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Learning outside the factory: the impact of technological change on the rise of adult education in nineteenth-century France

Claude Diebolt, Charlotte Le Chapelain, Audrey Rose Menard[1]

Abstract: The paper provides an empirical examination of the effect of the use of steam engine technology on the development of adult education in nineteenth-century France. In particular, we exploit exogenous regional variations in the distribution of steam engines across France to evidence that technological change significantly contributed to the development of lifelong training during the 1850-1881 period. Our research shows that steam technology adoption in France was not deskilling. We argue that this process raised the demand for new skills adapted to the development of French industries.

Key-words: Adult Education, Cliometrics, France, Human Capital, Industrialization, Steam Engines, Technological Change.

JEL Classification: A12, C18, C80, I21, N13, N33, 014, 033.

1 Introduction

Factory work experience was, for workers and employees, one important way to accumulate the skills demanded by the industrialization process and by technological change in the nineteenth century. Alongside "learning-by doing", lifelong training occurred through the development of education for adults in nineteenth-century France. Until recently, little attention has been paid, in the French historiography, to this form of education. But the rapid development of classes for adults and employees in the first stages of the French industrialization process has been underlined, and the issue of adult education is currently subject to ongoing work by French historians (see Christen, 2014a, Christen and Besse 2017).

This paper provides an empirical investigation of the role of technological change in the rise of new education paths for adults. We ask whether "industrial education" developed in response to steam technology adoption in French industry, using a county-level analysis.

Our study contributes to the ongoing debate, in cliometrics, over the role industrialization and technological change played in the formation of human capital.

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Until recently, the industrialization process at the time of the steam engine was usually considered to have been a deskilling process. Technological change was argued to support unskilled as opposed to skilled labor, meaning that technological innovation and human capital were substitutes for each other (e.g., Nicholas and Nicholas 1992, Mokyr 1993, Mitch 1999). Goldin and Katz (1998) provided evidence that new technological adoption and human capital formation became complementary only in the early twentieth century with the shift from steam power technology to that driven by electricity.

The debate has recently been revived. Following Feldman and Van der Beek (2016), the number of apprentices and their weight in the adult population increased in response to inventions in eighteenth-century England. Franck and Galor (2016) confirmed the "skill-biased technological change" hypothesis for early nineteenth-century France, and Katz (2016) found a positive association between industrialization and literacy rates in the United States during the period 1850-1900. Yet, according to De Pleijt et al. (2016), the effect of industrialization on human capital remains ambiguous. Technological adoption improved the average skills of workers, but did not support the development of elementary education. Contrastingly, De Pleijt and Weisdorf (2017) showed 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 claimed that deskilling occurred globally 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.

This paper aims at contributing to this debate by investigating the effect of the adoption of steam technology in French industries on the development of lifelong learning. To our knowledge, the effect of technological change on the rise of adult education has not been subject to analysis, neither for the French case nor for other national experiences, although historians have underlined the importance of this form of education in the accumulation of human capital.

Our approach relies on the use of an original panel database depicting the number of steam engines in use in French industries at the county level and the number of adults enrolled in classes for adults from 1850 to 1881.

Our IV results bring a new element to the debate. We provide evidence that more steam engines in use is associated with higher enrolment rates in adult classes in the second half of the nineteenth century.

The paper is organized as follows. Section 2 provides the historical foundations, economic ideas and institutional markers of the development of this form of education intended for workers and employees. We present our data in Section 3, and the empirical strategy and results in Section 4. Section 5 concludes.

2 Historical background

Condorcet's project of public instruction is recognized as having been the first to pay careful attention to the issue of adult education. In the *Mémoires sur l'instruction publique (1791-1792)* and the *Rapport et projet de décret sur l'organisation générale de l'instruction publique* (1792-1793), Condorcet stressed the need for the instruction system to provide education to adults, and set out detailed guidelines to organize this form of education.

The "common instruction for men",[2] in line with the objectives assigned to the system of public instruction, had to spread reason among citizens, and, by the way, had to reduce inequalities between them. In particular, the "common instruction for men" had to provide every citizen with the necessary knowledge so that he could enjoy his rights. It also had to prepare future citizens who would be able to pronounce on laws and the constitution, and it became essential to ward off the dangers associated with an increasing division of labour. Finally, according to Condorcet, adult education had to contribute to the dissemination of the early principles of science and to their evolution. It was also designed to promote applications of these advances to the arts. Therefore, adult education was seen as a vehicle for spreading the progress of science and, all above, for developing its usefulness through the spread of its applications.

Adult education really began to take off in the nineteenth century. Outlining this form of education is complicated, because it developed in very different forms and at that time had multiple objectives (see Christen 2014a). However, a common feature can be emphasized: classes for adults had to palliate the insufficiencies of instruction for the popular and laboring class. Indeed, the workers, employees and apprentices of the nineteenth century were those who would come to complete (or even begin) their education. Some classes for adults in the first half of the nineteenth century were intended to fill gaps in basic knowledge, starting with learning to read and write. But the development of adult education was not only a vehicle for literacy. It also provided basic knowledge in sciences, in law, and courses on trade. Bodé (2014) identified nine categories of courses for adults provided in the Restauration period and during the July Monarchy: linear drawing, geometry and

[2] « l'instruction commune pour les hommes ». See the third thesis, *Mémoires sur l'instruction publique (1791-1792).*

mechanics, chemistry and physics, mathematics, law and legislation, trade, marine and hydrography, industrial courses for workers, and blended courses.[3]

In particular, since the second half of the nineteenth century, when illiteracy had already sharply declined, classes for adults were intended to offer more extensive instruction. Adult education took gradually the form of an "industrial education". This education then allowed the acquisition of scientific and technical knowledge and provided qualifications as complements to those acquired in the context of learning by doing or in the context of apprenticeships. As a consequence, the age of the audience for these courses was very diverse. Classes for adults included adults – mainly men – but also young apprentices, sometimes aged 12 years.

From the Guizot law (1833) – the first major law organizing primary education – classes for adults were attached to primary education. But classes for adults had already developed earlier than this, as a fruit of various initiatives and among very diverse establishments. Hence, private initiatives, be they from professional, scientific, philanthropic or religious organizations or associations, led to the emergence of those classes (see Doria 2014). For instance, the "Association Polytechnique" offered elementary and practical teaching to the working classes. Likewise, in Lyon in 1828, Philibert Pompey established a class for workers making drawing learning adapted to the needs of workers a specialty of this class. No matter the establishment, Guizot noticed the eagerness of the listeners – whether adult pupils, workers or apprentices.[4]

The Guizot law of June 1833 was, as mentioned, the first to organize adult classes (see Terrot 1997, p.63-5).[5] The law did not make the creation of classes for adults compulsory, but supervised their development. Therefore, classes for adults could have resulted from the initiative of anyone holding a certificate of competence and a certificate of morality; for example, public schools for adults were

[3] « *Dessin linéaire, géométrie et mécanique, cours de chimie et physique, Mathématiques, Droit et législation, commerce, marine et hydrographie, cours industriels pour ouvriers, cours mixtes* », see Bodé (2014, p. 34).

[4] « *Monsieur le Préfet, le nombre des écoles et des cours publics spécialement destinés aux adultes et aux ouvriers a reçu depuis quelque temps à Paris un accroissement notable. Des personnes et des associations qui diffèrent essentiellement, soit par leur origine, soit par leurs idées, ont également concouru à ce résultat. La société des méthodes, l'Association polytechnique, l'Association libre pour l'instruction du peuple, les Frères des Ecoles chrétiennes, les associations protestantes, de simples instituteurs, ont, à l'envi, offert aux classes laborieuses cet enseignement élémentaire et pratique qui convient à leur situation et à leurs travaux. Et partout, quelle que soit la diversité des établissements, l'empressement des auditeurs répond au zèle des fondateurs ; les élèves adultes, ouvriers ou apprentis, affluent aux leçons des Frères de la Doctrine chrétienne comme aux cours de l'Association polytechnique, dans les écoles catholiques aussi bien que dans celles de la religion protestante ou de la pure philanthropie.* », Guizot's instructions to the Prefect of the Seine, February 2, 1833.

[5] « *Mais, ainsi que les salles d'asile sont nécessaires pour préparer aux écoles primaires les enfants à qui leur jeune âge ne permet pas encore de les suivre, de même, il doit exister, au-delà des écoles primaires, et pour les jeunes gens et pour les hommes faits qui n'ont pu en profiter, des établissements spéciaux où la génération déjà laborieuse, déjà engagée dans la vie active puisse venir recevoir l'instruction qui a manqué à son enfance : je veux parler des écoles d'adultes.* », Circular of July 4, 1833 related to the Guizot law.

those hosted by a public teacher, while free classes for adults were the fruit of private initiatives. But because of the political risk that any adult gathering represents, Guizot placed adult classes under surveillance. The opening of a class for adults was conditional on the authorization of the county council, and the subjects provided in such a class were only those detailed in law (see Lelièvre, 1988). Besides, classes for adults did not necessarily receive a public subsidy, and existing subsidies were fluctuating. Though the constraints set by the Guizot law made it difficult to develop these classes, the number of adults enrolled in them increased threefold between 1837 and 1848.

The Falloux Law (1850) stipulated that primary schools for adults could be officially opened but still did not make them compulsory. It was not until 1863 that teachers were consulted by Rouland on the needs of primary education. More than a quarter of those who responded to this call spontaneously expressed the wish that classes for adults be reorganized. Duruy (Rouland's successor) emphasized adult education as a key priority to overcome the shortcomings of primary education. While literacy made considerable progresses in the second half of the nineteenth century, Duruy assigned adult education courses an objective of disseminating intermediate knowledge, in particular giving knowledge a practical and even professional focus. In a circular of July 11, 1865, after recalling that a large number of classes for adults had been created in 1864, he asked that the effort be further increased. Classes for adults then started upon a significant evolution.
Duruy detailed his instructions to the Rectors on classes for adults in the circular of November 2, 1865. He mentioned that the lessons taught in these classes had to diffuse knowledge, with no theoretical demonstration of science, but raising awareness about the discoveries in science, and popularizing their main applications. Indeed, Duruy related the need for the diffusion of intermediate knowledge to the growth of welfare and wealth, the expansion of commerce, and the development of the arts and industry. Grew and Harrigan (1991, 184) reported that 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.*"

Historians have emphasized the interpenetration of economic, political and social dimensions as a key determinant of the development of adult education in the nineteenth century (see, for instance, Christen (2014b)). Focusing on the second half of the nineteenth century and based on the attendance of public and free classes for adults at the departmental level, we investigate whether this development is related to the technological choices made by French industries, for example those related to the heterogeneity of adoption of steam power within French industries in the nineteenth century.

3 Data

The research examines the effect of steam technology adoption on adult education. This section presents the data used for this analysis and the data sources. Table A.1 reports the descriptive statistics for the variables in the empirical analysis across French counties.

Quantitative assessments of steam power use in nineteenth-century France generally draw upon the sporadic statistical information contained in the industrial censuses (1839-1847, 1860-1865 and 1896). We build on a new dataset which we compiled using two sources of information. In particular, the use of steam power in France was organized and regulated at the legislative level by the ordinances of 2 April 1823, 29 October 1823, 7 May 1828, 25 May 1828, 23 September 1829, and 25 March 1830.

The use of steam engines in factories (ordinances of 23 September 1829 and 25 March 1830) was subject to prefectoral authorizations. Supervisory responsibilities were assigned to the French mining engineers (*Ingénieurs des Mines*) who had the duty to guarantee safe usage of this new power source. Thus, all steam engines installed in French industries were first controlled by engineers. They reported information, by county, about their number first in the *Compte rendu des travaux des ingénieurs des mines* (*Direction générale des Ponts et Chaussées et des Mines*), and then from 1838 onwards in the *Statistique de l'industrie minérale et des appareils à vapeur*. Our dataset compiles statistical information contained in these two historical sources.

The adoption of steam technology varied greatly among the French counties. This heterogeneity remained substantial at the end of the nineteenth century. In 1850, 878 steam engines were in use in the *Nord* county whereas eight counties had no machines at all (*Hautes-Alpes, Cantal, Charente, Corrèze, Côtes-du-Nord, Gers, Lot-et-Garonne,* and *Hautes-Pyrénées)*. Close behind the *Nord*, the *Seine* implemented almost 750 machines. The next-most-endowed counties were the *Seine-Inférieure* (425 machines), the *Loire* (320 machines), and the *Rhône* (300 machines). In 1881, the number of machines installed in industries was still higher in the *Nord* with more than 4 900 machines. The *Seine* was in second place, just behind the *Nord* with 4 700 engines in use in the county. For comparison, in 1881, nine counties were still endowed with less than 50 steam engines.

Our last data source is derived from the *Statistique Générale de la France.* We use the number of adults enrolled in classes for adults (public and *libres)* per 10 000 inhabitants in 1850, 1863, 1867, 1869, 1872, 1876 and 1881 to depict lifelong training development. Our data show strong variations among counties. In 1850, while 13 counties recorded no classes for adults (*Hautes-Alpes, Basses-Alpes, Alpes-Maritimes, Ardèche, Belfort, Côte d'or, Creuse, Doubs, Gers, Lot, Savoie, Haute-Savoie,* and *Haut-Rhin*), the *Seine*, the *Rhône*, the *Nord*, and the *Meuse* recorded more than 4 000 adults enrolled in these paths of education. Three decades later, the *Seine* and the *Nord* remained the two counties recording the highest number of inhabitants enrolled in classes for adults (32 411 and 18 590, respectively), just ahead of *Seine-Inférieure*, *Aisne* and *Seine-et-Oise*, located in the North of the country.

To avoid a population size effect, we consider the number of adults enrolled in adult classes per 10 000 inhabitants to proxy for the development of lifelong learning attainment during the second half of the nineteenth century.

Our analysis also accounts for geographic county characteristics and for pre-industrial development indicators. In particular, it captures the potential confounding effect of these factors on the observed relationship between steam engine adoption and adult education.

First, we employ a set of controls to capture geographical differences between French counties. We use the share of cultivable land and the number of square kilometres of fertile soil to measure the extent of agriculture. Counties dominated by agriculture during the first stage of the French industrial revolution are expected to record a lower number of steam engines. Besides, landowners may have less interest in schooling because land and human capital have low complementarity (Galor et al., 2009). We also make use of a dummy that accounts for counties having a maritime border, say access to sea, and a land border, say located along the border with Belgium, Luxembourg, Germany, Switzerland, Italy and Spain. Foreign contacts may have accelerated the steam technology adoption as well as influenced human capital formation. We add a control for the latitude of each county, measured in the location of the county administrative centres. Latitude could have influenced natural land productivity and therefore the profitability of the development of industries.

Second, heterogeneity in the level of development across France in the pre-industrial era may have influenced the subsequent process of industrialization, in particular the adoption of steam technology. Hence, our regression analysis includes the population recorded in each chef-lieu in 1789, as a proxy for pre-industrial urbanization. This process can be associated with pre-industrial development, because populated places allow for specialization, known to support industrial growth and a learning technology. Besides, we expect that the more urbanized counties were more prone to develop human capital.

Third, to measure pre-industrial human capital stocks, we use the earliest available measure of literacy, say the share of Frenchmen who signed their marriage license in 1686-1690. We argue that 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 also control for basic literacy skills in 1846-1850, which may have influenced adult education, and for upper tail skills using as a proxy the number of inhabitants per doctor in 1847.

Fourth, we control for the extent of infrastructures at the very beginning of the industrialization process using the number of royal roads in each county in 1824. We add the number of windmills and the number of watermills in 1861-1865 to measure the extent of other power sources at the county level.

Finally, our research accounts for the aerial distance from Paris to each county administrative centre and includes a dummy variable for Paris suburbs (i.e., *Seine*, *Seine-et-Marne* and *Seine-et-Oise*). The *Seine* is an industrial centre and concentrates the political institutions that might have influenced differentially the adoption of the steam technology and human capital formation in Paris and counties surrounding Paris.

4 Methodology and Results

4.1 OLS estimates and Panel fixed effects estimates

Firstly, we apply an OLS estimator to investigate the relationship between the number of steam engines in use in French industries from 1850 to 1881 and adult education.

$$Adult\_classes_{it} = \alpha + \beta Steam\_engine_{it} + \lambda_i + \varepsilon_{it}\ , \qquad (1)$$

where $Adult\_classes_{it}$ is the number of adults enrolled in classes for adult per 10 000 inhabitants of county *i* in year *t*, $Steam\_engine_{it}$ is the log of the number of steam engines of county *i* in year *t*, λ_i stands for county fixed effects; and ε_{it} is the error term of county *i* in year *t*. The standard errors are robust to heteroskedasticity.

Table 1. The effect of technological adoption on adult education – OLS estimates

	OLS (no control)	OLS (FE)
Steam engine	27.153***	55.194***
	(7.60)	(15.00)

Constant	20.298	
	(1.07)	
County fixed effects	No	Yes
Observations	606	606
R^2	0.0246	0.297

Notes: The dependent variable is the number of adults enrolled in classes for adults per 10 000 inhabitants. Steam engine is in logarithm (using the ln(x+1) transformation). The dependent variable is the number of people enrolled in classes for adults per 10 000 inhabitants. T-statistics are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

We run a univariate analysis, regressing adult education on the steam technological adoption (see Column 1 in Table 1). 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 start showing univariate results. We observe a positive and significant correlation between the number of steam engines in use at the county level and the number of people enrolled in classes for adults per 10 000 inhabitants.

Secondly, in order to mitigate the impact of confounding factors, we report fixed effects estimates of Equation (1), controlling then for all time-invariant characteristics at the county level (see Column 2 in Table 1). This empirical strategy ensures that county specific factors are not the source of the differential pattern of adult education across these counties. The estimate remains highly significant and positive when county fixed effects are added.

4.2 IV estimates

The inclusion of fixed effects reduces endogeneity biases due to omitted variables. But, assessing for the causal relationship between the adoption of the steam technology and adult education implies controlling for other possible endogeneity biases. First, the statistical relationship between the number of steam engines in use and lifelong learning can be driven by reverse causality, namely by the effect of lifelong learning on the use of this industrial technology. Better educated individuals may be prone to enhance the diffusion of new technologies. Second, steam engines in use and classes for adults can have a common determinant explaining variations in the use of steam technology and variations in adult education, while these two variables do not affect each other. A statistical relationship between the number of steam engines in use and adult education could then only reflect a third common variable.

To overcome these issues, we use exogenous county variations in the distribution of steam engines across France. We apply the methodology used by Franck and Galor (2016) for France at the beginning of the French process of industrialization (1839-1847) to the second part of the nineteenth century. In particular, they use the aerial distance of each county administrative centre to Fresnes-sur-Escaut, in the *Nord* county, as an instrument for the number of steam engines recorded in each county. Steam engines were indeed 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 centres, including the *Loire*, the *Rhone*, the *Seine*, the *Seine-Inférieure* and the *Loire-Inférieure*. Franck and Galor (2016) argue that the steam technology adoption started diffusing to the rest of France from Fresnes-sur-Escaut. We extend the use of this instrument to the 1850-1881 period in France showing that the regional diffusion continues explaining the adoption of new steam engines decades after the 1840s (as established by the first stage results reported in Table 3, Columns (1), (3) and (5)).

To be sure that this instrument is strictly exogenous, we test whether the distance of each county administrative centre to Fresnes-sur-Escaut is orthogonal to measures of pre-economic and educational development. First, we approximate literacy in the pre-industrial era by the share of Frenchmen who were able to sign their marriage license in 1686-1690 (*Literacy in 1686-1690*). Second, we approximate pre-economic development with the number of inhabitants in each administrative centre in 1789 (*Population in 1789*). Table 2 shows the results.[6] In particular, the geographical distance from Fresnes-sur-Escaut is not correlated with possible important pre-existing correlates of industrialization. We conclude that this instrument only reflects the extent of steam technology adoption. Distance to Fresnes-sur-Escaut can then be used as an available instrument.

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

Dependent variable	Literacy in 1686-1690	Population in 1789	Literacy in 1686-1690	Population in 1789
Distance to Fresnes-sur-Escaut	-5.446	-0.179	-4.233	-0.037
	(-1.58)	(-0.73)	(-1.23)	(-0.17)
Latitude	77.575	-0.168	41.608	-2.793
	(1.63)	(-0.05)	(0.83)	(-0.96)
Fertile soil (1837)	0.208	0.013	0.358	0.041**
	(0.69)	(0.74)	(1.18)	(2.37)
Cultivable land (1834)	-0.039	0.014**	-0.106	0.004
	(-0.35)	(2.02)	(-0.93)	(0.54)
Maritime border	-1.864	0.523***	-0.340	0.681***
	(-0.78)	(3.25)	(-0.14)	(4.54)

[6] We note that the distance of a county from Paris had a significant association with pre-economic and educational development, which reveals a geographical diffusion of development across France in the pre-industrial era from Paris.

Distance to Paris			-5.298*	-0.468***
			(-1.91)	(-4.33)
Constant	-247.891	11.305	-85.692	23.312*
	(-1.25)	(0.85)	(-0.40)	(1.89)
Observations	75	85	75	85
R^2	0.365	0.234	0.397	0.382

Notes: All variables except the dummies and ratios are in logarithms. Aerial distances from Fresnes-sur-Escaut and from Paris are measured in kilometres. T-statistics are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

This available instrument, highly correlated to the adoption of steam technology (see first-stage result in Table 2) and presumably not correlated with the error term (see Table 3), is time-invariant. Thus equation (2) cannot be estimated using the fixed-effects estimator. To reduce the possible omitted variable biases and unobserved heterogeneity, we therefore employ a set of time-invariant controls, available for most of the French counties, and presented in Section 3.

Following this instrumentation strategy, we now turn to estimate the effect of steam technology adoption on classes for adults using 2SLS.

In the first stage, the log of the number of steam engines installed in county *i* at time *t*, SE_{it}, is implemented by the aerial distance (in kilometers) between the administrative centre of county *i* and Fresnes-sur-Escaut (called D_i).

$$SE_{it} = \delta D_i + X_i\theta + \mu_{it} \quad , \quad (2)$$

where X_i is a vector of county-specific characteristics and μ_{it} is an error term for county *i* at time *t*.

The second stage gives an estimate of the relationship between the number of steam engines in each county *i* at time *t* and adult education.

$$Adult_{it} = \alpha + \beta SE_{it} + X_i \ \gamma + \varepsilon_{it} \quad , \quad (3)$$

where $Adult_{it}$ is the number of adults enrolled in classes for adults per 10 000 inhabitants of county *i* in year *t*, SE_{it} is the log of the number of steam engines in use in county *i* in year *t*, X_i is the same vector of control variables used in the first stage 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.

The first stage estimates confirm the relevance of our instrument for the second half of the nineteenth century. The distance from Fresnes-sur-Escaut is significantly negatively correlated with the number of steam engines installed in each county and first-stage F-statistics are very high. Besides, this negative relationship remains highly significant, even after controlling for the county-specific geographical and institutional characteristics that may have affected the adoption of the steam technology. In particular, our estimates suggest that pre-industrial urbanization, captured by the population in administrative centres in 1789, had a persistent positive effect on the adoption of steam technology. The extent of infrastructures at the very beginning of the process of industrialization in France, captured by the number of royal roads in 1824, was also associated with more steam engines. In addition, counties located along the border with Belgium, Luxembourg, Germany, Switzerland, Italy and Spain, tend to record higher numbers of steam engines installed in their industries, suggesting either the role of foreign influences or the role of trade potential in the diffusion of technology.

Table 3 reports the IV estimates of Equation (1), regressing the log of the number of steam engines on the share of people enrolled in classes for adults. The estimates are based on data available at seven points, say 1850, 1863, 1867, 1869, 1872, 1876, and 1881.

We successively add different sets of time-invariant covariates presented in Section 3 to reduce unobserved heterogeneity and to assess the robustness of the observed relationship. The second stage of our 2SLS analysis evidences a positive association between the adoption of steam technology and the rise in the number of people enrolled in classes for adults, which confirms the fixed-effects estimates (in terms of significance and coefficients size). While technological change is usually considered as a deskilling process in the nineteenth century, our 2SLS results emphasize that adopting steam engines in the French industries triggered the development of lifelong learning during the second part of the nineteenth century.

Table 3 – Estimates for the 2SLS analysis

	Geography		Infrastructures		Human capital	
	1st stage	2nd Stage	1st stage	2nd Stage	1st stage	2nd Stage
Steam engine		38.819**		46.554**		21.709*
		(2.20)		(2.27)		(1.73)
Distance to Paris	0.316	-40.246**	0.414*	-51.247***	0.303	-56.255***
	(1.54)	(-2.44)	(1.84)	(-2.77)	(1.21)	(-3.09)
Latitude	1.670	-856.925***	1.733	-865.324***	0.574	-682.646**
	(0.46)	(-2.75)	(0.45)	(-2.61)	(0.16)	(-2.54)
Fertile soil (1837)	0.022	1.332	0.015	1.994	0.012	2.436*
	(1.04)	(0.77)	(0.68)	(1.09)	(0.68)	(1.90)
Cultivable land (1834)	-0.001	-0.196	-0.003	-0.069	-0.005	-0.510
	(-0.10)	(-0.30)	(-0.29)	(-0.10)	(-0.82)	(-1.04)
Maritime border	-0.245	26.080	-0.376	39.465**	-0.532***	29.328**
	(-1.24)	(1.62)	(-1.63)	(1.98)	(-2.95)	(1.97)
Border county	-0.754***	50.105***	-0.778***	57.484***	-0.94***	55.475***
	(-3.52)	(2.90)	(-3.39)	(3.03)	(-5.36)	(4.13)
Paris suburb	0.961	-23.769	0.755	-3.213	0.335	13.770

	(1.40)	(-0.43)	(1.01)	(-0.05)	(0.61)	(0.35)
Population (1789)	0.981***	-78.079***	0.942***	-82.124***	1.014***	-48.882***
	(7.47)	(-3.81)	(6.79)	(-3.68)	(9.26)	(-3.15)
Windmill (1861-1865)			0.011	0.179	0.012	3.438
			(0.27)	(0.05)	(0.41)	(1.53)
Watermill (1861-1865)			0.092	-8.424	0.126	-4.513
			(0.98)	(-1.12)	(1.54)	(-0.75)
Royal roads (1824)			0.598*	-67.672**	0.540*	-58.637**
			(1.73)	(-2.04)	(1.93)	(-2.52)
Inhabitants per doctor					-0.000	0.663
					(-0.00)	(0.17)
Literacy (1686-1690)					-0.35***	1.669**
					(-4.17)	(2.09)
Literacy (1846-1850)					0.022***	-0.175
					(4.96)	(-0.37)
Constant	-6.095	4285.813***	-8.570	4557.940***	-4.273	3593.796***
	(-0.39)	(3.18)	(-0.52)	(3.12)	(-0.28)	(3.15)
R^2		0.1779		0.1883		0.2779
F-statistics 1st stage		27.36		27.41		79.63
Observations		580		580		520

Notes: The dependent variable is the number of adults enrolled in classes for adults per 10 000 inhabitants. All variables except the dummies and ratios are in logarithms. Aerial distances from Fresnes-sur-Escaut and from Paris are measured in kilometres. T-statistics are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Turning to our control variables, the results stress a negative relationship between the distance to Paris and adult education, suggesting the influence of Paris as a political and industrial centre on the process of adults' skills accumulation. Human capital formation seemed to have benefited from a diffusion of development from nearby regions or countries, as suggested by the positive coefficients of land and maritime borders. Surprisingly, pre-industrial urbanization (e.g., *population in administrative centre in 1789*) and infrastructures (e.g., *number of royal roads in 1824*) seem to have a negative effect on adult education in the second half of the nineteenth century. The possible positive association between pre-industrial urbanization and industrial education may only be mediated through the positive influence of such pre-economic development on the adoption of steam technology, as revealed by the first-stage estimates. Finally, counties with higher literacy rates at the end of the seventeenth century tend to display higher lifelong learning.

The watermill was the main competitive power source for French industries in the nineteenth century. Adherence to waterpower is recognized as a distinctive mark of the French industrialization process. This power 'choice' was a strong argument to support the 'retardation-stagnation' thesis – as it was named by Crouzet (2003) – that claims that the French economy performed less well than the British.[7] Water-powered industries indeed remained very important throughout the French industrial revolution, despite the development of steam power. Yet water power technology doesn't display any effect on adult education. We therefore argue that the skills accumulated thanks to adult education were skills required only by steam technology.

We also consider that lifelong learning could display strong gender differences. Given that we observe very low attendance for women compared to men, we perform a gender analysis (see Table 4). Our data confirm that men played the major role in the development of lifelong learning. The adoption of steam technology is only statistically related to men's education.

Table 4 – Estimates for the 2SLS analysis by gender

Dependent variable	Number of women enrolled in classes for adults per 10 000 inhab.	Number of men enrolled in classes for adults per 10 000 inhab.
Steam engine	0.876	21.167*
	(0.20)	(1.94)
Distance to Paris	5.339	-62.365***
	(0.84)	(-3.94)
Latitude	-69.810	-619.309***
	(-0.75)	(-2.65)
Windmill (1861-1865)	-0.485	3.964**
	(-0.62)	(2.03)
Watermill (1861-1865)	-1.050	-3.459
	(-0.50)	(-0.66)
Royal roads (1824)	-0.567	-59.264***
	(-0.07)	(-2.93)
Fertile soil (1837)	0.595	1.869*
	(1.33)	(1.67)
Cultivable land (1834)	-0.013	-0.500
	(-0.07)	(-1.17)
Maritime border	0.268	29.841**
	(0.05)	(2.30)
Land border	3.925	51.424***
	(0.84)	(4.40)
Paris suburb	21.251	-7.867
	(1.53)	(-0.23)
Population (1789)	-4.977	-44.547***
	(-0.93)	(-3.30)
Inhabitants per doctor (1847)	2.934**	-2.430
	(2.14)	(-0.71)

[7] On this matter, see for instance, Clapham 1936, Kindleberger 1964, O'Brien and Keyder 1978, Cameron 1985, Crouzet 2003.

Literacy (1686-1690)	0.520*	1.159*
	(1.87)	(1.67)
Literacy (1846-1850)	-0.044	-0.143
	(-0.27)	(-0.35)
Constant	288.142	3343.147***
	(0.73)	(3.37)
Observations	520	520
R^2	0.1376	0.2763

Notes: All variables except the dummies and ratios are in logarithms. Aerial distances from Fresnes-sur-Escaut and from Paris are measured in kilometres. T-statistics are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

Furthermore, we test whether our results are driven by extreme values. We delete some excessive outliers using the Billor et al. (2000) procedure, in particular their "blocked adaptive computationally efficient outlier nominators" (BACON) algorithm. Inspecting for remarkable values in our data, 10 observations were dropped. The exclusion of outliers does not alter any sign of the coefficients (see Column 1 in Table 5).

Additionally, we considered the 1863-1881 period, the time period during which Duruy called for efforts to develop classes for adults (see Column 2 in Table 5). We therefore exclude the first year (1850) of our panel to perform our 2SLS regression of Equation (3). Signs are not sensitive to this change but, compared to Table 3 (Column 6), the coefficient of steam engines increases, revealing a stronger effect of new technology adoption on the development of adult education after 1863.

Finally, we do not observe any significant change in terms of the gender differences observed for the whole period. Even in the subsequent period (1863-1881), the effect of new steam engines in use in French industries on adult education is only significant for men (see Columns 3 and 4, Table 5).

Table 5 – Additional 2SLS estimates

	Without outliers	Since 1850	Since 1850	Since 1850
Dependent variable	Nb. of adults enrolled per 10000 inhab.	Nb. of adults enrolled per 10000 inhab.	Nb. of women enrolled per 10000 inhab.	Nb. of men enrolled per 10000 inhab.
Steam engine	21.374*	31.152*	0.964	30.472*
	(1.80)	(1.77)	(0.17)	(1.95)
Distance to Paris	-60.004***	-65.480***	6.194	-72.289***
	(-3.48)	(-2.79)	(0.84)	(-3.48)
Latitude	-682.010***	-913.154**	-81.890	-836.899***
	(-2.67)	(-2.50)	(-0.71)	(-2.59)
Windmill (1861-1865)	3.650*	2.779	-0.584	3.388
	(1.72)	(0.93)	(-0.62)	(1.29)
Watermill (1861-1865)	-4.684	-5.527	-0.971	-4.562

	(-0.82)	(-0.71)	(-0.39)	(-0.66)
Royal roads (1824)	-58.951***	-73.062**	-0.214	-73.790***
	(-2.67)	(-2.41)	(-0.02)	(-2.74)
Fertile soil (1837)	2.420**	2.969*	0.687	2.306
	(1.99)	(1.80)	(1.32)	(1.58)
Cultivable land (1834)	-0.411	-0.533	-0.027	-0.507
	(-0.88)	(-0.84)	(-0.14)	(-0.90)
Maritime border	32.085**	38.513**	0.277	38.859**
	(2.27)	(1.96)	(0.05)	(2.23)
Land border	57.909***	65.413***	4.801	60.533***
	(4.54)	(3.66)	(0.85)	(3.83)
Paris suburb	8.416	11.187	24.484	-13.639
	(0.22)	(0.22)	(1.52)	(-0.30)
Population (1789)	-48.727***	-62.744***	-5.992	-57.262***
	(-3.31)	(-3.06)	(-0.93)	(-3.15)
Inhabitant per doctor (1847)	-0.766	1.818	3.527**	-1.826
	(-0.20)	(0.36)	(2.20)	(-0.41)
Literacy (1686-1690)	1.543**	2.229**	0.623*	1.614*
	(2.03)	(2.10)	(1.86)	(1.72)
Literacy (1846-1850)	-0.266	-0.371	-0.058	-0.322
	(-0.59)	(-0.58)	(-0.29)	(-0.57)
Constant	3621.933***	4672.256***	337.524	4366.283***
	(3.35)	(3.02)	(0.69)	(3.18)
Observations	518	445	445	445
R^2	0.2811	0.2054	0.1616	0.1863

Notes: All variables except the dummies and ratios are in logarithms. Aerial distances from Fresnes-sur-Escaut and from Paris are measured in kilometres. T-statistics are reported in brackets. *** indicates significance at the 1%-level, ** indicates significance at the 5%-level, * indicates significance at the 10%-level.

5 Conclusion

The study brings a new element to the debate on the relationship between technological change and human capital formation. Using panel data techniques, it establishes that the number of steam engines in use in French industries during the second half of the nineteenth century was a significant influence in triggering adult education. There is evidence of such an effect in the OLS, the fixed effects and the IV regressions. This relationship holds irrespective of the controls and the alternative specification, specifically for men's lifelong learning.

The research therefore nuances the idea that French industrialization was a deskilling process. We argue that the adoption of steam engines affected the demand for useful knowledge to perform new jobs in industry. Indeed, the development of steam technology required new types of skills. Adult courses were designed precisely to increase practical and even professional knowledge. It appears, clearly that the new modes of training were adapted to the needs of the new industry.

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Appendix

Table A.1: Summary statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
Number of adults enrolled in classes for adults per 10 000 inhab.	610	146.993	109.5454	0	641.951
Number of men enrolled in classes for adults per 10 000 inhab.	610	125.6563	90.27008	0	470.308
Number of women enrolled in classes for adults per 10 000 inhab.	610	21.33667	30.35063	0	230.86
Number of steam engines in use	614	290.4674	543.5609	0	4903
Distance to Fresnes-sur-Escaut	637	495.2527	217.6917	43	999.5
Distance to Paris	637	365.4654	185.7738	0	918.86
Fertile soil in 1837 (squared kilometres)	602	84608.93	100273.1	0	429000
Land border	637	0.230769	.4216561	0	1
Literacy in 1686-1690	532	18.96816	10.81471	3.68	45.66
Literacy in 1846-1850	602	63.3093	18.67736	25.7	97
lnlatitude	623	6.42664	2.094901	41.9192	50.6292
Maritime border	637	.2527473	.4349288	0	1
Thousands of inhabitants per doctor in 1847	602	3.946834	1.546319	1.15731	8.15126
Number of royal roads in 1824	602	6.953488	3.168243	3	25
Number of water mills in 1861-1865	623	1177.64	5489.269	35	52467
Number of wind mills in 1861-1865	623	254.6517	1211.894	0	11333
Paris suburb	623	.0337079	.1806212	0	1
Population in administrative centres in 1789	602	43128.19	58995.86	7836	530516
Share of cultivable land in 1834	602	35.8169	13.48576	8.51271	64.9284