Why did the industrialization of cotton spinning happen so early in Switzerland (1801-1848)?

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Abstract

Abstract: This paper examines the remarkably early development of Switzerland's cotton-spinning industry. The corresponding history differs in crucial ways from the British case by occurring in a landlocked country without colonies or domestic coal-fields. Nevertheless, Switzerland's pioneering cotton-spinning mills were highly profitable. Extra transportation costs from importing raw cotton could be offset by hiring textile workers from a preindustrial cottage industry at relatively low wages. The coal handicap could be overcome by exploiting water power from Alpine rivers. As a result, the cotton-spinning industry spread along these rivers rather than being concentrated in large cities.

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1 Introduction

Historical narratives of the Industrial Revolution must answer two thought-provoking questions. Why did the industrialization begin in Western Europe around the year 1800, rather than in historically more advanced civilizations, such as China (see e.g. Landes, 1999, ch.2, 14; Pomeranz, 2001; Mokyr, 2016, ch.16-17)? Why did Britain, and especially the cotton-spinning factories concentrated in Lancashire, take the lead within Western Europe rather than, say, the Netherlands, which had been at the forefront of financial modernization, trade, or urbanization before 1800 (see e.g Mokyr, 2000; De Vries and Van Der Woude, 1997)? These questions are thought-provoking, because they are not easily answered by some popular and plausible theories on the origin of the industrialization and the early breakthroughs in mechanized cotton spinning. For example, arguing that cheap coal was imperative to fuel the steam engines of mechanized textile production overlooks that corresponding deposits were also available outside Britain and Europe (Mokyr, 2009, pp.100ff.; McCloskey, 2010, ch. 21-22). In a similar vein, theories of exploitation arguing e.g. that cotton was produced by means of slavery on colonial plantations are unconvincing, because these preindustrial forms of exploitation were neither unique to Western Europe in general, nor to Britain in particular (Eltis and Engerman, 2000; McCloskey, 2010, ch.26-17). Similar things could be said about the role of seaports and navigable rivers to foster trade, or scientific progress as steppingstone for economic progress through mechanized production.

Against this background, a convincing narrative about the origins of the industrialization must draw on profound changes that first occurred in Western Europe and/or Britain around 1800. The Enlightenment was such a historically unprecedented, and far-reaching development. Establishing a link with the novel industrial technologies that soon followed is

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plausible, insofar as enlightened thinking cultivated a belief in innovation and progress, fostered the creation of useful knowledge, strengthened measurement and scientific methods, or welcomed the dialogue between savants of why things work (prospective knowledge) and practitioners with skills to actually make things work (prescriptive knowledge) (Mokyr, 2002, ch.5; 2016, ch.15). Like this, the Industrial Enlightenment might well have laid the foundation for a culture of innovation and technological progress that became, in turn, the engines of sustained economic growth; first in British cotton spinning, and later across sectors and economies around the world (Mokyr, 2009). Focusing on the question why the industrialization began in Britain, Allen (2009) has suggested that its preindustrial economy was characterized by a unique combination between high wages and low energy costs (i.e. cheap coal). Arguably, this combination meant that labor-saving cotton-spinning machines were much more profitable, and hence much more in demand, than across the English Channel or overseas. Although this argument has been challenged by Clark (2012, pp.88ff.) or Crafts (2010, pp.155ff.), industrial technologies could obviously not have thrived without being lucrative.

This paper revisits these questions by focusing on Switzerland as one of the earliest followers of the British cotton-spinning industry. In general, entrepreneurs on the European Continent tried almost immediately to catch up with the technological revolution that had begun during the last part of the eighteenth century. In particular, by copying—or stealing—the early industrial technology, spinning machines installed in dedicated factories began to appear in Eastern Switzerland around two decades after the corresponding breakthroughs had been made by Samuel Crompton at the end of the 1770s, and only a couple of years after they had appeared in France or Belgium. Until the mid-1830s, an industrial cluster with around 150 cotton-spinning mills and more than 600'000 spindles had catapulted Switzerland's preindustrial textile production into the modern age (Dudzik, 1987, pp.478-479; Mitchell, 1992, p.497). Although Britain had during this decade around 10 million, and France around 2.5 million spindles, Switzerland is a much smaller country with a population at the time of around 2 million, as compared with 15 million in Britain, and 33 million in France (Mitchell, 1992, pp.4,8). As another comparison, early industrialized Belgium with a population of around 4 million had in the 1830s only around 200'000 cotton spindles (Mitchell, 1992, pp.3, 496). Contemporary observers were aware of this development (Bergier, 1983, p.216). For example, the British merchant and Member of Parliament John Bowring (1792-1872) wrote, with a certain admiration, in an official "Report on the Commerce and Manufactures of Switzerland" that:

> "Switzerland, almost unobserved, [has] been gradually [...] forcing [its] way into all the markets of the world"[...] Such a remarkable result was not the consequence of geographical position is evident, for Switzerland neither produces the raw material which she manufactures nor when manufactured, has a shiny outlet port [...] The cotton she manufactures must be conveyed hundreds of miles from the Mediterranean and a greater distance from the Atlantic Ocean. [...] Notwithstanding the natural disadvantages of the geographical position of the Swiss cantons, I am persuaded there does not exist in the world a manufacturing industry more sound, healthy, and elastic than that of Switzerland.

Resonating with Bowring's words, the early development of Switzerland's cotton-spinning industry has also gone "almost unobserved" by the international literature on economic history.[1] This ignorance is, perhaps, unfortunate, because the Swiss case differs in crucial ways from that of Britain, and those of other early industrialized followers, such as Belgium or France. In particular, as alluded to in the quote above, landlocked Switzerland is obviously no seafaring nation, never had colonies, and therefore did not directly benefit from the

[1] There is a small, domestic literature with key contributions from Bergier (1983, part 2) on Switzerland's industrialization in general, and Vayrassat (1982) and Dudzik (1987) on the cotton industry in particular.

corresponding trade. Furthermore, there are no domestic coalfields. Before 1800, there were also no big cities, and thereafter large industrial centers did not emerge. Before the Federal Constitution of 1848, Switzerland was not even a country in the modern sense, i.e. there was no central government, nationally integrated market, or common currency. Rather, to cope with the internal linguistic and religious fragmentation, the so-called "Old Swiss Confederation" represented until the second part of the nineteenth century no more than a loose club of sovereign cantons (e.g. Swiss provinces). How an early industrialization was possible despite these handicaps is an intriguing question, which could shed light on the broader debate mentioned at the outset.

As elsewhere, cotton spinning was important for Switzerland's industrialization by being the high-technology sector that showed the way for the subsequent mechanization of other parts of the economy; including textile machinery and chemical products as early followers (see Bergier, 1983, pp.218ff, pp.247ff.). Moreover, this paper's focus on the first half of the nineteenth century can be motivated as follows. The year 1801 witnessed the opening of the first mechanized cotton-spinning mill in Switzerland. In the year 1848, the modern Swiss Confederation was established by means of the above-mentioned Federal Constitution. The result was a profound transformation of the political and economic environment, including the national integration of the domestic market that paved the way for a railway construction boom, or for the nowadays iconic banking sector (Herger, 2023, ch.5). Across Western Europe, the mid-nineteenth century also roughly coincides with the end of the first wave of industrialization dominated by mechanized textile production (Mokyr, 2002, pp.78ff.; Allen, 2009, p.2)

Against this background, this paper describes, quantifies, and analyzes the early history of mechanized cotton spinning in Switzerland. In the light of recent research, particular attention is given to the following questions: In how far did Switzerland participate in the Enlightenment? How was a successful mechanization possible without domestic coalfields? How high were the wages in Switzerland's cotton-spinning sector? What was the typical background of entrepreneurs in this sector? What about the profitability of their mills when compared with the arguably low return in neighboring France, and high return in Britain?

The paper is organized as follows. The next section provides a synoptic background on the geographical conditions and key historical developments around Switzerland's early industrialization. Section 3 portrays the early industrialization of cotton spinning in Switzerland. Section 4 briefly discusses the Swiss (Industrial) Enlightenment. Section 5 estimates the profitability of cotton-spinning mills in Switzerland. Section 6 concludes.

2 Geographical and historical background

2.1 Geography: A lot of mountains and lots of rain

Perhaps the most iconic feature of Switzerland's geography is a topography dominated by the foothills and peaks of the Alpine mountain range. Combined with a location on the Western side of the European Continent and a climatic zone characterized by drifting western winds, this topography gives rise to quite abundant precipitation from humid air coming off the Atlantic Ocean (see Figure 1). To illustrate this precipitation despite the landlocked location, average rainfall in the Swiss capital city of Bern—with roughly 100cm and 125 days with rain per year—is well above that of wet London—with around 60cm and 110 days with rain per year. As a result, Switzerland is the source of some of the largest rivers of Western Europe, including the Rhine and the Rhone as well as tributaries to the Danube. At the local level, smaller rivers and streams with strong currents throughout the year can be found in most valleys and creeks.

Figure 1: Average annual precipitation (in cm) across Western Europe

Source: Schweizer Weltatlas (2019, p.62). Modern borders of Switzerland have been added.

2.2 Switzerland's cultural and political environment in the eighteenth century

Although the nexus between natural environments and cultural and political developments should not be overrated, the mountainous terrain has probably plaid a role for the corresponding development in Switzerland (Bergier, 1983, pp.12ff.). In particular, the Alps have long been a formidable, although not insurmountable, barrier for travelling and trade. Therefore, it is perhaps no coincidence that they mark a cultural border within Europe with Germanic languages and culture dominating to the north, while Latin-based languages (Italian and French) and culture dominate to the south and west. In a similar vein, especially with preindustrial weapons technology, high ground and narrow gorges were easier to defend than the lowlands. This could be a reason why the Swiss cantons of the so-called "Old Swiss Confederation" (Alte Eidgenossenschaft) managed to survive so long as small, independent republics. In contrast, during the seventeenth and eighteenth century, their direct neighborhood, and especially France under the Bourbon monarchy, witnessed the rise of centrally organized forms of government.

The relatively independent, and with respect to military conflicts traditionally neutral, status from the emerging absolutist monarchies in Europe acted occasionally as magnet for refugees (see Bonjour, 1946, pp.27ff.). Above all, before 1800, "Huguenots" fleeing from the counter-reformation in France, but also Protestants reacting to religious oppression in Italy, had arrived in several waves since the sixteenth century (Thürer, 1970, pp.62ff.). By the eighteenth century, the financial, economic, and technological expertise of these religious refugees had fostered the development of banking in Geneva (Herger, 2023, ch.3), the watch industry in areas next to the French border (Bergier, 1983, 165-166), and last, but not least, early textile manufacturing around Basel or Zurich (Bergier, 1983, pp.161ff.). Nevertheless, cities like Geneva or Zurich remained relatively small. For example, around 1800, Geneva with around 25'000 inhabitants was Switzerland's largest city, while Vienna had a population of around 250'000, Paris around 500'000, and London around 1 million. Moreover, by European standards at the time, especially the rural parts of Switzerland were not particularly wealthy. They rather suffered from chronic emigration, most famously in the form of mercenaries recruited into foreign armies, as the mountainous terrain could not support a growing local population (Thürer, 1970, p.72).

For the Old Swiss Confederation, the eighteenth century was largely a peaceful period. However, religious tensions still lingered from the Reformation, when Huldrych Zwingli (1484-1531) and Jean Calvin (1508-1564) had turned, respectively, Zurich and Geneva into epicenters of Protestantism (see e.g. Fahrni, 1987, pp.32ff.). Conversely, especially the cantons in the Alpine hinterland had remained faithful to Roman Catholicism. Probably more than the linguistic fragmentation, the antagonism between these different interpretation of Christian faith hindered the formation of centralized government. Rather, decentralization of political power across small territories was imperative to accommodate religious differences. Indeed, until the end of the eighteenth century, the Old Swiss Confederation could not be turned into a state in the modern sense, but remained a loose club of sovereign cantons. This lack of modernization implied that there was no central bureaucracy, national law, shared tax system, or common currency. Although all cantons were republics, their political systems, power, and status were far from being uniform. The rural cantons in the Alpine hinterland were early, although highly imperfect, democracies with public assemblies (Landsgemeinden), where decisions on political issues took place (Möckli, 1987). Elsewhere, elements of an estate-based society, which characterized Europe's social structure during the Ancien Régime, were much more evident. The Cantons of Bern, Fribourg, and Solothurn were, for example, essentially governed by a group of aristocratic families, and Basel or Zurich by the leading members of the craft guilds (Fahrni, 1987, p.38). Furthermore, Geneva or St.Gallen were only contractually aligned protectorates of the Old Swiss Confederation, and other parts, such as the current cantons of Aargau and Thurgau, were no more than subordinate territories (see e.g. Thürer, 1970, p.69).

In contrast to the intellectual vigor of the Enlightenment, which will be further discussed in Section 4, stagnation characterized the eighteenth-century political and social environment of the Old Swiss Confederation (Thürer, 1970, pp. 77-79). More specifically, until the French Revolution of 1789, the inherited privileges within the estate-based society, the separation between autonomous cantons and their protectorates, and in cases like Zurich or Bern the prerogatives of the city over rural areas were maintained (Thürer, 1970, pp.69-72). However, owing to the traditionally close economic and cultural ties with France, enlightened ideas like the equality before the law, or that all human-beings are endowed with unalienable rights fell on fertile ground in Switzerland. Hence, their breakthrough during the French Revolution also undermined the authority of the aristocracy and the guilds in Switzerland's city cantons and, to a smaller extent, the elites of the rural cantons. It is therefore not surprising that the Old Swiss Confederation collapsed with little opposition when the revolutionary armies of the French Republic invaded in 1798 (Thürer 1970, pp.80-84).

2.3 Pervasive instability between 1798 and 1848

As mentioned above, the period of the Ancien Régime had largely been peaceful for the Old Swiss Confederation. Furthermore, Switzerland has not been involved in military conflicts since the mid-nineteenth century. Conversely, the years between 1798 and 1848 were highly instable by witnessing foreign invasions and occupations, domestic coups d'état, severe internal tensions within and between cantons, and even a brief civil war (see e.g. Thürer, 1970, pp.85ff; Fahrni, 1987, pp.51-52). At the beginning of this period, in 1798, the Old Swiss Confederation was replaced by a centrally governed, progressive, and in the French sense enlightened "Helvetic Republic" (Helvetische Republik; Republique Helvétien). However, it soon became clear that a unitary puppet state is ungovernable in such a fragmented environment as Switzerland. The Helvetic Republic quickly decayed into chaotic politics including a series of coups d'état. Hence, in 1803, Napoleon decided to bring back the sovereignty of the cantons, although their former protectorates and subject territories were reorganized into six new cantons joining the Swiss Confederation, and the aristocracy and craft guilds lost their political privileges for good (Bergier, 1983, p.204). Of course, the more or less complete subordination to the French Empire and the connection with Napoleon's fate remained. Hence, it was only with the Congress of Vienna in 1815 when the Swiss Confederation actually regained its independence (Bonjour, 1946 pp.54ff.). As elsewhere in Europe, the following decades were characterized by political struggles between conservative parts of society wanting to restore as much as possible from the Ancien Régime, and progressive parts wanting to regenerate the ideals of the French Revolution. Unfortunately, within Switzerland, these conflicts were aggravated by religious tensions between Catholic, and mostly conservative, and Protestant, and mostly progressive, cantons. Tensions regularly turned into violence and in November 1847 boiled over into fully blown, although brief, civil war referred to as "Sonderbundskrieg".[2] The quick and decisive progressive victory during this war paved the way for far-reaching reforms adopted, or for some Catholic cantons imposed, through the Federal Constitution of 1848. In particular, a modern Federal government was installed, press censorship was abolished, and the freedom of speech was guaranteed across the nation (Thürer, 1970, pp.113ff.; Herger, 2023, pp.17ff.).

The Napoleonic Wars were also fought with the means of economic warfare. In this regard, the Continental System ("blocus continental") to strangle British trade between 1806 and 1814 represented another major upheaval for landlocked Switzerland (Thürer, 1970, p.93). However, even after 1815, many obstacles to free trade remained in place. For example, to protect the domestic industry, France imposed tariffs on Swiss exports in 1816 and some German states followed suit when the "Zollverein" was founded in 1834 (Somm, 2022, pp.233ff.). More absurd was the obstruction of domestic trade by literally hundreds of internal tariffs levied at bridges and cantonal borders as well as the parallel circulation of dozens of different currencies (Thürer, 1970, p.100; Baltensperger and Kugler, 2017, pp.21-26). Another area, where the lack of economic and political integration mattered, were the problems with constructing a national railway system, which began in Switzerland more than a decade later than e.g. in Belgium, France, or Germany. Against this background, it is perhaps not surprising that the Federal Constitution of 1848 also served as an instrument for integrating the domestic market; especially through the abolishment of internal tolls and tariffs as well as the establishment of nationally organized postal, telegraphic, and railway systems. Moreover, the Swiss franc was introduced as national currency in 1850 (Baltensperger and Kugler, 2017, p.135). Within this modernized political and economic environment, the industrialization in machinery, foodstuff, chemical products, or banking gathered pace during the second half of the nineteenth century (Bergier, 1983, pp.228ff.; Herger, 2023, pp.61ff.). Remarkably, a first wave of industrialization, mostly in cotton spinning, had already taken place under the less favorable economic and political conditions before 1848. The next section focuses on this development.

[2]The "Sonderbund" was a clandestine alliance of the Catholic cantons to secure the backing of France and Austria-Hungary in the event of an armed conflict with the Protestant cantons. When the existence of this alliance was leaked out, it provided the casus belli.

3 Portrait of the early industrialization of cotton spinning in Switzerland

3.1 Preindustrial textile manufacturing in Switzerland

As illustrated by Lancashire in Britain, or Flanders in Belgium, revolutionary textile industries usually emerged within preexisting centers of textile manufacturing. This pattern also applies to the case of Switzerland. More specifically, Eastern Switzerland, and especially the city of St.Gallen, had become a noteworthy center for manufacturing linen since at least the sixteenth century (Bergier, 1983, pp.159ff.). Furthermore, as already mentioned in Section 2.2, Protestant refugees had brought along the skills and commercial connections to develop export-oriented silk manufacturing clusters, especially in the Cantons of Zurich and Basel (Bergier, 1983, pp.161-162). For both linen and silk products, France used to be the most important foreign market (Bergier, 1983, p.175).

Until mechanized production arrived in Europe, textile manufacturing was largely a cottage industry (see e.g. Mokyr, 2002, pp.122ff., Mokyr, 2009, pp.96ff.). In Switzerland, and in other German-speaking areas, this way of organizing the production process was referred to as "Verlagssystem", or putting-out system (Bergier, 1983, pp.146, 157, 167). Thereby, an intermediary, called "Verleger", was responsible for procuring raw material, such as cotton, and supplying it to self-employed spinners, and selling the finished yarn on local or foreign markets (see also Fahrni, 1987, p.58). Meanwhile, the actual manual work was outsourced, or put-out, to peasants, for whom spinning was usually no more than a part-time occupation. As they typically worked on their own premises, this production system is also known as "home-industry". Among other reasons, textile production was outsourced to the countryside to bypass stifling regulations imposed by e.g. the guild of tailors or wavers in cities like St.Gallen or Zurich. Furthermore, labor was typically cheaper in rural areas. For peasants in the hinterland of Zurich or Eastern Switzerland, the putting-out system was nevertheless worthwhile, as it offered a source of income when agriculture lay idle during wintertime.

In preindustrial Switzerland, wool and flax had long been the dominant textile fibers. However, during the eighteenth century, cotton became increasingly popular (Bergier, 1983, pp.164, 170ff.; Im Hof *et al.*, 1986, pp.461ff.). Raw cotton was usually imported from the Levant or Egypt via ports in Italy, such as Trieste or Genoa, or Southern France, such as Marseille. By the 1780s, cotton had become the most popular textile fiber in Switzerland. Especially the Canton of Zurich and the eastern part of the country had emerged as a cotton-manufacturing centers of European importance (Bergier, 1983, pp.202, 207). In its heyday during the 1780s, the corresponding sector provided work to some 50'000 people in the Canton of Zurich, and another 25'000 in Eastern Switzerland and produced around 1'500 tons yarn annually (Dudzik, 1987, p.64).[3] To put these numbers into context, according to estimates for the year 1795, the Canton of Zurich had at the time a population of roughly 180'000, and Eastern Switzerland (Cantons Appenzell, St.Gallen, Thurgau) of roughly 250'000 (Schuler, 2023, p.34).

As mentioned in Section 2.3, the 1780s were followed by massive economic setbacks as well as extraordinary levels of political instability. For the textile manufacturing sector around Zurich and St.Gallen, serious problems emerged when Bourbon France resorted to protect its struggling economy during the 1780s through tariffs and import restrictions on Swiss textile products (Bergier, 1983, pp.184ff.). The resulting downturn was, of course, aggravated by the turmoil that spread across Europe after the French Revolution of 1789. As a consequence, around the year 1800, the number of home-based cotton spinners in Switzerland had almost halved to around 40'000 (Dudzik, 1987, p.65).

[3] Owing to the seasonality and part-time character of the putting-out system, these kind of figures should be interpreted as rough estimates (see Mokyr, 2009, p.96).

3.2 Pioneering age of mechanization

Further to the extremely instable political environment, the revolutionary machinery that appeared in textile production in Britain during the late eighteenth century posed another fatal threat to Switzerland's cotton manufacturers. In particular, the development of the "Mule-Jenny" by Samuel Crompton (1753-1827) during the late 1770s had opened the door for mechanized spinning on a massive scale in the novel mills (i.e. factories) of Lancashire (see e.g. Allen, 2009, pp.188ff.; Dudzik, 1987, p.41). This technological breakthrough, or macro-invention, was followed by decades of continuous improvements, or micro-inventions, that e.g. increased the number of spindles per Mule-Jenny, allowed for partially automatized spinning with the Selfactor, or for continuous-action instead of intermitted spinning with the Throstle Frame (see Maw *et al.*, 2021; Dudzik, 1987, pp.13, 45-49). In a similar vein, downstream and upstream production stages, such as cleaning raw cotton with the help of the Batteur invented in 1797, were sooner or later mechanized. Switzerland almost immediately felt the effects of the transition from home-based manual, to factory-based mechanized spinning. In particular, as early as the 1780s, merchants in Eastern Switzerland began to supply local wavers with machine-made British yarn (Dudzik, 1987, pp.64-65). As it offered the irresistible combination between better quality at a lower price, traditional hand spinners found themselves plainly and simply outcompeted (see also Somm, 2022, p.199).

The only option to deal with the machine-made British yarn was to emulate the novel technology. As early as the 1780s, there were attempts to do so in traditional cotton-manufacturing centers on the European Continent, such as the regions around Rouen and Mulhouse in France, Ghent in Belgium, or Chemnitz and Leipzig in the German state of Saxony. However, it was anything but easy to get the revolutionary machines going without outside help, which was difficult to obtain due to the British export ban of the novel technology. Furthermore, local mechanics and technicians often lacked the practical skills to operate (illegally) imported, let alone to successfully construct replicas of the British cotton-spinning machines.[4] Finally, in contrast to Britain, the return on corresponding investments was arguably low in countries, such as France (Allen, 2009, pp.203ff.).

Corroborating the experiences on the European Continent, the first experiments to build cotton-spinning machines in Switzerland, as e.g. by the mechanic Hans Ulrich Sonderegger in 1780 or the enlightened scholar Franz Xaver Bronner in 1794, ended in failure (Somm, 2022, p.201; Lemmenmeier, 2014, p.8). Success only arrived in 1801, when the merchants Christian Näf and Marc Antoine Pellis set up the "Baumwollspinnerei in St.Gallen", and managed to put 26 Mule-Jennies with around 5'300 spindles into operation (Bergier, 1986, pp.204-205; Dudzik, 1986, pp.72ff.). The corresponding machines were probably imported from France, and locally assembled with the help of two highly paid British mechanics. Despite the short-term success, this pioneering factory was not thought through, because it was not built along a river. Without access to water power, and with no local coalfields to provide fossil energy for steam engines, the first Mule-Jennies in Switzerland had to be driven with the help of oxen. Lacking the option of energy-intensive production, the "Baumwollspinnerei in St.Gallen" was probably doomed to failure and, actually, went bankrupt in 1819.

A more promising venture began with the second Swiss cotton-spinning mill, the "Spinnerei Hard", which was founded in 1802 in the Canton of Zurich near the town of Winterthur, right next to a fast-flowing river. Its strong current throughout the year provided ample energy to power the novel machines, which had again been installed with the help of a British technician. Initially, there were 8'000 spindles from Throstle Frames, which were, however, replaced after a couple of years with 10'000 spindles from 44 Mule-Jennies. The

[4] For the early development of British textile machines that actually worked, the practical contributions of skilled craftsmen, applied mechanics, and dedicated tinkerers were arguably also crucial (see e.g. Kelly *et al.*, 2023, pp.64ff.).

initial capital had been raised from four local textile merchants (Dudzik, 1987, pp.72-73; Bergier, 1983, p.205). During the next couple of years, similar mills were built in Rapperswil (Canton of St.Gallen), and in Trogen (Canton of Appenzell). Unfortunately, the latter burned down in 1814. The year 1805 marks the establishment of Escher, Wyss & Co., named after its founders Hans Caspar Escher, who was born into a prominent textile-merchant family in the city of Zurich, and the private banker Salomon von Wyss. This company, which started production with 5'000 spindles, became an early landmark of Switzerland's industrialization by striving after cutting-edge technology in cotton spinning. To this end, an internal workshop was set up to maintain, repair, and improve the company's machinery. In this workshop, mechanics soon learned how to construct own textile machines. Like this, Escher, Wyss & Co. stumbled across a new business and, indeed, become an early textile-machine producer on the European Continent (Bergier, 1983, pp.211, 218ff.).

3.3 Development under the Continental System

Between 1806 and 1814, Switzerland's cotton-spinning industry developed under economic conditions dictated by the Continental System (see also Sec 2.3). As a direct consequence of the efforts to strangle British trade with the European Continent, yarn imported from across the English Channel into Switzerland declined from around 500 tons in 1799 to an annual average of less than 300 tons between 1806 and 1812 (Dudzik, 1987, pp.75-76). Conversely, Swiss yarn enjoyed strong demand in large parts of Europe (Bergier, 1983, pp.207-208). To meet this lucrative demand, dozens of mechanized mills were founded.

The first steps of the industrialization in Switzerland are associated with a pioneering group of cotton-spinning entrepreneurs, 30 of which are listed in Table 3 of Appendix A (see also Dudzik, 1987, pp.112ff.). Probably, this list provides a quite comprehensive picture given that only several dozens of factories existed during the first decades of the nineteenth century. As regards the personal background of these entrepreneurs, virtually all of them were locally born, raised, and educated. There are personal connections; most obvious those within families (e.g. Brändlin or Bebié). Furthermore, a professional background in textile trading or manufacturing, including family connections in this trade as indicated by the father's profession, stands out. Otherwise, a link to technical craftsmanship or as mechanic was relatively common. However, in this regard, connections with watch or clock-making, which were prominent crafts in nearby Western Switzerland (Bergier, 1983, p.219), are strikingly absent; in contrast to the early British industrialization (Allen, 2009; pp.204-205; Kelly *et al.*, 2023, pp.64ff.). Last, but not least, the pioneering Swiss entrepreneurs neither emerged from a peasant or workman background (except for Johannes Beugger), nor were they born into leading families of the Ancien Régime (except for Hans Caspar Escher). By and large, the personal and professional circumstances of Switzerland's pioneering entrepreneurs concur with what has been found elsewhere (see Crouzet, 1985).

Perhaps, the protectionism of the Continental System reduced the pressure to modernize, or establish state-of-the art factories (see e.g. Somm, 2022, p.211). Indeed, apart from the renowned companies mentioned above, most mills founded until 1814, especially in the Canton of Zurich, were actually *not* comparable with the Spinnerei Hard or Escher, Wyss & Co. They rather represented a mechanized version of the traditional home-industry in terms of operating no more than a couple of spinning machines with less than 1'000 spindles in small workshops or on private premises (see Dudzik, 1987, p.75; Bergier, 1983, p.205). Often, these "mechanized workshops" were not even mills in the proper sense of the term, as their machines were driven by hand, instead of using water power.

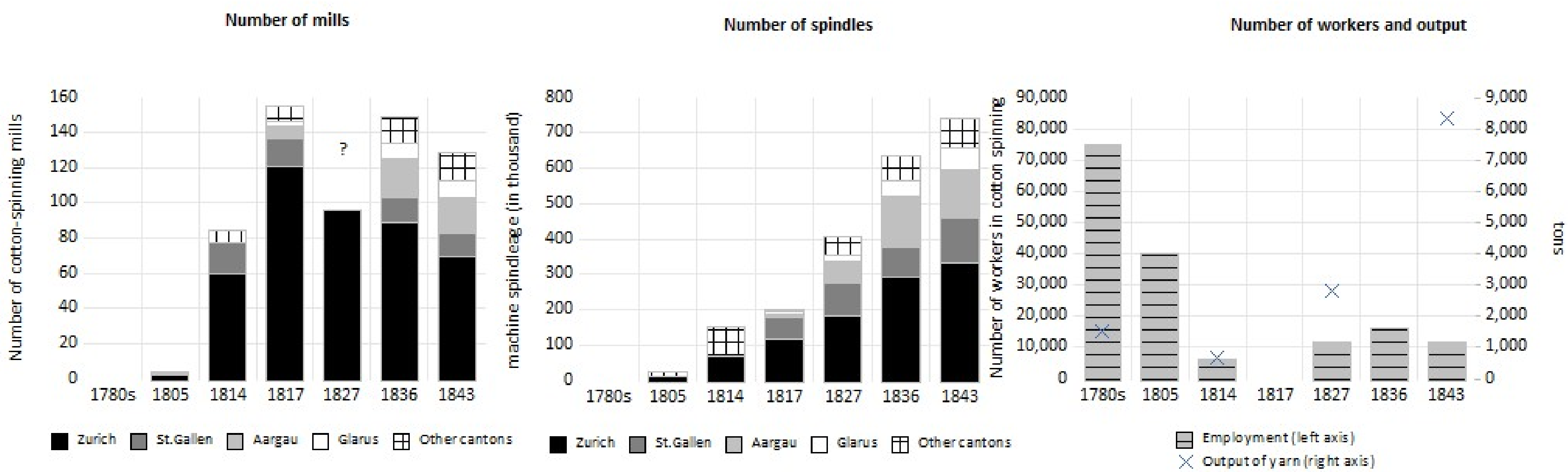
Figure 2 quantifies the development of Switzerland's cotton-spinning industry. As shown by the left panel, an official count during the year 1814 recorded 85 mechanized cotton-spinning mills, which represents an increase by a factor of seventeen when compared with 1805. According to the middle panel, during the same period, the total machine spindleage had climbed from 25'000 to around 150'000. This increase by "only" a factor of six suggests that the mills established during the Continental System were, on average, substantially smaller than those founded before. According to the right panel, in 1814, total annual output stood at around 700 tons of yarn, which is less than half the 1'500 tons manufactured during the heyday of the cottage industry in the 1780s. Bearing witness to the creative destruction of the transition from manual to mechanized production, employment in cotton spinning had dropped massively, from around 75'000 in the 1780s to only 5'000 in 1814. During this year, the average cotton-spinning mill in Switzerland had around 1'800 spindles and employed around 60 workers. For comparison, in England at the time, there were between 1'000 and 1'500 cotton-spinning factories with a combined spindleage of almost five million (Maw *et al.*, 2021 p.27). Hence, in terms of the average number of spindles, an English mill was at least double the size of a Swiss mill. Corroborating these data are contemporaneous eyewitness reports from Hans Caspar Escher during a visit to Britain in 1814. From this study tour—or, in fact, a trip in industrial espionage—he was fascinated to seeing steam-powered factories with forty to fifty thousand spindles, and streets in Manchester with more spinning machines than in entire Switzerland (Somm, 2022, pp.213-215).

Mechanised workshops, which sometimes consisted of no more than one spinning machine installed in a farm building, were, of course, badly positioned to compete with British factories, whose yarn began to recapture the European market after the dismantling of the Continental System in 1814. Surprisingly, the following years did not see a wave of bankruptcies among these small companies, but first dealt the mortal blow to the few remaining hand spinners (Bergier, 1983, p.206; Dudzik, 1987, p.66). Actually, until 1817, another 60 mechanized mills appeared in the Canton of Zurich, and another 11 in Eastern Switzerland pushing their total number to 155 (see left panel of Fig. 2). Given the increase of the total spindle capacity by only around 50'000 (see middle panel of Fig. 2), or one third, many of them were again relatively small. For the year 1817, the first comprehensive data for the Canton of Zurich underscore this development. At the time, this canton officially counted 121 mills, or more than three-quarters of the total number of Switzerland, and a spindleage of 117'000, or less than two-thirds of the total of Switzerland. A detailed breakdown reveals that 99 companies belonged to the group of mechanized workshops with typically less than 1'000 spindles, 10 had between 1'000 and 3'000, and another 10 between 3'000 and 5'000 spindles (Dudzik, 1987, pp.107). Finally, the biggest mills, the above-mentioned "Escher, Wyss & Co." and the "Spinnerei Hard" had, respectively, 8'580 and 15'552 spindles (Dudzik, 1987, p.74). Overall, the cotton-spinning industry of Switzerland was at the time characterized by a bimodal structure. At the top end, there were a handful of genuine factories with dozens of more or less up-to-date Mule-Jennies and thousands of spindles installed under one roof. These mass-producing companies dominate the historical image of the early industrialization. What is less well known, there were also more than one hundred "mechanized workshops" with a spindleage below 1'000.

3.4 Decades-long consolidation process

At the dawn of the 1820s, the mechanized cotton-spinning industry of Switzerland embarked on a decades-long consolidation process, which gradually eroded the bimodal structure from the pioneering age (Bergier, 1883, pp.211ff.). Data for the Canton of Zurich bear witness to this structural change in terms of a marked decline of the number of companies with fewer than 1'000 spindles from 99 in 1817, to 88 in 1821, 46 in 1826, 21 in 1836, and just 5 in 1853 (Dudzik, 1987, p.107). At the other end of the size distribution, large factories equipped with micro-improved technology, such as Selfactors and Throstle Frames, and tens of thousands of spindles capable of genuine mass-production eventually prevailed. This consolidation process was not linear, but rather characterized by short economic downturns with waves of bankruptcies, as around the years 1825 or 1837, while the establishment of increasingly large factories often took place during periods of robust economic growth, as

Figure 2: Swiss Cotton-Spinning Industry: Number of mills, spindles, employment, and output (1780s-1843)



Notes: Compiled from Dudzik (1987, pp.478-479) and Bergier (1983, pp. 205, 209, 214). For the year 1827, the number of mills has not been recorded (unlike the number of cotton spindles). For the Canton of Zurich, the corresponding observation for 1827 has been filled with cantonal data from 1826.

during the first part of the 1820s or the years between 1828 and 1837 (see Dudzik, 1987, pp.107ff.).

As regards the initial stages of this consolidation process, the comeback of attractively priced yarn made in Britain put pressure on spinning margins, i.e. the difference between prices for yarn and raw cotton on the Swiss market (Dudzik, 1987, p.75, pp.103f.). In addition, despite the downfall of the Continental System, France had developed a taste for protectionist trade policies and, hence, retained some tariffs on Swiss textile products (Thürer, 1970, p.100; Somm, 2022, p.233). This difficult economic environment posed an existential threat to inefficiently small, and technologically backward, mills, many of which only stayed in business for couple of years. In fact, around two thirds of the 155 mills that existed in 1817 went out of business during the 1820s (Dudzik, 1987, p.109). Although also more than 100 new mills were founded during this period, half of them had met the same fate by the year 1831 (Dudzik, 1987, p.109). In general, larger cotton-spinning factories were better positioned to survive in this brutally competitive environment. Nevertheless, around a dozen of them also went bankrupt between 1817 and 1829 (see Dudzik, 1987, pp.110, 126).

As an industry, mechanized cotton spinning continued to grow in Switzerland during the 1820s. In particular, the middle panel of Figure 2 shows that the overall spindleage more than doubled within a decade from 198'000 in 1817 to 407'000 in 1827. Unfortunately, for the 1820s, no data about the number of mills outside the Canton of Zurich is available (see left panel). However, in this canton, whose 184'000 spindles accounted for almost half of Switzerland's capacity during the late 1820s, the average number of spindles per mill had essentially doubled from slightly less than 1'000 in 1817 to roughly 1'900 in 1827. Meanwhile, the average workforce per mill remained more or less constant at around 50. An outstanding feature of the Swiss cotton-spinning industry was its ongoing reliance on water power, which drove roughly 84 per cent of Zurich's spindles in 1827, while 14 per cent were still manually operated, and no more than 2 per cent relied on steam power (Bergier, 1983, p.213).[5] According to the right panel, in 1827, Switzerland's cotton-spinning industry directly employed more than 10'000 people. Thanks to productivity gains from the new machinery, within a decade, yarn output had more than quadrupled to around 3'000 tons per year.

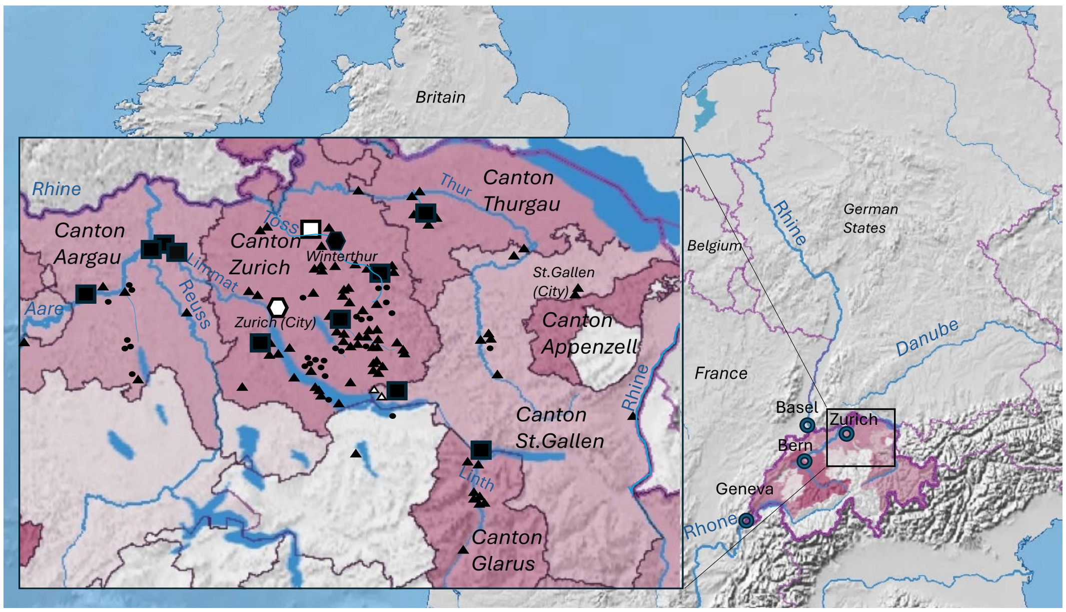
After a brief economic downturn around the year 1825, the consolidation process continued under relatively benign conditions until 1836. During this decade, Switzerland's spindle capacity expanded yet again by more than 50 per cent to 634'000 (see middle panel of Fig. 2). With roughly 150 mills in 1836, according to the left panel, the average number of spindles per mill had increased further to more than 4'000. Of note, more than 220'000 spindles were added through the construction of two dozen large factories, two of which boasted almost 25'000, and one even 33'000 spindles (Dudzik, 1987, p.147). Many of them were located outside the traditional cotton-spinning centers of Zurich and St.Gallen, especially in neighboring Aargau and Glarus to exploit the strong currents of large rivers as well as the cheaper labor in these cantons. Moreover, these new factories were built to accommodate the latest machinery, such automatized Selfactor Mule-Jennies, or Throstle Frames that allowed for efficient continuous-action spinning (Dudzik, 1987, pp.148ff.). Technologically, Switzerland no longer lagged far behind the level of Britain, and had even began to produce own textile machinery in landmark companies, such as Escher, Wyss & Co. and J. J. Rieter & Co. With a typical workforce of around 100, the leading Swiss cotton-spinning mills had also a similar size than their competitors in Lancashire (Dudzik, 1987, p.151). Taken together, the age of mass-produced yarn had begun in Switzerland (Dudzik, 1987, p.35). It was this industrial environment that John Bowring came across during his visit in 1836.

[5] For comparison, steam accounted for almost three quarters of total installed power in Lancashire in 1838 (Crafts and Wolf, 2014, p.1124).

3.5 Location of the Swiss cotton-spinning industry in 1836

The map of Figure 3 depicts the location and size of Switzerland's cotton-spinning mills in 1836 as compiled from a list published in Dudzik (1987, p.485-489). A mill with less than 1'000 spindles is marked with a small circle, with 1'000 to 10'000 spindles by a medium-sized triangle, and with more than 10'000 spindles by a large square. Mills that also produced cotton-spinning machines are marked with a hexagon. The location of the few mills whose roots dated back the pioneering age before 1806 are marked by a white interior. Predominantly Protestant cantons have a shaded background.

Figure 3: Location of cotton-spinning mills in Switzerland in 1836



Source: Own map.

There are similarities between the location of the cotton-spinning industry of Switzerland in 1836, and that of Britain in 1837 as studied by Crafts and Wolf (2014). In particular, the breakthrough of mechanized spinning had occurred within preindustrial centers of textile manufacturing, i.e. Zurich and St.Gallen in the case of Switzerland (see Figure 3), and Lancashire in the case of Britain (Crafts and Wolf, 2014). Also, the pioneering areas of the industrialization were at the time rather peripheral with remarkably rugged terrains and quite unfavorable conditions for agriculture. Maybe even more than in Lancashire, the hills and mountains of Zurich and Eastern Switzerland had long put severe constraints on feeding the local population, wherefore additional income from a new industry was perhaps highly welcome.

Crafts and Wolf (2014, pp.1107ff.) have employed a standard firm location-choice framework to econometrically study the geographic structure of the British cotton-spinning industry at the county level. In particular, they have regressed the number of cotton-spinning mills per district on explanatory variables, such surface area, the ruggedness of the terrain, humidity, the availability of water power, water hardness, coal prices, preindustrial capabilities in textile manufacturing, the distance to ports, and local market potential. The corresponding Poisson regressions have uncovered consistently significant effects from the ruggedness of the terrain, i.e. the cotton industry tended to locate in unfavorable areas for agriculture, the availability of cheap coal and water power, which was also important for driving England's pioneering textile machines, the existence of preindustrial textile manufacturing capabilities, and preindustrial population size, which proxies for local market potential and corresponding agglomeration effects from dense networks of workers and suppliers.

Table 1 employs a similar location-choice framework (Poisson count regression) to study Switzerland's cotton-spinning industry as mapped in Figure 3. The dependent variable is either the number of mills, or the number of spindles for each of the 175 districts of Switzerland.[6] These dependent variables suggest that the early Swiss cotton-spinning industry was geographically concentrated. In particular, 149 districts had no mill at all, while slightly more than half of them were located in just five districts of the Canton of Zurich (Hinwil, Pfäffikon, Winterthur, Horgen, Meilen). However, this comes across as a lower concentration than in Lancashire, which accounted for two-thirds of the British cotton-spinning industry by 1850, and almost 80 per cent at the turn of the twentieth century (Crafts and Wolf, 2014, p.1103). Conversely, as early as the 1830s, cotton-spinning mills in Switzerland began to spread out along larger rivers. This trend is manifested when looking at the number of spindles. In particular, thanks to recently built large factories, the cantons of Aargau and Glarus suddenly accounted for almost one third of Switzerland's total spindle capacity.

Wherever sensible, the results of Table 1 employ the same explanatory variables as in Crafts and Wolf (2014). Hence, relative humidity is measured in terms of average per cent per year. Arguably, higher values should support the cotton industry, because humid air makes textile fibres more pliable and, hence, prevents yarn from breaking (Crafts and Wolf, 2014, p.1105). Reliable water power is measured by the low-water flow metric $Q347$, i.e. the discharge that the main river of a district exceeds during 95 per cent (347 days) of the year. Area measures the surface of a district. Local market potential is proxied by the district population before the industrialization as taken from a national census mandated by the Helvetic Republic in 1798. In a slightly different way than in Crafts and Wolf (2014), ruggedness of the terrain is measured as percentage of the district surface officially classified as mountainous and, hence, poorly suited for agriculture. Furthermore, it is impossible to reflect cotton traditions by the number of patents filed in this industry, as there was no patent law in Switzerland before 1888. Hence, a dummy variable simply indicates the well-known districts with preindustrial cotton centers (compare Sec 3.1). As a landlocked country in the center of Western Europe, all Swiss districts are a long way from ports. In a similar vein, explanatory variables related to coal, such as its price or the required softness of the water to protect boilers and steam engines, are not included, because coal plaid a negligible role in Switzerland's early industrialization (compare Sec. 3.4). Table 4 of Appendix B contains detailed definitions, units, and sources of the variables.

The coefficient estimates of columns 1 and 2 of Table 1 confirm the nexus between preindustrial cotton centers and the early industrialization. The market-potential effect is also significantly positive. In contrast to Crafts and Wolf (2014), no significant effect from the ruggedness of the terrain arises. This insignificance could reflect that, unlike the British Isles, Switzerland consists almost entirely of uphill and mountainous terrain that does not lend itself for intensive agricultural production. As regards water power, the effect on the number of mills across Swiss districts is insignificant. Perhaps, this reflects that rivers and streams capable of driving early cotton-spinning mills can be found in almost any district. Still, when employing the number of spindles per district as the dependent variable in column 2, a significant effect from water power arises. This result could underscore the importance of stronger rivers for powering the increasingly large factories after the pioneering age. Furthermore, in columns 3 and 4, significantly positive effects are also found from the annual

[6] Using cantons instead of districts as geographical units would only leave 26 observations for the Poisson regression. Nevertheless, the corresponding results confirm that preindustrial textile traditions and water power mattered for the location of the early Swiss cotton-spinning industry.

Table 1: Poisson count regression of cotton-spinning industry location (Switzerland, 1836)

Dependent Variable:	#Mills	#Spindles	#Mills	#Spindles	#Mills	#Spindles
	(1)	(2)	(3)	(4)	(5)	(6)
Ruggedness	-0.09	-0.08	-0.17	-0.19	-0.08	-0.09
(% Mountain Terrain)	(0.07)	(0.07)	(0.10)	(0.12)	(0.07)	(0.08)
Relative Humidity	-0.55	0.04	-0.13	1.86	-0.36	-0.18
(annual average in %)	(2.92)	(3.43)	(3.36)	(3.84)	(2.89)	(3.55)
Water Power	0.14	0.58***	0.10	0.54***	0.14	0.58***
(Q347 in m^3/sec)	(0.12)	(0.17)	(0.12)	(0.17)	(0.13)	(0.17)
Preindustrial Cotton Center	2.58***	2.01***	2.21***	1.59***	2.44***	2.11***
	(0.36)	(0.36)	(0.43)	(0.47)	(0.43)	(0.40)
Area	-0.001	-0.08	-0.03	-0.05	0.03	-0.11
	(0.22)	(0.17)	(0.22)	(0.20)	(0.23)	(0.20)
Market Potential	2.04***	2.40***	2.00***	2.23***	2.01***	2.41***
(Population in 1798)	(0.43)	(0.48)	(0.43)	(0.46)	(0.43)	(0.47)
Rainfall			2.44**	2.81**		
(mm. per year)			(1.20)	(1.35)		
Protestantism					0.44	-0.29
					(0.63)	(0.61)
Number of Observations	175	175	175	175	175	175
Pseudo R^2	0.66	0.55	0.65	0.48	0.66	0.55
$\ln L$	-135.1	-495'363	-129.3	-462'827	-134.3	-492'798

Notes: The dependent variable is the number of mechanized cotton-spinning mills or the number of their spindles per district in the year 1836. Estimation is by maximum likelihood of a Poisson count regression. Aside from the dummy variables (Preindustrial Cotton Center, Protestantism), the explanatory variables have been transformed into logarithms. Hence, the coefficients reflect constant elasticities. All regressions include a constant. Furthermore, $\ln L$ reports the maximized value of the log-likelihood function. Heteroscedasticity robust standard errors are reported in parentheses. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.

rainfall depicted in Figure 1.[7] These results hint at a notable difference between Britain and Switzerland regarding the potential of hydraulic energy. Indeed, on average, the low-water flow metric (Q347) across Swiss districts of 1.7 $m^3/sec.$ is one and a half times larger than the 1.1 m^3/sec of Britain (see Crafts and Wolf, 2014, p.1122). In practice, these numbers implied that early British cotton mills could be driven by water wheels, but areas like Lancashire soon lacked rivers with regular and sufficiently strong currents to scale up production (Crafts and Wolf, 2014, p.1105). Turning to steam power fuelled with local coal provided an alternative (Balderston, 2010). The result was a concentration of the cotton industry on the coalfields of Manchester (Crafts and Wolf, 2014, p.1106). Conversely, water power long remained the dominant source of energy for Switzerland's industrialization. Larger cotton-spinning factories were simply built along rivers with stronger currents, and water wheels were constantly improved and eventually replaced by more efficient turbines (Bergier, 1983, p.213; Dudzik, 1987, pp.24, 296ff.). As a result, in Switzerland, cotton-spinning mills did not concentrate in increasingly large industrial towns, but rather lined up along rivers, such as the Töss in the Canton of Zurich, the Thur in Eastern Switzerland, the Linth in the Canton of Glarus, or the Aare and Limmat in the Canton of Aargau (see Fig. 3).

Finally, Switzerland's religious diversity within a small country provides an interesting environment to gauge whether cultural factors have fostered the early industrialization. Striking about Figure 3 is the emergence of the early cotton-spinning mills in predominantly Protestant cantons (Zurich, St.Gallen, Thurgau, Glarus), while a corresponding development is virtually absent in nearby Catholic cantons (Lucerne, Schwyz, Zug). This pattern, and the resulting difference in income and wealth, was already noticed by contemporary observes (see Im Hof *et al.*, 1986, p.532). Surprisingly, columns 5 and 6 of Table 1 report no significant effect of predominantly Protestant districts on the size of their cotton industry. Of course, Protestant beliefs could still have had an indirect effect, as preindustrial cotton centers owed much of their existence to the influx of Protestant refugees (see Sec. 2.2, 3.1).

3.6 1840s and beyond

As of 1843, the number of cotton-spinning mills had decreased to 129, while total spindleage had continued to grow to 740'000 (see Figure 2). Mainly the Canton of Zurich witnessed a substantial reduction in the number of mills. Taken together, in 1843, the Swiss cotton-spinning industry employed around 12'000 workers and produced roughly 8'300 tons of yarn per year (see Figure 2). This threefold increase in output produced with a similar level of employment as compared with the 1820s, reflects productivity gains from improved textile machinery (Selfactor, Throstle Frame) that had prevailed by the early 1840s (Dudzik, 1987, pp.148ff., 200ff.).

Switzerland's mechanized cotton-spinning industry entered a stage of maturity during the 1840s. The experimental workshops of the pioneering age had largely disappeared. As reflected by an average of almost 6'000 spindles per mill in 1843, mechanized cotton was henceforth the domain of medium-sized or large factories. Owing to small internal market, spinning was mainly done for export (Dudzik, 1987, p.35).

The export-dependence made Switzerland's cotton-spinning industry vulnerable to international disruptions. Indeed, the revolutionary uprisings that swept across Europe around 1848 briefly threatened the very survival of even the most productive mills. However, in the medium and long-term, Switzerland emerged from this turbulent year in Europe history as modernized country with an integrated national market (see Sec. 2.3). Political and economic modernization laid, in turn, the foundation for several decades of strong industrial growth (Herger, 2023, ch.5; Bergier, 1983, ch.13). Although no longer at the forefront of the

[7] The results are also robust to using the average, instead of the low-water flow (Q347), or inserting cantonal fixed effects. For the sake of brevity, these results are not reported here, but are available on request.

new wave of industrialization, mechanized cotton-spinning continued to thrive within this environment. With around 1.9 million spindles, the peak was reached during the 1880s.[8] Thereafter, a gradual relocation of the cotton-spinning industry from Switzerland to low-wage countries occurred. Like this, until the outbreak of World War I, Switzerland's spindle capacity had decreased to around 1.4 million. The following decades witnessed a further decline to around 1 million spindles until the 1960s. The negative trend continued during the age of economic globalization. In the end, the last Swiss cotton-spinning mill closed down in 2016.

4 Swiss (Industrial) Enlightenment

The Enlightenment of the eighteenth century was a historically unprecedented, and distinctively Western European movement and, hence, would fit the time and place for bringing about the economic takeoff that soon followed. More concretely, according to Mokyr (2002, ch.1-2; 2005; 2009, ch.2-3; 2016, ch.15), the Enlightenment was associated with an expansion of useful knowledge, which is thought to flourish when propositional elements–explaining how technical achievements work—and prescriptive elements—making sure that they actually do work—reinforce each other. A case in point for these synergies was the development of the steam engine, which exploits the physical laws of thermodynamics, but could not have become reality without tedious trials, detailed planning, and meticulously fabricated components. Arguably, the characteristic debate-clubs and academic societies of the Enlightenment served as fora for the crucial dialogue between the elite bearers of propositional knowledge (scholars, intellectuals, academics, etc.) and prescriptive knowledge (instrument makers, mechanics, engineers, etc.). As such, these clubs and societies helped to remove entrenched barriers between "savants" and "fabricants" that had characterized preindustrial, estate-based societies in Western Europe and elsewhere. In doing so, the Enlightenment is not only thought to have fostered technological breakthroughs (or macro-inventions), such as spinning machines, but also the search for incremental improvements of existing technical designs (or micro-inventions). The result was a marked upsurge in the pace of technological innovations that are broadly recognized as engines of modern economic growth.

According this narrative, Britain was the pioneering nation in exploiting industrial synergies between "savants" and "fabricants" (Mokyr, 2009). But what about the case of Switzerland? A priori, it is unclear whether the Enlightenment would fall onto fertile ground in the Old Swiss Confederation (see Sec. 2.2). On the one hand, in this staunchly republican and highly fragmented political environment, there could be nothing like a royal academy or society, which were e.g. founded Britain (in 1660), France (in 1666), Prussia (in 1799), Russia (in 1724), or Sweden (in 1739) to foster scientific debates and knowledge (see Mokyr, 2009, pp.48ff.). On the other hand, the absence of absolutist rule made it perhaps harder to suppress ideas that challenged established forms of political authority and economic power. Overall, enlightened ideas, such as the appeal to human reason, the belief in economic and political progress, or scientific programs to observe and catalogue the natural environment, flourished in eighteenth-century Switzerland, especially among the local elites in cities like Geneva, Basel, Bern, or Zurich (see e.g. Im Hof and Marti, 2012). The most famous representatives of Jean Jacques Rousseau (1712-1778), who was born in Geneva but for many years made Paris his home, and Voltaire (1694-1778), who was born in Paris but for many years made Geneva his home, bear witness to close cultural ties with France. Other Swiss protagonists of the Enlightenment include the anatomist and physiologist Albrecht von Haller (1708-1777), the geologist Horace Bénédict de Saussure (1740-1799), or the pedagogue and educational reformer Johann Heinrich Pestalozzi (1746-1827). Outstanding were also the Basel mathematicians Leonhard Euler (1707-1783) and Daniel Bernoulli (1700-1782), who embarked on their academic careers in the oldest, and until the nineteenth century only, Swiss university founded in that city in 1460. As such, intellectual movements like

[8] This and the following numbers have been taken from Mitchell (1992, p.479).

the Enlightenment are inherently difficult to quantify. Still, it is remarkable that in the rudimentary attempts to do so, Switzerland occupied, again almost unobserved, a leading position when looking at the number of lines in the Encyclopedia of the Enlightenment referring to a given country, the number of scientific journals per capita, or the number of scientific societies during the eighteenth century (Mokyr, 2005, pp.327ff.).

As elsewhere in Western Europe, enlightened debates in Switzerland took mainly place in private clubs, most famous among which was the Helvetic Society founded in 1761 (see e.g. Thürer, 1970, pp.75-76). Many of these societies and debate clubs dedicated themselves to practical problems (Im Hof and Marti, 2012). In this regard, the discussion, dissemination, and implementation of improved techniques in agriculture, which dominated the eighteenth-century economy, loomed large (see also Mokyr, 2009, pp.184ff.). In Switzerland, so-called "economic societies" (Ökonomische Gesellschaften) focusing on these problems were e.g. founded in Zurich (in 1746), Bern (in 1759), Fribourg (in 1761), Solothurn (in 1761), Geneva (in 1776), Chur (in 1778), and Basel (in 1795) (Erne, 2008). Another example were the so-called "reading societies" (Lesegesellschaften) that aimed at increasing literacy by opening libraries to make newspapers, magazines, and books available to the broad public (Erne, 2010). These kinds of societies appeared in Geneva (in 1750), Neuchâtel (in 1759), Schaffhausen (in 1770), Lucerne (in 1786), Basel (in 1787), and Bern (in 1791).

Allen (2009, pp.250ff.) has pointed out that there was only scant contact between the proponents of propositional knowledge and the early practitioners advancing mechanized designs of cotton-spinning in Britain. Similar things can be said about Switzerland, where hardly any of the pioneering entrepreneurs mentioned above or listed in Table 3 were involved in the just-mentioned societies and debate clubs. An exception was Franz Xaver Bronner, who not only took part in an unsuccessful attempt to build a cotton-spinning machine (see Sec. 3.2), but was also a partisan of the enlightened Helvetic Republic, and later became provost of the Swiss Academy of Sciences (Radspieler, 1965). However, the early industrialization in Switzerland seems rather to have suffered from a narrow base of prescriptive knowledge; or concretely lacked skilled mechanics, who not only understood technical designs, but were also capable of building cotton-spinning machines that actually worked. From the discussion of Section 3.2, it is remarkable that none of the earliest mechanized mills became operational without the outside help of British mechanics. Moreover, the biographies of Johannes Beugger and Johann Jakob Corrodi, who belonged to the first group of locally trained cotton-spinning mechanics and soon became pioneering entrepreneurs in their own right, further underscore the early value of these skills (see Tab. 3 of Appendix A). Taken together, the Swiss cotton-spinning industry emerged largely without a direct connection with the propositional knowledge of the Enlightenment. Of note, the corresponding learning initially did not go beyond reproducing, or blatantly copying, existing British designs. Although gradual improvements soon followed, especially in leading mills, such as Escher, Wyss & Co., genuine industrial inventions made in Switzerland were largely absent during the first part of the nineteenth century.[9]

Taken together, Swiss society was transformed by the Enlightenment. However, as a transnational movement, it can hardly explain why the Industrial Revolution was adopted relatively early in Switzerland in comparison to other parts of Western Europe. In this regard, and as discussed in the next section, other factors should matter.

[9]An exception was the improvement of the mechanical loom by Caspar Honegger (1804-1883) during the early 1840s.

5 Profitability of cotton-spinning mills in a low-wage-no-coal environment

The negligible role plaid by steam engines during Switzerland's early industrialization raises questions as regards historical narratives, such as Wrigley (1962) or Balderston (2010), emphasizing the corresponding role of coal as crucial source of energy. In a similar, but more refined vein, Allen (2009) has suggested that a unique combination between high wages and cheap coal made investments in labor-saving, but energy-intensive, machinery exceptionally profitable in Britain. In particular, Allen (2009, pp.215-216) has calculated a return on investment into a state-of-the-art cotton-spinning mill with Mule-Jennies in the 1780s of 40 per cent in Britain, but, mainly due to lower wages, only 9 per cent in France.[10] Then again, Switzerland also differed from Britain by being a low-wage economy within Europe prior to the industrialization. In fact, Studer (2008) and Lemmenmeier (2014) have complemented the comparisons of Allen (2001; 2009, ch.2) with data for Zurich, where wages during the eighteenth century were substantially lower than in London, and even slightly lower than in Paris. It is also remarkable that cheap labor has been cited in the literature as reason why the cotton-spinning industry could appear so early in Switzerland despite the unfavorable location far away from major ports and trading centers for cotton (Veyrassat, 1982, pp.26-28; Bergier, 1983, p.169; Dudzik, 1987, p.24).

So how profitable were the early cotton-spinning mills in Switzerland's low-wage-no-coal environment? Following Allen (2009, pp.213ff.), this question can be answered by means of internal rate-of-return calculations for a capital investment K to establish a cotton-spinning mill at time $t = 0$, as given by

$$K = \sum_{t=1}^{T} \frac{R}{(1+i)^t} = \sum_{t=1}^{T} \frac{PY - Lw}{(1+i)^t}. \tag{1}$$

In (1), R refers to the average return expected across future years t, and i represents the internal rate of return to be calculated. The very right-hand side splits the return into its revenue and cost components. The revenue involves the price margin P, i.e. the price difference between yarn and raw cotton on the Swiss market, multiplied by output Y. Costs consist of wages w multiplied with the workforce L. Here, the potentially ambiguous wage effects manifest themselves. Relatively high wages w indirectly promised more cost savings when spinning occurred with labor-saving machinery, which lowers L. Yet, wages are themselves a direct cost component reducing revenue and, hence, profitability. Of note, as in Allen (2009, pp.215-216.), (1) does not include energy costs. In the case of Switzerland, this is maybe unproblematic given the virtually free access to numerous streams and rivers to provide water power.[11]

Internal rates of return can be gauged from (1) with data from Dudzik (1987) and other sources. For the pioneering age after 1805, these data are highly incomplete. Nevertheless, an early guess for the capital K required to install Mule-Jennies in Switzerland can be obtained from the share capital of the pioneering Baumwollspinnerei in St.Gallen—190'000 francs for 5'300 spindles—and Escher, Wyss & Co.—183'000 francs for 5'000 spindles.[12]

[10] Along a similar line of argument, Broadberry and Gupta (2009) suggest that Britain benefitted from low capital costs. With typical long-term interest rates during the eighteenth century of up to 10 in France, but only 3 to 5 per cent in Britain (Homer, 1977, pp.161, 170), the implications of a (risky) return of 40 or 9 per cent for the demand of cotton-spinning machines are evident.

[11] Obviously, K includes outlays for infrastructure to exploit water power. Yet, in a project to build a factory by Escher, Wyss & Co. in 1830, this kind of infrastructure accounted for less than 1 per cent of the total capital investment (Dudzik, 1987, p.53).

[12] Francs refer to French currency that circulated widely in premodern Switzerland (Baltensperger and Kugler, 2017, pp.21ff.).

These values come down to around 36 francs per spindle.[13] Turning to the components of R, the protectionism of the Continental System gave rise to several years with extraordinarily high spinning margins. Around 1810, Escher, Wyss & Co. reportedly earned some 6.1 francs per kilogram of yarn (see Dudzik, 1987, p.75).[14] Furthermore, the early machines of Escher, Wyss & Co. were capable of producing 2.7 kilograms per spindle and year.[15] Almost the same value for Y is reported for early Mule-Jennies in Switzerland operated without water power, as e.g. used in the Baumwollspinnerei in St.Gallen, for the decade between 1800 and 1810 (Dudzik, 1987, p.512). Apparently, at the dawn of mechanized spinning, the productivity gains from using water-powered were unimportant. Turning to costs, it is not easy to pin down the number of workers employed per spindle (L) during the pioneering age. The Baumwollspinnerei in St.Gallen reportedly employed around 120 workers (Bergier, 1983, p.205), or 0.023 per spindle. This value will be used as benchmark. However, a higher value results from Escher, Wyss & Co., where probably some 200 workers were employed in 1810 (Dudzik, 1987, p.80), i.e. $L = 0.04$. This value will be used for robustness checks. In a similar vein, data on Swiss wages w in mechanized cotton spinning are patchy before 1820. However, in 1810, Escher, Wyss & Co. had wage costs of 1.97 francs per kilogram yarn, and produced 20'481 kilograms yarn per year (Dudzik, 1987, p.425). Taking again a workforce of 200, this would imply an annual wage of roughly 200 francs per worker. Finally, as in Allen (2009, p.215), a linear depreciation rate of 10 per cent per year is assumed implying that a Mule-Jenny was expected to last for a decade. This assumption is perhaps not unreasonable given the inexperience with servicing and maintaining these machines and the rapid technological progress during the pioneering age of mechanization. Inserting these value for the conditions after 1805 into (1) yields

$$36\,\frac{\text{Fr.}}{\text{spindle}} = \sum_{t=1}^{10} \frac{6.1\,\frac{\text{Fr.}}{\text{Kg}} \cdot 2.7\,\frac{\text{Kg.}}{\text{spindle}} - 0.023\,\frac{\text{workers}}{\text{spindle}} \cdot 200\,\frac{\text{Fr.}}{\text{worker}}}{(1+i)^t} \approx \sum_{t=1}^{10} \frac{11.9\,\frac{\text{Fr.}}{\text{spindle}}}{(1+i)^t}. \tag{2}$$

As reported in column 1 of Table 2, solving (2) for i yields an internal rate of return of $i \approx 31\%$. Thus, investing in cotton-spinning mills in Switzerland during the 1810s could be very lucrative.[16]

The return depends, of course, on the underlying parameters, which in (2) reflect the conditions of large, professionally managed, and technically advanced mills. They are not representative for the mechanized workshops that popped up during Switzerland's early industrialization (see Sec. 3.2). As these rudimentary "mills" typically lagged behind in technology, were often only operated on a part-time basis, and usually lacked possibilities for scaling up production with the help of water power, the return from investing in this mechanized form of the home industry was, in all likelihood, much lower. Unfortunately, gauging the corresponding return is difficult, as this highly informal part of Switzerland's

[13] The pioneering Spinnerei Hard raised a share capital of 343'000 francs to install 8'000 spindles, i.e. almost 43 francs per spindle. Recall, however, from the discussion of Section 3.2 that the Spinnerei Hard started with Throstle Frames, which were apparently more expensive to install at the dawn of the nineteenth century.

[14] Competition in cotton spinning not only involved the price, but also the quality of the yarn; especially its fineness as measured by the ratio between fiber length and weight (see Dudzik, 1987, pp.29ff.). More specifically, ratios between 8 and 30 were considered as coarse, ratios between 40 and 60 as medium-fine, and ratios above 70 as fine yarn. Typically, higher count yarn fetched a higher price. The spinning margins of Dudzik (1987) refer to medium-fine yarn.

[15] The quality of the yarn needs again taking into account, because cotton-spinning machines were typically capable of producing considerably more coarse (low-count), than fine (high-count) yarn. During the pioneering age, Switzerland's cotton-spinning mills lacked the skill to produce fine yarn. However, they gradually developed these skills during the following decades (Dudzik, 1987, p.39). The values of Dudzik (1987, pp.504ff.) have been calculated for a benchmark of medium-fine yarn.

[16] The return of 31 per cent compares also favorably with alternative capital investments. Until the mid-nineteenth century, Switzerland's financial environment was characterized by so low long-term interest rates that investments in France and Britain were seen as highly lucrative and, hence, became quite popular (Herger, 2023, pp.32ff.).

Table 2: Rates of return in Switzerland's early cotton-spinning industry

	Pioneering age	Age of consolidation		
Decade after:	1805	1817	1827	1836
	(1)	(2)	(3)	(4)
Parameters:	K=36, T=10, P=6.1, Y=2.7, L=0.023, w=200	K=17, T=10, P=3, Y=3, L=0.023, w=180	K=19, T=10, P=2, Y=4.4, L=0.027, w=210	K=27, T=10, P=1.35, Y=6.1, L=0.014, w=285
Rate of return:	31%	26%	10%	9%
	19% (T=5)	2% (P=2)	4% (w=240)	12% (K=24)
	33% (T=15)	1% (L=0.04)	16% (Y=4.8)	7% (K=30)
	20% (L=0.04)			
	-1% (P=3)			

Notes: Internal rates of return have been calculated from equation (1). Table 5 of Appendix B contains detailed definitions and sources of the parameters.

early industrialization has largely gone undocumented. However, even for the renowned cotton-spinning mills, some parameters of (2) are subject to uncertainty. For example, there were strategic blunders, such as overlooking the future role of water power by the Baumwollspinnerei in St.Gallen or the decision of the Spinnerei Hard to rely on premature Throstle Frames rather than Mule-Jennies. These kinds of beginners' mistakes could imply that machines had to be updated or replaced well before a decade. To account for this risk, column 1 of Table 2 also considers a scenario with $T = 5$ years. Although this lowers the return, the resulting value of $i \approx 19\%$ is still very satisfactory. When moving in the opposite direction by setting $T = 15$ years, the internal rate of return increases when compared with the benchmark, although only slightly to $i \approx 33\%$. Finally, given the above-mentioned uncertainty about L at the dawn of the nineteenth century, the value of 0.04 derived from the conditions at Escher, Wyss & Co. is also used. The resulting return of $i \approx 20\%$ is again very satisfactory.

Arguably, the high profitability of Switzerland's cotton-spinning industry during the pioneering age owed much to the Continental System (see e.g. Bergier, 1983, p.207). However that may be, the subsequent reemergence of inexpensive British yarn posed a major challenge, insofar as the corresponding imports compressed the spinning margin in Switzerland from 6 francs per kilogram around 1810, to roughly 3 francs around 1820, and thereafter even further towards 2 francs (Dudzik, 1987, pp.103f.). Probably, this decline had a disproportionably large effect on the internal rate of return. At least, according column 1 of Table 2, the estimated return is slightly negative when using a margin of $P = 3$, but keeping the technological and cost parameters from the pioneering age unchanged. In other words, without the Continental System, technologically outdated mills were no longer lucrative. Yet, by the time British yarn began to reappear en masse on the European Continent, some Swiss mills had technologically progressed. In particular, incremental improvements, i.e. the above-mentioned micro-inventions, had boosted the average output Y to 3.1 kilograms per spindle in 1815 (Dudzik, 1987, pp.513.). Meanwhile, e.g. the cotton-spinning mill of Kölliger, Pfister & Co. built in 1815/16 required a capital of 17 francs per spindle, i.e. less than half of the pioneering age. Almost the same value of 16 francs per spindle is reported for an expansion of Escher, Wyss & Co. in 1821 (see Dudzik, 1987, p.178). There is still considerable uncertainty as regards the value of L. Data for the Canton of Zurich suggest that, on average across all mills, around 40 workers were needed to operate 1'000 spindles, i.e. $L = 0.04$ (see Dudzik, 1987, p.105). However, recall from the discussion above that small, and hence probably relatively inefficient, mills dominated in this canton. Therefore, the value of $L = 0.023$ from the pioneering age is retained as a benchmark. The wage level had probably not changed much from a decade earlier (see Studer, 2008, pp.440ff.). In fact, in 1820, daily wages of 0.6 Fr. and 300 working days were common in Switzerland's cotton-spinning industry (see Dudzik, 1987, pp.519, 557, 568). This yields an annual wage of 180 francs per worker. Taken together, inserting the benchmark values ($K = 17, P = 3, Y = 3, L = 0.023, w = 180, T = 10$) into (1) yields an estimated rate of return for the decade after 1817 of 26 per cent (see column 2 of Table 2). As regards robustness checks, a spinning margin of 2 francs per kilogram, which became common after 1822, lowers the return to 3 per cent. An even lower value results when using $L = 0.04$ for the number of workers per spindle. As this value could be representative for the rudimentary mechanized workshops, it is perhaps not surprising that many of them went bankrupt during the 1820s (see Sec. 3.4.).

By the year 1827, further technological progress meant that the average spindle produced 4.4 kilograms of yarn per year, which reflects an increase of almost 50 per cent across the preceding decade (Dudzik, 1987, p.513). In the 1820s, Escher, Wyss & Co. reached even 4.8 kilograms per spindle (Dudzik, 1987, p.512). These kinds of productivity increases were vital to offset the further decline in spinning margins, which stood, on average, at 2 francs per kilogram during the decade after 1827 (Dudzik, 1987, p.144). Meanwhile, the capital cost per spindle had increased slightly to 19 francs per spindle (Dudzik, 1987, p.178). Moreover, in the Canton of Zurich, on average, 27 workers were employed per 1'000 spindles, i.e. $L = 0.027$ (Dudzik, 1987, p.105). Probably, this value had became representative for large cotton-spinning factories, because, by then, they began to dominate even in Zurich. Finally, nominal wages in the Swiss cotton-spinning industry began to raise to 0.7 francs per day during the late 1820s, and to 0.8 francs during the first half of the 1830s (Dudzik, 1987, p.568). With 300 working days, this yields annual wage costs of, respectively, around 210 francs and 240 francs per worker. Taken together, inserting the values ($K = 19, P = 2, Y = 4.4, L = 0.027, w = 210, T = 10$) into (1) gives rise to an estimated rate of return of 10% during the decade after 1827 (see column 3 of Table 2). Of course, this return is again susceptible to parameter changes. Examples are higher wage cost of $w = 240$, implying $i \approx 4\%$, and productivity increases to $Y = 4.8$, implying $i \approx 16\%$.

Finally, the years after 1836 mark the advent of factories with tens of thousands of spindles, powerful hydraulic systems, and more and more automatized machinery. In financial terms, it is perhaps not surprising that these factories required more capital, with Dudzik (1987, p.178) reporting initial investments between 24 and 30 francs per spindle for mills built between 1836 and 1839. On the upside, technological innovations, such as continuous-action spinning by means of Throstle Frames, boosted average productivity to 6.1 kilograms per spindle (see Dudzik, 1987, p.513). Progress in automatization as with the Selfactor lowered the required workforce per spindle towards 0.014 per spindle (Dudzik, 1987, p.105). For the Swiss cotton-spinning industry, these productivity gains were again necessary to offset the further drop in spinning margins to an average of 1.35 francs during the decade after 1836 (see Dudzik, 1987, p.190). As regards costs, typical wages in cotton-spinning had also increased to 0.95 francs per day, or 285 francs per year with 300 working days still being normal (Dudzik, 1987, pp.557, 568). Taken together, inserting the benchmark values ($K = 27, P = 1.35, Y = 6.1, L = 0.014, w = 285, T = 10$) into (1) yields a rate of return after 1836 of 9 per cent (see column 4 of Table 2). Varying the initial capital to values from $K = 24$ to $K = 30$ changes this return to, respectively, 12 and 7 per cent.

Although the rate-of-return calculations of Table 2 are gross estimates, during the first half of the nineteenth century, the broad picture reveals a clear downward trend from an initially very high level. In all likelihood, technologically advanced cotton-spinning mills were extremely profitable during the pioneering age. Above all, these handsome profits were made possible by the high spinning margins due to the Continental System. It is therefore reasonable to argue that the corresponding protectionism incidentally supported Switzerland's infant cotton industry. Furthermore, amid the collapse of home-spinning, an underemployed pool of workers familiar with textile production could be hired at low wages by the standards of Western Europe. However, the protectionism of the Continental System soon vanished. Eventually, wages in the Swiss textile industry began to rise during 1820s and thereafter. Against this background, cotton-spinning mills could only remain in business with the help of constant technological improvements. In this way, the early Swiss cotton-spinning industry caught up with their British competitors and, by their accounts, had reached a similar technological level by the beginning of 1840s (Dudzik, 1987, pp.150-151). Peculiarly, coal had plaid virtually no role in this development.

6 Conclusion

So why did the industrialization of cotton spinning happen relatively early in Switzerland? As mentioned at the outset, similar questions have been the focus of a large literature about the origin of the industrialization in Britain and, more broadly, in Western Europe. Therefore, it is not surprising that answers to these questions partially overlap. In particular, as in Lancashire, mechanized cotton spinning in the Cantons of Zurich and St.Gallen took off during the first decade of the nineteenth in areas with preindustrial traditions in textile manufacturing. Apparently, the pioneering mills benefitted from the practical knowledge of a skilled workforce and existing merchant networks. In Switzerland, these outstanding skills and networks owed much to an earlier influx of Protestant refugees. As a consequence, the cotton-spinning industry emerged in predominately Protestant areas. Turning to the broader question as why the industrialization began in Western Europe, the modern literature points to the (Industrial) Enlightenment of the eighteenth century as a game-changer. The scholarly, economic, and political elites of Switzerland participated to a surprisingly large extent in this pan-European intellectual movement. To be sure, there was only scant direct overlap between these elites and the entrepreneurs and mechanics that actually made the revolutionary cotton-spinning mills work. However, from the Swiss experiences it is reasonable to argue that an intellectual environment believing in social and economic progress, and fostering the exchange between "savants" and "fabricants", helped to prepare the ground for the profound economic changes that soon followed.

Yet, the early Swiss industrialization is also insightful, because it differed in astonishing ways from the much more famous case of Britain (or France or Belgium). Remarkably, the early success of Switzerland's cotton-spinning mills happened in a landlocked, and at the time remote, country. A consequence of this geography was that raw cotton from foreign ports had to be transported overland without the help of railways. Offsetting the corresponding extra cost warranted relatively low wages when compared with other economic areas of Western Europe. Furthermore, Switzerland has never been a protagonist of colonial trade and until the mid-nineteenth century had not even a central government or integrated domestic market. Last, but not least, there are no coalfields in, or nearby, the Alpine mountain range. Instead, during the pioneering age and beyond, the Swiss cotton-spinning industry consisted literally of "mills" with machines being often driven by water power. This source of energy had, in turn, considerable effects on how the industrialization developed. Above all, rather than gathering in large cities in coal-mining areas, the Swiss industrialization occurred in a more decentralized manner with mills lining up over larger areas along rivers with accessible and sufficiently strong currents.

In a nutshell, the idiosyncratic features of the economic history of Switzerland suggest that domestic coalfields, high wages, colonial trade, or direct access to ports were no necessary conditions for an early industrialization. Crucial were rather preindustrial traditions in textile manufacturing and an enlightened culture of growth cleverly combining traditional and emerging knowledge of why and how technologies, including water power, can be used and improved.

7 References

Allen, R.C. (2001). The Great Divergence in European Wages and Prices from the Middle Ages to the First World War. *Explorations in Economic History* 38, 411-447.

Allen, R.C. (2009). *The British Industrial Revolution in Global Perspective.* Cambridge: Cambridge University Press.

Balderston, T. (2010). The economics of abundance: coal and cotton in Lancashire and the world. *Economic History Review* 63, 569-590.

Baltensperger, E., and P. Kugler. (2017). *Swiss Monetary History since the Early 19th Century.* Cambridge: Cambridge University Press.

Bergier, J.F. (1983). *Die Wirtschaftsgeschichte der Schweiz— Von den Anfängen bis zur Gegenwart* Zurich: Benziger Verlag.

Bonjour, E. (1946). *Swiss Neutrality—Its History and Meaning.* London: Routledge.

Broadberry, S., and B. Gupta. (2009). Lancashire, India, and Shifting Competitive Advantage in Cotton Textiles, 1700-1850: The Neglected Role of Factor Prices. *Economic History Review* 62, 279-305.

Clark, G. (2012). A Review Essay on "The Enlightened Economy. An Economic History of Britain, 1700-1850" by Joel Mokyr. *Journal of Economic Literature* 50, 85-95.

Crafts, N. (2010). Explaining the first Industrial Revolution: two Views. *European Review of Economic History* 15, 153-168.

Crafts, N., and N. Wolf. (2014). The Location of the UK Cotton Textiles Industry in 1838: A Quantitative Analysis. *Journal of Economic History* 74, 1103-1139.

Crouzet, F. (1985). *The First Industrialists—The Problems of Origins.* Cambridge: Cambridge University Press.

De Vries, J., and A. Van Der Woude. (1997). *The First Modern Economy—Success, Failure, and Perseverance of the Dutch Economy, 1500–1815.* Cambridge: Cambridge University Press.

Dudzik, P. (1987). *Innovation und Investition—Technische Entwicklung und Unternehmerentscheide in der schweizerischen Baumwollspinnerei 1800 bis 1916.* Zurich: Chronos.

Eltis, D., and S.L. Engerman. (2000). The Importance of Slavery and the Slave Trade in Industrializing Britain. *Journal of Economic History* 60, 123-144.

Erne, E. (2008). Ökonomische Gesellschaften. in: *Historisches Lexikon der Schweiz (HLS).*

Erne, E. (2010). Lesegesellschaften. in: *Historisches Lexikon der Schweiz (HLS).*

Fahrni, D. (1987). *An Outline History of Switzerland—From the Origins to the Present Day.* Zurich: Pro Helvetia (4^{th} ed.).

Herger, N. (2023). *Switzerland and its Banks—A Short History.* Cham: Springer Nature.

Homer, S. (1977). *A History of Interest Rates.* New Jersey: Rutgers University Press (2^{nd} ed.).

Im Hof, U., P. Ducrey, G.P. Marchal, N. Morard, M. Körner, F. De Capitani, G. Andrey, R. Ruffieux, H.U. Jost, P. Gilg, and P. Hablützel. (1986). *Geschichte der Schweiz und der Schweizer.* Basel: Helbing and Lichtenhahn.

Im Hof, U., and H. Marti. (2012). Aufklärung. in: *Historisches Lexikon der Schweiz (HLS).*

Kelly, M., J. Mokyr, and C. Ó Gráda. (2023). The mechanics of the industrial revolution. *Journal of Political Economy* 131, 59–94

Landes, D.S. (1999). *The wealth and poverty of nations—Why some are so rich and some so poor.* New York: W.W. Norton.

Lemmenmeier, A. (2014). Arbeitskosten und Industrielle Revolution— Der Fall Schweiz im internationalen Kontext. Master Dissertation, University of Zurich.

Maw, P., P. Solar, A. Kane, and J.S. Lyons. (2021). After the great inventions: technological change in UK cotton spinning, 1780-1835. *Economic History Review* 75, 22-55.

McCloskey, D.N. (2010). *Bourgeois Dignity—Why Economics can't Explain the Modern World.* Chicago: University of Chicago Press.

Mitchell, B.R. (1992). *International Historical Statistics. Europe 1750-1988.* New York: Stockton Press.

Möckli, S. (1987). *Die schweizerischen Landsgemeinde-Demokratien.* Bern: Verlag Paul Haupt.

Mokyr, J. (2000). The industrial revolution and the Netherlands: Why did it not happen? *De Economist* 148, 503–520.

Mokyr, J. (2002). *The Gifts of Athena—Historical Origins of the Knowledge Economy.* Princeton: Princeton University Press.

Mokyr, J. (2005). The Intellectual Origins of Modern Economic Growth. *Journal of Economic History* 65, 285-351.

Mokyr, J. (2009). *The Enlightened Economy—Britain and the Industrial Revolution 1700-1850.* London: Penguin Books.

Mokyr, J. (2016). *A Culture of Growth—The Origins of the Modern Economy.* Princeton: Princeton University Press.

Pomeranz, K. (2000). *The Great Divergence: China, Europe, and the Making of the Modern World Economy.* Princeton: Princeton University Press.

Radspieler, H. (1965). Franz Xaver Bronner. Leben und Werk 1794-1850. *Jahresschrift der Historischen Gesellschaft des Kantons Aargau* 77/78. 5-188.

Schuler, M. (2023). *Volkszählungen in der Schweiz vor 1850— Die Bevölkerungszahlen auf lokaler Ebene.* Neuchâtel: Bundesamt für Statistik (BFS).

Somm, M. (2022). *Warum die Schweiz reich geworden ist—Mythen und Fakten eines Wirtschaftswunders.* Bern: Stämpli Verlag.

Studer, R. (2008). When did the Swiss get so rich? Comparing living standards in Switzerland and Europe, 1800-1913. *Journal of European Economic History* 37, 405-452.

Thürer, G. (1970). *Free and Swiss—The Story of Switzerland.* London: Oswald Wolff.

Veyrassat, B. (1982). *Négociants et fabricants dans l'industrie cotonnière suisse 1760-1840: Aux origines financières de l'industrialisation.* Lausanne: Editions Payot.

Wrigley, E.A. (1962). The Supply of Raw Materials in the Industrial Revolution. *Economic History Review* 15, 1-16.

A Pioneering cotton-spinning entrepreneurs in Switzerland

Table 3: Pioneering entrepreneurs of the cotton-spinning industry in Switzerland

Surname	First Name	Born	Died	Education	Profession of father
Bebié	Heinrich	1764 (Dürnten/ZH)	1832	Miller	unknown
Bebié	Caspar	1800 (Bubikon/ZH)	1877	unknown	Cotton-spinning entrepr.
Bebié	Heinrich	1788 (Dürnten/ZH)	1860	Mechanic	Cotton-spinning entrepr.
Bebié	Rudolf	1790 (Dürnten/ZH)	1855	Mechanic	Cotton-spinning entrepr.
Beugger	Johannes	1778 (Itzikon/ZH)	1852	Locksmith/Mechanic	Locksmith
Brändlin	Jakob	1775 (Richterswil/ZH)	1845	Cotton merchant	Butcher/Mayor
Brändlin	Rudolf	1780 (Richterswil/ZH)	1837	Merchant	Butcher/Mayor
Brändlin	Heinrich	1777 (Richterswil/ZH)	1848	Merchant	Butcher/Mayor
Brändlin	Johannes	1783 (Richterswil/ZH)	1860	unknown	Butcher/Mayor
Corrodi	Johann Jakob	1788 (Bubikon/ZH)	1871	Mechanic	Miller
Escher‡	Hans Caspar	1775 (Zürich/ZH)	1859	Architect/Merchant	Silk merchant
Grossmann	Jakob	1754 (Aarburg/AG)	1838	unknown	Textile dyer and bleacher
Herzog	Johannes	1773 (Effingen/AG)	1840	Merchant	Cotton merchant
Huber*	Caspar	1759 (Stäfa/ZH)	1832	unknown	unknown
Huber	Hans Jacob	1792 (Stäfa/ZH)	1849	unknown	Cotton-spinning entrepr.
Hürlimann	Johannes	1767 (Richterswil/ZH)	1854	Textile Merchant	Boatman
Jenny	Fridolin	1784 (Ennenda/GL)	1857	Merchant/Weaver	Logger
Kunz	Heinrich	1793 (Oetwil/ZH)	1859	Textile merchant	Farmer
Näf†	Christian	1742 (Hemberg/SG)	1820	Textile merchant	unknown
Pellis†	Marc Antoine	1753 (Romainmôtier/VD)	1809	Merchant/Diplomat	Pastor
Rieter‡	Johann Jacob	1762 (Winterthur/ZH)	1826	Cotton merchant	Goldsmith
Schmid	Heinrich	1806 (Thalwil/ZH)	1888	Merchant	Miller
Strickler	Heinrich	1766 (Hombrechtikon/ZH)	1831	unknown	unknown
Sulzer	Johann Rudolf	1749 (Wintherthur/ZH)	1828	Merchant/Theologist	Theologist
Trümpler	Jean Jacques	1768 (Küsnacht/ZH)	1845	Cotton merchant	Farmer
Wild	Johannes	1790 (Bubikon/ZH)	1853	unknown	Cotton-spinning entrepr.
Zangger	Hans Heinrich	1792 (Uster/ZH)	1869	Politician/Cavalryman	unknown
Zellweger	Johann Casar	1768 (Trogen/AR)	1855	Merchant	Merchant
Zellweger	Jacob	1770 (Trogen/AR)	1821	Merchant	Merchant
Ziegler	Johann Heinrich	1738 (Winterthur/ZH)	1818	Physician/Theologist	Tanner

Notes: AG=Canton of Aargau; AR=Canton of Appenzell; SG=Canton of St.Gallen; VD=Canton of Vaud; ZH=Canton of Zurich.
†Pioneer in mechanical cotton-spinning. ‡Pioneer in cotton-spinning machine industry. * Pioneer in using steam power.

B Data

Table 4: Data pertaining to location-choice model

The variables refer to 175 Swiss districts and, unless stated otherwise, to conditions in 1836.

Variable	Unit	Description	Source
#Mills	Number	Number of mechanized cotton-spinning mills in a given district.	Compiled from Dudzik (1987, pp.485-489).
#Spindles	Number	Number of spindles of mechanized cotton-spinning mills in a given district.	Compiled from Dudzik (1987, pp.485-489).
Area	Km^2	Area of the district.	Federal Statistical Office.
Market Potential	Number	Population size per district in 1798.	Schuler (2023).
Preindustrial Cotton Center	Nominal	Cotton manufacturing center in a district before the industrialization.	Compiled from Dudzik (1987, p.64).
Protestantism	Nominal	District that is predominantly Protestant.	Compiled from Schweizer Weltatlas (2019, p.39).
Relative Humidity	Per cent	Annual average humidity measured at the main city of a given district. Averages have been calculated from the maximum number of years of the available data.	Compiled from Federal Office of Meteorology.
Rainfall	Millimeter	Annual average rainfall measured at the main city of a given district. Averages have been calculated from the maximum number of years of the available data.	Compiled from Federal Office of Meteorology.
Ruggedness	Percent	Per cent of terrain officially classified as mountainous.	Compiled from Federal Statistical Office.
Water power	m^3 per second	Water power measured by the low-water flow exceeded during 95 per cent of the days (i.e. 347 days) of a given year (Q347). The data refer to annual averages of the main stream or river of a given district across the maximal available data.	Compiled from the Hydrological Atlas of Switzerland and Federal Office of the Environment (Hydrological data and forecasts).

Table 5: Parameters of internal rate-of-return calculations

Parameters refer to the conditions in Swiss cotton-spinning mills around 1805, 1817, 1827, and 1836.

Parameter	Unit	Description	Source
K	Francs per spindle	Capital intensity in terms of investment required to establish a cotton-spinning mill.	Dudzik (1987, pp.72, 178).
L	Number per spindle	Workforce required on average in a cotton-spinning mill per spindle.	Dudzik (1987, p.105).
P	Francs per kilogram.	Average spinning margin, i.e. the price difference between yarn and raw cotton, in Switzerland. The values typically refer to averages for a given decade. Prices refer to a yarn of no.40 fineness.	Dudzik (1987, pp.75, 103, 144, 190).
w	Francs per year.	Typical wage in the Swiss cotton-spinning industry. Wages are usually derived from daily payments and the number of working days per year.	Dudzik (1987, pp.557, 568).
Y	Kilograms per spindle	Output of yarn per spindle of an up-to-date cotton-spinning mill. These values refer to the base capacity (Basisleistung) calibrated for the spinning of yarn of no.40 fineness.	Dudzik (1987, pp.504-513).

C Reviewer's Appendix to backup footnotes 6 and 7 (not for publication)

Table 6: Poisson count regression of cotton-spinning industry location (Switzerland, 1836)

Dependent Variable:	#Mills	#Spindles	#Mills	#Spindles	#Mills	#Spindles
Robustness check:	**Mills/Spindles per canton**		**Average instead of low water flow**		**Cantonal fixed effects**	
	(1)	(2)	(3)	(4)	(5)	(6)
Ruggedness	-0.37***	-0.37**	-0.09	-0.11	0.06**	0.07
(% Mountain Terrain)	(0.12)	(0.17)	(0.07)	(0.08)	(0.03)	(0.05)
Relative Humidity	3.05	3.55	-0.66	-1.29	-4.67	-6.40
(annual average in %)	(5.43)	(6.43)	(3.15)	(3.74)	(4.91)	(6.70)
Water Power	1.51**	1.93***			-0.02	0.34***
(Q347 in m^3/sec)	(0.70)	(0.76)			(0.08)	(0.11)
Preindustrial Cotton Center	1.87**	1.29	2.55***	1.86***	1.64***	1.05***
	(0.77)	(0.93)	(0.36)	(0.36)	(0.24)	(0.36)
Area	0.04	0.04	-0.01	-0.21	-0.22	-0.11
	(0.46)	(0.51)	(0.22)	(0.21)	(0.38)	(0.54)
Market Potential	0.69	0.93	1.95***	2.02***	1.75***	2.00***
(Population in 1798)	(0.82)	(0.99)	(0.44)	(0.46)	(0.43)	(0.63)
Rainfall						
(mm. per year)						
Water Power			0.06	0.45***		
(MQ in m^3/sec)			(0.51)	(0.16)		
Number of Observations	26	26	175	175	175	175
Pseudo R^2	0.97	0.90	0.67	0.47	0.94	0.77
$\ln L$	-51.2	-154'582	-136.1	-515'754	-74.4	-225'059

Notes: The dependent variable is the number of mechanized cotton-spinning mills or the number of their spindles per district (*in columns 1 and 2 per canton*) in the year 1836. Estimation is by maximum likelihood of a Poisson regression. Aside from the dummy variables (Preindustrial cotton center, Protestantism), the explanatory variables have been transformed into logarithms. Hence, the coefficients reflect constant elasticities. All regressions include a constant. *Columns 5 and 6 contain fixed effects for cantons.* Furthermore, $\ln L$ reports the maximized value of the log-likelihood function. Heteroscedasticity robust standard errors are reported in parentheses. * Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level.