07. Also, I estimate the ratio of available raw materials in Spain, both isolated and with the integrated market. For three fibers (cotton, linen-hemp, and wool), I assess the availability in continental Spain as the addition of internal production and imports after subtracting exports. In the case of cotton and linen, I estimate internal production using the cultivated area in 1929. In the case of wool, I estimate internal production using the 1890 cattle census and assuming an average yearly production of 2 kg per sheep and a reduction of 0.57% after scour. I calculate an availability in 1895 of 72,940 tons of cotton, 9,126 tons of wool, and 21,081 tons of linen (hemp). Jointly, these numbers implied a ratio of cotton to other fibers of 2.4 in continental Spain and with $\lambda = 1.4$ a ratio of 1.7 in the whole integrated market.

[56]These are prices of fabrics without any finishing process (in Spanish *empesas*)

[57]I use five different types of cotton products that the firm produced between 1878 and 1910 and whose prices were available at the inventory ledgers. *La España Industrial* produced several products of different qualities for each cotton variety of product, and therefore, the quality composition of the basket changes over time. Cotton thread prices are for warp thread without size, warp thread with size, and weft thread. Cotton fabric prices are *Madras* and *Molesquin* prices. Even though the firm produced several fabric types, these are the only types that were constantly produced during the entire period of my analysis and, hence, were on the company stock when inventories were made.

in the overall quality and not in prices levels. To overcome this issue, I control for the quality of product q_j. This is a quality index for each product j based on observed prices following the assumption that difference in prices between threads and fabrics within the same year only reveals differences in quality between the basket products[58]. I include time trend t since the series evidences some downward trend before the colonies lost. Appendix figure D.13 shows the behavior of prices and qualities for the five products I am considering. In general, there was an increase in prices before 1898 though this is more pronounced for the fabrics whose prices increased more than 60%. In the case of qualities, those values are more stable though there is a positive increase in qualities of one type of fabric. I expect to observe a significant positive effect during the colonies' lost period and a nonsignificant effect in the coefficients before 1898. Finally, I estimated Newey-West standard errors using a lag of three periods[59].

FIGURE 8. **Behavior of cotton thread and fabric prices**



Notes: This figure shows the coefficients γ_k^P from regression 6.2 for each year starting from 1896. 95% confidence intervals using Newey-West standard errors with three lags. Biannually data from 1878h1 to 1910h2. Total number of observations 913.

[58]See appendix B for a detailed explanation of the construction of this index.

[59]Another problem with this estimation is the data periodicity. Even though most of the information is available biannually, this is not true after 1903, when the firm made only one inventory per year. I treat the price observed in those years as the price for the last half-year and leave a missing observation for the price of the first half-year. Since the firm conducted the inventory at the end of the year, this price coincides with the periodicity of that part of the year before 1903. Also, due to information quality, I do not observe 1899 last half-year and 1891 first half-year prices.

Figure 8 shows that there are no significant changes in the relative prices during the metropolis-colonies integration. However, there was a substantial increase in prices after 1898. In particular, there is a jump in the difference after 1900. Furthermore, this increase remained stable and significant after that year. Although these results might have some potential issues, as previously mentioned, there is some evidence of an increase in relative prices that motivated the change towards weaving innovation. These results are consistent with the theory that predicts that the change remains even after the adjustment of technology, suggesting a 25% increase in cotton weaving product price in relation to the period before the full market integration period.

6.3. **Cotton workers' wages after colonies lost:** Finally, the relative cost of a worker in the cotton industry should also translate to a change in workers' payments within different production stages. The change in relative use cost between spinners and weavers affected the relative demand for each type of worker and, then, salaries. My argument is that these two workers complement each other in the production of cotton-finished textiles. Therefore, I hypothesize that this change translated into a final increase in weavers' wages even in the presence of endogenous changes in the sector's innovation[60].

Appendix section C shows this analysis. I show that there is a significant change in relative wages after 1898. Moreover, the increase in the wage ratio did not happen immediately after the loss of colonial markets. Although it started to increase after 1901, it is only significant after 1907. It is also interesting to note that point estimates are smaller in this case when compared to the changes in relative prices of workers' final products. This is consistent with the two types of workers being complements and with the biased technology theory. Two forces work together when determining the change in relative wages in the presence of innovation. First, the increase in the relative cost of weaver translates into an increase in the price of the final product and, then, into the demand of weavers. Second, once innovation adjusts, this change is mitigated by the change in relative innovation in these sectors that pushed salaries down for the costly labor sector. In fact, those two estimations allow me to get a sense of the elasticity of substitution between weavers and spinners. If I assume that the changes observed in 1901 do not reflect the adjustments on technology yet, these coefficients would suggest

[60]When the two goods complement each other, an increase in price translates into a more significant relative demand for the costly worker, and at the same time it translates into a rise in the relative wage of these workers. This would not be the case if the two goods were substitutes. In this case, an increase in prices translates into lower relative demand for the costly worker and, at the same time, a reduction in relative wages.

an elasticity of substitution ($\epsilon^{h,l}$) of 0.24 and an implied increase of weavers' cost due to the entrance in new markets of 5.5%[61].

7. Machines' Acquisition

Next, I turn to installed capital and how innovation translated into a tangible adoption of new technologies. I look at the behavior of installed machines for different processes in different industries and in the different regions. The hypothesis is that I should observe an increase in all machines dedicated to cotton during the 1891-1898 period and an increase in loom installed after the 1898 war in comparison to other textile sectors. Formally, I compare cotton machines with wool and linen machines using the following *difference-in-differences* model where subindex p denotes the province, m denotes material, and subindex t denotes period.

$$\begin{aligned} Y_{ptm} =& \beta_1(\text{Integration}_t \times \text{Cotton}_m) + \beta_2(\text{Early lost}_t \times \text{Cotton}_m) \\ &+\beta_3(\text{Late lost}_t \times \text{Cotton}_m) + \left[\sum_{g\in\mathbf{X_p}}\sum_{k\in 1879}\gamma'(g \times \text{Years}_k)\right] \\ &+\alpha_m + \alpha_t + \alpha_p + \varepsilon_{ptm} \end{aligned} \tag{7.1}$$

Y_{ptm} is one type of the machines per 10.000 inhabitants, and Cotton_m is a dummy that takes the value of one if the machine is used in the cotton industry. Integration_t is a dummy that takes the value of one during the integration period. That is, for the years 1893-94 and 1895-96, Early lost_t is a dummy that takes the value of one after the colonies lost between 1900 and 1904 and Lost lost_t is a dummy that takes the value of one after the colonies lost between 1905 and 1909. α_m and α_p are province and material fixed effects that capture any time-invariant category characteristics and α_p aggregate time shock. A province with cotton industry is different from provinces with other industries. Therefore, I combined the province characteristics measure in 1877 ($\mathbf{X_p}$) with the time fixed effects to control for differential trends by each one of those attributes. ε_{jt} is the error term that I cluster at the province-year level, that is I control for correlation between industries in the same province at the same year[62].

[61]See appendix sections A for more details. Without a technology adjustment γ^W_{1901} is equal to $\left(\frac{1-\epsilon^{l,h}}{\epsilon^{l,h}}\right)\ln\left(\frac{\phi_h^{1901}}{\phi_h^{1882}}\right)$. With the same assumption γ^P_{1901} is equal to $\left(\frac{1}{\epsilon^{l,h}}\right)\ln\left(\frac{\phi_h^{1901}}{\phi_h^{1882}}\right)$. Using these two conditions I can compute the elasticity of substitution $\epsilon^{l,h}$ as $1-\gamma^W_{1901}/\gamma^P_{1901}$ that is $1-0.17/0.23$ and the change in the relative cost as $\%\Delta_{\phi_h} = \exp(\epsilon^{h,l} * \gamma^P_{1901}) - 1$

[62]I only have a small number of provinces (45 provinces). Therefore, I followed Imbens and Kolesár (2016) and I calculated HC2 standard errors tested against a t-distribution.

The key coefficients are β_1, β_2 and β_3 that capture the differential change in machines between each period and the baseline period 1879[63].

Table 1 presents the empirical estimates of the equation model 7.1 for machines used at the weaving stage. I compare cotton machines with machines in other textile sectors. Panel A shows the effect on machines per 10.000 inhabitants: either mechanical looms, manual looms, or jacquard looms[64].Odd columns compare against the behavior of wool and linen machines, while even columns compare only with the wool industry. The purpose of this is to have robustness and compare the cotton industry with one industry that has no significant presence in the colonies (wool). This table reveals a positive effect on the capital installed at the weaving stages in all three different periods. All three point estimates are similar. For instance, according to them, there were, on average around ten more mechanical looms per 10,000 inhabitants during the colonial-metropolis integration period. After the colonial market lost, the positive effect was also present. There was an increase of jacquard looms of around 0.84 cotton looms each year after the war. When analyzing the behavior of manual looms, I do not observe a differential effect. This shows that technical change helped the industry's mechanization. Finally, when comparing only with the wool industry, these results are robust. I reach the same conclusions: the results are consistent with innovation findings, and they show that the increase in patents at the weaving stage translated into more mechanical and jacquard looms working on cotton fabric production.

Panel B in this table evaluates if an increase in firms using new technologies drives the previous findings. Columns 7 and 8 reveal an increase in firms that reported and paid taxes on mechanical looms after 1891. This rise explains the increase in the number of installed looms. That means that in order to increase competitiveness, firms chose to change looms technology. On the other hand, there are no changes in the firms reporting jacquard looms, which suggests that in this case, an existing firm with those technologies would introduce more of those types of looms. Finally, while there are no changes in the reported manual looms, there seems to be a positive effect on firms reporting this type of technology which suggests that existing manual looms were acquired for other firms and technology was not totally discarded. Overall, I can conclude that the positive effect on patent applications tended to correspond to the introduction of new looms.

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[63]Again, the standard identification applies here. Without the market integration and the entry to global markets, the machines used to create cotton textiles would have behaved similarly to wool and linen machines.

[64]This type of technology has its own classification: patterns cards or chains and punching of cards. Jacquard looms include both manual and mechanical looms.

As robustness, appendix table E.5 shows the same exercise for machines at the spinning stage (Panel A) and the finishing stage (Panel B). In the case of mechanical spindles, the coefficient that measures the impact during the market integration period between 1891-1898 is positive although non-significant, while in the manual spindles cases, the point estimate is negative and non-significant. On the other hand, during the colonies lost period, I observed that the coefficients of mechanical spindles were negative. This is consistent with the previous results that show an increase of general cotton patents only in the first period. Unfortunately, the data for that period is not complete for the whole-time range, and I lack the power to get a precise positive estimation. Finally, for the shearing and raising machines case (finishing stage)[65], I do not observe any significant effect on the installed machinery. Overall, I did not observe any differential changes after the colony lost on the spinning and finishing machines between cotton and other industries.

TABLE 1. Response of cotton textiles machines on weaving stage to market integration and colony lost

	Panel A Machines per 10.000 inhabitants						Panel B Firms per 10.000 inhabitants					
	Mechanical Looms		Jacquard Looms		Manual Looms		Mechanical Looms		Jacquard Looms		Manual Looms	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Cotton ...												
... x Market integration	10.01*	9.14	0.26	0.26	2.81	−12.29	0.08	0.04	−0.00	−0.01	1.59***	0.28
	(5.96)	(5.79)	(0.17)	(0.26)	(7.74)	(7.70)	(0.05)	(0.03)	(0.02)	(0.05)	(0.55)	(0.60)
	[[0.044]]	[[0.101]]	[[0.227]]	[[0.350]]	[[0.687]]	[[0.082]]	[[0.107]]	[[0.347]]	[[0.927]]	[[0.848]]	[[0.001]]	[[0.548]]
... x Early colonies lost	11.22**	10.38**	0.84**	0.88**	3.21	−11.41	0.14**	0.10**	0.02	0.01	1.87***	0.77
	(4.45)	(4.40)	(0.35)	(0.40)	(7.72)	(7.67)	(0.06)	(0.05)	(0.02)	(0.04)	(0.54)	(0.56)
	[[0.003]]	[[0.019]]	[[0.010]]	[[0.024]]	[[0.645]]	[[0.106]]	[[0.007]]	[[0.074]]	[[0.436]]	[[0.880]]	[[0.000]]	[[0.085]]
... x Late colonies lost	12.13***	11.09**	0.84***	0.94***	3.35	−11.10	0.14**	0.09	0.04*	0.03	1.85***	0.72
	(4.60)	(4.53)	(0.28)	(0.33)	(7.72)	(7.67)	(0.06)	(0.05)	(0.02)	(0.04)	(0.54)	(0.56)
	[[0.002]]	[[0.014]]	[[0.002]]	[[0.005]]	[[0.630]]	[[0.116]]	[[0.014]]	[[0.135]]	[[0.127]]	[[0.413]]	[[0.000]]	[[0.104]]
Observations	1716	1144	1716	1144	1716	1144	1716	1144	1716	1144	1716	1144
Material fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	tex ✓	✓
Time fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Province fixed effects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Comparison Cotton vs.	W and L	W	W and L	W	W and L	W	W and L	W	W and L	W	W and L	W

Notes: Control variables include logarithm of population, men shared , share residents, single shared population, married shared population, catholic shared , share of illiterate, share of born in same province, share of nationals born in different province, share of regular residents in the same municipality. W stands for wool and L for linen and hemp. Columns 1 and 3 compare the cotton industry with wool and linen (hemp) industry and columns 2, 4, 5 and 6 compare the cotton industry only with wool industry. Comparison period 1979. P-values from a test based on HC2 standard errors tested against a t-distribution are in double squared brackets. I follow the correction proposed by IImbens and Kolesár (2016). Standard errors in parentheses are clustered on province-year level. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

[65]Shearing and raising are not a process widely used in the linen industry.

8. CONCLUSION

This paper used two natural experiments to illustrate the effects of international trade on technological progress direction. Indeed, I show that gaining access to foreign markets had different consequences in the Spanish textile industry at the end of the 19th century. I found that the demand features play a significant role when identifying the consequences of output shocks. While privileged access to colonial markets created incentives to develop cotton augmenting technologies, competitive access to more sophisticated markets, due to the colonies' independence, created incentives to develop cotton-weaving augmenting technology.

This is the first paper that explores the effects of output shocks in the direction of technical change. I filled the gap in the literature that has focused its efforts on the analysis of input shocks. I argue that while input shocks are alike, output shocks are unique in their own way. Thus, the answer about to how much openness to trade affects the development of new technologies depends on demand features and characteristics of the new markets. Although the findings from this specific event in the history of the Spanish industry do not provide a unique answer about the effects of trade, they light up the transforming mechanisms behind commerce. This point suggests that for to understand the consequences of opening and closing to foreign markets, it is also crucial to understand each policy's features in their particular context.

My findings also suggest that one crucial benefit source for European empires was trade with their colonies. My results suggest one possible explanation of the industrialization in Western Europe during the 18th and 19th centuries in that it resides in important structural transformations that colonial relationships incentivized. To do so, then it is important to ununderstandthe mechanism effects through which trade shock improves other sectors. Given that the cotton textile industry was one of the first industrialized industries and the driver of industrial transformation, it may be that other economic sectors were also beneficiaries of trade shocks. The spillover effects of trade shocks and the new technology developed after trade is a road for future work. A deeper understanding of innovation clusters and the importance of agglomeration economies in knowledge is important to comprehend possible multiplicative effects of trade on economic growth.

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ONLINE APPENDIX

Appendix A. Two models of Trade and Innovation

A.1. **Cotton and other fibers textiles.** In this section I show a model of innovation between two sectors: cotton textile and other fibers textiles.

A.1.1. *Set up and assumptions.* There is an unique final produced good (apparel), produced competitively using cotton textiles (Y_z) and other textiles (Y_x) as inputs, according to the following aggregate production function

$$Y_f = \left[Y_z^{\frac{\epsilon-1}{\epsilon^{z,x}}} + Y_x^{\frac{\epsilon^{z,x}-1}{\epsilon^{z,x}}} \right]^{\frac{\epsilon^{z,x}}{\epsilon^{z,x}-1}} \tag{A.1}$$

where $\epsilon^{z,x} \in (0, +\infty)$ is the elasticity of substitution between the two inputs. Then the producers of textiles $k \in \{Z, X\}$ maximize their production Y_k under a regular inputs constraint giving the relative demand function:

$$\frac{P_z}{P_x} = \left(\frac{Y_z}{Y_x} \right)^{-\frac{1}{\epsilon^{z,x}}} \tag{A.2}$$

Where P_z and P_x are the prices of the two textiles[66]. Textiles Y_z and Y_x are produced using a continuum of sector specific intermediates ($y_z(i)$ and $y_x(i)$ respectively). Where A_z and A_x is the measure of machines and innovation in each sector[67].

$$Y_z = E_z \left[\int_0^{A_z} y_z(i)^\alpha di \right]^{\frac{1}{\alpha}} \quad \text{and} \quad Y_x = E_x \left[\int_0^{A_x} y_x(i)^\alpha di \right]^{\frac{1}{\alpha}} \tag{A.3}$$

Both textile producers sell in competitive markets and they maximize profits taking intermediate goods prices $p_z(i)$ and $p_x(i)$ as given. This gives the following demands functions for each intermediate good

$$y_z(i) = Y_z \left(\frac{A_z^{2\alpha-1}}{p_z(i)} \right)^{\frac{1}{1-\alpha}} \quad \text{and} \quad y_x(i) = Y_x \left(\frac{A_x^{2\alpha-1}}{p_x(i)} \right)^{\frac{1}{1-\alpha}} \tag{A.4}$$

and the following relative demand equation

$$\frac{y_z(i)}{y_z(j)} = \left(\frac{p_z(j)}{p_z(i)} \right)^{\frac{1}{1-\alpha}} \quad \text{and} \quad \frac{y_x(i)}{y_x(j)} = \left(\frac{p_x(j)}{p_x(i)} \right)^{\frac{1}{1-\alpha}} \tag{A.5}$$

The production function for each intermediate input is linear in the type of material employed ($y_z(i) = \frac{Z(i)}{\phi_z}$ and $y_x(i) = \frac{X(i)}{\phi_x}$. Where ϕ_z and ϕ_x measure the cost in terms of the material needed to produce the intermediate good. This production is subject to resource constraints $\int_0^{A_z} z(i)di \leq Z$ and $\int_0^{A_x} x(i)di \leq X$. The intermediate good sector

[66] Y_f is the numeràire.

[67] Terms $E_z \equiv (A_z)^{\frac{2\alpha-1}{\alpha}}$ and $E_x \equiv (A_x)^{\frac{2\alpha-1}{\alpha}}$ are two externality terms that assures the existence of a balanced-growth path.

is monopolistic since the producer owns a patent for this product. The monopolist face a demand curve with the constant price elasticity $1/1-\alpha$ and the optimal price in each sector is:

$$p_z(i) = \frac{w_z\phi_z}{\alpha} \quad \text{and} \quad p_x(i) = \frac{w_x\phi_x}{\alpha} \tag{A.6}$$

Where w_z and w_x is the price of each raw material Z and X. This implies that the profits of these firms is equal to a fraction $(1-\alpha)$ of the total sales

$$\pi_z(i) = (1-\alpha)\frac{p_z(i)z(i)}{\phi_z} \quad \text{and} \quad \pi_x(i) = (1-\alpha)\frac{p_x(i)x(i)}{\phi_x} \tag{A.7}$$

Using the market clearing conditions on the raw materials I can write the production function as $Y_z = \dfrac{A_z Z}{\phi_z}$ and $Y_x = \dfrac{A_x X}{\phi_x}$. Using these equations in the relative demand function (A.2) I found the relative price function equation

$$p \equiv \frac{P_z}{P_x} = \left(\frac{A_z Z}{A_x X}\frac{\phi_x}{\phi_z}\right)^{-\frac{1}{\epsilon^{z,x}}} \tag{A.8}$$

Using (A.4) I can rewrite intermediate prices as $P_z A_z = p_z(i)$ and $P_x A_x = p_x(i)$ and the relative profits of monopolistic in each sector as

$$\frac{\pi_z(i)}{\pi_x(i)} = \frac{p_z(i)z(i)}{p_x(i)x(i)}\frac{\phi_x}{\phi_z} = \left(\frac{A_x}{A_z}\right)^{\frac{1}{\epsilon^{z,x}}}\left(\frac{\phi_x Z}{\phi_z X}\right)^{\frac{\epsilon^{z,x}-1}{\epsilon^{z,x}}} \tag{A.9}$$

Using this same condition I can write the raw materials prices ratio as

$$\omega \equiv \frac{w_z}{w_x} = \left(\frac{A_z}{A_x}\frac{\phi_x}{\phi_z}\right)^{1-\frac{1}{\epsilon^{z,x}}}\left(\frac{Z}{X}\right)^{-\frac{1}{\epsilon^{z,x}}} \tag{A.10}$$

A.1.2. *Endogenous technological change.* Introduction of new machines has a fixed cost μ as units of the numeràre. Each innovator decide between designing machines for one of the two sector. Patents are infinitely lived and therefor at the balanced growth path the discounted value in each sector (V_z and V_x) of the profit stream cannot exceed the innovation cost. This implies that innovators are indifferent between the two technologies. That is $V_z = V_x = \mu$ or $\frac{\pi_z}{\pi_x} = 1$. Using this condition jointly with A.9 I find the the technology direction that is compatible with balanced growth.

$$\frac{A_z}{A_x} = \left(\frac{\phi_x Z}{\phi_z X}\right)^{\epsilon^{z,x}-1} \tag{A.11}$$

Also on balanced growth the textiles price ratio and and the endowments payment ratio can be written as

$$p^{**} = \left(\frac{\phi_x Z}{\phi_z X}\right)^{-1} \quad \text{and} \quad \omega^{**} = \left(\frac{\phi_x}{\phi_z}\right)^{\epsilon^{z,x}-1} \left(\frac{Z}{X}\right)^{\epsilon^{z,x}-2} \tag{A.12}$$

A.1.3. *Market Integration.* In this section now I develop the effect of market integration. Now consider Spain with endowments Z^S and X^S get integrated with its colonies that have endowment Z^C and X^C. The endowments of materials in the market are defined as the sum of both the metropolis and the colonies endowments (i.e. $Z^I = Z^S + Z^C$ and $X^I = X^S + X^C$.). Then the relative price equation (A.8) from the integrated market is

$$p^I \equiv \frac{P_z}{P_x} = \left(\frac{A_z(Z^S + Z^C)}{A_x(X^S + X^C)} \frac{\phi_x}{\phi_z}\right)^{-\frac{1}{\epsilon^{z,x}}} = \lambda^{1/\epsilon^{z,x}} p \tag{A.13}$$

Colonies copy technology from the metropolis without any differential cost. Adjusting technology equation (A.9) becomes

$$\frac{A_z^I}{A_x^I} = \left(\frac{\phi_x Z}{\phi_z X}\right)^{\epsilon^{z,x}-1} \lambda \tag{A.14}$$

Where $\lambda \equiv \dfrac{1 + X^C/X^S}{1 + Z^C/Z^S}$. If I assume that cotton is relative more abundant in Spain compare with its colonies (i.e. $\frac{Z^S}{X^S} > \frac{Z^C}{X^C}$) then $\lambda > 1$. Or what is the same a market integration produce an increase on innovation on the relative more abundant product (i.e. cotton). Also when technology is allowed to adjust the price ratio becomes equal to the levels before the market integration

$$p^{I**} = \left(\frac{\phi_x Z}{\phi_z X}\right)^{-1} = p^{**} \tag{A.15}$$

A.1.4. *Change on textile prices.* Coefficients γ_k^F in equation 6.1 identify the relative change between other fibers and cotton (p) before and after the integration, that is $\ln(p^I/p^{**})$ that can be expressed as:

$$\ln\left(\frac{p^I}{p^{**}}\right) = \frac{1}{\epsilon^{z,x}} \ln \lambda \tag{A.16}$$

finally the increase on the technology after the market integration can be expressed as

$$\frac{A_z^I/A_x^I}{A_z/A_x} = \lambda \tag{A.17}$$

A.2. **Spinning and weaving sectors.** In this section I show a model of innovation between two sectors in the cotton textile industry: spinning and weaving sector.

A.2.1. *Set up and assumptions.* There is an unique final good of cotton (textile), produced competitively using two inputs: threads (Y_h) and fabrics (Y_l). Each one is produced using two different type of workers spinners (H) and weavers (L) respectively. The production function is expressed as

$$Y_z^* = \left[Y_l^{\frac{\epsilon^{l,h}-1}{\epsilon^{l,h}}} + Y_h^{\frac{\epsilon^{l,h}-1}{\epsilon^{l,h}}} \right]^{\frac{\epsilon^{l,h}}{\epsilon^{l,h}-1}} \tag{A.18}$$

As in the last section products Y_l and Y_h are produced using a continuum of sector specific intermediates ($y_l(i)$ and $y_h(i)$ respectively). Where A_l and A_h is the measure of machines in each input produced with the two types of labor

$$Y_l = E_l \left[\int_0^{A_l} y_l(i)^\alpha di \right]^{\frac{1}{\alpha}} \quad \text{and} \quad Y_h = E_h \left[\int_0^{A_h} y_h(i)^\alpha di \right]^{\frac{1}{\alpha}} \tag{A.19}$$

The production function for each intermediate input is linear in the type of labor employed in the world $y_l(i) = \frac{l(i)}{\phi_l}$ and $y_h(i) = \frac{h(i)}{\phi_h}$. Where ϕ_l and ϕ_h measure the cost in terms of the workers need to produce either threads or fabrics. Using the sames steps as the previous model I can obtain the price relation between fabric and threads

$$p_{lh} \equiv \frac{P_l}{P_h} = \left(\frac{A_l L}{A_h H} \frac{\phi_h}{\phi_l} \right)^{-\frac{1}{\epsilon^{l,h}}} \tag{A.20}$$

and the wage ratio between weavers and spinner

$$\omega_{lh} \equiv \frac{w_l}{w_h} = \left(\frac{A_l}{A_h} \frac{\phi_h}{\phi_l} \right)^{1-\frac{1}{\epsilon^{l,h}}} \left(\frac{L}{H} \right)^{-\frac{1}{\epsilon^{l,h}}} \tag{A.21}$$

A.2.2. *Endogenous technological change.* Introduction of new machines has the same structure as the in previous section that is fixed cost μ as units of the numeràre. Therefore the technology direction compatible with balanced growth can be expressed as

$$\frac{A_l}{A_h} = \left(\frac{\phi_h L}{\phi_l H} \right)^{\epsilon^{l,h}-1} \tag{A.22}$$

Also on balanced growth the price ratio between fabrics and threads and and the wage ratio between weavers and spinners can be written as

$$p_{lh}^{**} = \left(\frac{\phi_h L}{\phi_l H} \right)^{-1} \quad \text{and} \quad \omega_{lh}^{**} = \left(\frac{\phi_h}{\phi_l} \right)^{\epsilon^{l,h}-1} \left(\frac{L}{H} \right)^{\epsilon^{l,h}-2} \tag{A.23}$$

A.2.3. *Entrance to international market.* In this section I develop the effect of the introduction to global markets. I assume that with the new tastes the cost of weaver increase since they are need to produce more varieties of products, that is an increase of ϕ_l. Given the fact that the two sectors are complements that is $\epsilon^{l,h} < 1$ it is straightforward to observe a positive relation with innovation ratio $\frac{A_l}{A_h}$ as well price ratio p_{lh}^{**} and wage ratio ω_{lh}^{**}

A.2.4. *Change on fabric-thread price.* Coefficient γ_k^P in equation 6.2 identify the change between thread price and fabric price before and after the increase on weaver cost ($\phi_h^0 \to \phi_h^1$), that is $\ln(p_{lh}(\phi_h^1)/p_{lh}(\phi_h^0))$ that can be expressed as

$$\ln\left(\frac{p_{lh}(\phi_h^1)}{p_{lh}(\phi_h^0)}\right) = \frac{1}{\epsilon^{l,h}} \ln\left(\frac{\phi_h^1}{\phi_h^0}\right) \tag{A.24}$$

A.2.5. *Change on weavers spinners wages.* Coefficient γ_k^W in equation C.1 identify the change between weaver wages and spinner wavers before and after the increase on weaver cost ($\phi_h^0 \to \phi_h^1$), that is $\ln(\omega_{lh}(\phi_h^1)/\omega_{lh}(\phi_h^0))$ that can be expressed as

$$\ln\left(\frac{\omega_{lh}(\phi_h^1)}{\omega_{lh}(\phi_h^0)}\right) = \frac{1-\epsilon^{l,h}}{\epsilon^{l,h}} \ln\left(\frac{\phi_h^1}{\phi_h^0}\right) \tag{A.25}$$

Appendix B. Cotton textile products quality index

In this section, I explain in detail the construction of the quality index for each cotton product observed on the inventory ledgers. During each period of time, I observe data of two different types of products: thread and fabrics. Inside each type, I observe different varieties. I observe three thread varieties (warp thread without size, warp thread with size, and weft thread) and two fabric varieties (moleskin and madras). Finally, I observed the price for different products inside each variety only if the product was available on the stock of the company. To construct the quality, I assume that the prices differences observer on the same product (thread or fabrics) reflect only differences in the qualities. I follow the following procedure:

(1) I calculated the lower price for each product type in 1878. And calculate the prices of all prices based on that prices. This allows me to estimate the price in terms of a first prices
(2) Then, I calculated the lower of those previously estimated price ratios for each period.
(3) I calculated then a new price ratio between each period minimum and original ratio. With this estimation I measure the quality of each observed product in terms of the low-quality product of each type.
(4) I estimate the average of this indicator by product across all years in which it was observed and take the measure as the quality indicator. This estimation assumes that inside each product of type, the lower quality product was always available in all the periods. This seems a reasonable assumption since i) for the three varieties of cotton thread, I always observed the lower quality (thread with numbers lower than 20, and ii) the lower fabric price was always associated with a madras fabric with similar characteristics.

Appendix C. Effect of bias technology on relative wages

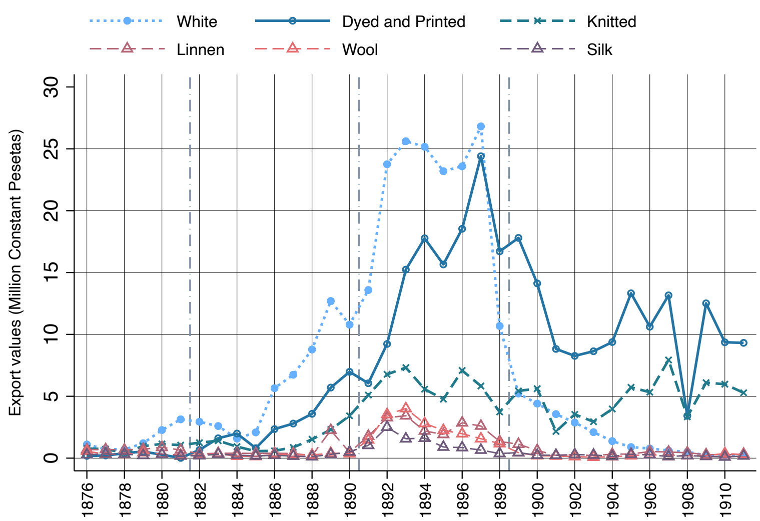
In this section, I show the analysis of wages of two cotton textile workers: spinners and weavers. Figures D.14 give the first evidence that this is the case. After the Spanish-American war, weavers' wages started to follow an upward trend, and they constantly increased while the spinners' wages remained constant during this period. I follow a similar strategy than in equation 6.2, and I compare weavers' wage to spinner wage after the loss of the colonies in 1898. Formally, I estimate the following model:

$$\begin{aligned} \ln(W_{jt}) =& \gamma^W_{1891-95} \times \text{Integration}_t \times \text{Weaver}_j + \left[\sum_{k=1896}^{1910} \gamma^W_k \times \text{Years}_k \times \text{Weaver}_j \right] \\ &+ \left[\sum_{l \in \mathbf{X_t}} \gamma'(l \times \text{Weaver}_j) \right] + \alpha_j \times t + \alpha_t + \alpha_j + \varepsilon_{jt} \end{aligned} \tag{C.1}$$

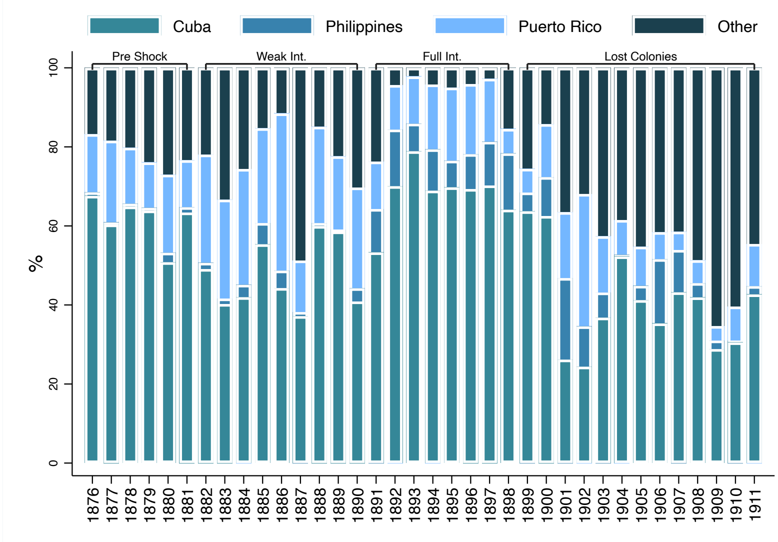
where W_{jt} is the wage received by type of worker j (spinner or weaver) at time t, Years_k are dummy indicators for each year, Integratio_t is an indicator for the first years of the full integration period (1891-1895) and Weaver_j is an indicator if the salary is for workers at weaving stage. I include a differential trend in the estimation since the data evidence that the two series had different trends (see Appendix figure D.14). Spinners' salaries had a downward trend before the colonies lost while the weavers remained relatively constant before 1899. Finally, I also control for the wages of other workers at the weaving stage like personal in charge and warpers at each period $\mathbf{X_t}$. These two variables allow me to control for changes in the amount of work needed from each weaver since both are correlated with the quality and weight of the average produced piece (features that I do not observe in the data). Then the inclusion of those variables reduces the concerns that salaries changes are being driven by movements in the amount of work needed to produce different fabric qualities. My interest is on coefficients γ^W_k that captures the change of weavers wages relative to spinner wages at each period of time in comparison to the average relative wage before 1891.

Appendix D. Figures

Figure D.1. **Textiles exports to colonies**



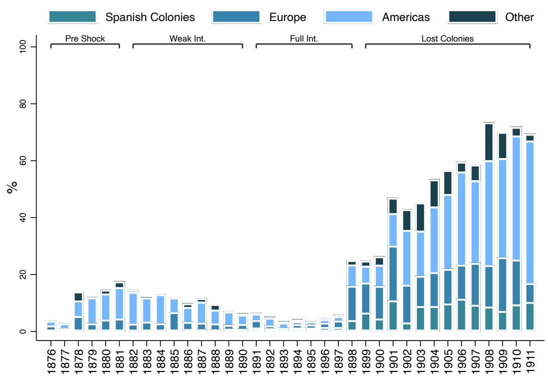
A Textile trade value to colonies



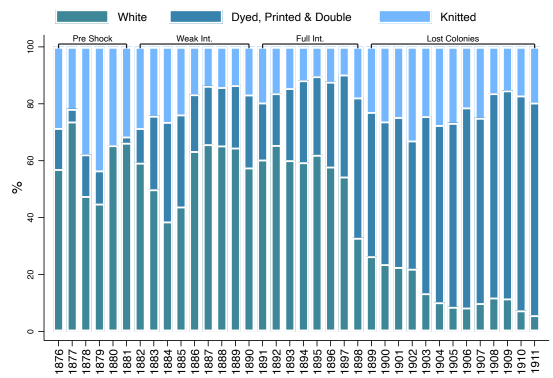
B Linen exports by destination

Source: Same as table 1
Notes: Panel A shows the value of textiles imports to colonies by type of material. I measure values using constant pesetas. I divided cotton fabrics into three different type of fabrics. Despite the known problems of this type of measure (Sudrià, 1983) this capture the relatively quality difference among fabrics. Panel B shows the share of colonial markets in the total linen exports.

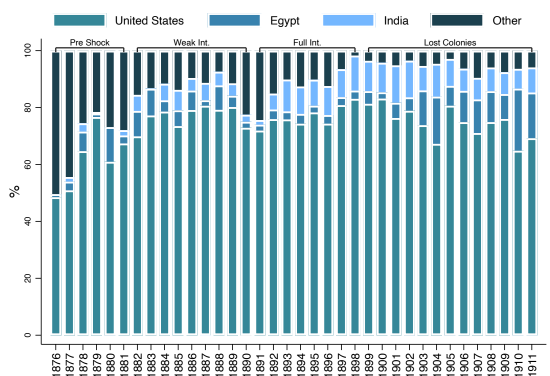
Figure D.2. **Cotton textiles exports and imports**



A Cotton textile by destination (Others)



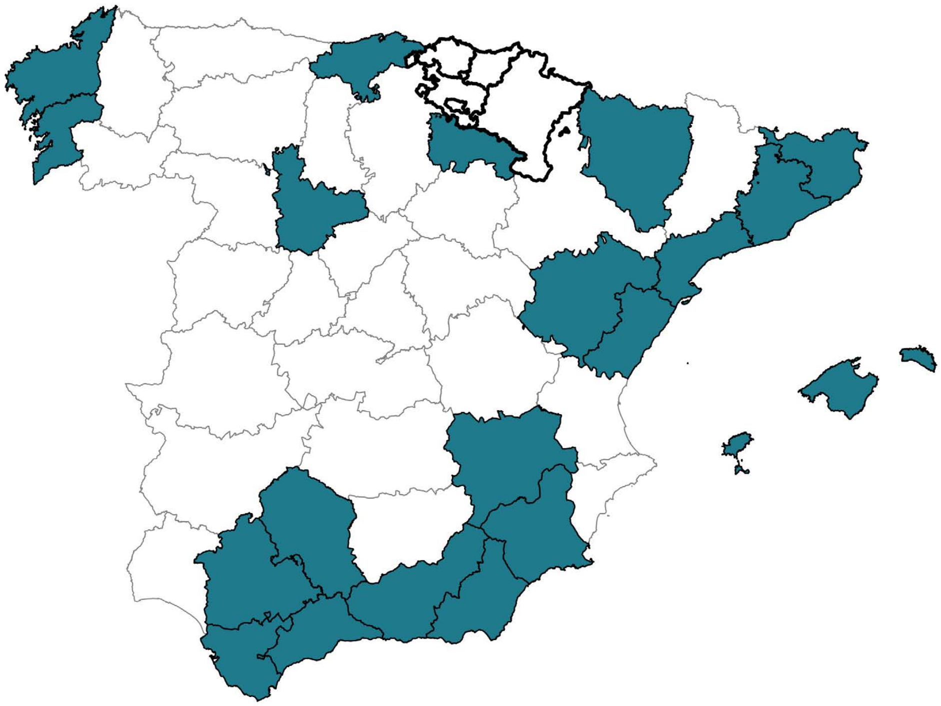
B Cotton textile exports by type



C Raw cotton imports by origin

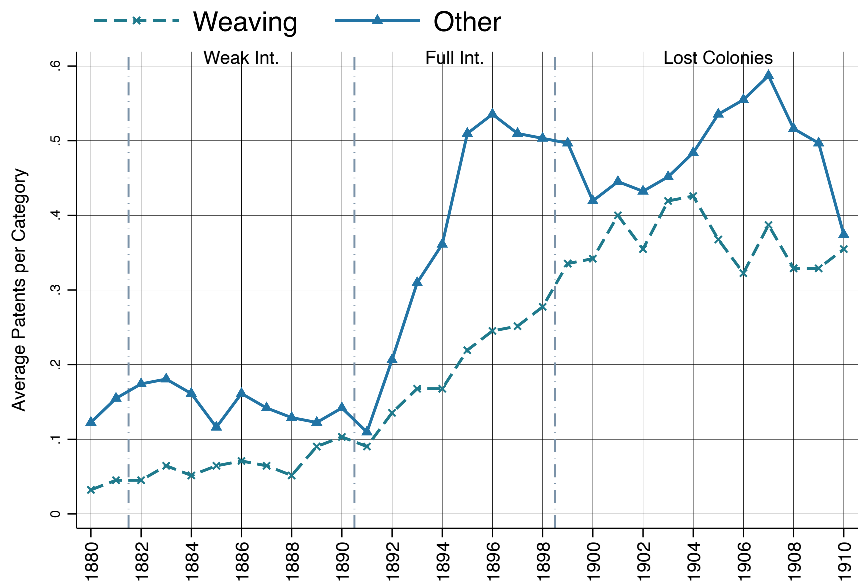
Sources: Same as table 1
Notes: Panel A shows desegregation of cotton textile destination . It groups countries on American republics, Europe, other Spanish colonies and other regions of the world. Panel B shows the distribution of exports according to the textile type, following Spanish authority categorization. Panel C shows raw cotton country of origin shares.

FIGURE D.3. **Cotton textile industry location 1879**



Notes: This maps shows the location of cotton industry in 1879. Cotton industry location is define according to the presence of either spindles or looms. Provinces in the Basque County and Navarra did not have information (Shown on thick lines). Canary Islands not shown in the map.

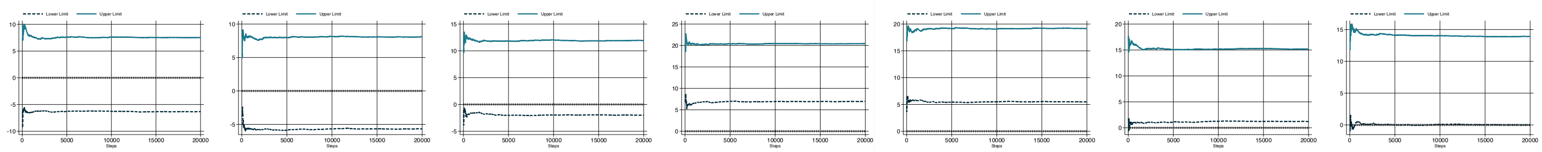
FIGURE D.4. **Cotton textile patents by stage production**



Notes: This graph shows the evolution of non-cotton related textile patents for weaving and other production stages. I show the 2 years moving average of the raw numbers for each series.

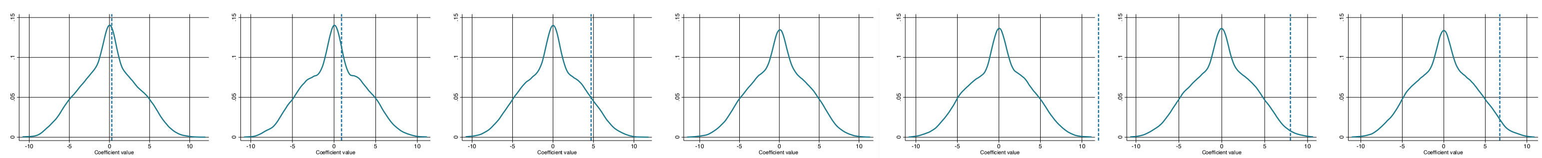
FIGURE D.5. **Randomization Inference Event Study**

Panel A: Lower and Upper Bounds Confidence Interval Convergence



a) Cotton x 1883-1886 **b)** Cotton x 1887-1890 **c)** Cotton x 1891-1894 **d)** Cotton x 1895-1898 **e)** Cotton x 1899-1902 **f)** Cotton x 1903-1906 **g)** Cotton x 1907-1910

Panel B: Placebo Coefficients Distribution

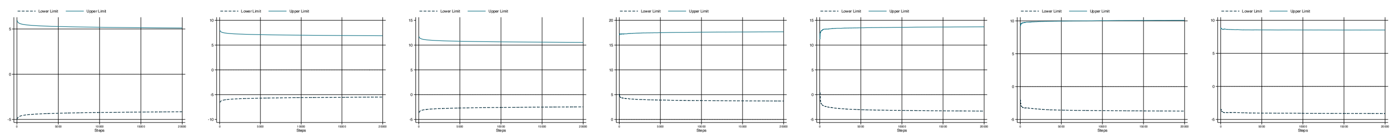


a) Cotton x 1883-1886 **b)** Cotton x 1887-1890 **c)** Cotton x 1891-1894 **d)** Cotton x 1895-1898 **e)** Cotton x 1899-1902 **f)** Cotton x 1903-1906 **g)** Cotton x 1907-1910

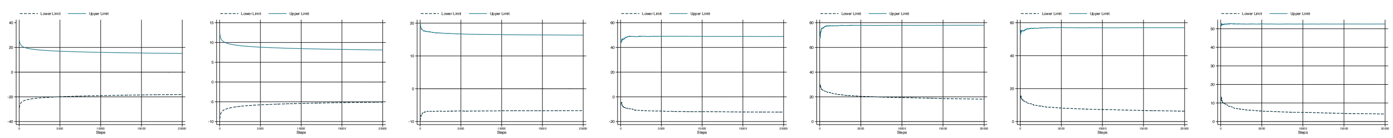
Notes: Panel A shows confidence intervals lower and upper bound convergence path ifor Figure 5 results. I follow the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Panel B shows the distribution placebo coefficients and the position of the coefficient presented in Figure 5. I estimated them using 10.000 randomization allocations.

Figure D.6. **Randomization Inference Event Study Triple Difference**

Panel A: Lower and Upper Bounds Confidence Interval Convergence

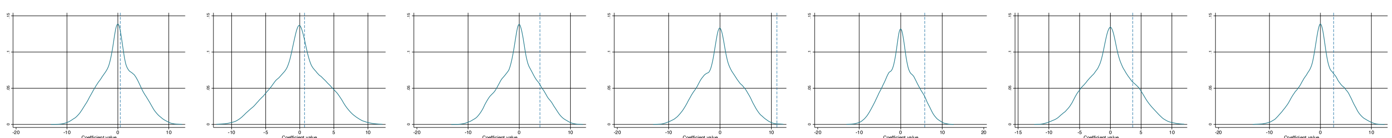


a) Cotton x 1883-1886 **b)** Cotton x 1887-1890 **c)** Cotton x 1891-1894 **d)** Cotton x 1895-1898 **e)** Cotton x 1899-1902 **f)** Cotton x 1903-1906 **g)** Cotton x 1907-1910

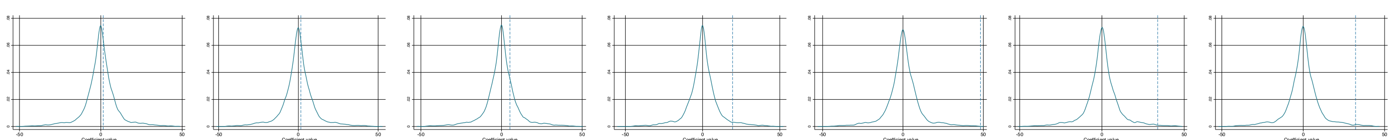


h) Cotton x Weaving x 1883-1886 **i)** Cotton x Weaving 1887-1890 **j)** Cotton x Weaving x 1891-1894 **k)** Cotton x Weaving x 1895-1898 **l)** Cotton x Weaving x 1899-1902 **m)** Cotton x Weaving x 1903-1906 **n)** Cotton x Weaving x 1907-1910

Panel B: Placebo Coefficients Distribution



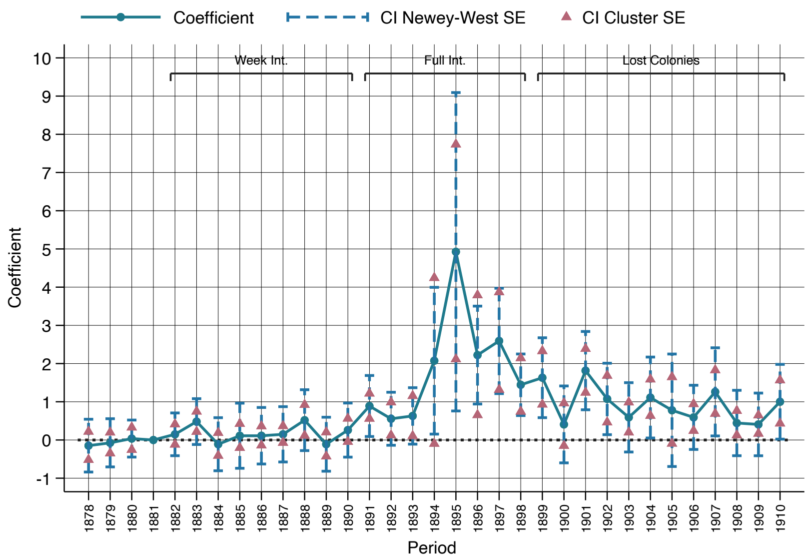
a) Cotton x 1883-1886 **b)** Cotton x1887-1890 **c)** Cotton x 1891-1894 **d)** Cotton x 1895-1898 **e)** Cotton x 1899-1902 **f)** Cotton x 1903-1906 **g)** Cotton x 1907-1910



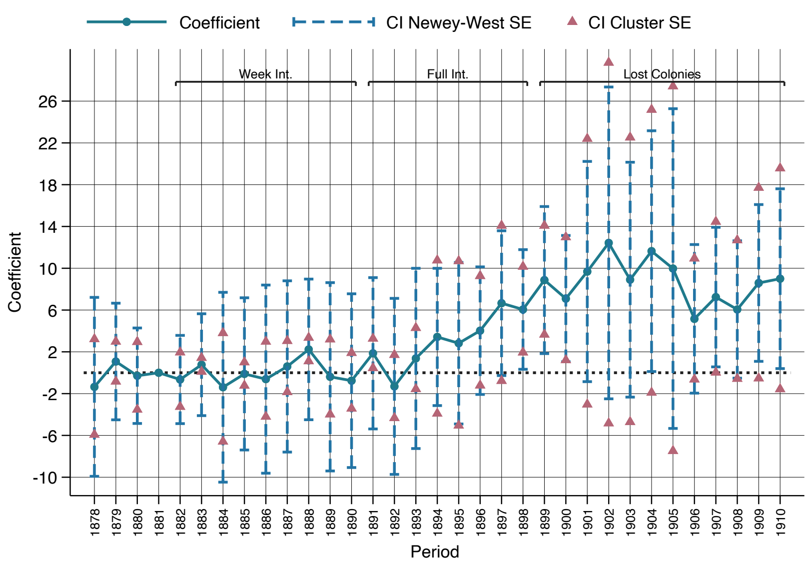
h) Cotton x Weaving x 1883-1886 **i)** Cotton x Weaving x 1887-1890 **j)** Cotton x Weaving x 1891-1894 **k)** Cotton x Weaving x 1895-1898 **l)** Cotton x Weaving x 1899-1902 **m)** Cotton x Weaving x 1903-1906 **n)** Cotton x Weaving x 1907-1910

Notes: Panel A shows confidence intervals lower and upper bound convergence path ifor Figure 6 results. I follow the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Panel B shows the distribution placebo coefficients and the position of the coefficient presented in Figure 5. I estimated them using 10.000 randomization allocations.

FIGURE D.7. **Event study: Effect on cotton and weaving patents using yearly panel**



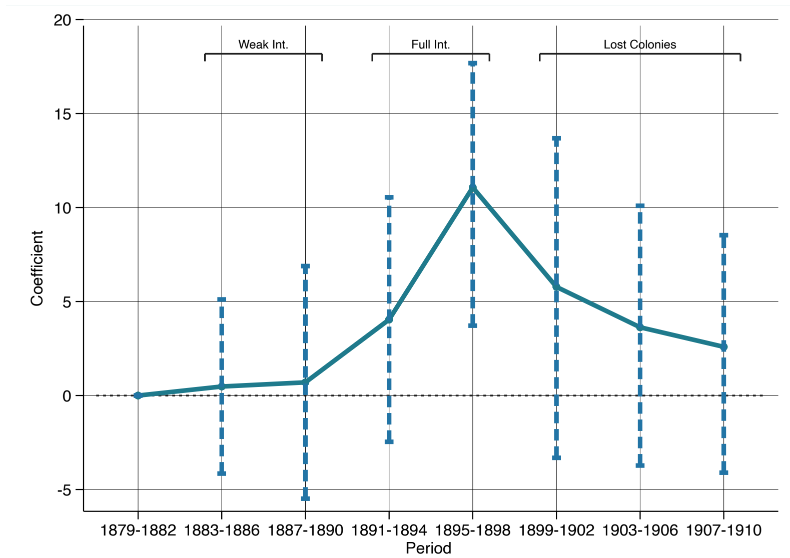
A. Cotton x ....



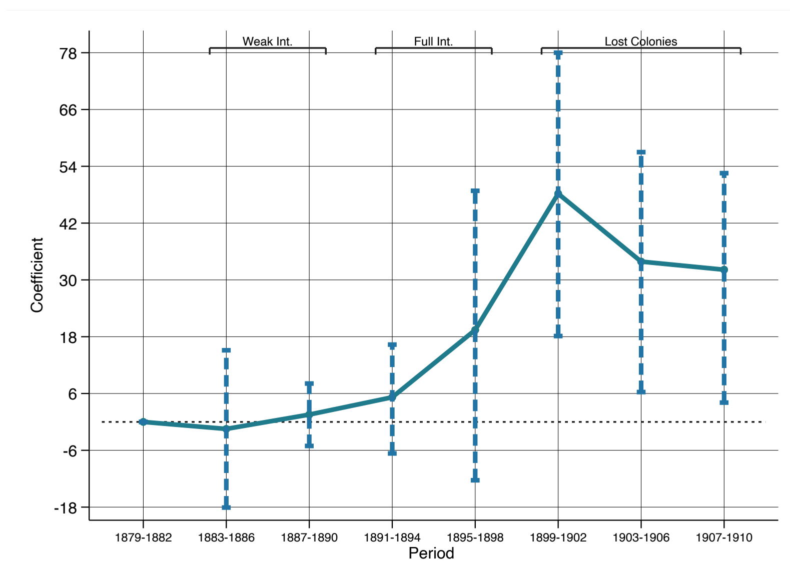
B. Cotton x Weaving....

Notes: Yearly panel form 1878-1911 estimation of the triple difference model including differential technology group trends. Newey–West standard error with a lag length of 3, based onGreene's rule-of-thumb lag length of $T^{1/4}$ rounded upwards. Double cluster standard errors at group and year.

FIGURE D.8. **Event study: Effect market integration and colonies lost on cotton and weaving patents (Only Spanish residents)**



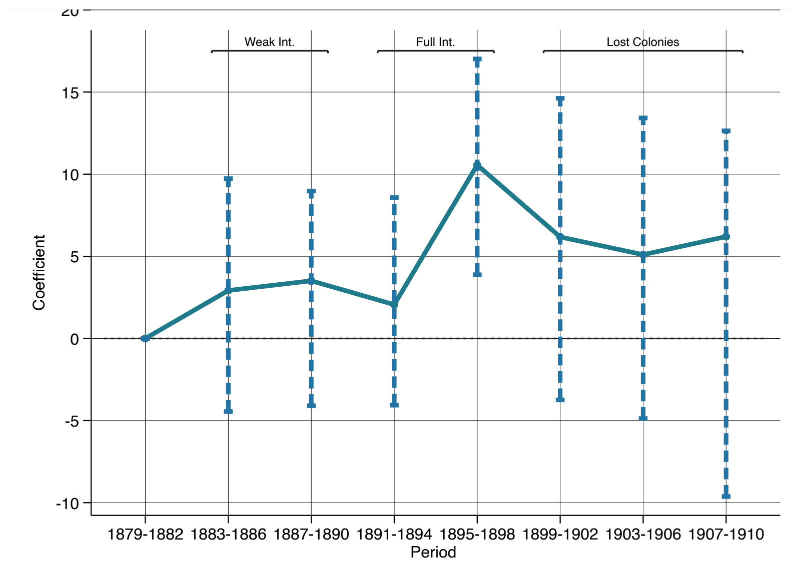
A. Cotton x ....



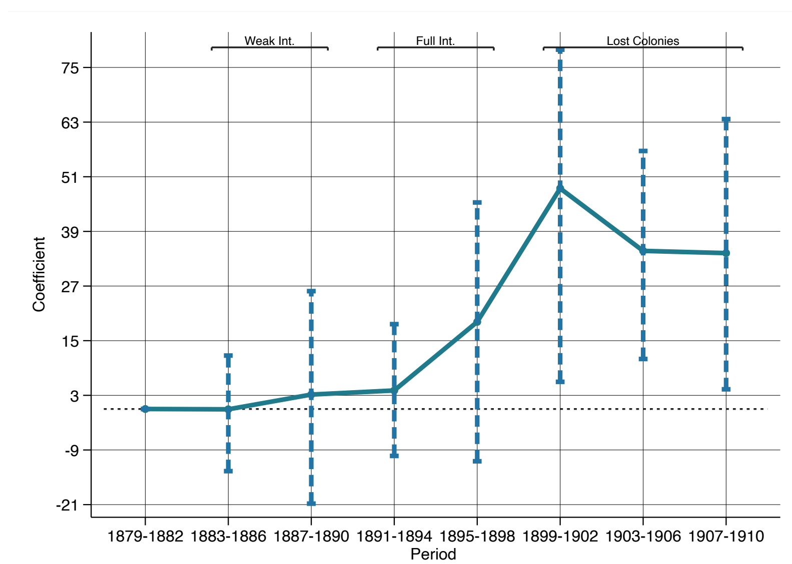
B. Cotton x Weaving x ....

Notes: This figure presents the regression results from equation 5.2 using only Spanish resident's patents. Panel A shows γ_k^1 coefficients and panel B shows γ_k^3 coefficients . 95% Confidence Intervals using randomized inference. I followed the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Total number of observations 496.

FIGURE D.9. **Event study: Effect market integration and colonies lost on cotton and weaving patents (Controlling by Argentina imports)**



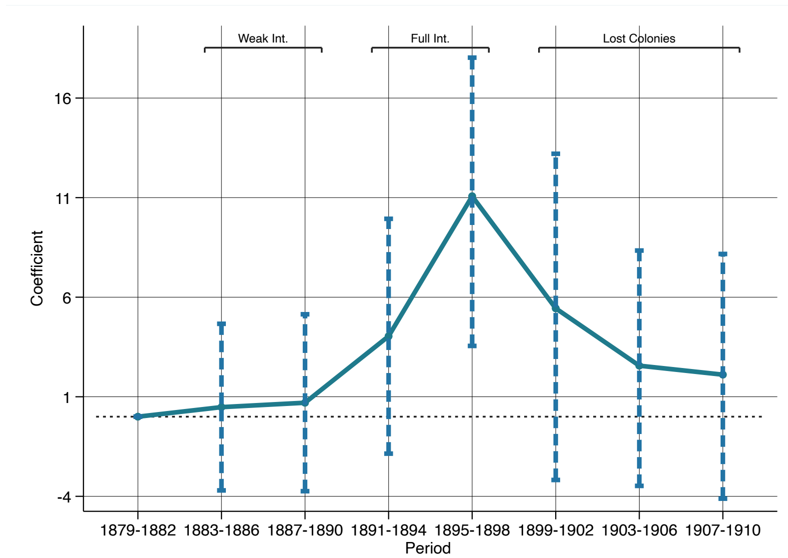
A. Cotton x ....



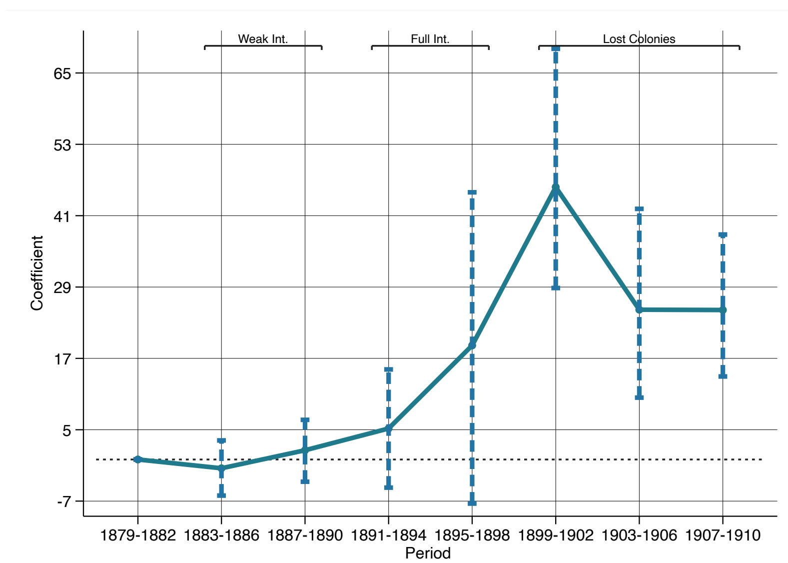
B. Cotton x Weaving x ....

Notes: This figure presents the regression results from equation 5.2 using total patents applications controlling by total Argentinian imports values. I interact the yearly log of total Argentinean imports with technology-category fixed effects. Panel A shows γ_k^1 coefficients and panel B shows γ_k^3 coefficients . 95% Confidence Intervals using randomized inference. I followed the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Total number of observations 496.

Figure D.10. **Event study: Effect market integration and colonies lost on cotton and weaving patents (Innovation patents)**



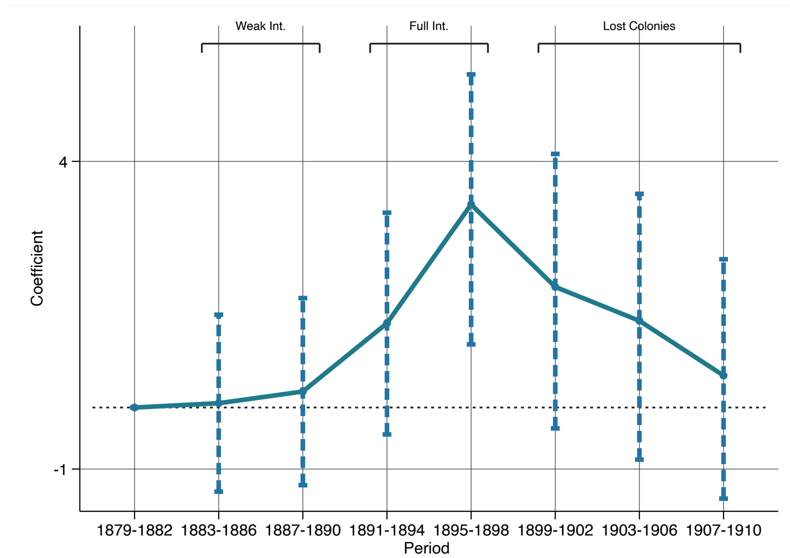
A. Cotton x ....



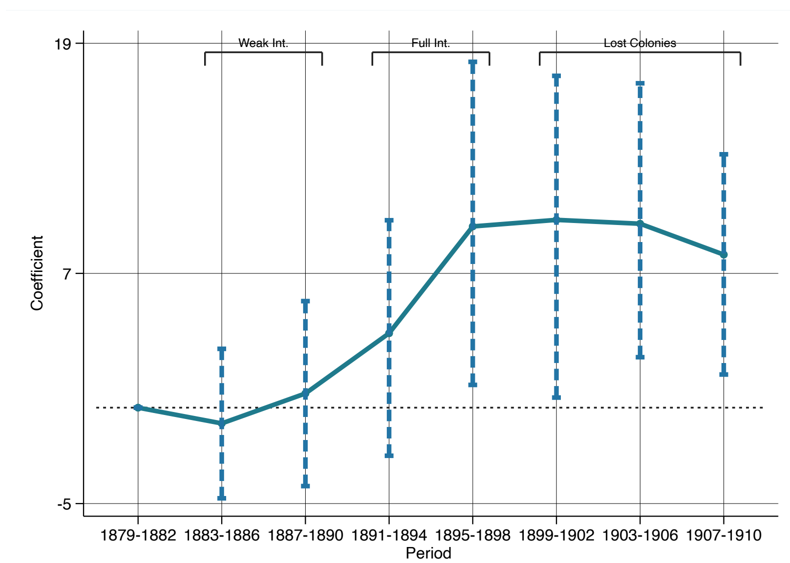
B. Cotton x Weaving x ....

Notes: This figure presents the regression results from equation 5.2 using only innovation patents. Panel A shows γ_k^1 coefficients and panel B shows γ_k^3 coefficients . 95% Confidence Intervals using randomized inference. I followed the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Total number of observations 496.

FIGURE D.11. **Event study: Effect market integration and colonies lost on cotton and weaving patents (High quality patents)**



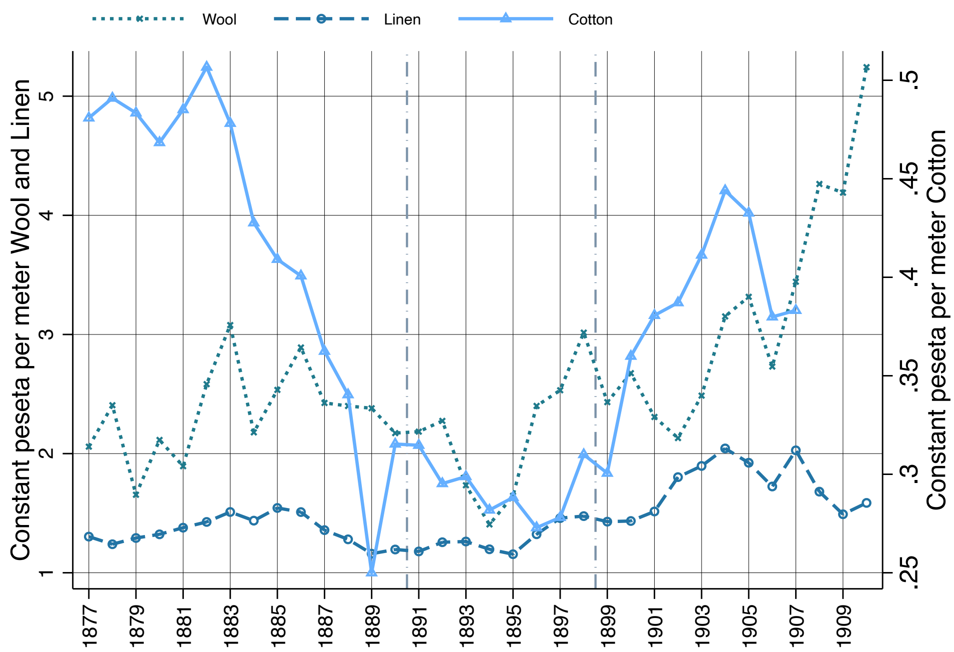
A. Cotton x ....



B. Cotton x Weaving x ....

Notes: This figure presents the regression results from equation 5.2 using only patents have confirmation of being used during the first 2 years after the application. Panel A shows γ_k^1 coefficients and panel B shows γ_k^3 coefficients . 95% Confidence Intervals using randomized inference. I followed the algorithm proposed by Garthwaite (1996) using 20.000 randomization allocations. Total number of observations 496.

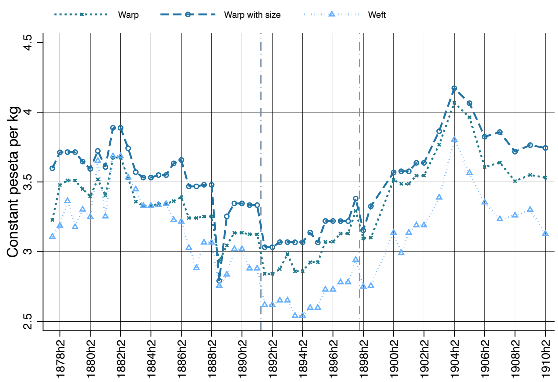
FIGURE D.12. **Cotton, wool and linen prices**



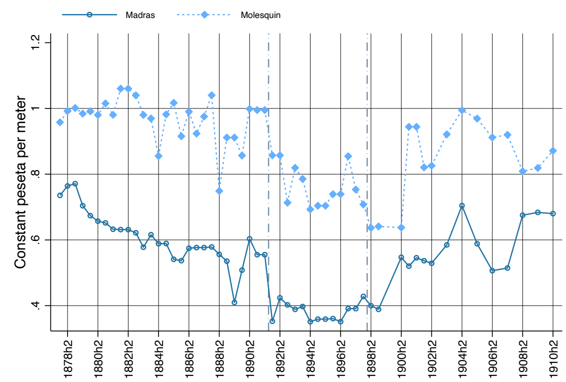
Notes: This graph shows prices series for cotton, linen and wool finished fabric. Cotton price correspond to *Percalina superior lisa* found on inventory ledgers of *La España Industrial*. Wool and linen prices correspond to English export prices to Spain gathered by Nadal Ferreras (1978) in pounds and converted to pesetas using historical series provided online by Rodney Edvinsson. All prices measured in constant pesetas per meter.

Figure D.13. **Cotton textile prices and quality**

Panel A: Prices

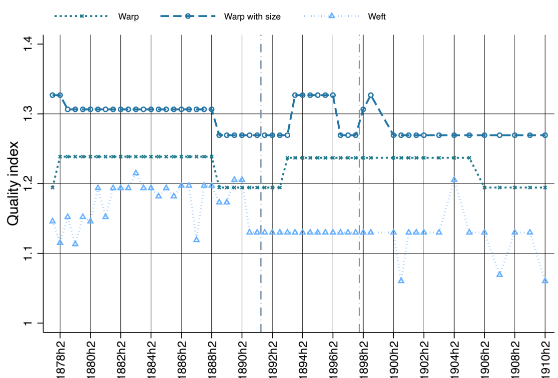


A. Thread

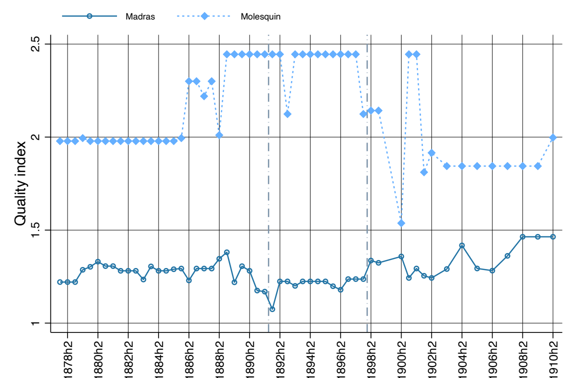


B. Fabric

Panel B: Quality index



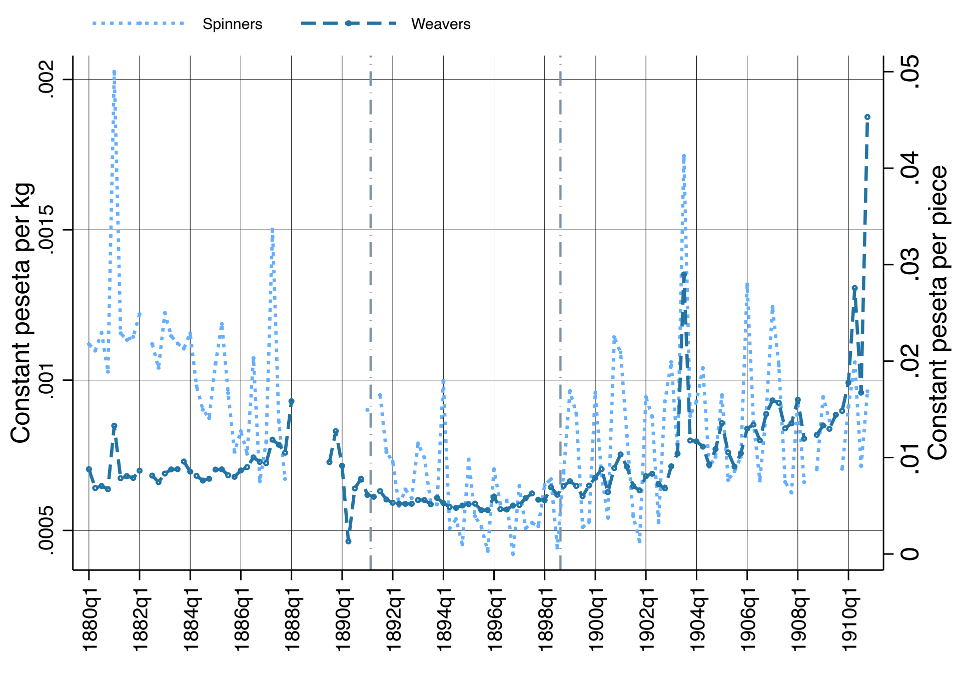
C. Thread



D. Fabric

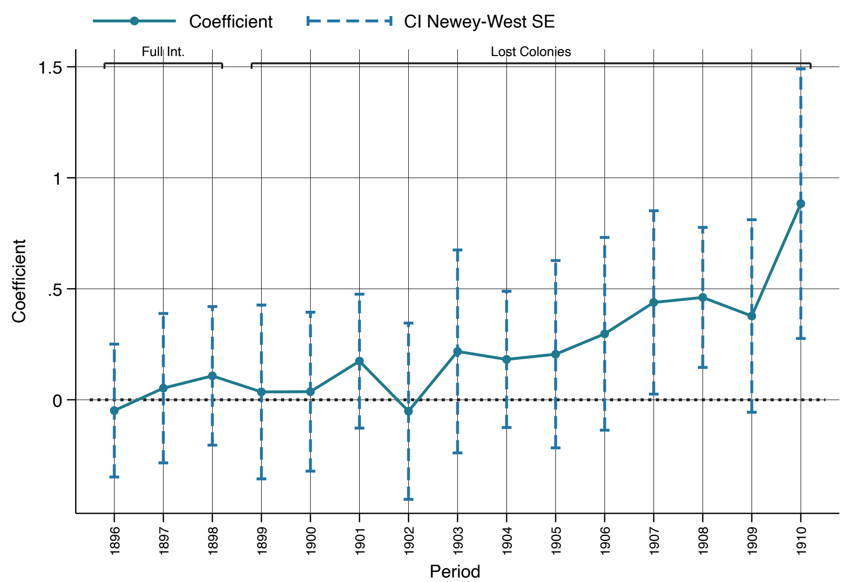
Notes: This graph shows prices (Panel A) and quality index (Panel B) for different product varieties of cotton thread and fabrics. Each series is constructed as an average for price or quality of the available product on the inventory ledgers on each time of period. Data is semi-annually between 1898 and 1902 and yearly between 1903 and 1910. Graphs A and C shows the series for three different thread types: warp thread without size, warp thread with size and weft thread. Thread price is measure as constant pesetas per kilogram. Graphs B and D shows the series for two different fabric types: madras and molesquin. Quality index is measure with respect the lower price product inside the thread or fabric products. Fabric price is measure as constant pesetas per meter.

Figure D.14. **Cotton textiles wages**



Notes: This graph shows wages on cotton industry: spinners and weavers salaries recorded from weekly payroll ledgers of *La España Industrial*. Quarterly data from weeks 1, 14, 27 and 40 from 1880 to 1910. Spinners wage measured as average constant pesetas paid to workers per thread kilogram produced. Weavers wage measured as average constant pesetas paid to workers per fabric piece produced. Information not available between 1888-1890.

FIGURE D.15. **Behavior of spinners and weavers salaries cotton industry**



Notes: This figure shows the coefficients γ_k^W from regression C.1 for each year starting from 1896. 95% confidence intervals using Newey-West standard errors with 4 lags. Quarterly data from 1880q1 to 1910q4. Total number of observations 219.

Appendix E. Tables

Table E.1. textile patent technology classification: 1879-1911

Category	No Cotton	Cotton
Preparation and Spinning		
Mechanical treatment of natural fibrous or filamentous material to obtain fibers or filaments	110	87
Chemical or biological treatment of natural filamentous or fibrous material to obtain filaments or fibers for spinning	46	28
Mechanical methods or apparatus in the manufacture of man-made filaments, threads, fibers, bristles or ribbons	20	21
Chemical features in the manufacture of man-made filaments, threads, fibers, bristles, or ribbons	12	11
Preliminary treatment of fibers	25	96
Spinning or twisting	38	146
Crimping or durling fibers, filaments, yarns or threads, yarns or threads	14	28
Warping, beaming or leasing	6	28
Finishing or dressing of filaments, yarns, threads, cords, ropes ot the like	8	40
Weave		
Shedding mechanism; patterns cards or chains; punching of cards; designing patterns	21	98
Woven fabrics; methods of weaving; looms	184	836
Auxiliary weaving apparatus; wavers tools; shittles	5	106
Knitting	11	82
Textile and Finishing		
Braiding or manufacture of lace, including bobbon-net or carbonised lace; breading machine; braid; lace	35	64
Trimming; ribbons, tapes or bands	13	34
Making nets by knotting of filamentous material; making knotted carpets or tapestries	15	10
Making textile fabrics from filamentous material; non-woven fabrics; wadding	53	172
Sewing	16	147
Embroidering	8	58
Treating textile materials using liquids, gases ar vapours	16	76
Finishing, dressing, tentering or stretching textile fabrics	17	66
Laundering, drying, ironing, pressing or folding textile articles	14	127
Mechanical or pressuring cleaning of carpets, rugs, sacks, hides or other skin or textile articles or fabrics	6	10
Marking, inspecting, seaming or severing textile materials	6	34
Pleating, kilting or goffering textile fabrics or wearing apparel	2	12
Dry-cleaning, washing or bleaching fibers, filaments, threads, yarns, fabrics. Bleaching leather or furs	18	60
Treatment, not provided for elsewhere in class	26	71
Wall, floor or like covering materials	28	3
Dying of printing textiles; dyeing leather, furs or solid macromolecular substances	39	219
Decorating textiles	12	53
Ropes or cables in general	16	26

Notes: List of all patent categories with at least one patent between 1878-1911.

Table E.2. Descriptive statistics province by cotton industry presence

	No cotton presence (1)	Cotton presence (2)	Difference (3)
Log population	12.638	12.768	0.129
	(0.419)	(0.392)	[0.298]
Share of men	0.493	0.488	-0.005
	(0.014)	(0.021)	[0.349]
Share of regular residents	0.963	0.965	0.002
	(0.039)	(0.044)	[0.883]
Share of single	0.535	0.541	0.006
	(0.029)	(0.025)	[0.490]
Share of married	0.400	0.390	-0.010
	(0.031)	(0.029)	[0.253]
Share of literate	0.272	0.195	-0.077
	(0.113)	(0.095)	[0.019]
Share of catholics	0.999	0.998	-0.002
	(0.001)	(0.006)	[0.203]
Share born in the same province	0.933	0.925	-0.008
	(0.088)	(0.056)	[0.716]
Share of regular residents in the same municipality	0.970	0.956	-0.014
	(0.017)	(0.085)	[0.475]

Notes: Column 1 reports mean and standard errors for province without cotton machines in 1879. Column 2 reports mean and standard errors for province with cotton machines in 1879. Column 3 reports differences between province with and without presence of cotton machines. p-value in square brakets.

TABLE E.3. Cross sectional dependence and serial correlation tests Difference-and-difference Model

	Yearly Model (1)		*4 Years Model* (2)	
	Panel A: Cross sectional dependance			
Pesaran CD-test	7.881		14.419	
	[0.000]		[0.000]	
	Panel B: Serial Correlation			
	AR(1)	AR(2)	AR(1)	AR(2)
Q-stat	5.469	5.488	1.610	4.238
	[0.019]	[0.064]	[0.204]	[0.120]
LM-stat			15.915	26.387
			[0.026]	[0.015]

Notes: This table presents the test for cross sectional dependence (Panel A) and serial correlation (Panel B) for difference-and-difference models errors. Panel A null hypothesis is cross section independence against alternative hypothesis of correlation among panel groups. Panel B null hypothesis is not serial correlation against the alternative hypothesis of serial correlation up to order 1 or 2. Q-stat is Born and Breitung (2016) biased corrected test. LM is portmanteau test for serial correlation developed by Inoue and Solon (2006). This test is designed for panels with small number of period observations (T), as in the case of 4 year panel. With moderate number of periods the test is not adequate since its dimension increases with the number of periods. Therefore the test is not suitable in the yearly panel. P-values in double brackets.

TABLE E.4. Cross sectional dependence and serial correlation tests
Triple difference model

	Yearly Model (1)		*4 Years Model* (2)	
	Panel A: Cross sectional dependance			
Pesaran CD-test	5.300		5.879	
	[0.000]		[0.000]	
	Panel B: Serial Correlation			
	AR(1)	AR(2)	AR(1)	AR(2)
Q-stat	6.474	7.083	2.835	5.045
	[0.011]	[0.029]	[0.092]	[0.080]
LM-stat			10.516	18.871
			[0.161]	[0.127]

Notes: This table presents the test for cross sectional dependence (Panel A) and serial correlation (Panel B) for triple difference models errors. Panel A null hypothesis is cross section independence against alternative hypothesis of correlation among panel groups. Panel B null hypothesis is not serial correlation against the alternative hypothesis of serial correlation up to order 1 or 2. Q-stat is Born and Breitung (2016) biased corrected test. LM is portmanteau test for serial correlation developed by Inoue and Solon (2006). This test is designed for panels with small number of period observations (T), as in the case of 4 year panel. With moderate number of periods the test is not adequate since its dimension increases with the number of periods. Therefore the test is not suitable in the yearly panel. P-values in double brackets.

TABLE E.5. Response of cotton textiles machines on spinning and finishing sector to market integration and colony lost

	Dependent Variable: Machines per 10.000 Inhabitants					
	Panel A: Spinning				Panel B Finishing	
	Mechanical Spindles		Manual Spindles		Mechanical	
					Raising	Shearing
	(1)	(2)	(3)	(4)	(5)	(6)
Cotton ...						
... x Market integration	73.80	117.70	−0.21	2.03	0.02	0.03
	(184.17)	(153.64)	(1.96)	(3.21)	(0.11)	(0.09)
	[[0.662]]	[[0.412]]	[[0.912]]	[[0.496]]	[[0.715]]	[[0.802]]
... x Early colonies lost	−49.04	−4.12	−0.30	1.92	0.04	0.08
	(101.56)	(92.68)	(2.07)	(3.51)	(0.11)	(0.09)
	[[0.672]]	[[0.963]]	[[0.884]]	[[0.555]]	[[0.292]]	[[0.600]]
... x Late colonies lost	−107.70	−5.35	0.93	4.39	0.07	0.07
	(95.94)	(72.15)	(1.90)	(3.05)	(0.10)	(0.09)
	[[0.296]]	[[0.937]]	[[0.612]]	[[0.126]]	[[0.341]]	[[0.389]]
Observations	1716	1144	1716	1144	1144	1144
Material fixed effects	✓	✓	✓	✓	✓	✓
Time fixed effects	✓	✓	✓	✓	✓	✓
Province fixed effects	✓	✓	✓	✓	✓	✓
Controls	✓	✓	✓	✓	✓	✓
Comparison Cotton vs.	W and L	W	W and L	W	W	W

Notes: Control variables include logarithm of population, men share, share residents, single shared population, married shared population, catholic shared, share of illiterate, share of born in same province, share of nationals born in different province, share of regular residents in the same municipality. W stands for wool and L for linen and hemp. Odd columns compare the cotton industry with wool and linen (hemp) industry and even columns compare the cotton industry only with wool industry. Comparison period 1979. P-values from a test based on HC2 standard errors tested against a t-distribution are in double squared brackets. I follow the correction proposed by Imbens and Kolesár (2016). Standard errors in parentheses are clustered on province-year level. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.