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Steam Engines and Human Capital in XIXth Century France

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Abstract: Was technological progress conducive to human capital accumulation or was industrialization a deskilling process? Our paper investigates the effect of the French industrialization process on human capital accumulation throughout the nineteenth century. The novelty of the research is twofold: (i) we explore the deskilling hypothesis for the whole process of industrialization by implementing a panel analysis; (ii) we introduce a disaggregated human capital perspective to examine changes in skills demand at different stages of the process. Our analysis builds upon a new comprehensive dataset providing an exhaustive assessment of the diffusion of the steam technology in France at the county (*Département*) level over the 1839-1900 period. We use exogenous geographic variations as an instrument for the number of steam engines erected in each French department. We perform panel and cross-section regression analyses to compare the effect of technological change on *basic vs. intermediate* human capital accumulation. Our contribution reveals that French industrialization was not deskilling but that a shift in the type of the skills demanded occurred in the second half on the nineteenth century.

Keywords: Technological change, steam engines, industrialization, human capital, education

JEL Codes: N33, 014, 033

1 Introduction

The relationship between technological change and human capital is ambiguous. In the contemporary period, a consensus surrounds the idea that technological change is skill-biased, that it favors skilled over unskilled labor. Paradoxically, the industrialization process of the XVIIIth-XIXth centuries is usually regarded as a deskilling process. The view that has prevailed until very recently is that, in the first stage of industrialization, technological advances increases relative demand for unskilled labor and therefore that technological innovation and skills were not complementary (see, for instance, Nicholas and Nicholas 1992, Mokyr 1993, Mitch 1999). According to Goldin and Katz (1998), the complementarity took place in the early XXth century when the technological shift from steam power to electricity occurred.

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The view that the process of industrialization –in the time of the steam machine– was deskilling has recently prompted renewed attention. It gives rise to contrasting results. Feldman and Van der Beek (2016) claim that technological progress was conducive to skills acquisition in eighteenth century England by showing that the number of apprentices and their share in the cohort of the fifteen year-olds increased in response to inventions. Franck and Galor's (2016) analysis also supports the 'skill-biased technological change' hypothesis for the French case in the early nineteenth century. Using data on the share of workers employed in manufacturing as a measure of industrialization, Katz (2016) highlights a positive effect of industrialization on literacy rates (and on fertility) in the United-States during the period 1850-1900. For De Pleijt, Nuvolari and Weisdorf (2016), the effect of industrialization on human capital is mixed. They show that technological adoption was skill demanding since it improved the average skills of workers. But they also highlight that adopting new technologies was not conducive to elementary education (approximated by literacy rates and enrolment rates). Contrastingly, De Pleijt and Weisdorf (2017) show a large decrease in average skills in agriculture and industry from the end of the sixteenth century to the beginning of the nineteenth century in England. They claim that deskilling globally occurred with technological progress, despite a modest increase in the share of 'high-quality' workers. This finding gives support to the view, already defended by Mokyr (1990, 2005) and, more recently for the French case, by Squicciarini and Voigtländer (2015), that upper-tail knowledge played a prominent role in early industrialization.

Our paper contributes to this open debate by providing analysis of the effects of the French industrialization process on human capital accumulation throughout the nineteenth century. The novelty of the research is twofold: (i) we explore the deskilling hypothesis not only for the very first phase of the French industrialization, but also for the subsequent stages of the process by implementing a panel analysis; (ii) we introduce a disaggregated human capital perspective so as to examine changes in skills demand at these different stages.

Our approach builds on Mokyrs' injunction to consider that human capital is not made of one piece and that it can blend very different types of skills, not all equivalently important ('*useful')* as soon as economic development is concerned: "*Clearly human capital as a concept is indispensable, but we need to be far more specific as to what kind of human capital was produced, for and by whom, what was the source of the demand for it, and how it was distributed over the population*." (Mokyr 2005, 1155).

The idea that it exists different forms of human capital and that they have different impacts regarding the process of industrialization is now taken seriously. It has led to qualify the dominant view that human capital played a minor role in the industrialization process, at least in its first phase. On the basis that Britain experienced low and stagnant level of education at the time of its industrial take-off, Mitch (1999) was one of the first to assert that differences in human capital endowments do not give a convincing explanation of the industrialization process. This view has been confirmed by a number of scholars (see, for instance, Mc Closkey 2010, Mokyr 2005, Sandberg 1979). But these studies mainly consider differences in basic knowledge, namely differences in literacy without considering the other forms of accumulated skills.

Other forms of human capital have recently been investigated. De La Croix *et al.* (2016) stress the important role of apprentices institutions for pre-industrial growth. Differentiating between average and upper-tail skills, Squicciarini and Voigtländer (2015) provide evidence that human capital endowment of the elites in the XVIIIth century played a significant role on the French industrial take-off, contrary to average human capital. Our approach focuses on a specific form of human capital accumulated in nineteenth century France, which has not yet been investigated. We build upon the idea of 'useful knowledge' and of the disaggregation of the human capital variable to examine the effect of the French industrialization process on skills accumulation. In our analysis of the 'deskilling hypothesis', we distinguish between *basic human capital,* which is characterized by basic literacy skills and *intermediate human capital,* which started to develop in the early XIXth century. This human capital refers to intermediate skills formed by the diffusion of basic general knowledge that goes beyond basic literacy and numeracy skills. It is different from specific vocational skills provided by technical and vocational schools, and from top scientific skills linked to any intellectual elite. Basic and general scientific knowledge in sciences (e.g., geometry, history and geography), but also in foreign languages composes this form of human capital. This extensive general knowledge was spread by education courses designed to be a kind of continuation of the elementary school. These paths were mainly of two types: '*Ecoles Primaires Supérieures'* (*EPS* henceforth) and *Cours d'adultes et d'apprentis.* If they were intended for different audiences – pupils of 12-16 years old in the case of *EPS* and workers and employees for *Cours d'adultes),* their common purpose was to enhance the general level of skills in the population, and more precisely to foster the teaching of sciences.

We develop a panel data approach in order to study the effect of the number of steam engines in use in French counties on the accumulation of *intermediate* human capital, measured by enrolments in *EPS* and *Cours d'adultes.* Our results show that technological change was conducive to the accumulation of this specific intermediate human capital. This effect has become stronger as industrialization progressed. Further, we implement cross-sectional analysis so as to compare the effects of technological adoption on *basic* human capital *vs. intermediate* human capital. Hence, we employ two sets of proxies, a set to measure the accumulation of *basic* literacy skills and a set to measure the formation of intermediate skills. We consider three time-spans (1839, 1861 and 1886) corresponding respectively to the first and second stages of the industrial revolution and to the period recognized as the second industrial revolution[2]. Here, our 2SLS results contradict the conventional wisdom that the French industrialization process was a deskilling process. It supports Galor and Franck (2016)'s approach regarding early French industrialization. Furthermore, deskilling did not arise from the subsequent phases of the process, but a shift in the type of the skills demanded occurred. We highlight that the adoption of the nineteenth century's 'General Purpose Technology' (see Rosenberg and Trajtenberg 2004) was conducive to the accumulation of *basic* human capital (literacy) at the first stage of the process but in subsequent stages, and even more during the second industrial revolution by demanding enhanced skills. The late stage of the French industrialization process triggered *intermediate* human capital accumulation.

The paper is organized as follows. Section 2 provides a historical sketch of the development of *intermediate* human capital in nineteenth century France, shedding light on the new paths *intermediate* education which developed at that time. We present our data in section 3, the empirical strategy and results in section 4. Section 5 concludes.

2 Historical background

Throughout the nineteenth century, France experienced great progress in literacy rates. By the end of the century, mass literacy was achieved. As shown in Diebolt *et al.* (2005), literacy skills were spread among the French population well before the famous Ferry laws passed in 1881 and 1882. Furet and Ozouf (1977) have also analysed the substantial progress made in literacy as a consequence of the dramatic expansion of the primary education system since the July Monarchy.

Alongside the accumulation of this *basic* human capital, another form of skills began to spread in early nineteenth century France. The movement for literacy was accompanied by the rise of new tracks of education providing post-elementary instruction. Secondary schools (*Collèges* and *Lycées)* already offered such post-elementary education but they were primarily focused on the humanities (*classics*) and were intended to a social *élite*[3]. Social stratification characterized the organization of the French education system at this period and, as reminded by Grew and Harrigan (1991, 192): "*elementary and secondary schools had been thought of more as distinct responses to different needs than as the lower and higher levels of a single system*". Post-elementary education "for the people" began to spread in the first half of the nineteenth century with the development of two branches of

[2]At this period, steam power remained the main source of energy for production. The first International Exposition of Electricity took place in Paris in 1881, but the use of electricity power in manufactures was scarce (if null). According to David (1990, 356): "*At the turn of the century, farsighted engineers had envisaged profound transformations that electrification would bring to factories stores, and homes. But the materialization of such visions hardly was imminent.*"

[3]According to Grew and Harrigan (1991, 192), enrolments in secondary schools were only about 3 percent of the enrolments in primary schools in the 1870s.

education: the *Enseignements Primaires Supérieurs* provided in the *Ecoles Primaires Supérieures* (EPS) and the *Cours d'adultes.*

The Guizot law (1833) provided that the *EPS,* which belong to the primary education system, were set up in every town of over 6,000 inhabitants. Intended for pupils from the age of twelve to sixteen, these '*Collèges du Peuple*' (see Briand and Chapoulie 1994) provided intermediate education for the growing middle-classes. This education, which went beyond the teaching of basic literacy skills provided in elementary schools, and which was not the classics taught in secondary schools to the *bourgeoisie,* developed also through another channel: the education for adults. The number of adult courses (and enrollments) grew substantially throughout the nineteenth century. These courses were in part dedicated to fight illiteracy, but they were firstly dedicated to provide extended instruction to the working class. As reported by Grew and Harrigan (1991, 184), this second purpose was prominent: "*Yet, even in 1876-77, less than 6 percent of the men and only about 8 percent of the women enrolled in adult courses were struggling with reading and writing. Even then the most popular course of study, for both men and women, had been history and geography, followed (for men) by geometry and surveying and then by bookkeeping and commercial arithmetic, which was second in popularity for women.*" The kind of knowledge taught in the courses for adults was henceforth very close to the one taught in the *EPS*[4]*.* These two branches have in common to offer further education to people by spreading skills that goes beyond basic literacy skills, but that differ from vocational knowledge offered in technical schools. They included subject matters such as history, geography, drawing, mathematics, surveying, commercial arithmetic, accounting, elementary knowledge in physics and chemistry and notions of law (see Briand and Chapoulie 1994, 6-7, Grew and Harrigan 1991, 184).

Since both offered to the masses the possibility to continue their instruction beyond the acquisition of basic reading, writing and numeracy skills, *adults courses* as well as *EPS* contributed to the accumulation of *intermediate* human capital in nineteenth century France. But what type of effect had the industrialization process on the accumulation of this *intermediate* human capital in comparison to *basic* human capital?

[4]"*Rather different ambitions were met in adult courses designed for graduates of primary school who wanted to extend their education in courses that offered occupational or apprenticeship training or presented material rather like that provided in the école primaire supérieure.*" (Grew and Harrigan 1991: 182). Note that adult courses were taught, like the *Enseignements Primaires supérieurs,* by teachers of the primary schools (*instituteurs)*.

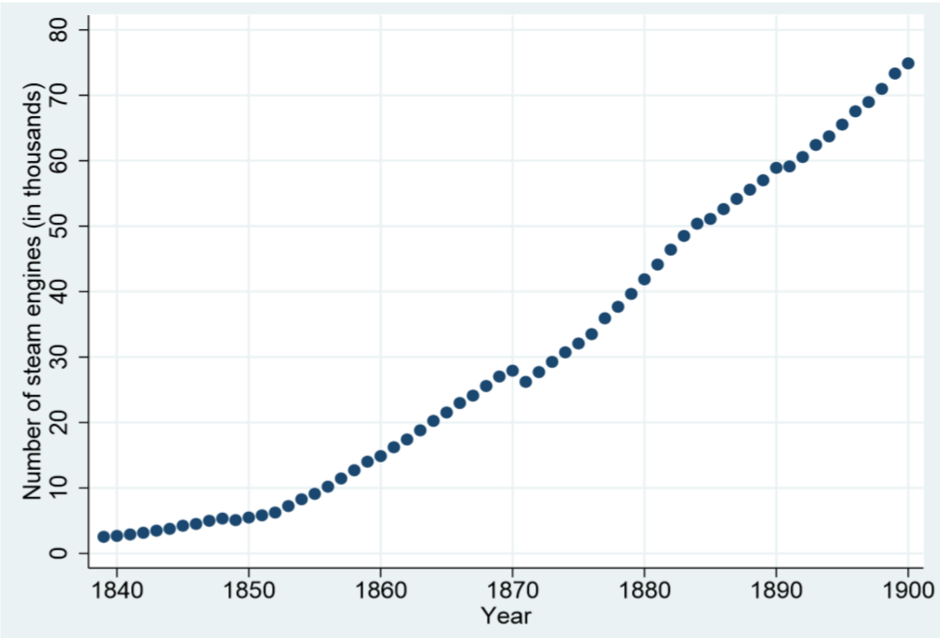
3 Data

We consider the number of steam engines used in each county between 1839 and 1900 as a proxy for technological change. We also implement several proxies depicting *basic* and *intermediate* human capital accumulation.

Steam Engines

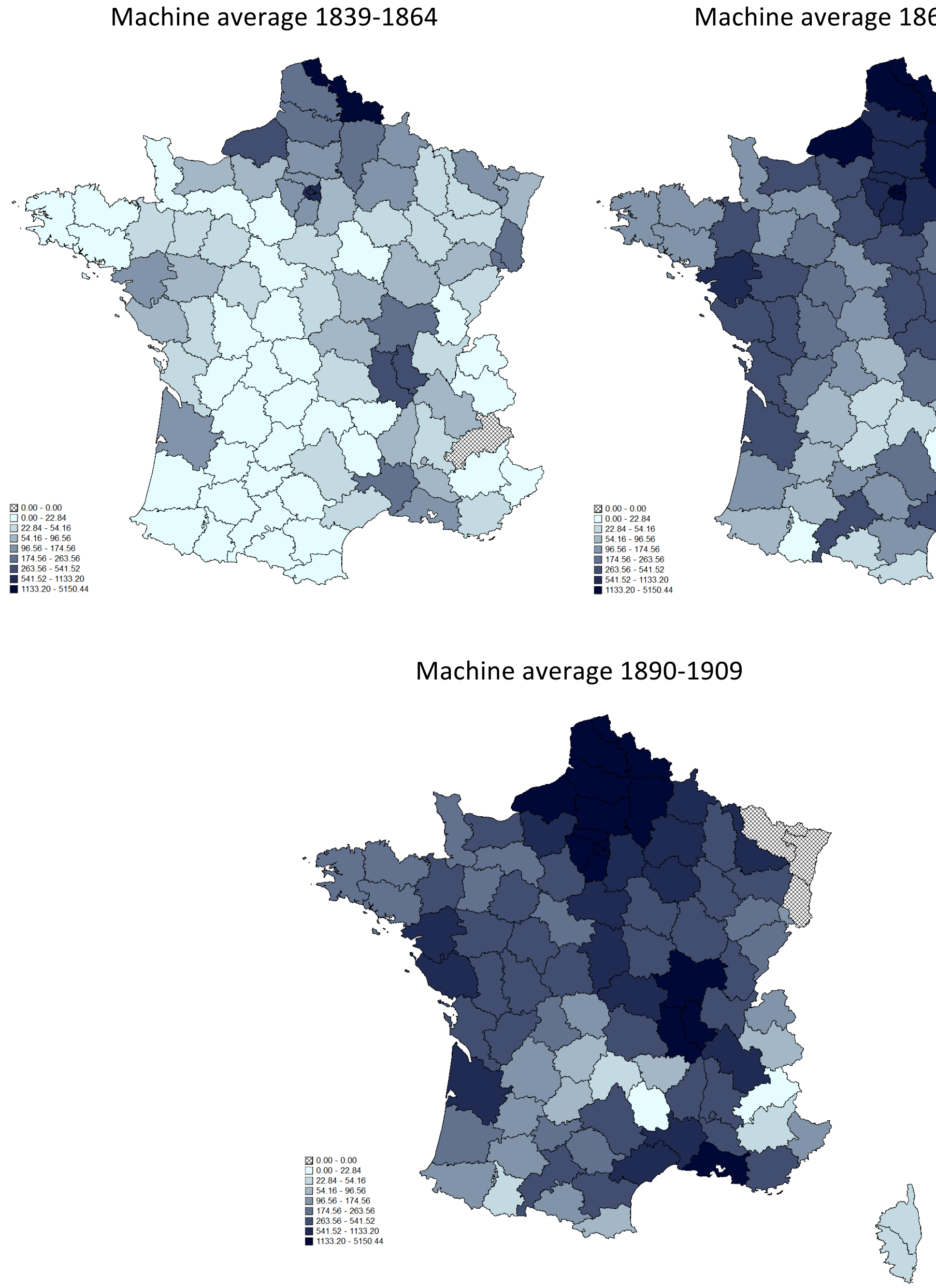
We built a new comprehensive dataset on the adoption of steam engines in French counties throughout the nineteenth century. The dataset provides an exhaustive assessment of the diffusion of steam technology in France at the county level. It gathers information on the number of steam engines used in industries, the number of steam appliances, the number of industries in each French county that uses steam technology, and the steam power in use (horsepower). In line with Nuvolari, Verspagen and Von Tunzelmann (2011), our empirical analysis draws upon the number of steam engines to approximate regional heterogeneity in the adoption of steam technology.[5] Figure 1 shows the spread of our data availability for France from 1839 to 1900. Figure 2 depicts the geographical diffusion of steam technology from 1839 to 1909.

Figure 1: Number of steam engines used in France from 1839 to 1900 (in thousands)



[5]Figure A.1 in Appendix A shows that the number of steam engines is highly correlated with the number of steam appliances, the number of industries in each French county that uses steam technology and the steam power in use.

Figure 2: The geographical diffusion of steam technology



The adoption of the steam technology varied greatly among the French counties. This heterogeneity remained substantial at the end of the nineteenth century. In 1839, 500 steam engines were in use in the *Nord* county whereas 16 counties have no machine at all.[6] Close behind the *Nord*, the *Seine* implemented 413 machines. The following counties were the *Seine- Inférieure* (260 machines), the *Loire* (256), the *Rhône* (96), the *Haut-Rhin* (86), and the *Saône-et-Loire* (86). At that time, 26 counties

[6] *Basses-Alpes, Hautes-Alpes, Ariège, Cantal, Corrèze, Corse, Creuse, Landes, Lot, Lot-et-Garonne, Lozère, Basses-Pyrénées, Hautes-Pyrénées, Pyrénées-Orientales, Haute-Vienne* and *Yonne.*

recorded one to five machines. In 1861, only seven counties recorded 1 to 5 machines but two counties still had no steam engine at all (*Hautes-Alpes* and *Ariège)*. The *Nord* maintained its leading position with 2195 machines. *Seine* also remained the second one (2001). At the same time, two counties located in the North of France (*Pas-de-Calais* and *Aisne)* accelerated their adoption of the steam engine. In 1886, the number of machines in use in the *Seine* county exceeded the number of machines in the *Nord.* But, the highest level experienced by the *Seine* county was reached in 1901 with 5926 machines. Finally, the maximum number of steam engines in use in the *Nord* was reached in 1908 (7049 machines). For comparison, in 1908 the *Hautes-Alpes* was endowed with only 22 steam engines.

Human Capital

We explore the effect of industrialization on two different types of human capital: *basic* and *intermediate* human capital. *Basic* human capital refers to literacy skills. Here we use these three indicators: (i) the literacy rate, (ii) the number of primary schools per 10 000 inhabitants and (iii) the number of towns with no school.

Literacy rate is our direct measure for basic literacy skills. We approximate it by the share of army conscripts who are able to read at least. We deepen our evaluation of the heterogeneity in *basic* human capital endowments among the French counties with the two other indicators used as proxies for education supply. We rely on the number of primary schools per 10 000 inhabitants because primary schools diffused in fact primarily basic literacy skills. Alternatively, we use the number of municipalities in each county that have no school at all. These two proxies depict the density of the French education network at the county level. They provide information on differences in basic human capital accumulation since a county with a sparse educational network is prone to perform less in terms of literacy than a county where the density of the education supply is higher.

Intermediate human capital refers to general knowledge that goes beyond basic literacy skills but that was neither vocational nor top scientific knowledge of the elite. In nineteenth century France, it spreads through two main channels: the *Ecoles Primaires Supérieures (EPS)* and the *Classes for adults*. We consider enrollments in these two educational paths as indicators for the accumulation of *intermediate* human capital. We use the number of pupils enrolled in upper elementary schools *("EPS"*) and the number of men and women enrolled in adult classes per county.

Confounding variables

Turning to our set of control variables, we account for specific regional variations that could have been decisive to explain both industrialization and human capital formation, namely for the geographic county characteristics and for pre-industrial development indicators. Our control variables refer to the number of royal roads in 1824. They reflect, for each county, the extension of infrastructure investments that favored the diffusion of industrialization. Our research also accounts for the population density recorded in 1801, as a proxy for pre-industrial urbanization. The process of urbanization can be associated to pre-industrial development, because a growing population allows for specialization, which in turn can foment industrial growth and a learning technology. Besides, more urbanized counties were more prone to develop human capital. To measure pre-industrial human capital stocks, we use the share of Frenchmen who signed their marriage license in 1686-1690. For us, the intensity in the use of the steam engine and human capital formation during the industrial era may have been favoured by the pre-existence of such human capital stocks.

We capture the geographical differences between French counties with the following indicators. First, we use the number of squared kilometres of cultivable land and the number of squared kilometres of fertile soil to measure the land quality. Land quality may have influenced the adoption of steam engines and the development of schooling. In particular, landowners may have less interest in public schooling due to low complementarity between land and human capital (as argued in Galor, Moav and Vollrath 2009). Second, we include a dummy to account for counties having a maritime border, say access to sea and foreign contacts. Such connections may have enhanced the steam technology adoption as well as human capital formation. Third, we control for the latitude of each county, measured in the location of the county administrative centers, to capture also the possible influence of climate change among counties.

Finally, our regression analysis includes the aerial distance from Paris to each county administrative center. The *Seine* is an industrial center and gathers the political institutions that might have more influence on industry and human capital formation in closer counties.

4 Methodology and Results

Empirical strategy

Assessing the causal relationship[7] between industrialization and human capital implies controlling for possible (and presumable) endogeneity biases. The statistical relationship between industrialization

[7] *"I define cliometrics as the quantitative projection of social sciences in the past. Cliometrics is, more precisely, the combination of causal explanations embedded in (economic) models, with or without counterfactual*

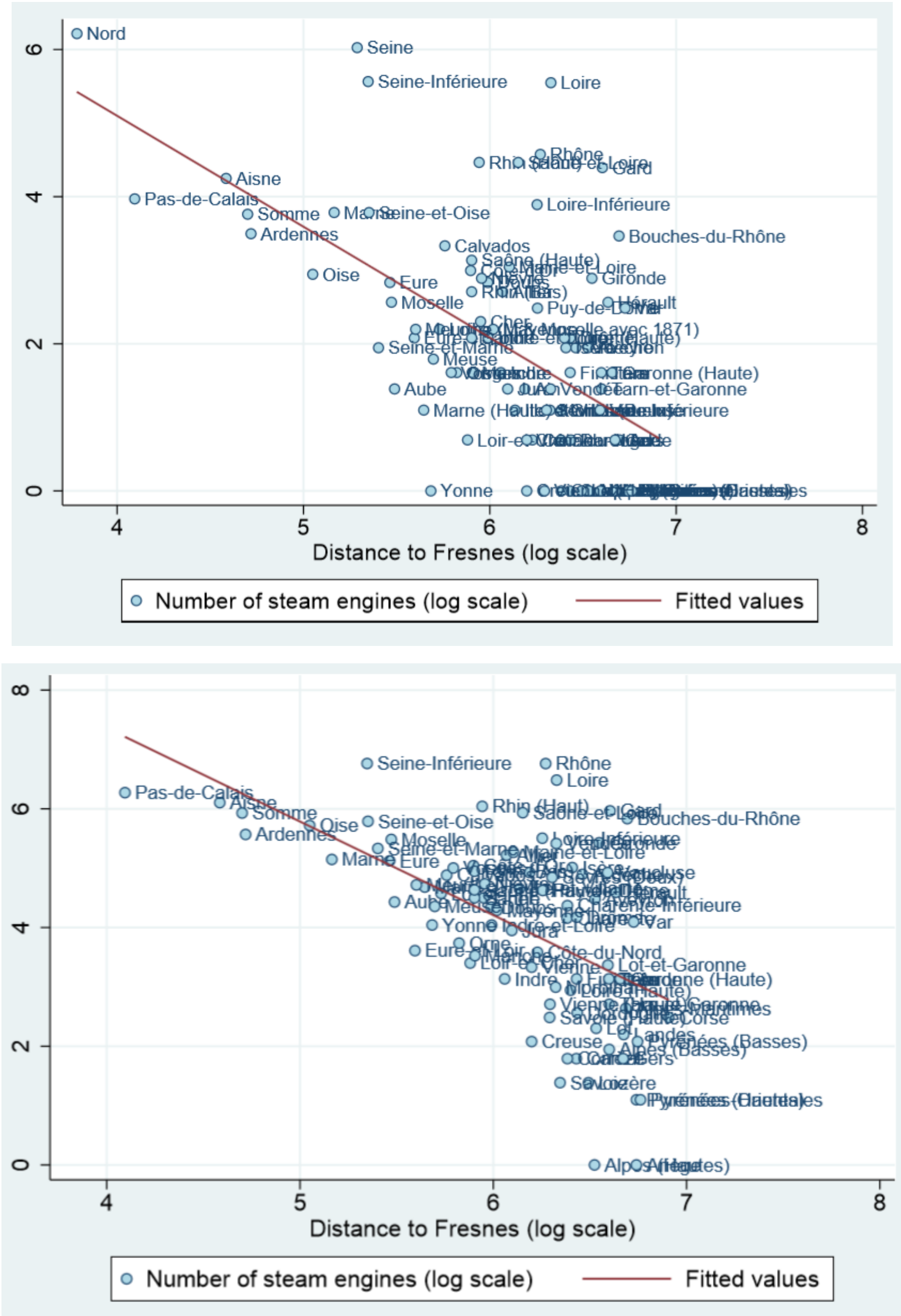
and human capital formation can be driven by reverse causality, namely by the effect of human capital on the use of industrial technology (see, for instance, Tamura (2002)). Besides, both can have a common determinant explaining variations in industrialization and variations in human capital, while these two variables do not affect each other. A statistical relationship between industrialization and human capital accumulation could then only reflect a third common variable.

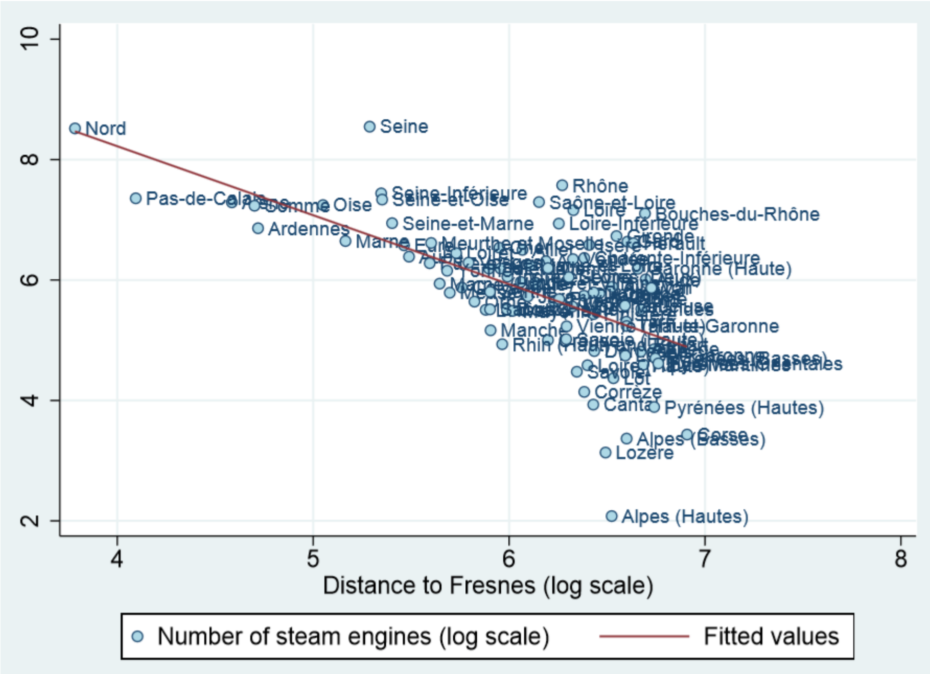
Hence, we use exogenous county variations in the distribution of steam engines across France to be able to analyze the causal relationship between technological change and human capital accumulation. We use the aerial distance of each county administrative center to Fresnes-sur-Escaut as an instrument for the number of steam engines recorded in each county. Fresnes-sur-Escaut has been the first place in 1732 where the steam engine has been used for a commercial purpose in France. This instrumentation strategy relies on Frank and Galor's proposition and Mokyr (1990)'s conclusion, according to which industrialization and the use of the steam engine are positively correlated. The regional diffusion of the steam engine from the Fresnes-sur-Escaut starting point can be used to pinpoint the effect of local variations in the distribution of the steam engine on human capital accumulation. Franck and Galor use the distance between each French county and Fresnes-sur-Escaut to instrument the use of the steam engine in 1839-1847. We extend this use to the whole process of industrialization in France showing that the regional diffusion continues explaining the adoption of new steam engines decades after the 1840s.

The intensity in the use of the steam engine has been very heterogeneous across the French counties, no matter the stage of industrialization, as shown in Figure 3. Accordingly, we observe a negative correlation between the distance of each county to Fresnes-sur-Escaut and the number of steam engines in use in three different stages of the French process of industrialization (1839, 1861 and 1886). Steam engines were globally more common in counties close to the *Nord* than elsewhere, as for instance the *Somme*, the *Aisne*, the *Marne*, and the *Pas-de Calais,* except for industrial centers, including the *Loire*, the *Seine*, the *Seine Inférieure* and the *Loire Inférieure*.

speculation, in order to screen the relative importance of various factors, i.e., of forces (in natural sciences) believed to have been operative in a given historical situation." (Diebolt 2016, 1).

Figure 3: Number of steam engines against Distance to Fresnes, in 1839, 1861 and 1886: scatter plots and linear prediction





In the first stage of our 2SLS analysis, the log of the number of steam engines in county *i* in year *t* ($Steam\_engine_{it}$) is instrumented by the aerial distance in kilometres between the county *i*'s administrative centre and Fresnes-sur-Escaut ($Distance\_to\_Fresnes_i$):

$$Steam\_engine_{it} = \delta_1 Distance\_to\_Fresnes_i + X'_{1,i}\delta_2 + \mu_{it}\ , \qquad (1)$$

where $X'_{1,i}$ is the vector of control variables and μ_{it} is the error term. Specific county characteristics may have contributed to the diffusion of the steam engine and the process of development. Therefore, $X'_{1,i}$ includes geographical controls (*land suitability, fertile soil, latitude, maritime*, and *distance to Paris*) and pre-industrial development indicators (*population density in 1801,* the *number of royal roads in 1824*, and the share of Frenchmen who could sign their marriage license in 1686-1690) in order to reduce unobserved heterogeneity. The standard errors are robust to control for the possibility of heteroskedasticity.

Table 1.A: The geographical diffusion of the steam engine (panel OLS analysis)

	1	2	3	4	5
	Dependent variable: number of steam engines (in log)				
	No control	Distance to Paris	Geographic controls	Development controls	All controls
Distance to Fresnes	-1.048***	-0.875***	-0.512**	-0.647***	-0.567**
	(-7.25)	(-7.02)	(-2.17)	(-3.51)	(-2.24)
Distance to Paris		-0.175***	-0.318**	0.113	0.079
		(-2.65)	(-2.57)	(0.58)	(0.36)
Cultivable land			0.132		0.426
			(0.43)		(1.10)
Fertile soil			0.058**		0.046**
			(2.50)		(2.11)
Latitude			3.009		0.292
			(0.71)		(0.06)
Maritime			0.630*		0.236
			(1.78)		(0.59)
Density in 1801				0.185	0.157
				(1.64)	(1.57)
Number of royal roads				1.024**	0.696
				(2.20)	(1.40)
Literacy 1686-1690				-0.064	-0.153
				(-0.25)	(-0.60)
Constant	10.758***	10.701***	-4.575	4.564*	-1.429
	(13.01)	(14.23)	(-0.27)	(1.82)	(-0.08)
Observations	5023	5023	4838	4233	4233
R^2	0.1057	0.1063	0.1360	0.1211	0.1392

Notes: All variables except the dummies are in logarithm. The dependent variable is the number of steam engines (in log). Aerial distances are measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Table 1.B: The geographical diffusion of the steam engine (cross section analysis)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: number of steam engines (in log)					
	OLS					
	With no control			With controls		
	1839	1861	1886	1839	1861	1886
Distance to Fresnes	-1.510***	-1.645***	-1.145***	-1.099***	-0.781**	-0.469*
	(-7.91)	(-8.51)	(-8.37)	(-3.19)	(-2.40)	(-1.98)
Latitude				-5.260	-0.211	-2.432
				(-0.97)	(-0.04)	(-0.54)
Number of royal roads				0.852	0.498	0.341
				(1.58)	(0.78)	(0.80)
Distance to Paris				-0.049	-0.086	-0.160
				(-0.34)	(-0.47)	(-0.84)
Population				1.984***	1.798***	1.345***
				(5.26)	(4.26)	(4.98)
Cultivable land				-0.659***	0.019	0.211
				(-2.85)	(0.06)	(0.68)
Fertile soil				0.075***	0.023	0.020

				(3.41)	(0.73)	(0.91)
Density in 1801				-0.037	-0.040	-0.115*
				(-0.66)	(-0.42)	(-1.98)
Maritime				-0.257	-0.242	-0.094
				(-0.88)	(-0.78)	(-0.37)
Constant	11.145***	14.108***	12.798***	9.778	-14.020	-0.931
	(9.71)	(12.65)	(16.29)	(0.42)	(-0.65)	(-0.05)
Observations	87	89	87	85	85	80
R^2	0.343	0.376	0.371	0.595	0.577	0.702

Notes: All variables except the dummies are in logarithm. Population is measured by the size of population in 1836 for Equation (1) applied to 1839 (Column 2), the size of population in 1861 for Equation (1) applied to 1863 (Column 4), and the size of population in 1886 for Equation (1) applied to 1886 (Column 6). Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Table 1.A reports panel estimates of Equation (1). We exploit the large panel dimension of the data to measure the strength of our instrument for the use of the steam engine, namely the distance of each county administrative center to Fresnes-sur-Escaut. We do so across the whole time period during which France experienced the steam technological change (1839-1900). Because data on human capital are much less available, we will focus our analysis on different years, each year corresponding to a stage of the French industrialization process. It will give us a picture of the deskilling hypothesis at different phases of the steam technological change. We present the corresponding cross section estimates of Equation (1) in Table 1.B.

Specifically, we present estimates for Equation (1) using different sets of controls. Adding controls reduces unobserved heterogeneity. But due to data restrictions for several counties, we end up with a constrained sample when all controls are included. We therefore show univariate (Column 1, Table 1.A; Columns 1 to 3, Table 1.B) and multivariate results (Columns 2 to 4, Table 1.A; Columns 4 to 6, Table 1.B). Our estimates strengthen the finding presented by Frank and Galor (2016). Not only is the relationship negative and strongly significant in the early stage of industrialization (Columns 1 and 4, Table 1.B), but the relationship holds during all the French industrialization process. We also note that no covariate affects the negative association between the distance from Fresnes-sur-Escaut and the number of steam engines. The relationship remains robust across all specifications.

In Table 2, we test that the distance of each county administrative centre to Fresnes-sur-Escaut is orthogonal to several measures of pre-economic and educational development, i.e. not related to possible important pre-existing correlates of industrialization. Human capital formation in the pre-industrial era is approximated by the share of Frenchmen who signed their marriage license in 1686-1690. The distance from Fresnes-sur-Escaut is uncorrelated with this measure of literacy. In extension, we find no statistical relationship between the population density in 1801 and the distance from Fresnes-sur-Escaut. However, the closer to Paris a county is, the more the population density and literacy rates increase (see Columns 3 and 4). The distance from Paris is correlated with economic development across France in the pre-industrial era. To conclude, the distance to Fresnes-sur-Escaut is a valid instrument for the distribution of steam engines.

Table 2: Pre-industrial development and the distance from Fresnes-sur-Escaut

	(1)	(2)	(3)	(4)
	Dependent variable: number of steam engines (in log)			
	OLS			
	Population density, 1801	Literacy, 1686-1690	Population density, 1801	Literacy, 1686-1690
Distance to Fresnes	-0.136	-0.213	0.027	-0.126
	(-1.07)	(-0.79)	(0.17)	(-0.48)
Latitude	8.011**	5.058*	5.676*	3.555
	(2.62)	(1.79)	(1.80)	(1.44)
Cultivable land	-0.413	-0.071	-0.299**	-0.153
	(-1.47)	(-0.34)	(-2.08)	(-0.72)
Fertile soil	-0.014	0.015	-0.005	0.020
	(-0.91)	(1.00)	(-0.35)	(1.45)
Distance to Paris			-0.265**	-0.255*
			(-2.10)	(-1.89)
Constant	-18.104	-14.668	-10.053	-6.994
	(-1.59)	(-1.23)	(-0.78)	(-0.70)
Observations	85	76	85	76
R^2	0.177	0.348	0.210	0.381

Notes: All variables except the dummies are in logarithm. Aerial distances from Fresnes and from Paris are measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

The second stage of our 2SLS analysis provides both a panel data estimate and a cross-section estimate of the relationship between industrialization and the levels of human capital across the French industrialization process.

First we exploit the time dimension of our data to assess the strength of the relationship between industrialization and *intermediate* human capital:

$$H_{it} = \alpha + \beta Steam\_engine_{it} + X_i'\gamma + \varepsilon_{it}\ , \qquad (2)$$

where H_{it} is the log of our human capital variable of county *i* in year *t*, $Steam\_engine_{it}$ is the log of the number of steam engines of county *i* in year *t*, X_i' is a vector of control variables that includes diverse time-invariant characteristics of county *i*; and ε_{it} is the error term of county *i* in year *t*. The standard errors are robust to heteroskedasticity. X_i' does not differ from $X_{1,i}'$ in Equation (1) because no covariate can be seen as endogenous to the adoption of the steam engine.

Second we with test several cross-section estimates of this relationship, focusing on three time periods, e.g 1839, 1861 and 1886. Each year reflects a different stage of industrialization.[8] We therefore take benefit from the wider range of human capital indicators at the cross-section level to

[8] Results for 1896 are also available upon request. Estimates remain very similar but, due to data limitations, we proxy intermediate human capital in 1896 by its value of 1886.

improve our understanding of this relationship. The cross-section estimates allow us to compare the effect of industrialization on *basic* human capital accumulation to the effect of industrialization on *intermediate* human capital accumulation.

Results

Panel analysis: the effect technological change on *intermediate* human capital

We implement panel analyses to examine the effect of technological adoption on the accumulation of *intermediate* human capital for the 1839-1900 period.

We start by considering the effect of industrialization on the number of pupils enrolled in upper elementary education (*EPS*). The estimates are based on data available at seven points, say 1840, 1850, 1882, 1886, 1891, 1897 and 1906. Table 3 reports our results. They highlight a positive and significant association, at the 5% level, of the number of steam engines used in industries and enrolments in this path of education. This relationship remains significant after progressively controlling for the confounding effects of geography, demography and pre-industrial development. The estimate indicates that a 1% increase in the number of steam machines installed in a county is in average associated with a 0.616% increase in EPS enrolments (Column (6)).

Table 3: The effect of industrialization on EPS adding control variables

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Enrolments in EPS (in log)					
	2SLS					
Number of steam engines	0.429**	0.492**	0.557**	0.568**	0.609***	0.616**
	(2.39)	(2.08)	(2.34)	(2.36)	(2.81)	(2.56)
Distance to Paris	-0.088	-0.079	-0.039	-0.010	0.304	0.320
	(-0.62)	(-0.55)	(-0.24)	(-0.06)	(1.56)	(1.40)
Latitude		-1.014	-0.140	-0.614	-0.728	-0.636
		(-0.36)	(-0.05)	(-0.24)	(-0.23)	(-0.20)
Cultivable land			-0.402**	-0.385**	-0.064	-0.071
			(-2.30)	(-2.09)	(-0.25)	(-0.26)
Fertile soil			0.042**	0.041**	0.019	0.018
			(2.11)	(2.04)	(0.85)	(0.77)
Density in 1801				0.082	0.007	0.010
				(0.82)	(0.07)	(0.10)
Literacy in 1686-1690					0.202	0.205
					(1.17)	(1.15)
Maritime						-0.045
						(-0.20)
Constant	3.817**	7.364	7.949	8.795	3.476	3.068
	(2.34)	(0.73)	(0.86)	(0.95)	(0.30)	(0.26)
Observations	602	602	587	580	520	520

Note: All variables except the dummies are in logarithm. The *Number of steam engines* is instrumented with the *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Since the positive impact of steam technology adoption on the accumulation of intermediate skills spread through the *EPS* may be expected to have varied as the industrialization process deepened, we estimate our model on different panel subsamples (Table 4). We choose to exclude the early stages of the process. We first exclude 1840; then we exclude 1840 and 1850. In a third model, we consider the sample without outliers. We observe that the positive effect of technological adoption on the development of upper elementary education holds when excluding the outliers and that the magnitude of the effect increases when early periods of the French industrialization process are dropped. When excluding the early period of industrialization (1840), our results highlight that a 1% increase in the log of steam machines led to a 0.964% increase in *EPS* enrolments. The increase in *EPS* is of 0,780% when excluding the years before 1850 what highlights a stronger effect than the one observed for the whole sample.

Table 4: The effect of industrialization on EPS on subsamples

	(1)	(2)	(3)
	Since 1850	Since 1882	Excluding outliers
	Dependent variable: enrolments in EPS (in log)		
	2SLS		
Number of steam engines	0.964***	0.780***	0.400***
	(3.58)	(3.07)	(2.72)
Controls	Yes	Yes	Yes
Observations	370	296	479

Note: All variables except the dummies are in logarithm. The *Number of steam engines* is instrumented with the *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Adult courses

We turn now to the analysis of the second path of education through which *intermediate* skills were accumulated in nineteenth century France. Tables 5.1 and 5.2 report the IV estimates of Equation (1), regressing first the log number of steam engines on enrolments in adult classes and employing the whole available panel dataset. Results with any controls are displayed in Table 5.1. We observe that adopting the steam technology has a positive and significant influence at the 1% level on the development of education for adults (Columns (1), (2) and (3) of Table 5.1). Table 5.2 presents estimates of Equation (1) with all the time-invariant covariates presented in the data section of this paper. The significance drops when our set of controls is included into the regression.

The data show important gender differences in enrolments regarding lifelong learning. We observe very low attendance for women compared to men. We therefore put our investigation further and perform separate analysis for men and women (see Table 5.1, Columns (4) to (7) and Table 5.3). Besides, we expect –as for upper elementary education (*EPS*)– that the effect of technological change on *intermediate* human capital accumulation strengthened as industrialization proceeds. We run additional panel regressions excluding the first industrialization period (years prior to 1850). Finally, we delete some excessive outliers using the Billor *et al.* (2000) procedure, namely their blocked adaptive computationally efficient outlier nominators algorithm. Results are reported in Table 5.4.

Controlling for all time invariant covariates, we observe no statistical relationship between the adoption of steam engines and enrolment in classes for adults from 1839 to 1900, neither for men nor for women (Table 5.3). However, when we turn to focus to the second half of the nineteenth century (namely since 1863), we find evidence for a positive influence of the steam technological adoption and total enrolment in Adult classes (see Table 5.4, columns (1) and (2)) In particular, in the subsequent stages of industrialization, this relationship is driven only by male enrolments (see Table 5.4, Columns (3) and (4)). From 1863 onward, a 1% increase in the number of steam machines installed in a French county is associated in average with a 0.402% increase in male enrolments in adult classes, while the effect remains insignificant for female enrolment.

Table 5.1: estimates for the whole dataset, all adults (no control)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Dependent variable: enrolments in adult classes (in log)						
	Adult classes			Men only		Women only	
	OLS	2SLS	FE	OLS	2SLS	OLS	2SLS
Nb of steam engines	1.045***	0.436***	2.158***	0.861***	0.477***	0.970***	0.474***
	(17.18)	(3.34)	(3.94)	(15.94)	(5.98)	(13.48)	(4.35)
Constant	2.984***	5.587***		3.754***	5.389***	0.742*	3.018***
	(9.27)	(9.81)		(12.90)	(15.48)	(1.78)	(5.93)
Observations	708	708	708	699	699	611	611
R^2	0.3169	0.3169	0.276	0.3790	0.3790	0.2311	0.2311

Note: All variables are in logarithm. Columns (1), (4) and (6) report OLS estimates of Equation (1). Columns (2), (5) and (7) report 2SLS estimates of Equation (1). The *Number of steam engines* is instrumented with the *Distance to Fresnes*, measured in kilometres. Column (3) reports IV estimates of model (1) applying a fixed effects estimator. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Table 5.2: IV estimates for the whole dataset, all adults (with controls)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: enrolment in adult classes					
	2SLS					
Number of steam engines	0.255	0.374	0.325	0.334	0.344	0.241
	(1.16)	(1.59)	(1.32)	(1.35)	(1.61)	(1.03)
Distance to Paris	-0.272	-0.187	-0.292*	-0.262	-0.135	-0.372
	(-1.23)	(-1.24)	(-1.71)	(-1.63)	(-0.65)	(-1.58)
Latitude		-0.982	-2.843	-3.431	0.138	-0.961
		(-0.26)	(-0.77)	(-0.98)	(0.04)	(-0.25)
Cultivable land			0.255	0.278	0.159	0.258
			(1.31)	(1.38)	(0.56)	(0.86)
Fertile soil			0.012	0.012	0.005	0.018
			(0.49)	(0.46)	(0.19)	(0.65)
Density in 1801				0.092	0.101	0.060
				(0.76)	(0.88)	(0.52)
Literacy in 1686-1690					-0.112	-0.127
					(-0.61)	(-0.67)
Maritime						0.717***
						(3.11)
Constant	7.904***	10.783	15.523	16.668	3.934	8.767
	(3.79)	(0.78)	(1.19)	(1.31)	(0.28)	(0.61)
Observations	708	701	682	674	597	597

Note: All variables except the dummies are in logarithm. The *Number of steam engines* is instrumented with the *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Table 5.3: IV estimates for the sub dataset (with controls)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Dependent variable: enrolments in adult classes (in log)											
	Adult classes men only						Adult classes women only					
	2SLS											
Number of steam engines	0.360***	0.374*	0.320	0.329	0.355*	0.253	0.346*	0.437	0.494	0.495	0.412	0.379
	(2.64)	(1.77)	(1.33)	(1.36)	(1.71)	(1.11)	(1.92)	(1.50)	(1.55)	(1.55)	(1.48)	(1.27)
Distance to Paris	-0.175	-0.173	-0.262	-0.234	-0.165	-0.400*	-0.192	-0.184	-0.166	-0.114	0.068	-0.007
	(-1.29)	(-1.27)	(-1.56)	(-1.48)	(-0.81)	(-1.74)	(-1.06)	(-1.00)	(-0.77)	(-0.57)	(0.26)	(-0.03)
Latitude		-0.317	-1.229	-1.782	-0.391	-1.483		-2.052	-0.541	-1.540	2.855	2.497
		(-0.09)	(-0.34)	(-0.52)	(-0.11)	(-0.40)		(-0.43)	(-0.11)	(-0.35)	(0.61)	(0.54)
Cultivable land			0.172	0.193	0.181	0.279			-0.290	-0.234	-0.365	-0.330
			(0.90)	(0.98)	(0.65)	(0.96)			(-1.18)	(-0.91)	(-0.99)	(-0.86)
Fertile soil			0.015	0.014	0.004	0.017			0.022	0.023	0.045	0.049
			(0.61)	(0.58)	(0.16)	(0.63)			(0.71)	(0.73)	(1.39)	(1.46)
Density in 1801				0.086	0.088	0.048				0.192	0.207	0.195
				(0.72)	(0.79)	(0.42)				(1.25)	(1.42)	(1.35)
Literacy in 1686-1690					-0.129	-0.143					0.246	0.241
					(-0.72)	(-0.78)					(1.05)	(1.02)
Maritime						0.712***						0.228
						(3.17)						(0.80)
Constant	6.881***	8.036	10.024	11.116	5.874	10.672	4.697***	12.150	9.223	10.772	-6.311	-4.770
	(5.34)	(0.65)	(0.79)	(0.89)	(0.42)	(0.76)	(2.66)	(0.71)	(0.56)	(0.67)	(-0.35)	(-0.27)
Observations	699	699	681	673	597	597	611	611	593	586	521	521

Note: All variables except the dummies are in logarithm. The *Number of steam engines* is instrumented with the *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Table 5.4: IV estimates on subsamples

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: enrolments in adult classes (in log)					
	Whole sample		Men only		Women only	
	Since 1863	Excluding outliers	Since 1863	Excluding outliers	Since 1863	Excluding outliers
	2SLS					
Steam engines	0.380**	0.323***	0.402**	0.298***	0.394	0.194
	(2.30)	(3.18)	(2.49)	(2.83)	(1.21)	(0.77)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	447	519	447	480	446	386

Note: All variables except the dummies are in logarithm. The number of steam engines is instrumented with the *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

To summarize, our data show that the adoption of the steam technology has globally had a significant influence on the formation of *intermediate* human capital, more specifically during the second half of the nineteenth century. Indeed, enrolments in adult classes increase as a result of the adoption of more steam engines. In addition, the magnitude of this positive effect of technological change on upper elementary human capital accumulation improves as the process of industrialization goes forward.

Cross-sectional analysis: technological change and basic vs. intermediate human capital

Our cross-sectional analyses follows a twofold objective: (i) we take benefit from available but sporadic data at three time points (1839, 1861 and 1886) in order to compare the effects of industrialization on *basic vs. intermediate* human capital accumulation across different phases of the French process of industrialization: the initial stage of the process (1839), the expansion phase of the second Kondratieff cycle (1861), and the latter stage corresponding to the 'second' industrial revolution (1886); (ii) we put to scrutiny our hypothesis that *intermediate* human capital spread as a response to technological adoption more intensively in the second half of the nineteenth century.

Each time point chosen to investigate the three stages of industrialization allows us to consider specific human capital measures while controlling for the same set of variables. For 1839, 1861 and 1886, we use two sets of proxies for human capital, one for *basic* human capital, one for *intermediate* human capital. We use literacy rates (employing the share of army conscripts who can read at least), the number of primary schools per 10 000 inhabitants and the number of municipalities with no school in each county to depict the accumulation of *basic* human capital. For *intermediate* human capital, we consider enrolments in upper elementary education (*EPS*) and enrolments in classes for adults. IV estimates of Equation (2) are reported in Tables 6, 7 and 8.

Basic human capital

The first main conclusion we can draw from the cross-section regression analysis is that the first phase of the French industrialization process has been conducive to the accumulation of basic skills. Our results reveal that, for the two first periods, more steam engines in use is significantly associated with higher literacy rates (see Table 6, Column (6); Table 6, Column (5); Table 7, Column (6)) and with a denser educational network (Table 6, Column (7); Table 7, Column (7)).[9] In 1839, a 1% increase in the number of steam engines is significantly and positively associated with a 1.116% decrease in the number of municipalities with no school in the 1840s and with a 0.819% decrease if we consider a 10 years lag. In 1861, the magnitude decreases, but the relationship remains strongly significant: a 1% increase in the number of steam engines in 1861 decreased the number of towns with no school in 1863 by 0.631%. The positive influence of technological innovation on the educational network appears to be stronger in the early phase of industrialization. This downward tendency is confirmed by the regression results for 1886. In 1886, the steam technology adoption did no longer play any significant role on the accumulation of basic skills (see Table 8, Columns (6), (7) and (8)). Technological change needed basic human capital in the first stage of industrialization. As the adoption of the steam technology expended, basic skills started being less needed up to being not needed anymore. Is there a shift in the type of skills needed?

Intermediate human capital

Results reported in Table 8 confirm the hypothesis of a change in the nature of the needed skills. Our data show a positive and significant effect of industrialization on enrolments in *EPS* and enrolments in courses for adults, say on the formation of *intermediate* human capital. Columns (9) and (10) reveal that a 1% increase in the number of steam engines in use in 1886 increases by 0.874% the number of pupils enrolled in upper-elementary education and by 1.100 % the number of adults enrolled in adult classes. However this relationship was insignificant in the early stage of industrialization. Counties adopting more steam engines in 1839 did not ask for higher enrolments in the two educational paths spreading *intermediate* knowledge (see Table 6, Columns (9) and (10).[10] These cross-sectional analyses confirm our panel regressions conclusions: technological change started affecting the development of *intermediate* human capital later in the process of industrialization, i.e. in the second half of the nineteenth century. More precisely, a 1% increase in the number of steam engines installed in a county is associated with an increase of 1.236% in the

[9]Due to the lack of available data, we use the number of primary schools per 10 000 inhabitants and the number of municipalities with no school in 1837 as a proxy for the density of the educational network in the 1840s. We make the assumption that the educational network varied slowly. For robustness check, we test the number of municipalities with no school in 1850. Estimates are very similar.

[10]Due to data constraints, we consider enrolments in classes for adults in 1837 as a proxy for 1840. The relationship remains non-significant when considering a 10 years lag.

number of pupils enrolled in upper-elementary education (see Table 7, Column (9)). This relationship is significant at the 1% level. Enrolments in classes for adults increase by 0.470% for a 1% increase in the number of steam engines in use. These results suggest that a shift in the type of the skills needed occurred around this stage of industrialization.

The adoption of the steam technology during the French industrialization process did not led to basic human capital formation after the first stage of development. Instead, it led to *intermediate* human capital accumulation, allowed by the creation of *EPS* courses and the development of lifelong learning!

5 Conclusion

Relying on a comprehensive dataset describing the adoption of steam engines in French industries throughout the nineteenth century and exploiting departmental differences regarding steam power use, this paper shows that the type of skills needed for the French process of industrialization evolved as industrialization proceeded.

Our results are consistent with Galor and Franck's findings (2016) who claim that, in the early phase of the French industrialization, technological adoption fostered human capital accumulation. These results are strongly different from the British industrialization process, which is recognized for not having been demanding for basic skills. Recently, De Pleijt, Nuvolari and Weisdorf (2016) have confirmed that England's industrial revolution did not play a positive role on the formation of elementary education.

We account for a longer time span and for a disaggregated perspective of skills and knowledge provided by the French education system in the nineteenth century. Doing so, we evidence that, in the first phase of the industrialization process, the positive effect of technological change on human capital formation concerned only *basic* skills but vanished in the second half of the century. Instead, in the second half of the century, *intermediate* human capital (and no more *basic* human capital) developed in response to technological change. This form of human capital may open the path for a renewed approach linking education and industrialization in economic history.

Table 6: The effect of industrialization on human skills in 1839

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Share of conscripts in 1851-1855	Schools per 10000 inhabitants 1837	Number of towns with no school in 1837	Number of men in EPS in 1840	Number of men in classes for adults in 1837	Share of conscripts in 1851-1855	Schools per 10000 inhabitants 1837	Number of towns with no school in 1837	Number of men in EPS in 1840	Number of men in classes for adults in 1837
			OLS					2SLS		
Number of steam engines	0.016*	0.014	-0.161*	0.092	0.314	0.043*	0.229**	-1.116***	0.283	0.385
	(1.77)	(0.52)	(-1.86)	(1.11)	(1.45)	(1.75)	(2.38)	(-3.67)	(1.17)	(1.04)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance to Fresnes						-1.3755***	-1.3755***	-1.3755***	-1.3755***	-1.3755***
						(-3.56)	(-3.56)	(-3.56)	(-3.56)	(-3.56)
Observations	74	75	75	75	75	74	75	75	75	75
F-stat (1st Stage)						12.597	12.663	12.663	12.663	12.663
R^2	0.488	0.395	0.359	0.375	0.220					

Notes: All variables except the dummies are in logarithm. *Number of steam engines* is the log of the number of steam engines recorded in 1839. Columns (1) to (5) report OLS estimates of Equation (2) using all controls. Columns (6) to (10) report 2SLS estimates of Equation (2) using all controls using additional controls. *Number of steam engines* is instrumented with *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Table 7: The effect of industrialization on human skills in 1861

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Share of conscripts in 1871-1875	Schools per 10000 inhabitants in 1863	Number of towns with no school in 1863	Number of individuals in EPS in 1882	Number of individuals in classes for adults in 1863	Share of conscripts in 1871-1875	Schools per 10000 inhabitants in 1863	Number of towns with no school in 1863	Number of individuals in EPS in 1882	Number of individuals in classes for adults in 1863
			OLS					2SLS		
Number of steam engines	0.042**		-0.037	0.566***	0.431**	0.115*	0.125*	-0.631**	1.236***	0.470**
	(2.32)		(-0.35)	(4.41)	(2.49)	(1.95)	(1.74)	(-2.03)	(3.24)	(2.44)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Distance to						-1.1164***	-1.1164***	-1.1164***	-1.1201***	-1.1164***

Fresnes						(-3.90)	(3.90)	(-3.90)	(-3.93)	(-3.90)
Observations	75		75	74	75	75	75	75	74	75
F-stat (1st Stage)						15.241	15.241	15.241	15.428	15.241
R^2	0.521		0.280	0.288	0.418					

Notes: All variables except the dummies are in logarithm. *Number of steam engines* is the log of the number of steam engines in use in 1861. Columns (1) to (5) report OLS estimates of Equation (2) using all controls. Columns (6) to (10) report 2SLS estimates of Equation (2) using all controls using additional controls. *Number of steam engines* is instrumented with *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Table 8: The effect of industrialization on human skills in 1886

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Share of conscripts in 1886	Schools per 10000 inhabitants in 1886	Number of towns with no school in 1886	Number of individuals in EPS in 1886	Number of individuals in classes for adults in 1886	Share of conscripts in 1886	Schools per 10000 inhabitants in 1886	Number of towns with no school in 1886	Number of individuals in EPS in 1886	Number of individuals in classes for adults in 1886
			OLS					2SLS		
Number of steam engines	2.325***	-0.108***	0.080	0.757***	0.921***	2.632	0.083	-0.122	0.874***	1.225**
	(3.03)	(-3.88)	(0.97)	(5.69)	(2.96)	(1.25)	(0.92)	(-0.60)	(3.55)	(2.14)
Distance to Fresnes						-0.9042***	-0.9113***	-0.9113***	-0.9042***	-0.9042***
						(-3.96)	(-3.97)	(-3.97)	(-3.96)	(-3.96)
Observations	74	73	73	74	74	74	73	73	74	74
F-stat (1st Stage)						15.692	15.788	15.788	15.692	15.692
R^2	0.528	0.584	0.056	0.358	0.403					

Notes: All variables except the dummies are in logarithm. *Number of steam engines* is the log of the number of steam engines in use in 1886. Columns (1) to (5) report OLS estimates of Equation (2) using all controls. Columns (6) to (10) report 2SLS estimates of Equation (2) using all controls using additional controls. *Number of steam engines* is instrumented with *Distance to Fresnes*, measured in kilometres. Robust standard errors are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

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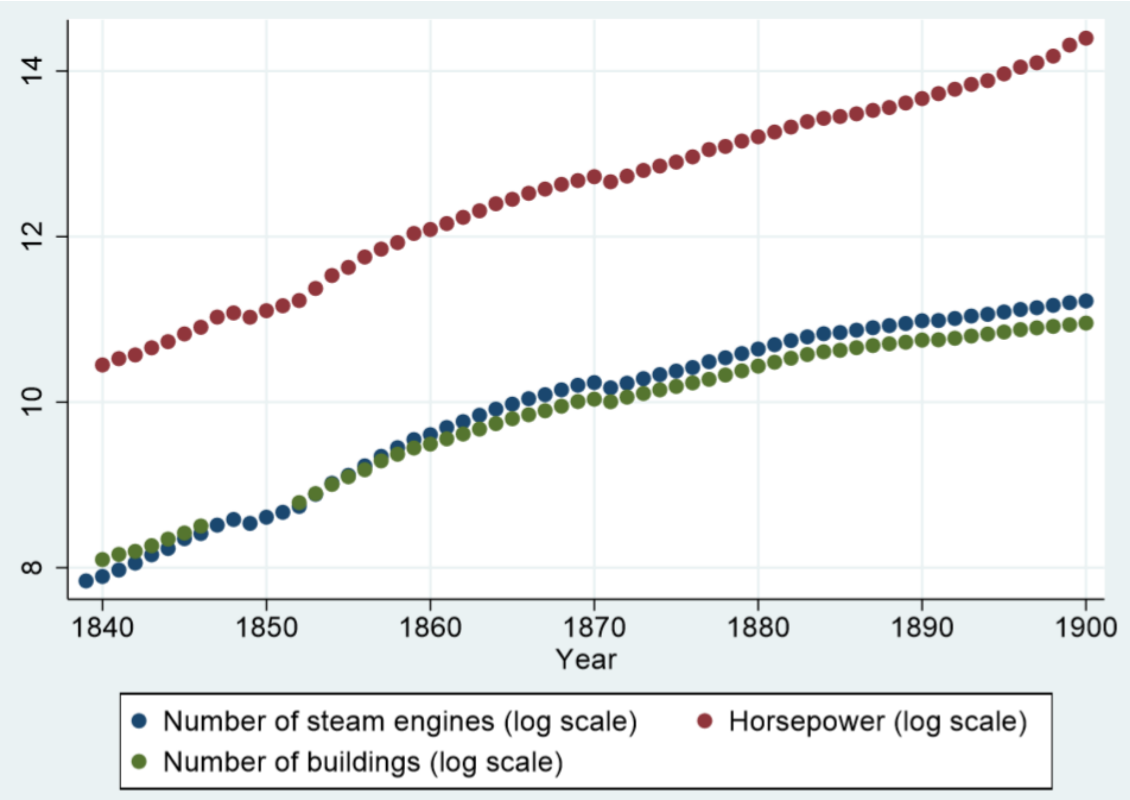
Appendix A

Figure A.1: Number of steam engines in use in France (1839-1900), number of industries in France using the steam technology (1840-1900) and the steam power in use in France (1840-1900)



Appendix B: Summary statistics for cross sectional analyses

Variable	Obs.	Mean	St. dev.	Min.	Max.
Steam engines					
Steam engines (number in 1839)	87	29.21839	78.66923	0	500
Steam engines (number in 1861)	89	177.5843	339.6053	0	2195
Steam engines (number in 1886)	87	603.1149	818.2184	7	5156
Human capital					
1839					
Basic skills					
Schools per 10000 inhabitants 1837	86	2.782725	.3890255	1.769855	3.594843
Number of towns with no school in 1837	86	3.639323	1.309271	0	5.605802
Share of conscripts in 1851-1855	87	4.414912	.1427784	3.949319	4.602166
Intermediate skills					
Number of men in classes for adults in 1837	86	3.868891	2.828521	0	8.37908
Number of men in EPS in 1840	89	4.204096	1.801403	0	7.74846
1861					
Basic skills					
Number of towns with no school in 1863	89	1.576429	1.223139	0	4.553877
Share of conscripts in 1871-1875	86	4.159111	.3021283	3.299534	4.577799
Schools per 10000 inhabitants in 1863	89	2.973543	.3845822	1.095273	4.139796
Intermediate skills					
Number of individuals in EPS in 1882	86	4.890744	1.744444	0	8.508556
Number of individuals in classes for adults in 1863	89	6.473152	1.650644	0	9.617004
1886					
Basic skills					
Schools per 10000 inhabitants in 1886	86	3.174718	.3401332	2.00148	4.09601
Number of towns with no school in 1886	85	.4150603	.6138968	0	2.564949
Share of conscripts in 1886	86	89.95814	6.946221	64.9	98.8
Intermediate skills					
Number of individuals in classes for adults in 1886	89	5.576273	2.956625	0	10.38502
Number of individuals in EPS in 1886	86	5.456978	1.301238	0	8.633553
Instrument and Controls					
Distance to Fresnes (aerial distance in km)	89	497.5562	220.6439	43	999.5
Distance to Paris (aerial distance in km)	89	365.4663	188.7642	0	918.86
Literacy (percent of individuals who signed their mariage license in 1686-1690)	76	18.96816	10.87633	3.68	45.66
Latitude	89	46.42664	2.105079	41.9192	50.6292
Fertile soil (in 1837)	86	84608.93	100777.4	0	429000
Cultivable land (in 1834)	86	215814.2	90405.15	29278	416770
Royal roads (number in 1824)	86	6.953488	3.184178	3	25
Population density (in 1801)	86	1314.895	2757.644	0	26316
Maritime	89	.258427	.4402502	0	1