Wheels of Change: Agricultural Automation and Human Capital in the 20th Century*

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Abstract

I analyze how human capital investments respond to automation shocks by studying the diffusion of one of the twentieth century's most labor-saving technologies: the tractor. I find large increases in high school attendance among U.S. farm youths exposed to the spread of the tractor, which I corroborate by exploiting terrain-induced variation in tractor adoption in a triple-differences design comparing more and less exposed children. High school graduates were more likely to exit farming for urban service jobs, but were more likely to remain in agriculture where tractor adoption was greater. Automation shocks can spur investments in human capital, partly because it facilitates adaptation within sectors undergoing rapid technological change.

Keywords: Automation; human capital; technological change; tractors

JEL Codes: I25; J24; N32; O33; Q16

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1 Introduction

A recurring concern since the Industrial Revolution is that labor-saving technologies may permanently displace workers. On the eve of the Great Depression, J.M. Keynes famously warned that rapid advances in agricultural automation could produce widespread "technological unemployment".[1] Yet technological unemployment did not materialize during the twentieth century despite pervasive automation (Autor, 2015; Mokyr et al., 2015; Frey, 2019), while recent evidence suggests that young workers adjusted with relative ease even to major automation shocks (Feigenbaum and Gross, 2024; Ager et al., 2026).

This paper examines one margin through which the next generation may adjust to an exposure to automation: human capital. I analyze the impacts of the diffusion of the farm tractor, one of the most labor-saving innovations of the twentieth century. Keynes anticipated the automation of agriculture, but vastly underestimated its scale. Agricultural employment has fallen in developed countries from more than 50% in the early twentieth century to a few percent today. While the decline of agricultural work had many causes, it was partly driven by the widespread diffusion of tractors. In the post-war era, Olmstead and Rhode (2001, pp. 666-667) estimate that tractors had reduced labor demand in U.S. agriculture by 1.7 million workers—almost a quarter of farm employment—and that there may have been about one million more farms in the absence of the tractor.

To analyze the impacts of the tractor on human capital investments, I focus on the early twentieth-century United States, which led the world both in tractor adoption and in the expansion of secondary schooling during the American "high school movement" and ask whether the widespread diffusion of farm tractors catalyzed investments in human capital among children more exposed to its diffusion. Drawing on census data, I show descriptively that the places that most rapidly adopted tractors were in large parts the same places that led the high school movement.

I first use linked U.S. census data to track the childhood origins of native-born White males observed in the 1940 census, the first census to report educational attainment.[2] By using links between all intervening census years between 1900 and 1940 (Ruggles et al., 2025),

[1] Keynes (2010, p. 325) argued that: "There is evidence that the revolutionary technical changes, which have so far chiefly affected industry, may soon be attacking agriculture. [...] In quite a few years—in our own lifetimes I mean—we may be able to perform all the operations of agriculture [...] with a quarter of the human effort to which we have been accustomed." Keynes's concerns were repeatedly echoed by international organizations and policymakers in the last decades of the twentieth century, as tractors diffused across the developing world prompting fears of pervasive labor displacement (Binswanger, 1986; Mrema et al., 2008).

[2] I focus on native-born White males because they constituted the vast majority of farmers. Moreover, historical census links are more reliable for that group, while linkage rates are lower for immigrants, Blacks, and especially women, for whom name changes at marriage substantially complicate matching across censuses (Ruggles et al., 2025).

I assign individuals observed in the 1940 census to their probable county of residence around the time when they would have made their choice to attend high school.

Using a flexible difference-in-differences approach, I document a relative increase in high school attainment among native-born White boys growing up on farms in areas where tractors were more intensively adopted by 1940 when controlling for state-by-year fixed effects and a wide range of baseline county characteristics that may shape both the adoption of tractors and schooling decisions. I find no differences in high-school attainment among farm children before the widespread adoption of tractors and there are no similar relative increases in high school attainment among children living in nonfarm households, which were arguably less exposed to the coming of the tractor.[3] The results are similar in triple-differences specifications that compare relative changes in educational attainment across cohorts of farm children and nonfarm children living in the same county, with relative attainment gains concentrated among farm children.

My main empirical analysis uses county-level data on the diffusion of tractors between 1900 and 1940 and school attendance rates constructed from the full-count U.S. population censuses. Using a staggered difference-in-differences approach, I compare relative differences in school attendance rates among White farm children in counties that saw greater adoption of tractors, while again absorbing state-by-year fixed effects and flexibly controlling for a wide range of baseline county characteristics. Estimates show that attendance rates increased sharply among high-school-aged White farm boys and girls in counties with greater tractor adoption, with more limited positive attendance gains also for nonfarm children. Reassuringly, there are no pre-existing differences in attendance among high-school-aged children before the widespread diffusion of the tractor, and there are no increases in attendance among children that are too young to attend high school. Lastly, a triple-differences approach comparing farm and nonfarm children within the same county indicates larger gains among farm children.

Although I find larger attendance gains among White farm children, there is no evidence of similar increases among Black farm children, highlighting unequal access to schooling (Margo, 1990; Aaronson and Mazumder, 2011; Carruthers and Wanamaker, 2017; Doxey et al., 2026), which may have hindered Black families in making investments necessary to adapt to growing agricultural mechanization and further contributed to slow Black economic and

[3]Although nonfarm children were arguably less exposed to the coming of the tractor, they could still be affected both because mechanization may have reduced the demand for agricultural labor and because it may have changed the local supply of schooling. Indeed, as noted in the *International Labour Review* in the 1930s, agricultural employers often recruited seasonal child workers also from neighboring towns and villages (Nelson, 1938, p. 755). However, the potential impacts of the tractor should be weaker for nonfarm children than for farm children, who were more directly tied to farm work and more likely to remain in agriculture as adults, making them more exposed to the longer-run effects of mechanization.

educational progress in the early twentieth century (Althoff and Reichardt, 2024).

My main analysis controls for a wide range of potential factors that may have shaped the adoption of tractors and high school attendance, but a remaining concern is that the association could be driven by omitted factors that correlate both with agricultural mechanization and the rise of the high school movement, or reverse causality if a greater investment in schooling reduced the agricultural workforce that in turn might have spurred the adoption of labor-saving technologies (Caselli and Coleman, 2001; Hornbeck and Naidu, 2014; Andersson et al., 2022; Porzio et al., 2022).

To strengthen a causal interpretation of these results, I exploit a fact widely underlined by contemporaries and empirically documented by agricultural historians and economists (Fishback et al., 2005; Boone and Wilse-Samson, 2023; French, 2026): tractors were more easily adopted in areas with smoother terrain. Using granular information on terrain ruggedness from the U.S. Geological Survey, I document a strong first-stage relationship showing that tractors were more rapidly adopted in counties with smoother terrain. To support the validity of the instrument, I show that areas with smoother terrain did not exhibit substantially different changes in a wide range of outcomes—for example, the size and structure of farms, sectoral composition, or high school attendance—prior to the widespread breakthrough of tractors.

IV estimates corroborate a large impact of adoption of tractors on schooling among White farm children. In triple-differences IV specifications that exploit relative changes in school attendance among farm and nonfarm children within the same county and year, I find relative increases in attendance among farm children. To examine the validity of the IV estimates, I show that the results are similar in a wide range of subsamples with less extreme variation in topography and I also show that there is no clear association between terrain ruggedness and schooling in areas where tractors were not heavily adopted, lending further support to the exclusion restriction.

A relative increase in high school attainment and attendance among farm children suggests that the diffusion of tractors may have increased the demand for human capital for two broad reasons.[4] First, farmers may have expected that many farm children would need to exit farming and move into the growing service sector, where schooling demands were higher (Goldin and Katz, 2008; Ager et al., 2026). Second, an influential literature argues that

[4]Additional mechanisms may also have operated through the opportunity cost of schooling or a shift in the supply of schooling. First, agricultural automation may reduce the demand for child labor, lowering the opportunity costs of schooling (Arthi, 2018; Baker, 2015; Baker et al., 2020; Jaworski et al., 2026). Yet I find no clear evidence that child labor declined substantially after tractors diffused, and part of the attendance response appears to reflect students who remained in the labor force while attending school. Second, the spread of tractors may have increased the supply of schooling. However, I find only limited evidence that teacher availability rose more in areas where tractors were adopted.

the demand for human capital increases in times of rapid technological change within the agricultural sector itself (Schultz, 1964, 1975; Welch, 1970; Foster and Rosenzweig, 1996), in part because automation of manual tasks may increase the returns to expertise in new tasks (Autor and Thompson, 2025). Indeed, operating a farm in the early twentieth century required relatively limited formal education: most agricultural implements—for example, sickles or smaller plows—were relatively simple to service using basic blacksmithing or carpentry skills. But the adoption of tractors altered the skills needed: by the outbreak of World War II, farmers were required to understand modern scientific advances in fields such as botany, chemistry, and electricity (Goldin and Katz, 2000; Parman, 2012), while also mastering modern accounting practices and requiring mechanical skills to perform tasks such as engine overhaul, electrical wiring, and machinery repair that were widely taught in high schools. Farmers were acutely aware that their children would be required to attain formal schooling to not be left behind in this "new world" of agricultural business (Goldin and Katz, 2008, p. 77).

To quantitatively explore these mechanisms, I use the linked census data to show that farm children who attained a high school degree were substantially more likely to migrate to urban areas and take up jobs in the rapidly growing services sector, consistent with the idea that part of the motivation to invest in human capital was to facilitate a transition out of agriculture. However, high-school-educated farm youth from areas that were more heavily exposed to tractors were also relatively more likely to remain in agriculture as farm owners as adults. While the evidence is suggestive, it is consistent with the idea that schooling investments helped farm youth to adapt to the rapid agricultural modernization brought by the tractor.

Although the early-twentieth century United States is a useful setting to examine the impact of tractors on schooling, it is an open question to what extent the results generalize to other contexts. To explore the external validity of my findings, I compile cross-country data to show that the diffusion of tractors across developing countries between 1960 and 2000 is associated with substantial increases in secondary enrollment in panel and event-study regressions. While these associations are merely suggestive, they are consistent with the idea that agricultural automation may have contributed to the global rise of secondary schooling in the second half of the twentieth century, just as it did in the United States in the first half of the century.

I study how a greater exposure to automation shapes human capital investments among the next generation thus contributing to the literature on the economic impacts of automation (for example, Acemoglu and Restrepo, 2020; Adachi et al., 2024; Dauth et al., 2021; Koch et al., 2021; Restrepo, 2024). In particular, my findings contribute to research on the intergenerational consequences of technological change (Arntz et al., 2025; Berger and Engzell, 2022; Feigenbaum and Gross, 2024; Heyman and Olsson, 2026). Most closely related is work by Eisner (2021) that studies the impacts of tractors in the U.S. Midwest showing that older farm workers are displaced, with more limited displacement among farm youths. In contemporaneous work, French (2026) examines the intergenerational consequences of aggregate agricultural machinery investment in the U.S. between 1910 and 1920, emphasizing the impact of mechanization on parents and their children's subsequent outcomes. By contrast, my analysis directly measures tractor diffusion and studies how it shaped human capital investments during the period covering the substantial expansion that mainly took place during the 1920s and 1930s, whereas relatively few farms used tractors by 1920, focusing on how exposure to agricultural automation during their formative years shaped decisions around attending high school.

I also provide suggestive evidence that additional schooling supported adaptation within agriculture. High school graduates were generally more likely to enter urban service employment, consistent with research emphasizing education as a means of transitioning into new types of work (Autor et al., 2024; Feigenbaum and Gross, 2024; Hobijn and Kaplan, 2024; Ager et al., 2026). However, the association between high school completion and agricultural exit was weaker among youths from counties with greater tractor adoption, which suggests that schooling could also help young workers adapt and remain in a modernizing agricultural sector. My findings therefore provide evidence consistent with Schultz's (1964, 1975) argument that education facilitates adjustment to technological change. By providing evidence of how agricultural mechanization fosters educational investments, my results complement studies showing that biological and chemical innovations increased the demand for skills during the Green Revolution (Foster and Rosenzweig, 1996; Gollin et al., 2021).

Finally, my findings identify agricultural automation as a source of increased demand for secondary schooling during the American high school movement. Existing explanations emphasize both the institutions that supported school provision and the economic returns that encouraged educational investment (Goldin and Katz, 2000, 2008). I provide evidence that tractor diffusion contributed to rising school attendance and attainment, helping account for the expansion of secondary schooling in farming communities.[5] By documenting schooling as a response to technological change, my findings complement and contrast research on human capital investments as a causal driver of structural change (Caselli and Coleman, 2001; Porzio et al., 2022).

[5] These findings also complement evidence that changes in agricultural labor demand following major external shocks affected human capital investments (Arthi, 2018; Baker, 2015; Baker et al., 2020; Jaworski et al., 2026).

2 Data

To analyze the link between the diffusion of tractors and human capital investments in the United States between 1900 and 1940, I construct two datasets that integrate information on individual- and county-level educational attainment and school attendance paired with county-level information on the diffusion of tractors.

2.1 Tractors

I use data on the number of tractors in each U.S. county for 1925, 1930, and 1940 from the U.S. agricultural census from Haines et al. (2018). To estimate the number of tractors in use in 1920, I digitize state-level tractor totals from the 1959 Census of Agriculture (U.S. Bureau of the Census, 1962, Table 13). I then allocate each state's total across counties in proportion to observed county tractor counts in 1925. Around 1910, only about 1,000 tractors were in operation and I follow Steckel and White (2012, p. 7) in treating 1910 as "pre-tractor". To account for the fact that county borders change over time, I use the crosswalks by Ferrara et al. (2024) and harmonize all data to 1900 county boundaries. Throughout most of the analysis, I scale the number of tractors in each county by the number of farms, though I present estimates using alternative exposure measures below.

To instrument for tractor diffusion, I use topography data from the U.S. Geological Survey (USGS) 1 arc-second (about 30 meters at the equator) digital elevation model. On the native elevation grid, I compute the Riley terrain ruggedness index (TRI) for each raster cell and then aggregate those cell-level values within each 1900 county using cell-area weights.[6] The resulting mean Riley TRI is therefore the area-weighted average ruggedness across all grid cells that fall inside the county boundary. I define terrain smoothness as the negative of this county-level mean, so higher values correspond to flatter and less rugged counties. Appendix Figure A1 provides elevation maps and county examples that illustrate the variation in elevation and ruggedness underlying this measure.

2.2 Linked Individual Data

To examine educational attainment, I create an individual-level dataset that links men observed in the 1940 census back to their childhood counties using the IPUMS Multigenerational Longitudinal Panel for the 1900–1940 censuses (Ruggles et al., 2025, 2024). I focus on

[6] For a focal raster cell with elevation z_0 and eight adjacent cells with elevations $z_1, \ldots, z_8$, the Riley terrain ruggedness index is $TRI = \sqrt{\sum_{j=1}^{8}(z_0 - z_j)^2}$. Larger values indicate greater local elevation differences and therefore more rugged terrain.

White native-born men observed in the 1940 census born between 1880 and 1920 with known schooling and retain men who are linked to a previous census, which allows me to observe them in their childhood household when they are aged between 0 and 20 and to observe the farm status of the household and the father's occupation. I again use the Ferrara et al. (2024) crosswalks to assign individuals to 1900 counties. Individuals observed in later census years can be assigned to multiple 1900 counties (for example, if a 1900 county is split into two counties in 1920) and I therefore create an individual-level fractional weight that sums to one for each individual, which is used in all individual-level regressions.

My main outcomes are based on an individual's highest grade of schooling in 1940, where I define high school attainment based on 12th grade attainment. I also observe years of completed schooling and detailed attainment categories, which I use in robustness exercises. Based on the 1940 census, I also construct additional outcomes capturing urban residence, migration, residence on a farm, labor-force participation from the 1940 labor-force-status question, sector of employment, farm occupations, and wage income.

The resulting dataset includes individual-level data on educational outcomes for about 616,000 linked White native-born men, which I pair with county-level data on exposure to tractors. Most of the analysis focuses on tractor exposure measured in 1940 assigned to childhood counties, but some specifications leverage time-varying exposure measures that assign tractor exposure in an individual's childhood county in the census decade closest to the calendar year in which he turned 15. If the closest census year is 1900 or 1910, tractor exposure is set to zero, as described above. Together, the linked sample lets me study how childhood exposure to tractors shaped the highest grade of schooling, but it does not allow me to examine contemporaneous changes in enrollment or school attendance in response to the diffusion of tractors.

2.3 County-Level Data

To examine the link between tractor diffusion and school attendance, I rely on the decadal full-count U.S. censuses 1900–1940 obtained from Ruggles et al. (2024), which provide individual-level outcomes including information on whether each individual attended school in the census year. To aggregate individual-level outcomes to the county level, I again rely on the crosswalks by Ferrara et al. (2024) to create a county-level panel with constant 1900 borders.

The main outcome is school attendance among youths ages 14 to 18 (which I interchangeably refer to as "high school attendance") with nonmissing school-status responses, which I construct separately by race, sex, and childhood farm status. School attendance is not fully comparable across censuses for two reasons. First, census day and the school-attendance referent period both vary across census years, so the effective recall window differs over time.[7] Second, the definition of what types of schooling was intended to be recorded in the attendance question also changed across censuses.[8] All specifications include county and state-by-year fixed effects that absorb (state-level) differences in attendance levels across census years, so measurement differences bias the estimates only if changes in the effective recall window or other measurement changes are systematically correlated with tractor diffusion within counties over time. This concern is further mitigated by a wide set of 1900 county characteristics interacted with year effects. However, to further account for potential differences in reporting conventions and to facilitate comparisons across census years, I standardize county attendance rates within each census year to have mean zero and SD one.

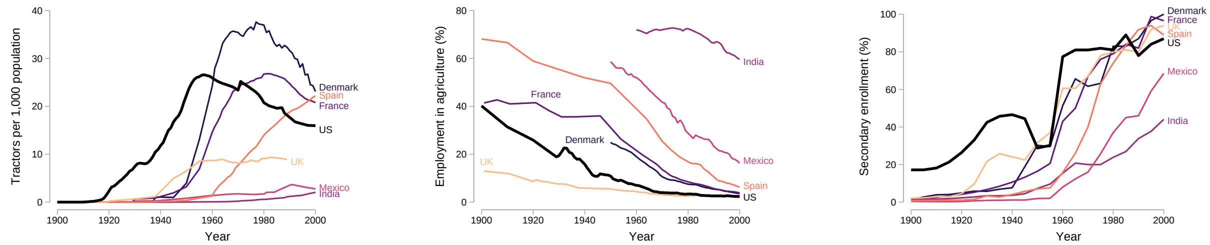
My baseline county sample is restricted to counties observed in all five census years 1900 to 1940 with (i) a 1900 population of at least 1,000; (ii) a 1900 farm share above 10 percent; and (iii) nonmissing school attendance data for White boys and girls ages 14 to 18 in all census years. I impose these restrictions to focus on a stable set of counties over time, focus on places where farm mechanization was economically relevant, and ensure that the main schooling outcomes are observed in each year.

3 Context: Tractors and the High School Movement

This section provides historical context on the diffusion of tractors in American agriculture and the rise of the high school movement to make three points. First, the rise of the American high school movement coincided with the rapid diffusion of tractors, predating these changes in other developed countries by several decades. Second, the areas where tractors were most intensively adopted were also leading the high school movement. Third, the spread of tractors is associated with a relatively greater rise in high school attainment among farmers compared to workers in non-agricultural sectors.

[7] The effective recall window varies substantially across censuses: roughly 12 months in 1900, 7.5 months in 1910, 4 months in 1920, 6 months in 1930, and 1 month in 1940. More specifically, the 1900 census was taken on June 1 and asked about attendance within the previous year. The 1910, 1920, and 1930 censuses asked about attendance since September 1, but were taken on April 15, January 1, and April 1, respectively. The 1940 census was taken on April 1 and asked about attendance since March 1.

[8] In 1900, the question refers to attendance at any school. In 1910 and 1920, it refers to any school, college, or educational institution. In 1930, night school is explicitly included. In 1940, school attendance includes school, college, university, and other educational institutions, but night school, extension classes, and vocational training count only if they are part of the regular school system, and correspondence courses are excluded. However, note that most high schools should have been included in all census years.



(A) Tractors (B) Agricultural Employment (C) Secondary Enrollment

Figure 1: Tractors, Structural Change, and Schooling, 1900–2000

Notes: This figure displays tractors per 1,000 population in Panel A, the share of employment in agriculture in Panel B, and secondary-school enrollment in Panel C from 1900 to 2000. Panel A uses tractor counts based on data from Binswanger (1986), Food and Agriculture Organization of the United Nations (2021), and U.S. Bureau of the Census (1975), with population data drawn from Bolt and van Zanden (2025). Panel B uses data on the share of employment in agriculture from Our World in Data (Roser, 2023), based on Herrendorf et al. (2014) and the GGDC 10-Sector Database (Timmer et al., 2015). Panel C uses secondary-school enrollment from Lee and Lee (2016).

Invention and Diffusion of the Tractor Modern gasoline-powered tractors had their widespread breakthrough in American agriculture in the first half of the twentieth century. Early models were expensive and large, which limited their practical use. But advances in tractor design in the 1910s and 1920s made it more commercially viable. In 1917, Henry Ford released the celebrated smaller Fordson, which by 1920 constituted one-third of all tractors sold (Ankli, 1980, p. 136). Further breakthroughs took place in the 1920s by International Harvester and John Deere, and by the 1930s general-purpose tractors that could perform a variety of tasks such as cultivating, planting, and harvesting, while also being used for row crops had their widespread breakthrough (Gross, 2018).

A large literature examines the diffusion of tractors emphasizing in particular the role of farm size and scale economies in shaping adoption rates (Ankli, 1980; Ankli and Olmstead, 1981; Clarke, 1991; Olmstead and Rhode, 2001), or the role of quality improvements and the widening scope of tasks that general-purpose tractors could perform (White, 2000; Manuelli and Seshadri, 2014; Gross, 2018). While the diffusion of the tractor is sometimes characterized as having been "too slow", Figure 1 shows that the United States was by far the world's leader in terms of adopting tractors. In 1910, there were about 1,000 farm tractors in operation and by 1940 more than 1.5 million tractors were in use (Cooper et al., 1947, p. 32).

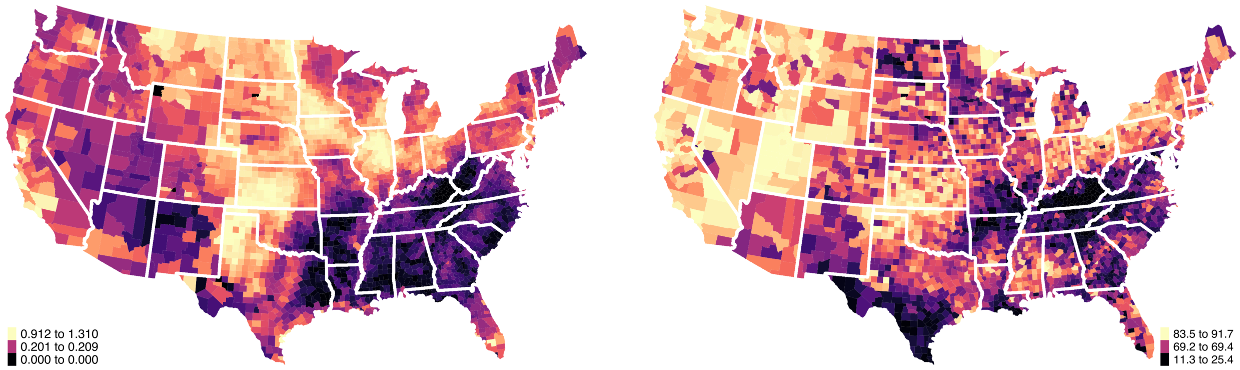
The widespread diffusion of tractors translated into substantial economic impacts: in the post-war era, social savings estimates suggest that tractors increased U.S. GDP by more than 8 percent (Steckel and White, 2012). In particular, the use of tractors had large potential effects on the demand for agricultural labor: by 1944, the U.S. Department of Agriculture estimated that the tractor saved 1.7 billion man-hours annually (Cooper et al., 1947, p. 19), or about 8 percent of the total agricultural labor requirements translating into a lower bound of about 850,000 workers (Olmstead and Rhode, 2001, p. 665).

America's High School Movement Figure 1 shows that the United States not only led the world in terms of agricultural automation, but also in terms of sending its youth to secondary school. America's lead can be ascribed to the "high school movement": in 1910, less than one in ten Americans aged 18 had graduated from high school and by 1940 the median American had a high school diploma, while enrollment rates among 15- to 18-year-olds had more than tripled to 73 percent (Goldin and Katz, 2008, p. 195). Notably, the rates of enrollment achieved by the United States in the early twentieth century would be attained by other wealthy European countries only in the post-war era (see Figure 1).

A key explanation of the rise of the high school movement is supply-side factors that enabled American communities to respond to the growing demand for human capital. To some extent, rising educational attainment was spurred by free tuition and compulsory schooling laws (Lleras-Muney, 2002; Goldin and Katz, 2011), but the high school movement was at its heart a grassroots movement, where the supply of high school education unfolded along county lines. The local supply of schooling advanced due to high levels of taxable income and wealth, and greater levels of equality and social capital (Goldin and Katz, 1999, 2000, 2008).

Another key driver of the high school movement was shifts in the labor market that raised the return to human capital. Human capital demands increased partly due to skill-biased technological change in industry and the expanding services sector, where jobs typically required a high school education (Goldin and Katz, 1998).[9] Indeed, while its main aim had been to prepare students for college, the American high school that emerged in the interwar period was a distinctively practical institution combining academic subjects with bookkeeping, commercial correspondence, and vocational coursework that prepared graduates for the labor market, with the diploma typically serving as the terminal degree (Angus and Mirel, 1999; Reese, 1999). Returns to high school education at the cusp of the high school movement were large: about 10 percent for each year of high school (Goldin and Katz, 2008, p. 76). In part, returns were large because it enabled workers to transition into better-paid white-collar jobs (Doxey et al., 2026), but also because there existed significant returns within occupational groups (Goldin and Katz, 2000; Feigenbaum and Tan, 2020).

[9] The tractor industry itself was among those that came to rely on high school graduates. According to the manager at Deere Tractor Works in 1902 they would "not take boys in the office unless they are at least



(A) Tractors per Farm (B) High School Attendance

Figure 2: Tractors and High School Attendance, 1940

Notes: This figure displays tractors per farm in Panel A and the school-attendance rate of White youths ages 14 to 18 in Panel B, based on data drawn from the 1940 agricultural and population censuses allocated to contemporary county boundaries (Haines et al., 2018; Ruggles et al., 2024; Schroeder et al., 2025).

A somewhat puzzling feature of the American high school movement, evident in Figure 2, is that it was led by farming states such as Iowa, Kansas, and Nebraska, despite the relatively lower demands for human capital in the agricultural sector (see Appendix Table E1). I next show that high school attainment and attendance increased sharply particularly among farm children in areas where tractors were most heavily adopted, and in Section 4.3 I provide suggestive evidence that the rising investments in schooling among farm households were due both to farm children exiting the agricultural sector for more human-capital-intensive sectors and to the spread of tractors spurring agricultural modernization that sharply raised the human capital requirements within the farming sector.

4 Tractors and the High School Movement

This section presents the main empirical analysis. First, I use linked individual-level census data to document a relative increase in high school attainment among White farm children in areas where tractors diffused more intensively. Second, I use county-level data to show that the spread of the tractor is associated with contemporaneous increases in school attendance rates among high-school-aged children. Third, I explore potential underlying mechanisms and provide descriptive evidence consistent with investments in high school education facilitating both the exit from farming to more human-capital-intensive sectors and adaptation within modernizing agriculture.

high school graduates" (Goldin and Katz, 2008, pp. 176-177).

4.1 Tractors and High School Attainment Across Cohorts

I first use the linked individual-level data on educational attainment for cohorts born between 1880 and 1920 to document a relative increase in high school attainment among farm children residing in counties where tractors were adopted more intensively.

Empirical Strategy I estimate individual-level OLS regressions using the following flexible difference-in-differences specification:

$$Y_{icb}^{f} = \alpha_c^f + \lambda_{s(c)b}^f + \sum_{k \neq 1890} \beta_k^f \left(\widetilde{T}_c^{1940} \times \mathbb{1}\{b = k\} \right) + X'_{c,1900} \Gamma_b^f + \varepsilon_{icb}^f, \tag{1}$$

where Y_{icb}^{f} is an indicator equal to 1 if linked individual i from childhood county c, cohort b, and household type $f \in \{\text{farm, nonfarm}\}$ had completed high school by 1940, and 0 otherwise, with the omitted cohort being those born in 1890–1894. $\widetilde{T}_c^{1940}$ is the number of tractors per farm in 1940 in childhood county c, which is standardized to have mean zero and SD one. I include county fixed effects α_c^f that absorb persistent differences in high school attainment across counties and $\lambda_{s(c)b}^f$ childhood-state-by-cohort fixed effects that absorb changes in attainment that are common to all cohorts residing in the same state.

To account for baseline county characteristics that may be correlated with the adoption of tractors and educational investments, I include a set of baseline county controls measured in 1900 in $X_{c,1900}$ that are interacted with cohort fixed effects. Specifically, I control for county population, county area, longitude, latitude, urban share, farm share, Black share, and immigrant share, partly to account for the fact that the high school movement was especially strong in smaller and more cohesive towns (Goldin and Katz, 1999), and partly because tractor adoption was more rapid in more urban and populous areas where farm labor was harder to obtain during harvests (Fishback et al., 2005; Hornbeck and Naidu, 2014). To account for the commitment to high school education predating the high school movement (Crosby, 1913), I control for literacy rates, teachers per capita, and the attendance rate of White farm boys ages 14 to 18. To account for the fact that the opportunity costs and demand for schooling were shaped by the structure of the local labor market (Goldin and Katz, 2008), I control for the prime-age industrial employment share. Lastly, I control for average farm size, average farm value, log implements-and-machinery value per farm, and wheat acreage share to capture farm organization and the margins along which tractors diffused earliest and most intensively (Olmstead and Rhode, 2001; Gross, 2018). All regressions are weighted using the fractional weights to account for the fact that an individual's childhood county may map to several counties using 1900 borders. Throughout, standard errors are clustered at the childhood county.

I also estimate a standard difference-in-differences specification that estimates the relative increase in high school attainment among the cohorts born after the widespread diffusion of the tractor began in the 1910s.[10] The specification follows the same notation as above with $Post_b$ equals one for cohorts strictly after 1895:

$$Y_{icb}^{f} = \beta^{f}\left(\widetilde{T}_{c}^{1940} \times Post_b\right) + \alpha_{c}^{f} + \lambda_{s(c)b}^{f} + X_{c,1900}^{\prime}\Gamma_{b}^{f} + \varepsilon_{icb}^{f}, \tag{2}$$

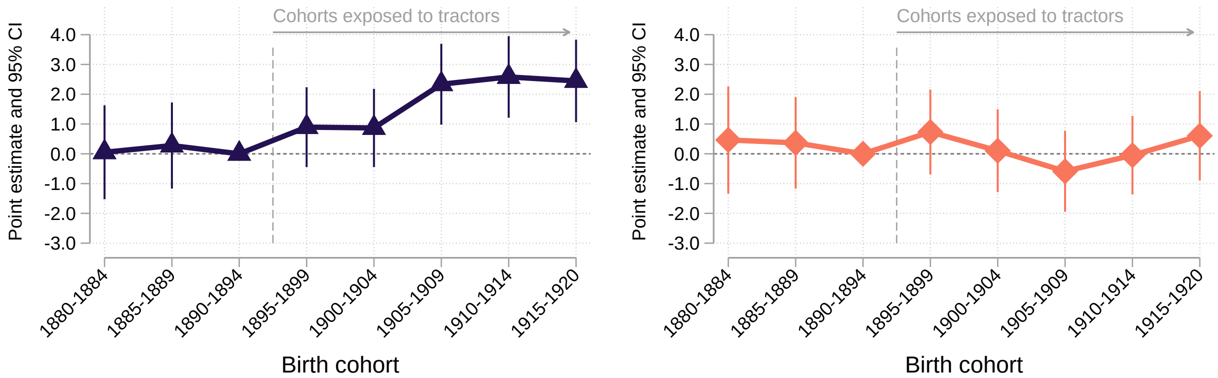
I also use a triple-differences approach where I compare relative differences in high school attainment among linked men from farm and nonfarm households within the same childhood county:

$$Y_{icb}^{f} = \delta\left(\widetilde{T}_{cb} \times Farm_f\right) + \alpha_{cb} + \eta_{cf} + \lambda_{bf} + \varepsilon_{icb}^{f}, \tag{3}$$

where $\widetilde{T}_{cb}$ denotes standardized tractor exposure for childhood county c and cohort b, either tractors per farm in 1940 interacted with $Post_b$ or the tractor measure assigned when the cohort is closest to age 15. The county-by-cohort fixed effects α_{cb} absorb any county-level shocks or baseline county characteristics that vary by cohort, the county-by-farm fixed effects η_{cf} absorb permanent differences between farm and nonfarm children within counties, and the cohort-by-farm fixed effects λ_{bf} absorb aggregate cohort differences between farm and nonfarm children. The coefficient δ therefore captures whether the individual-level high-school attainment response to tractor exposure was larger for farm children than for nonfarm children from the same county and cohort.

Results: Exposure to Tractors and High School Attainment Figure 3 displays estimates of Equation 1 separately for children residing in farm and nonfarm households. Before the widespread diffusion of tractors began in the 1910s, there are no differences in high school attainment among cohorts born in counties where tractors would later be adopted more intensively. The absence of pre-trends supports the identifying assumption that counties with different levels of eventual tractor adoption were on parallel trends before widespread adoption began. Panel A then shows a gradual increase for the first farm cohorts to reach high-school age in the tractor era, beginning around the 1895 birth cohort (that entered high school in the 1910s when tractor diffusion began to accelerate). Estimated gains stabilize at roughly two percentage points, indicating a substantial relative increase

[10] Equations 1 and 2 compare the evolution of high school attainment across cohorts from counties with different levels of tractor intensity in 1940. Using eventual tractor adoption permits pre-tractor comparisons but does not measure exposure when schooling choices were made. I therefore re-estimate Equation 2, replacing $\widetilde{T}_{c}^{1940} \times Post_b$ with standardized tractors per farm in county c from the census year closest to the year each individual turned 15 (with exposure set to zero in 1900 and 1910).



(A) Farm Origins (B) Nonfarm Origins

Figure 3: Exposure to Tractors and High School Attainment

Notes: This figure displays estimates from individual-level OLS regressions based on Equation 1. Panels A and B report estimates for White native-born men observed in 1940 and linked to farm and nonfarm childhood households, respectively. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The tractor measure is tractors per farm in 1940, standardized to mean zero and SD one. Panels A and B include county-of-origin and origin-state-by-cohort fixed effects. Both panels include county controls. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects. Vertical bars denote 95% confidence intervals based on standard errors clustered at the county-of-origin level.

in high school attainment among boys growing up on farms in counties where tractors were adopted more intensively. Panel B shows no similar relative increase among boys growing up in nonfarm households, consistent with a weaker response for nonfarm children to the diffusion of tractors. Figure 4 reports the corresponding triple-difference estimates.

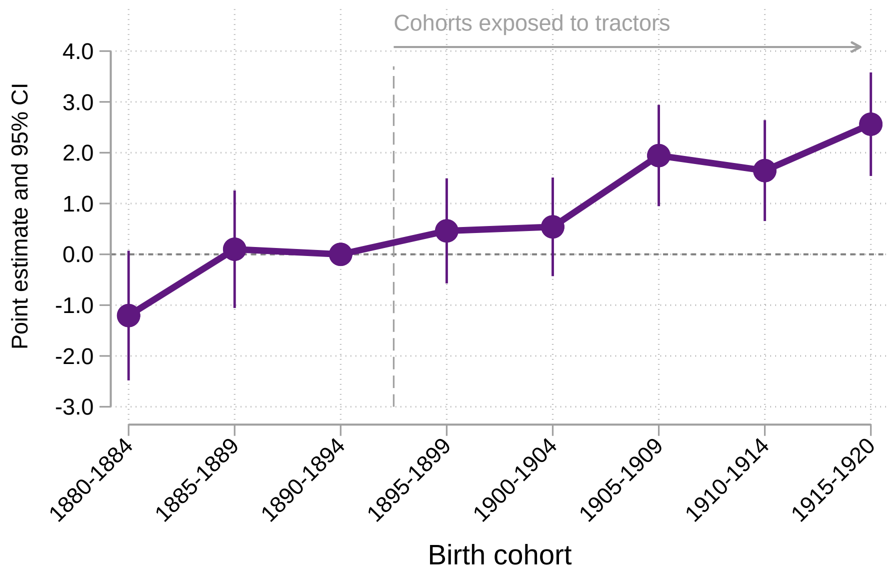


Figure 4: Exposure to Tractors and High School Attainment: Triple Difference

Notes: This figure displays estimates from individual-level triple-difference regressions based on Equation 3. It reports the farm-versus-nonfarm triple-difference estimates for White native-born men observed in 1940 and linked to farm and nonfarm childhood households. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The tractor measure is tractors per farm in 1940, standardized to mean zero and SD one. The specification includes origin-state-by-cohort, county-of-origin-by-farm-status, and cohort-by-farm-status fixed effects, and county controls. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects. Vertical bars denote 95% confidence intervals based on standard errors clustered at the county-of-origin level.

Table 1 reports the corresponding individual-level difference-in-differences estimates from Equation 2. Columns 1 and 2 show that farm boys in counties with greater tractor exposure were substantially more likely to attain a high school degree. A one SD increase in tractors per farm in 1940 is associated with an estimated 1.8 percentage point larger post-1895 increase in the probability of attaining a high school degree, which is relatively large considering that the share of individuals with high school was only about 22 percent in the sample. Columns 3 and 4 report the corresponding nonfarm estimates: estimates are imprecise and close to zero, suggesting that investments in human capital among nonfarm children did not respond to the diffusion of tractors. Column 5 reports the triple-difference specification from Equation 3, showing that a one SD increase in tractors per farm in 1940 is associated with a 2.0 percentage point larger post-1895 increase in high school attainment among farm children relative to nonfarm children from the same county.

To shed light on where in the educational attainment distribution these effects emerge,

Table 1: Exposure to Tractors and High School Attainment

	Outcome: high school (=1)				
	Farm (F)		Nonfarm (NF)		F vs. NF
	(1)	(2)	(3)	(4)	(5)
Tractors, 1940 (std.) × Post-1895 (=1)	1.416***	1.759***	-0.255	-0.292	
	(0.298)	(0.401)	(0.553)	(0.465)	
Tractors, 1940 (std.) × Post-1895 (=1) × Farm (=1)					1.951***
					(0.319)
Childhood county FE	Yes	Yes	Yes	Yes	No
Childhood state × cohort FE	Yes	Yes	Yes	Yes	No
County controls × cohort FE	No	Yes	No	Yes	No
Childhood county × farm FE	No	No	No	No	Yes
Cohort FE × farm FE	No	No	No	No	Yes
Childhood county × cohort FE	No	No	No	No	Yes
Mean outcome	22.361	22.355	42.889	42.879	34.077
Cohorts	1880–1920	1880–1920	1880–1920	1880–1920	1880–1920
Counties	2782	2772	2788	2777	2798
Observations	263342	262114	349648	348912	612284

Notes: Individual-level OLS and triple-difference regressions based on Equations 2 and 3, respectively. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940 with known schooling and linked to a childhood county closest to age 15 among ages 0 to 20. Tractors per farm in 1940 is standardized to mean zero and SD one. Columns 1–4 report coefficients on standardized tractors per farm in 1940 interacted with an indicator for cohorts born after 1895. Columns 1 and 2 report farm-origin estimates, and columns 3 and 4 report nonfarm-origin estimates; all four specifications include childhood-county and origin-state-by-cohort fixed effects, while columns 2 and 4 also include county controls. Column 5 reports the coefficient on the additional interaction with farm origin and includes childhood-county-by-cohort, childhood-county-by-farm-status, and cohort-by-farm-status fixed effects. County controls are not included in column 5 because the childhood-county-by-cohort fixed effects absorb them. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects. Regressions are weighted by fractional childhood-county crosswalk weights. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

I re-estimate the controlled triple-difference specification using standardized tractors per farm in 1940 interacted with the post-1895 indicator and farm origin. The outcome in each regression is an indicator for a different highest completed schooling category in 1940, multiplied by 100. Figure 5 shows that a one SD increase in tractors per farm in 1940 is associated with a 1.7 percentage point larger post-1895 increase in the probability that farm boys completed exactly twelfth grade relative to nonfarm boys. The estimates are negative for each of grades one through seven, close to zero for grades eight through eleven and the first three years of college, and positive but smaller for four or more years of college. The concentration of the estimated shift at twelfth grade suggests that tractor diffusion particularly increased high school completion.

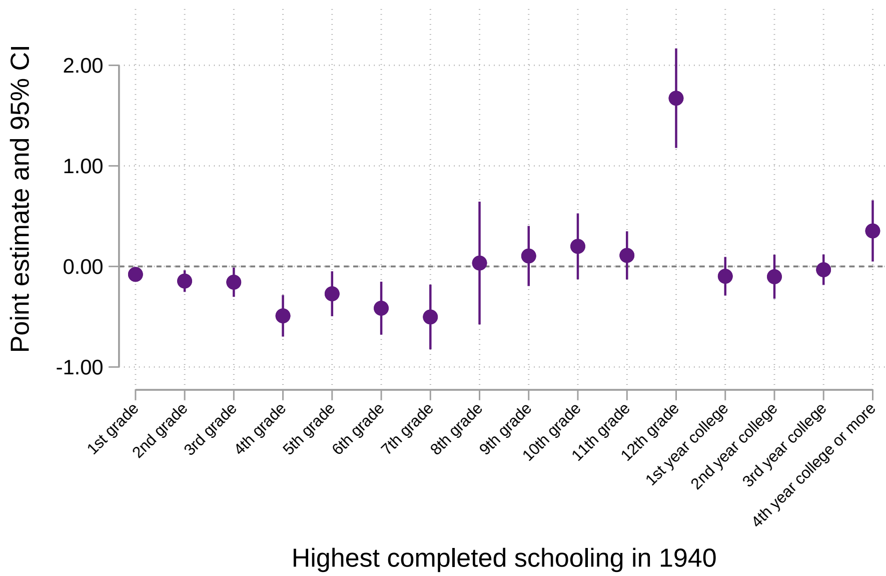


Figure 5: Exposure to Tractors and Highest Level of Schooling

Notes: This figure displays estimates from controlled individual-level triple-difference regressions. The outcome is an indicator for each highest completed schooling category in 1940, multiplied by 100 so the coefficients are expressed in percentage points. The plotted coefficient is on standardized tractors per farm in 1940 interacted with an indicator for cohorts born after 1895 and with farm origin. Each regression also includes standardized tractors per farm in 1940 interacted with the post-1895 indicator, origin-state-by-cohort, childhood-county-by-farm-status, and cohort-by-farm-status fixed effects, and county controls. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects. The sample includes White native-born men observed in 1940 with known schooling and linked to a childhood county closest to age 15 among ages 0 to 20. Regressions are weighted by fractional childhood-county crosswalk weights. Vertical bars denote 95% confidence intervals based on standard errors clustered at the county-of-origin level.

Additional Robustness Checks I next present additional robustness checks to show that the results are not driven by how tractor exposure is measured, the exact treatment cutoff, or linkage selection.

First, I show in Appendix Table B1 that results are similar when replacing the post-1895 indicator with a post-1900 cutoff and thus focusing on cohorts that are more intensively exposed to tractors.

Second, Appendix Table B2 assigns tractor exposure based on the census closest to when an individual is aged 15, rather than using 1940 tractor intensity, which produces similar results. Relatedly, Appendix Table B3 restricts the sample to boys assigned between ages 14 and 18 where individuals are more likely to live in the assigned childhood county during their high school years.

Third, a final concern is how representative the linked men are. Appendix Table B4 compares linked White native-born men to those eligible to be linked, which also makes it possible to examine whether tractor exposure in the 1940 county of residence predicts backward linkage. The linked sample is slightly less exposed to tractors in the adult county of residence, but the difference is only 0.011 standard deviations. Linked men are also younger and somewhat more educated than the 1940 comparison universe. Reassuringly, reweighting the linked sample by the predicted probability of being retained removes the adult-county tractor difference and substantially reduces differences in age, farm residence, and urban residence, though it does not fully eliminate the education gap. As a complementary check, Appendix Table B5 re-estimates the main specifications using inverse-probability weights based on the predicted probability that an eligible 1940 man is retained in the linked sample. The estimates remain nearly unchanged: the preferred farm-origin estimate is 1.71 percentage points, compared with 1.76 in Table 1, and the triple-difference estimate is 1.97 percentage points, compared with 1.95 in the baseline. Together, these results suggest that the main findings are not driven by selective linkage.

4.2 Tractors and School Attendance

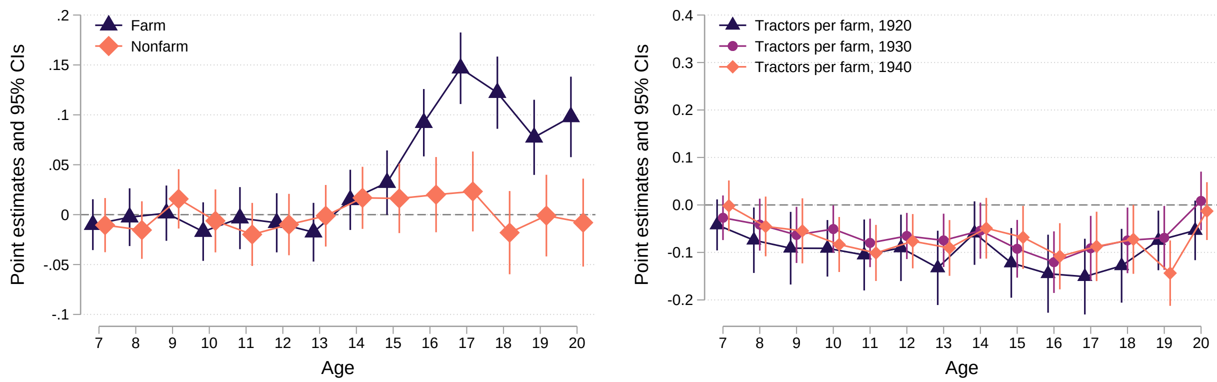
I next use the county-level data on school attendance and the spread of tractors to document a sharp increase in school attendance among high-school-aged children in areas where tractors were more intensively adopted.

4.2.1 OLS Estimates

Empirical Strategy I estimate county-level panel OLS regressions on the following form:

$$Y^g_{cst} = \beta^g T_{ct} + \alpha^g_c + \lambda^g_{st} + X'_{c,1900}\Gamma^g_t + \varepsilon^g_{cst}, \tag{4}$$

where Y^g_{cst} is the school-attendance rate for children ages 14 to 18 in county c, state s, and census year t for group $g \in \{\text{farm boys, nonfarm boys}\}$. As described above, attendance rates are standardized to have mean zero and SD one within each census year. T_{ct} corresponds to the standardized number of tractors per farm. α^g_c denotes county fixed effects, which absorb time-invariant differences across counties, and λ^g_{st} denotes state-by-year fixed effects, which absorb shocks common to counties within a state in a given census year, such as crop-price movements or compulsory-schooling laws. To account for other potential determinants of schooling and the adoption of tractors, the vector $X_{c,1900}$ includes the same set of baseline county controls as above interacted with year indicators. Throughout, I cluster standard errors by county.



(A) Farm and Nonfarm Boys, 1900–1940 (B) Pre-Tractor Placebo, 1900–1910

Figure 6: Exposure to Tractors and School Attendance

Notes: This figure displays estimates from county-level OLS regressions based on Equation 4. Panel A reports separate regressions of school attendance on tractor intensity for each age among White boys in farm and nonfarm households. Panel B reports placebo estimates for White farm boys using only 1900 and 1910 data, assigning each county its tractor intensity from 1920, 1930, or 1940 to 1910. Both panels cover ages 7 to 20. Tractor intensity and school attendance are standardized to mean zero and SD one. All specifications include county fixed effects and state-by-year fixed effects. Vertical bars denote 95% confidence intervals based on standard errors clustered at the county level.

I also use a triple-difference approach, where I compare farm and nonfarm children within the same county-year by stacking county-year observations by childhood farm status and estimate the following specification:

$$Y_{ct}^{f} = \delta \left(T_{ct} \times Farm_{f} \right) + \alpha_{ct} + \eta_{cf} + \lambda_{tf} + \varepsilon_{ct}^{f}, \tag{5}$$

where Y_{ct}^{f} is the standardized school-attendance outcome in county c and census year t for childhood-status group $f \in \{\text{farm, nonfarm}\}$. The indicator $Farm_f$ equals one for farm children. The term α_{ct} denotes county-by-year fixed effects, which absorb the direct effect of tractors per farm and any other shocks common to farm and nonfarm children within a county-year. The term η_{cf} denotes county-by-group fixed effects, which absorb time-invariant differences between farm and nonfarm children within counties, and λ_{tf} denotes year-by-group fixed effects, which absorb nationwide differences over time between farm and nonfarm children. The coefficient δ therefore captures whether school attendance rose more for farm children than for nonfarm children in the same county-year as tractors diffused. Again, I cluster standard errors by county.

Results: Exposure to Tractors and School Attendance Figure 6 presents estimates of Equation 4 where I estimate separate regressions for White boys residing in farm and

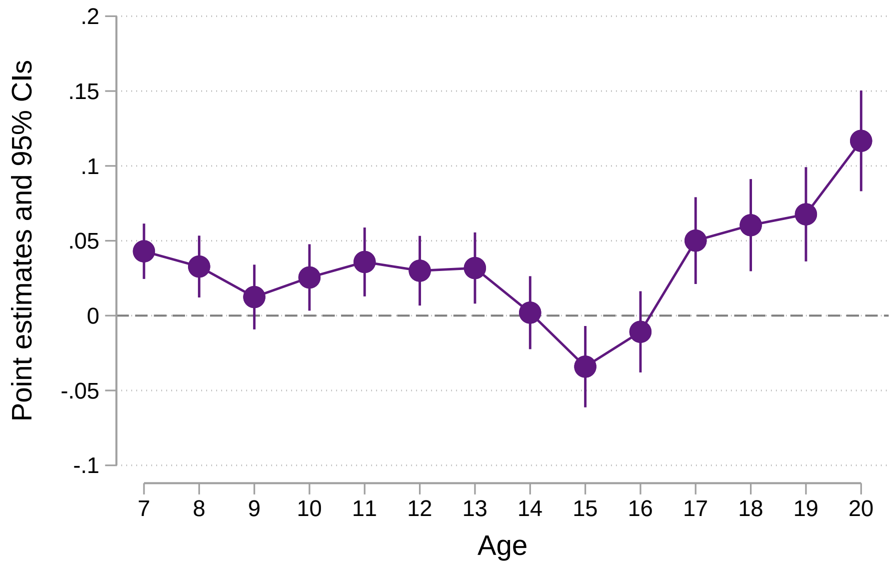


Figure 7: Exposure to Tractors and School Attendance: Triple Difference

Notes: This figure displays estimates from county-level triple-difference regressions based on Equation 5. It reports the farm-versus-nonfarm differential in school attendance by age for White boys ages 7 to 20. Tractor intensity and school attendance are standardized to mean zero and SD one. All specifications include county-by-year, county-by-farm-status, and year-by-farm-status fixed effects. Vertical bars denote 95% confidence intervals based on standard errors clustered at the county level.

nonfarm households, separately for each age. Panel A shows that the association between tractors per farm and school attendance for White boys is close to zero below age 14 both for children residing in farm and nonfarm households. Among White farm boys, greater adoption of tractors is associated with substantially higher school attendance rates among those aged 14 or above, who likely attended high school. By contrast, there are no similar increases among high-school-aged boys residing in nonfarm households.

A key concern is that the greater school attendance rates may reflect differences in schooling that predated the diffusion of tractors. Panel B of Figure 6 addresses this concern by assigning counties their observed 1920, 1930, or 1940 tractor intensity in 1910 and re-estimating the regressions for farm boys using only 1900 and 1910 data. The placebo estimates are generally negative, indicating that farm-boy attendance grew less between 1900 and 1910 in counties where tractors were later adopted more intensively.

Figure 7 displays triple-differences estimates from Equation 5 showing a relatively greater increase in school attendance among high-school-aged White farm boys compared to nonfarm boys. Together, these results show that the association between tractor diffusion and school attendance was greater among the (farm) youths most exposed to tractors and that the link does not reflect a general expansion of schooling across all ages in a county.

Table 2: Exposure to Tractors and School Attendance

	Outcome: High school attendance (std.)						
	Farm (F)			Nonfarm (NF)			F vs. NF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Tractors per farm (std.)	0.107***	0.105***	0.089***	0.009	0.043**	0.040*	
	(0.016)	(0.018)	(0.019)	(0.018)	(0.020)	(0.021)	
Tractors per farm (std.) × Farm (=1)							0.033***
							(0.013)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	No
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	No
County controls × year FE	No	Yes	Yes	No	Yes	Yes	No
Time-varying county controls	No	No	Yes	No	No	Yes	No
County × year FE	No	No	No	No	No	No	Yes
County × farm FE	No	No	No	No	No	No	Yes
Year × farm FE	No	No	No	No	No	No	Yes
Mean outcome	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)
Observations	13185	13185	13185	13185	13185	13185	26370
Counties	2637	2637	2637	2637	2637	2637	2637

Notes: County-level OLS and triple-difference regressions based on Equations 4 and 5, respectively. The outcome is the high-school attendance rate among White boys ages 14 to 18. Tractors per farm and the outcome are standardized to mean zero and SD one. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Time-varying controls are AAA grants per capita, non-AAA New Deal grants and loans per capita, and the county shares in medium and high Dust Bowl erosion zones. Standard errors clustered at the county level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 2 presents estimates from Equation 4 where the outcome is the school attendance rate among White boys aged 14 to 18. Columns 2 and 5 add the baseline set of controls and indicate that a 1 SD increase in tractors per farm is associated with a 0.105 SD increase in attendance among farm boys and a 0.043 SD increase among nonfarm boys. The positive nonfarm associations suggest that tractor diffusion may also have shaped the incentives to invest in schooling, or the local supply, among children less directly affected by the diffusion of tractors. Columns 3 and 6 show that the results are similar when accounting for an additional set of time-varying controls that may have shaped the diffusion of tractors: AAA grants per capita and non-AAA New Deal grants and loans per capita, both from Fishback and Kantor (2018), and the county shares in medium and high Dust Bowl erosion zones from Hornbeck (2012).

Table 2, column 7, reports the triple-difference specification from Equation 5. The estimate implies that attendance among White farm boys rose by 0.033 SD more than among White nonfarm boys in the same county, which is consistent with a relatively greater increase in school attendance among children who were most directly exposed to the tractor.

Table 3: Exposure to Tractors and School Attendance by Race and Sex

	Outcome: High school attendance (std.)				
	White	Black		Other	
	Girls	Boys	Girls	Boys	Girls
	(1)	(2)	(3)	(4)	(5)
Tractors per farm (std.)	0.107***	-0.062	-0.049	0.108	0.031
	(0.017)	(0.058)	(0.063)	(0.071)	(0.082)
County FE	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes
Mean outcome	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)
Observations	13185	7730	7467	1480	1395
Counties	2637	1773	1721	401	386

Notes: County-level OLS regressions based on Equation 4. The outcome is the high-school attendance rate among farm youths ages 14 to 18. Tractors per farm and the outcome are standardized to mean zero and SD one. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Standard errors clustered at the county level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

I focus on White men because they constituted the vast majority of American farmers, bu I next examine the association between the adoption of tractors and high school attendance for different racial groups and regions showing that while non-White children had more limited responses to the diffusion of the tractor, the association between tractor exposure and attendance among White farm children was prevalent throughout the United States.

Table 3 reports estimates for White girls, Black boys and girls, and youths not coded as White or Black ("other") in the census, all from farm households. In contrast to White boys and girls, Black farm children did not exhibit increased school attendance in areas where tractors diffused: estimates are negative and statistically insignificant. While I cannot disentangle the underlying mechanisms, the lack of a response among Black households is consistent with unequal access to schooling and the fact that high schools were often de jure or de facto segregated (Margo, 1990; Carruthers and Wanamaker, 2017; Card et al., 2022), which is evident in the fact that attendance rates did not increase among Black children as new high schools were opened (Doxey et al., 2026).[11]

[11] However, the construction of thousands of Rosenwald schools in the South led to substantial increases in attendance, literacy, and years of schooling among rural Black children (Aaronson and Mazumder, 2011). Appendix Table C1 examines whether the response to the diffusion of tractors among Black farm children differed in counties where Rosenwald schools were constructed, where access to schooling was arguably

Additional Estimates and Robustness Checks I next provide three sets of robustness checks. First, a key concern is that the county-level OLS results may depend on how tractor exposure is measured (per farm). To address this concern, I re-estimate Equation 4 using alternative exposure measures. Appendix Table C2 shows that a positive association persists when tractor exposure is measured as tractors per acre, tractors per farm population, or tractors divided by the number of farms in 1900 to account for the fact that tractor diffusion may affect the number of farms.

Second, I explore the sensitivity to standardizing school-attendance rates within census years to account for differences in reporting conventions across censuses. Appendix Table C3 therefore re-estimates the baseline specifications using the raw county attendance rate as the outcome. The estimates imply an increase in attendance of about 1 percentage point, or about a tenth of a standard deviation.

Third, a related concern is that the baseline estimates pool heterogeneous counties and regions, which may conceal differences in the impacts of tractors in different types of communities. To address this concern, Appendix Table C4 reports estimates of Equation 4 separately by census region, and Appendix Table C5 splits counties at the 1900 median urban share, farm share, and agriculture employment share. The positive association between tractor exposure and high-school attendance is evident in every census region and across all county groups with somewhat larger magnitudes in more agricultural and rural areas, which were likely the most affected by agricultural mechanization. Together, these estimates suggest that the results are not driven by a single region or by unusually rural or agricultural counties.

4.2.2 IV Estimates

Although the association between the adoption of tractors and high school attendance among farm children is a robust association, it does not necessarily reflect a causal link. A particular concern is that the association between the adoption of tractors and school attendance could be driven by reverse causality, or omitted variables. For example, greater school attendance may reduce the supply of agricultural child labor that in turn may further spur the adoption of labor-saving technologies.[12] Alternatively, unobserved local shocks—for example, the expansion of nearby manufacturing industries—could simultaneously raise both the demand for schooling and the incentive to mechanize agriculture. To strengthen a causal

greater. While the interaction effects are positive, the estimates are imprecise.

[12] Below I directly examine the extent to which tractor adoption reduced (agricultural) child labor supply, but find no evidence that child labor declined, which can partly be attributed to the fact that increases in school attendance partly were driven by part-time students who remained in the labor force.

interpretation, I therefore leverage variation in tractor adoption driven by differences in county topography that shaped the spread of tractors.

Empirical Strategy I estimate 2SLS panel regressions that instrument tractors per farm with terrain smoothness based on the USGS data interacted with year indicators. The first stage is:

$$T_{ct} = \alpha_c + \lambda_{st} + \sum_{\tau \in \{1910,1920,1930,1940\}} \pi_\tau \left(R_c \times \mathbb{1}\{t = \tau\}\right) + X'_{c,1900}\Gamma_t + \nu_{cst}, \tag{6}$$

where T_{ct} is the standardized tractors per farm in county c and year t, and R_c is the standardized terrain smoothness measure, as defined in Section 2 and discussed more in the next section. Because 1900 is the omitted baseline year, the excluded instruments are terrain smoothness interacted with the 1910, 1920, 1930, and 1940 indicators. As above, county fixed effects absorb time-invariant differences across counties, state-by-year fixed effects absorb shocks common to counties within a state in a given census year, and the county characteristics measured in 1900 interacted with year indicators control for baseline factors that may have shaped both the adoption of tractors and schooling.

The second stage replaces tractors per farm in Equation 4 with the fitted value from Equation 6 for farm boys:

$$Y^F_{cst} = \beta^F_{IV}\widehat{T}_{ct} + \alpha^F_c + \lambda^F_{st} + X'_{c,1900}\Gamma^F_t + \varepsilon^F_{cst}, \tag{7}$$

where Y^F_{cst} is the standardized school-attendance rate for farm boys. The coefficient β^F_{IV} captures the effect of a 1 SD increase in tractor intensity on school attendance for counties whose tractor adoption decisions were shaped by terrain smoothness.

I also estimate an IV version of the stacked triple-differences specification in Equation 5:

$$Y^f_{ct} = \delta_{IV}(T_{ct} \widehat{\times Farm_f}) + \alpha_{ct} + \eta_{cf} + \lambda_{stf} + \varepsilon^f_{ct}, \tag{8}$$

where $f \in \{\text{farm, nonfarm}\}$ and the endogenous regressor $T_{ct} \times Farm_f$ is instrumented with terrain smoothness interacted with farm status and census-year indicators. The county-by-year fixed effects α_{ct} absorb the direct effect of tractor intensity and any other county-year shocks common to farm and nonfarm children, the county-by-group fixed effects η_{cf} absorb permanent differences between farm and nonfarm children within counties, and the state-by-year-by-group fixed effects λ_{stf} absorb state-level shocks that may differentially affect farm and nonfarm children over time. The coefficient δ_{IV} therefore captures whether the attendance response to tractor adoption was relatively larger among farm children than among nonfarm children within the same county and year.

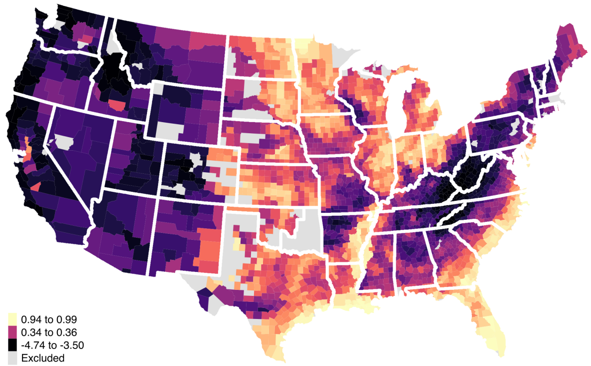
First Stage A key determinant of the early adoption of tractors emphasized both by contemporaries and agricultural historians was the ruggedness of the (potential) farmland: areas with more rugged terrain or greater slopes made it more challenging to adopt tractors.

By the early 1920s, Baker (1921, p. 23) underlined that "[t]he invention and extensive use in the United States of farm machinery [...] has greatly increased the influence of topography" arguing that more rugged areas "now suffer from the further disadvantage of being poorly adapted to the use of modern farm machinery". As later summarized in contemporary reports by the WPA National Research Project: "It is an accepted fact that tractors are more adaptable to use on level or slightly undulating land than on rolling or rough farm land." (McKibben and Griffin, 1938, p. 31). Similarly, Washburn and Merrick (1936, p. 42) noted in the mid-1930s that "where the prevailing topography is rolling to hilly, tractors have not displaced horses on grain farms as a source of power to draw field implements to so large an extent". United States Department of Agriculture (1932, p. 417) similarly attributed farm mechanization to topography: "Perhaps in no other agricultural region of the United States has there been a more fertile field for the mechanization of agriculture than in the Great Plains" where "comparatively large stretches of level land [...] have contributed to an agriculture that has grown and thriven on mechanical power." French (2026) documents that rugged terrain is associated with lower investments in agricultural machinery in the 1910s, while Fishback et al. (2005) and Boone and Wilse-Samson (2023) find that greater slopes are associated with slower tractor diffusion in the 1930s.

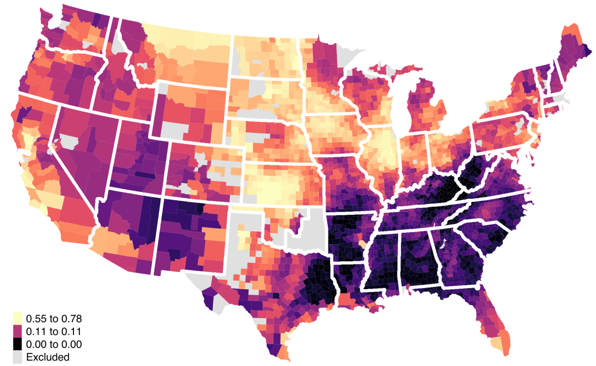
Figure 8, Panels A and B, map standardized terrain smoothness and mean tractors per farm over 1920–1940, as defined in Section 2, showing that tractors were more prevalent in counties with smoother terrain.[13] Panel C presents estimates of a flexible version of Equation 6, showing that the first stage relationship between terrain smoothness and tractor intensity emerged in 1920 and strengthened in the 1920s and 1930s.[14] Panel D shows the corresponding reduced-form estimates where I regress the attendance rate among White farm

[13] Appendix Figure A1 provides a visual counterpart to this first stage by showing the broader elevation surface together with three county examples consistent with smoother terrain facilitating tractor adoption: the less rugged example, Greene County, Iowa, had 0.73 tractors per farm, compared with 0.48 in the medium-rugged Winneshiek County, Iowa, and 0.28 in the more rugged Trempealeau County, Wisconsin.

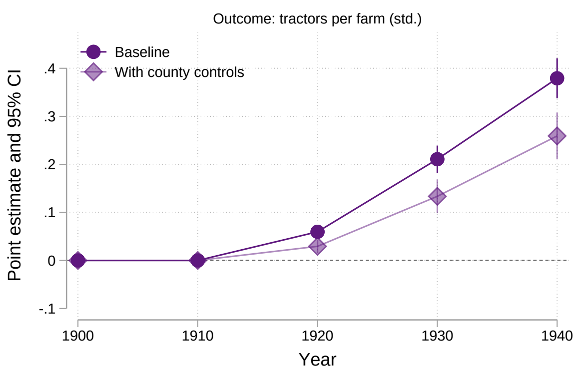
[14] More precisely, I estimate a flexible difference-in-differences style regression: $T_{ct} = \alpha_c + \lambda_{st} + \sum_{\tau\in\{1910,1920,1930,1940\}} \pi_\tau \big(R_c \times \mathbb{1}\{t=\tau\}\big) + X'_{c,1900}\Gamma_t + \nu_{cst}$ using the 1900–1940 county panel, with 1900 as the omitted reference year, so each π_τ measures the terrain-smoothness gradient in tractor intensity relative to 1900. Because tractor intensity is zero in every county in both 1900 and 1910, the estimated 1910 gradient is mechanically zero. The baseline series omits $X'_{c,1900}\Gamma_t$, while the controlled series includes the 1900 county characteristics interacted with year indicators. Both specifications include county and state-by-year fixed effects, with standard errors clustered by county.



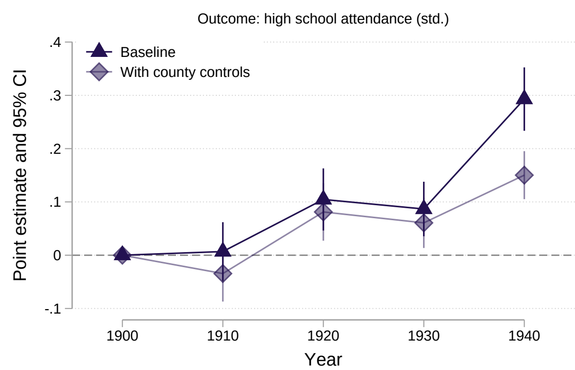
(A) Terrain Smoothness



(B) Mean Tractors per Farm, 1920–1940



(C) First Stage by Decade



(D) Reduced Form by Decade

Figure 8: First Stage and Reduced Form

Notes: This figure displays terrain smoothness in Panel A and mean tractors per farm over 1920–1940 in Panel B. Panel C reports decade-specific first-stage coefficients from county-level regressions of tractor intensity on terrain smoothness interacted with year indicators. Panel D reports the corresponding reduced-form coefficients from county-level regressions of high-school attendance among White farm boys ages 14 to 18 on terrain smoothness interacted with year indicators. Panels A and B use 1900 county boundaries. Terrain smoothness, tractor intensity in Panel C, and high-school attendance in Panel D are standardized to mean zero and SD one. Both regression panels include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Vertical bars denote 95% confidence intervals based on standard errors clustered at the county level.

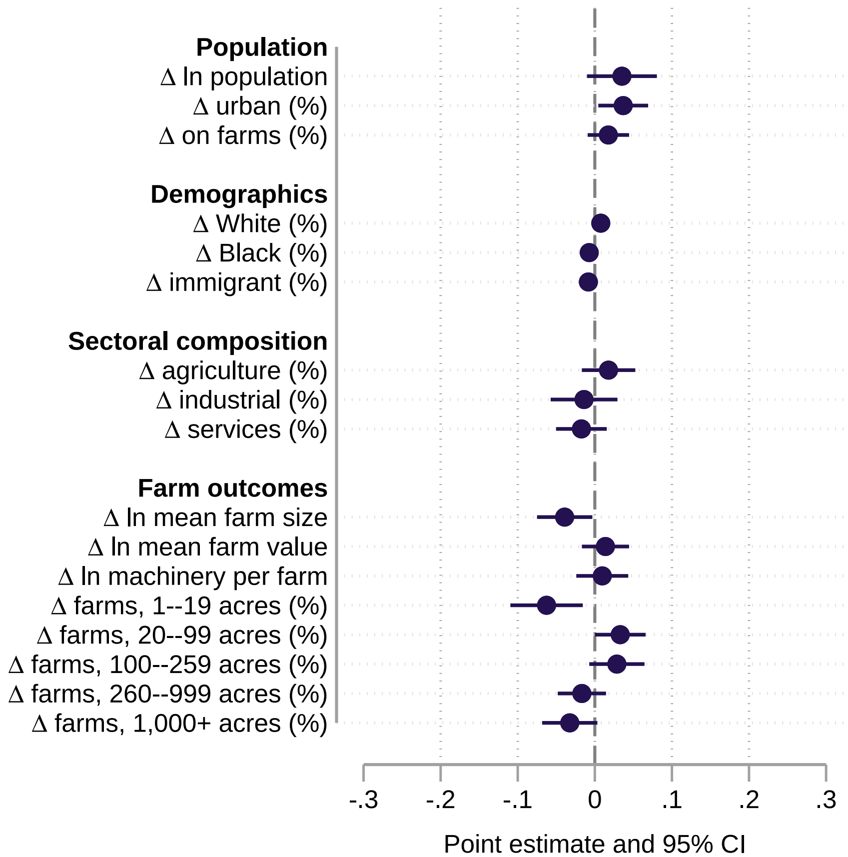


Figure 9: Terrain Smoothness and Pre-Tractor Trends

Notes: This figure displays coefficients from separate county-level regressions of changes in county characteristics between 1900 and 1910 on terrain smoothness. The outcomes are log population, the percentages urban and on farms, the percentages White, Black, and immigrant, the percentage employed in agriculture, the industrial employment share, the percentage employed in services, log mean farm size, log mean farm value, log machinery per farm, and the percentage distribution of farms across acreage bins. Terrain smoothness and all outcomes are standardized to mean zero and SD one. All regressions include state fixed effects. Horizontal bars denote 95% confidence intervals based on standard errors clustered at the state level.

boys aged 14 to 18 on terrain smoothness interacted with year indicators otherwise using a similar regression specification as for the first stage, which shows that high school attendance did not differ between more and less rugged areas before the diffusion of tractors, but that attendance rates increased in smoother areas after the diffusion of tractors.

The exclusion restriction requires that terrain smoothness did not affect changes in school attendance other than through the adoption of tractors. Despite controlling for a rich set of baseline county characteristics, a remaining concern is that smoother terrain may correlate with a wide range of observed or unobserved factors that may shape educational investments and tractor adoption. While not formally testable, I provide three pieces of supporting evidence that narrow these concerns. First, Figure 8, Panel D, shows that the reduced form is close to zero in 1910 and turns positive only after tractors began to diffuse, which is inconsistent with smoother counties already being on different school attendance trends before mechanization. Second, Figure 9 shows that smoother counties did not exhibit systematic and substantial differential changes in local economic or farm outcomes between 1900 and 1910 before tractors became widespread. Third, Appendix Figure D1 shows that there is no systematic increase in school attendance in counties with smoother terrain in a subsample where few tractors were adopted. Together, these results lend some support to interpreting the IV estimates as reflecting the school attendance response among counties where tractor adoption was shaped by the terrain, even though they naturally do not alleviate all threats to the exclusion restriction.

Results: Exposure to Tractors and School Attendance Table 4 reports the 2SLS estimates from estimating Equation 7. Column 1 shows that a 1 SD increase in tractors per farm raised school attendance by 0.669 SDs among White farm boys. However, one concern is that terrain smoothness may affect schooling through channels other than tractor adoption: for example, flatter counties may have had different agricultural production structures or more productive soils, better market access, or lower costs of providing secondary schooling. Columns 3 and 4 address these threats by combining the baseline controls with a terrain-channel control set: the 1900 farm-size distribution, GAEZ suitability measures for sugar, cotton, maize, rice, wheat, and oats, log market access, and teachers per capita, each interacted with year fixed effects. Column 4 further adds time-varying controls for the Dust Bowl and New Deal. Estimated increases in high school attendance are larger when adding these more extensive controls.

Column 5 presents triple-differences estimates of Equation 8, which compare farm and nonfarm children within the same county and year. The triple-difference IV estimate implies that a 1 SD increase in tractor adoption is associated with a 0.211 SD increase in attendance, which suggests that the diffusion of tractors raised the relative attendance of farm children compared to nonfarm children.

Across all specifications, the estimated increases in attendance are precisely estimated and the Anderson–Rubin p-values reported at the bottom of Table 4 are below 0.001. Consistently, the 2SLS estimates are larger in magnitude compared to the OLS estimates in Table 2. A possible explanation is that the OLS estimates suffer from attenuation bias due to measurement error. In addition, because the IV estimates identify a local average treatment effect, they recover the effect for complier counties where tractor adoption decisions were shifted by terrain. The larger 2SLS estimates are therefore consistent with stronger effects

Table 4: Exposure to Tractors and High School Attendance: 2SLS Estimates

	Outcome: High school attendance (std.)				
	Farm (F)				F vs. NF
	(1)	(2)	(3)	(4)	(5)
Tractors per farm (std.)	0.669***	0.551***	0.607***	0.754***	
	(0.068)	(0.095)	(0.151)	(0.195)	
Tractors per farm (std.) × Farm (=1)					0.211***
					(0.068)
County FE	Yes	Yes	Yes	Yes	No
State × year FE	Yes	Yes	Yes	Yes	No
County controls × year FE	No	Yes	Yes	Yes	No
Terrain controls × year FE	No	No	Yes	Yes	No
Time-varying county controls	No	No	No	Yes	No
County × year FE	No	No	No	No	Yes
County × farm FE	No	No	No	No	Yes
State × year × farm FE	No	No	No	No	Yes
First stage F-statistic	65.29	24.57	14.64	9.93	65.30
Anderson–Rubin p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Mean outcome	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)
Observations	13185	13185	12910	12910	26370
Counties	2637	2637	2582	2582	2637

Notes: County-level 2SLS regressions. Columns 1 to 4 report estimates based on Equations 6 and 7, while column 5 reports estimates from the stacked triple-difference specification in Equation 8. The outcome is the high-school attendance rate among White farm boys ages 14 to 18 in columns 1 to 4 and the corresponding farm-versus-nonfarm differential in column 5. The endogenous regressor is tractors per farm in columns 1 to 4 and its interaction with farm status in column 5. The excluded instruments are terrain smoothness interacted with year indicators in columns 1 to 4; column 5 additionally interacts these instruments with farm status. Tractors per farm and the outcome are standardized to mean zero and SD one. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Terrain controls are 1900 farm-size distribution shares, GAEZ crop-suitability measures for sugar, cotton, maize, rice, wheat, and oats, log county market access, and teachers per capita, each interacted with year fixed effects. Time-varying controls are AAA grants per capita, non-AAA New Deal grants and loans per capita, and the county shares in medium and high Dust Bowl erosion zones. Standard errors clustered at the county level are reported in parentheses. The table reports the first-stage Kleibergen-Paap rk Wald F-statistic and county-clustered Anderson–Rubin p-values for the joint null of a zero endogenous-regressor coefficient and valid instrument restrictions, testing the four excluded year interactions jointly. Stars refer to conventional 2SLS inference: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

in agriculturally intensive complier counties, for example in the Midwest and Great Plains, where local economies were especially exposed to agricultural mechanization.

Robustness Checks I next examine the sensitivity of the IV estimates to geographic coverage, the measurement of terrain smoothness, weak instruments, and violations of the exclusion restriction.

First, a key concern is that the terrain instrument may rely on topographical variation from a particularly rugged region (for example, the American West), or for counties with unusual topography or economic structure. Appendix Table D1 presents 2SLS estimates after excluding each census region in turn, then excluding major-mountain counties, highly urban counties, and counties with low baseline agriculture employment shares. The coefficients remain close to the baseline estimates, which suggests that the IV results are not driven by a narrow set of places.

Second, I show that results are similar when using alternative ways to define the "smoothness" of a county's terrain. Appendix Table D2 shows that the positive farm estimates remain when I replace the baseline instrument with mean slope, elevation dispersion, or the share of county land above a 5 percent slope. The estimates show that the results do not rely on using the Riley TRI to define terrain smoothness.

Third, I examine how large violations of the exclusion restriction must be to eliminate the statistical significance of the IV estimates. Following Caprettini and Voth (2023), I apply the approach of Conley et al. (2012) allowing joint direct effects of the instruments on attendance. Depending on the specification, making the conventional IV estimates insignificant at the 5% level requires allowing direct effects as large as 31.7–74.1% of the instruments' respective reduced-form effects (Appendix Figures D2 and D3). That terrain smoothness would have such large direct effects seem unlikely, given the fact that there is no substantial reduced-form association between attendance and terrain smoothness in the period pre-dating the arrival of the tractor (see Figure 8).

4.3 Why Did Farm Children Invest in High School?

A robust association between high school attainment and attendance and exposure to tractors particularly among youths living on farms raises the question of why American farmers sent their children to high school in areas more exposed to tractors. At first sight, a somewhat puzzling feature of the American high school movement is that it was led by the farming states, despite the relatively lower demands for human capital in the agricultural sector. Yet farm households may decide to send their children to high school for two broad reasons.

First, given the aggregate decline of agricultural work, families anticipating that their children might shift out of farming would have strong incentives to invest in a high school education, which would have facilitated transitions into the rapidly growing urban service sector where human capital requirements were higher (see Appendix Table E1).

Second, the pervasive agricultural modernization that followed in the wake of the tractor raised the requirements for formal schooling, as operating a modern farm increasingly required a wide range of skills taught in high school. Farm operation was fundamentally transformed due to the coming of the tractor and related changes involving accounting practices, animal inoculation, electric farm machinery, fertilizers, and new seed varieties.[15] Indeed, the focus on topics such as algebra, biology, bookkeeping, and chemistry in high schools were all geared towards providing future farmers with the required skills to maintain and operate a modern farm (Goldin and Katz, 2000).[16] Against that backdrop, it appears less puzzling that the high school movement was led by farming states in the Midwest, or that farmers actively supported the expansion of high schools to equip their children with the skills required to adapt to agricultural modernization (Crosby, 1913; Parman, 2012).

I next provide more systematic descriptive evidence to explore the role of these two mechanisms showing that while a high-school diploma enabled youths to transition into urban service jobs, high-school educated farm children were relatively more likely to remain in farming in areas where tractors were intensively adopted consistent with the idea that human capital enabled them to adapt to the rapid agricultural modernization that followed the tractor.

Exploring Mechanisms: Exit and Agricultural Adaptation To examine the two broad explanations, I use the individual-level linked data to descriptively examine the sectors and jobs that farm children ended up in. I estimate OLS regressions:

$$Y_{icb} = \beta_1 HS_i + \beta_2 \widetilde{T}_{cb}^{15} + \beta_3 \left(HS_i \times \widetilde{T}_{cb}^{15} \right) + \alpha_c + \lambda_{s(c)b} + X'_{c,1900}\Gamma_b + \varepsilon_{icb}, \tag{9}$$

[15] Appendix Section A.2 shows that the agricultural sector in counties with a greater share of farmers with a high-school diploma relied on more machinery such as tractors in 1940, was more commercialized, and had higher productivity, suggestive of a complementarity between human capital and agricultural modernization. Similarly, the growing requirement of education within agriculture is also evident from the fact that adapting to the stream of innovations coming from federal agricultural experiment stations established in the late nineteenth century was facilitated by the spread of education (Kantor and Whalley, 2019).

[16] Although the Smith-Hughes Act of 1917 marked the widespread diffusion of agricultural education in the high school curriculum, thousands of high schools had provided an agricultural education already at the start of the high school movement that serves as a testament to the perceived demand among farmers (Crosby, 1913). Notably, the growing role of agricultural education in the curriculum was viewed favorably by students because they perceived it "dealt with the realities of life, with real problems instead of imaginary ones" (Crosby, 1913, p. 481).

Table 5: Exposure to Tractors in Childhood and Adult Outcomes

	Place of residence			Industry			Occupation		
	Urban	Migrant	On farm	Agriculture	Industrial	Services	Farmer	Wage laborer	Family laborer
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A. High school attainment									
High school (=1)	15.035***	6.488***	-15.410***	-18.601***	-7.377***	25.978***	-11.194***	-6.005***	-1.147***
	(0.235)	(0.237)	(0.279)	(0.297)	(0.255)	(0.288)	(0.265)	(0.136)	(0.102)
Panel B. Tractor exposure									
Tractors per farm (std.)	-0.840***	-0.660**	1.168***	0.814**	-0.286	-0.527*	-0.378	0.517***	0.566***
	(0.247)	(0.293)	(0.286)	(0.346)	(0.273)	(0.297)	(0.291)	(0.197)	(0.141)
Panel C. Tractor exposure and high school attainment									
Tractors per farm (std.)	0.691***	0.514*	-0.675**	-0.341	-1.006***	1.347***	-2.254***	1.175***	0.619***
	(0.250)	(0.299)	(0.300)	(0.349)	(0.290)	(0.279)	(0.302)	(0.226)	(0.155)
High school (=1)	15.013***	6.472***	-15.383***	-18.558***	-7.346***	25.904***	-11.111***	-6.033***	-1.152***
	(0.231)	(0.236)	(0.274)	(0.293)	(0.251)	(0.272)	(0.258)	(0.137)	(0.103)
Tractors (std.) × HS (=1)	-4.194***	-3.101***	4.991***	3.402***	2.021***	-5.423***	5.082***	-1.558***	-0.110
	(0.209)	(0.215)	(0.257)	(0.271)	(0.215)	(0.253)	(0.241)	(0.178)	(0.142)
Childhood county FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Childhood state × cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean outcome	23.234	58.431	53.117	44.809	29.084	26.107	30.183	8.571	4.519
Observations	262118	262086	262118	247691	247691	247691	251201	251201	251201
Counties	2774	2774	2774	2771	2771	2771	2771	2771	2771

Notes: Individual-level OLS regressions based on Equation 9. The outcomes are indicators for place of residence, industry, and occupation in 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940 and linked to farm childhood households. The tractor measure is tractors per farm assigned when an individual was closest to age 15, standardized to mean zero and SD one. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

where Y_{icb} is an outcome observed in 1940 for linked individual i from childhood county c and birth cohort b, HS_i is an indicator for completing high school, and $\widetilde{T}^{15}_{cb}$ is standardized tractors per farm assigned to county c when cohort b is closest to age 15. The specifications restrict the sample to men from farm childhood households, include childhood-county fixed effects, origin-state-by-cohort fixed effects, and the baseline 1900 county controls interacted with cohort fixed effects, and cluster standard errors by childhood county.

Table 5 presents estimates of Equation 9 and compares the adult outcomes of boys from farm origins based on whether they attained a high school degree and their exposure to tractors.[17] Panel A includes only HS_i, Panel B includes only $\widetilde{T}^{15}_{cb}$, and Panel C reports the specification with the full interaction.

Panel A shows that attaining a high school degree is associated with a 15.0 percentage point increase in urban residence, a 6.5 point increase in migration away from the childhood county, and a 15.4 point decline in residence on a farm by 1940 when linked individuals have

[17] Appendix Table E2 documents similar results for children with farming fathers.

reached adulthood. High school attainment is also associated with a 26.0 point increase in service-sector employment, mainly offset by an 18.6 point decline in agriculture and an 11.2 point decline in the probability of appearing as a farmer. These results are consistent with the interpretation that farm children partly invested in a high school education because it facilitated the exit from farming and the transition into urban service jobs where the demand for human capital was greater.

I next examine the outcomes for boys with different exposure to tractors in childhood. In contrast to a simple labor displacement story, Panel B shows that those who grew up in areas where tractors were more heavily adopted were 1.2 percentage points more likely to remain on farms and 0.8 points more likely to work in agriculture in 1940, though the corresponding increases are concentrated among wage laborers and unpaid family workers rather than farmers.

Panel C presents the interaction effects showing that, in high-tractor counties, farm boys who attained a high school degree were 5.0 percentage points more likely to remain on farms, 3.4 points more likely to work in agriculture, and 5.1 points more likely to appear as farmers, while being 1.6 points less likely to appear as wage laborers. The fact that high-school graduates were relatively more likely to remain in farming in places more exposed to tractors is consistent with the second interpretation: farmers invested in the schooling of their children also as a way to keep pace with a modernizing agricultural sector, rather than solely to facilitate exiting to other sectors.

A relatively greater demand for human capital within the agricultural sector in areas that more intensively adopted tractors is further consistent with the descriptive patterns in Figure 10 that uses data from the 1940 census.[18] Panel A displays the share of men with a high school degree in farm and nonfarm households across counties based on the number of tractors per farm, while Panel B displays the share with a high school degree across different sectors and occupations (see Appendix Table E1 for more examples). Notably, in areas with high levels of tractor adoption both farm households and men in agriculture are relatively more likely to have attained a high school degree, while gaps are smaller among nonfarm households or workers in manufacturing or services in the same counties. Put differently, while farmers are much more likely to have a high school degree in areas with greater tractor adoption, bookkeepers or machinists have similar levels of educational attainment across the county distribution. Again, these patterns appears consistent with the idea that the diffusion of tractors raised the relative demand for human capital within the agricultural sector.

Together, these suggestive results are consistent with the idea that farmers sent their

[18] Appendix Figure E1 similarly shows a substantial relative increase in high school attainment among farmers by cohort in areas where tractors were more intensively adopted.

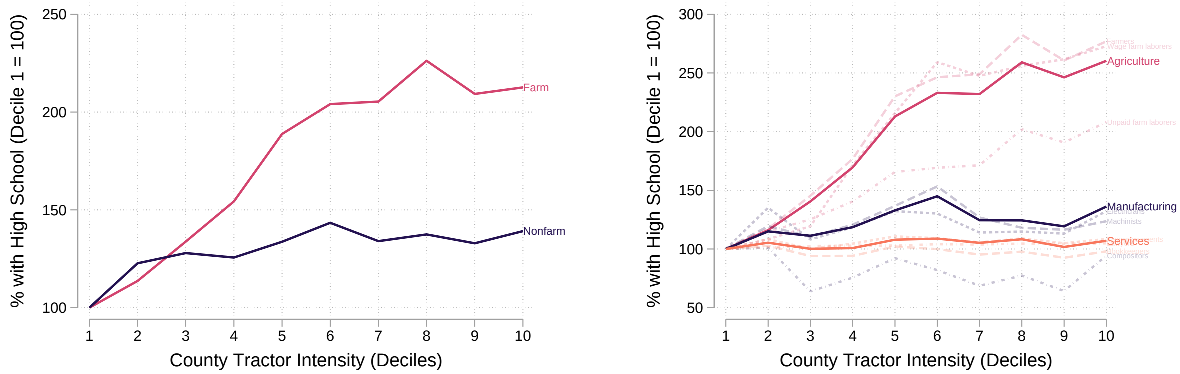


Figure 10: High School Attainment by Sector and County Tractor Intensity

Notes: This figure displays the share with at least a high school degree across counties grouped into deciles of tractors per farm in 1940 based on data from the 1940 full-count population census with county tractor counts from the 1940 agricultural census (Ruggles et al., 2024; Haines et al., 2018; Schroeder et al., 2025). All series are normalized so that the first decile equals 100. Panel A reports shares for men in farm and nonfarm households. Panel B reports shares for agricultural, manufacturing, and service and white-collar occupations, together with the three most common well-defined occupations in each group. The sample includes White native-born men ages 25 to 54 in 1940 with reported industry, known schooling, and an identifiable county. Occupation groups are defined using OCC1950 codes: agriculture includes farmers, farm managers, farm foremen, farm laborers, farm-service laborers, and unpaid family farm laborers; manufacturing includes production craft and operative occupations after excluding construction, repair, transport, mining, utilities, and broad or ambiguous operative categories; and services and white-collar occupations include professional and technical, managerial/proprietor, clerical, sales, and service-worker occupations. Appendix Table E1 reports similar data for additional detailed occupations.

children to high school partly because they realized that many of them would have to exit the agricultural sector and shift into more human-capital-intensive work. But at the same time, an important motivation seems to have been to enable farm children to adapt to the rapid agricultural modernization that followed in the wake of the tractor and remain within farming as adults.[19]

Other Complementary Mechanisms Although the evidence is consistent with farm children investing in human capital to transition into more human-capital-intensive sectors and to adapt to the pervasive modernization of agriculture, the link between exposure to tractors and the rise of schooling could also reflect a range of complementary mechanisms.

[19]Such an interpretation is also consistent with the fact that the returns to a high-school degree within the agricultural sector were high and typically higher for children originating from farm households (Goldin and Katz, 2000; Parman, 2012; Feigenbaum and Tan, 2020), which is also emphasized in the conclusion of Parman (2012, p, 326) arguing that the high returns to human capital among Iowa farmers “are consistent with the idea that in a time with technological innovation education would be useful to farmers through more advanced studies at the high school level where more specific scientific information can be taught and the ability to experiment and adapt can be developed. These skills can have a large impact on earnings in a period of innovation and it is therefore unsurprising to observe such large returns to high school education for farmers.”

First, agricultural mechanization could raise schooling by displacing child labor, thus lowering the opportunity cost of attending school. If tractors replaced tasks previously performed by children, the direct cost of schooling would fall even without a change in the return to education. Appendix Table E3 examines this idea using county-level OLS and IV estimates of labor-force participation among White children ages 10 to 14.[20] Neither specification shows a clear decline in child labor-force participation within agriculture in counties with greater tractor adoption, consistent with the fact that most child labor in agriculture was concentrated in tasks such as weeding and harvesting, which were not directly displaced by early tractors.[21]

Second, the supply of schooling may have expanded in counties that adopted tractors more rapidly if, for example, mechanization raised local tax revenue. Appendix Table E5 examines the diffusion of tractors and the supply of teachers and shows that teacher availability may have increased with tractor adoption, though the OLS estimates are relatively small in magnitude while the IV estimates are not statistically significant. While the adoption of tractors may have increased the supply of schooling, the small magnitudes suggest that a broad expansion in school resources is not the main explanation for the schooling response observed above.

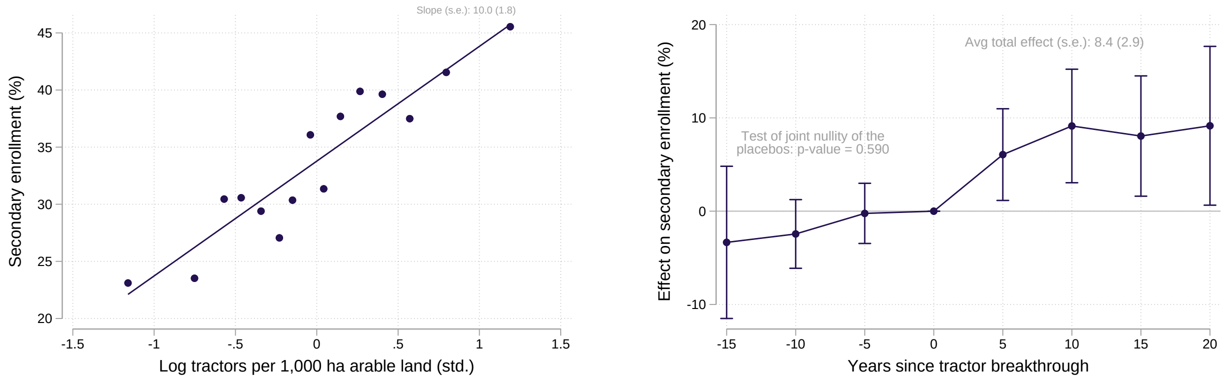
5 Epilogue: A Global View

Was the U.S. experience in the first half of the twentieth century mirrored elsewhere? Figure 1 shows that Western Europe followed similar trajectories in tractor adoption and secondary schooling in the post-war era, while international institutions and national leaders promoted tractors throughout the developing world as a central part of state-led modernization in the latter half of the twentieth century (Mrema et al., 2008; Binswanger, 1978, 1986). Notably, the diffusion of tractors coincided with a global rise in secondary schooling (Barro and Lee, 2013; Lee and Lee, 2016).

I lastly use country-level data for 81 non-advanced countries between 1960 and 2000 to provide descriptive evidence on the association between tractor diffusion and secondary schooling. Figure 11, Panel A, presents a binned scatterplot of boys' secondary-school enrollment from Lee and Lee (2016) against tractors per 1,000 hectares of arable land from Food and Agriculture Organization of the United Nations (2021), controlling for year fixed effects

[20] Labor-force participation is based on whether children reported a valid occupation in the census.

[21] I also examine the related question whether the rise in education reflected full- or part-time students. Appendix Table E4 shows that a substantial part of the attendance response, especially for nonfarm boys, appears on the part-time margin rather than through a rise in full-time attendance. That pattern is consistent with limited effects on child labor because many youths seemingly combined high-school study with work.



(A) Cross-Country (B) Within-Country

Figure 11: Tractors and Secondary Enrollment in Developing Countries, 1960–2000

Notes: This figure displays cross-country evidence on tractor intensity and secondary-school enrollment among boys from 1960 to 2000. Panel A reports a binscatter of secondary-school enrollment and log tractors per 1,000 hectares of arable land after residualizing both variables by year fixed effects and ln GDP per capita (Bolt and van Zanden, 2025). The tractor measure is standardized to mean zero and SD one. Panel B reports event-study estimates around the breakthrough of tractors, defined as the first five-year period in which a country reaches at least five tractors per 1,000 hectares of arable land. The estimates are obtained using the estimator developed by de Chaisemartin and D'Haultfœuille (2026). Vertical bars denote 95% confidence intervals based on standard errors clustered at the country level.

and ln GDP per capita.[22] Enrollment was substantially higher in countries with greater tractor intensity.[23]

A similar pattern emerges when I examine secondary enrollment before and after tractor breakthroughs in an event study framework. I define a country's "tractor breakthrough" as the first period in which it reaches at least five tractors per 1,000 hectares of arable land, about the sample median. Figure 11, Panel B, reports estimates using the estimator of de Chaisemartin and D'Haultfœuille (2026): enrollment rates were essentially flat before the breakthrough and increased sharply afterward.

Although these cross-country associations remain suggestive, they parallel the U.S. experience and are consistent with the idea that agricultural modernization may have contributed to the rise of secondary schooling over the twentieth century.

[22] Appendix Figure F1 reports the corresponding evidence for girls.

[23] Appendix Table F1 reports the corresponding country-level OLS regressions. In Panel A, column 3, a 1 SD increase in tractor intensity is associated with a 3.5 percentage point increase in boys' secondary-school enrollment after accounting for income per capita, about a tenth of the sample mean. Appendix Figure F2 displays the bivariate association between tractor intensity and boys' secondary-school enrollment: circles denote country means, while arrows show the direction and slope of the within-country association.

6 Conclusions

Agricultural automation contributed to the massive decline of agricultural employment over the twentieth century. Using data from the United States, I show that the diffusion of the tractor also was associated with substantial increases in high-school attainment among children growing up on farms in the first half of the twentieth century. Thus, agricultural automation appears to have been one part of the demand-side forces behind the American high school movement: areas where farming modernized fastest were also where farm children invested more heavily in secondary schooling, which complements traditional explanations that tend to more broadly focus on the rising returns to education in the expanding service sector, or supply-side factors (Goldin and Katz, 2008). While I cannot precisely delineate the underlying mechanisms, the evidence and statements of contemporary farmers appear consistent with farm households sending their children to school partly to adapt and persist in the rapidly modernizing agricultural sector.

References

Aaronson, Daniel and Bhashkar Mazumder, "The Impact of Rosenwald Schools on Black Achievement," *Journal of Political Economy*, 2011, *119* (5), 821–888.

Acemoglu, Daron and Pascual Restrepo, "Robots and Jobs: Evidence from US Labor Markets," *Journal of Political Economy*, 2020, *128* (6), 2188–2244.

Adachi, Daisuke, Daiji Kawaguchi, and Yukiko U. Saito, "Robots and Employment: Evidence from Japan, 1978–2017," *Journal of Labor Economics*, 2024, *42* (2), 591–634.

Ager, Philipp, Marc Goñi, and Kjell G. Salvanes, "Gender-Biased Technological Change: Milking Machines and the Exodus of Women from Farming," *American Economic Review*, 2026, *116* (1), 246–286.

Althoff, Lukas and Hugo Reichardt, "Jim Crow and Black Economic Progress after Slavery," *The Quarterly Journal of Economics*, 2024, *139* (4), 2279–2330.

Andersson, David, Mounir Karadja, and Erik Prawitz, "Mass Migration and Technological Change," *Journal of the European Economic Association*, 2022, *20* (5), 1859–1896.

Angus, David L. and Jeffrey E. Mirel, *The Failed Promise of the American High School, 1890–1995*, Teachers College Press, 1999.

Ankli, Robert E., "Horses vs. Tractors on the Corn Belt," *Agricultural History*, 1980, *54* (1), 134–148.

_ and Alan L. Olmstead, "The Adoption of the Gasoline Tractor in California," *Agricultural History*, 1981, *55* (3), 213–230.

Arntz, Melanie, Cäcilia Lipowski, Guido Neidhöfer, and Ulrich Zierahn-Weilage, "Computers as Stepping Stones? Technological Change and Equality of Labor Market Opportunities," *Journal of Labor Economics*, 2025, *43* (2), 503–543.

Arthi, Vellore, "'The Dust Was Long in Settling': Human Capital and the Lasting Impact of the American Dust Bowl," *The Journal of Economic History*, 2018, *78* (1), 196–230.

Autor, David and Neil Thompson, "Expertise," *Journal of the European Economic Association*, 2025, *23* (4), 1203–1271.

_, Caroline Chin, Anna Salomons, and Bryan Seegmiller, "New Frontiers: The Origins and Content of New Work, 1940–2018," *The Quarterly Journal of Economics*, 2024, *139* (3), 1399–1465.

Autor, David H., "Why Are There Still So Many Jobs? The History and Future of Workplace Automation," *Journal of Economic Perspectives*, 2015, *29* (3), 3–30.

Baker, Oliver E., "The Increasing Importance of the Physical Conditions in Determining the Utilization of Land for Agricultural and Forest Production in the United States," *Annals of the Association of American Geographers*, 1921, *11* (1), 17–46.

Baker, Richard B., "From the Field to the Classroom: The Boll Weevil's Impact on Education in Rural Georgia," *The Journal of Economic History*, 2015, *75* (4), 1128–1160.

_ **, John Blanchette, and Katherine Eriksson**, "Long-Run Impacts of Agricultural Shocks on Educational Attainment: Evidence from the Boll Weevil," *The Journal of Economic History*, 2020, *80* (1), 136–174.

Barro, Robert J. and Jong-Wha Lee, "A New Data Set of Educational Attainment in the World, 1950–2010," *Journal of Development Economics*, 2013, *104*, 184–198.

Berger, Thor and Per Engzell, "Industrial Automation and Intergenerational Income Mobility in the United States," *Social Science Research*, 2022, *104*, 102686.

Binswanger, Hans P., *The Economics of Tractors in South Asia: An Analytical Review*, New York and Hyderabad, India: Agricultural Development Council and International Crops Research Institute for the Semi-Arid Tropics, 1978.

_ , "Agricultural Mechanization: A Comparative Historical Perspective," *The World Bank Research Observer*, 1986, *1* (1), 27–56.

Bolt, Jutta and Jan Luiten van Zanden, "Maddison-Style Estimates of the Evolution of the World Economy: A New 2023 Update," *Journal of Economic Surveys*, 2025, *39* (2), 631–671.

Boone, Christopher D. A. and Laurence Wilse-Samson, "Structural Change and Internal Labor Migration: Evidence from the Great Depression," *The Review of Economics and Statistics*, 2023, *105* (4), 962–981.

Caprettini, Bruno and Hans-Joachim Voth, "New Deal, New Patriots: How 1930s Government Spending Boosted Patriotism During World War II," *The Quarterly Journal of Economics*, 2023, *138* (1), 465–513.

Card, David, Ciprian Domnisoru, and Lowell Taylor, "The Intergenerational Transmission of Human Capital: Evidence from the Golden Age of Upward Mobility," *Journal of Labor Economics*, 2022, *40* (S1), S39–S95.

Carruthers, Celeste K. and Marianne H. Wanamaker, "Separate and Unequal in the Labor Market: Human Capital and the Jim Crow Wage Gap," *Journal of Labor Economics*, 2017, *35* (3), 655–696.

Caselli, Francesco and Wilbur John Coleman II, "The U.S. Structural Transformation and Regional Convergence: A Reinterpretation," *Journal of Political Economy*, 2001, *109* (3), 584–616.

Clarke, Sally, "New Deal Regulation and the Revolution in American Farm Productivity. A Case Study of the Diffusion of the Tractor in the Corn Belt, 1920–1940," *The Journal of Economic History*, 1991, *51* (1), 101–123.

Conley, Timothy G., Christian B. Hansen, and Peter E. Rossi, "Plausibly Exogenous," *The Review of Economics and Statistics*, 2012, *94* (1), 260–272.

Cooper, Martin R., Glen T. Barton, and Albert P. Brodell, "Progress of Farm Mechanization," Miscellaneous Publication 630, U.S. Department of Agriculture 1947.

Crosby, Dick J., "Agriculture in Public High Schools," Yearbook Separate 607, United States Department of Agriculture, Office of Experiment Stations 1913.

Dauth, Wolfgang, Sebastian Findeisen, Jens Suedekum, and Nicole Woessner, "The Adjustment of Labor Markets to Robots," *Journal of the European Economic Association*, 2021, *19* (6), 3104–3153.

de Chaisemartin, Clément and Xavier D'Haultfœuille, "Difference-in-Differences Estimators of Intertemporal Treatment Effects," *The Review of Economics and Statistics*, 2026, *108* (4), 863–880.

Doxey, Alison, Ezra Karger, and Peter Nencka, "High Schools and the Uneven Rise in American Opportunity," Working Paper 35068, National Bureau of Economic Research 2026.

Eisner, Emily Murphy, "Have Robots Taken All of Our Jobs Before? The Case of Mechanization in US Agriculture," 2021. Unpublished manuscript.

Feigenbaum, James J. and Daniel P. Gross, "Answering the Call of Automation: How the Labor Market Adjusted to Mechanizing Telephone Operation," *The Quarterly Journal of Economics*, 2024, *139* (3), 1879–1939.

_ **and Hui Ren Tan**, "The Return to Education in the Mid-Twentieth Century: Evidence from Twins," *The Journal of Economic History*, 2020, *80* (4), 1101–1142.

Ferrara, Andreas, Patrick A. Testa, and Liyang Zhou, "New Area- and Population-Based Geographic Crosswalks for U.S. Counties and Congressional Districts, 1790–2020," *Historical Methods: A Journal of Quantitative and Interdisciplinary History*, 2024, *57* (2), 67–79.

Fishback, Price and Shawn Kantor, "New Deal Studies," Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor] November 18, 2018.

_ , _ , and Todd Sorensen, "The New Deal and the Diffusion of Tractors in the 1930s," 2005. Paper presented at the NBER Development of the American Economy Summer Institute.

Food and Agriculture Organization of the United Nations, "FAOSTAT: Machinery," 2021. Discontinued archive. Last update December 3, 2021. Coverage: 1961–2009. Accessed April 13, 2026.

Foster, Andrew D. and Mark R. Rosenzweig, "Technical Change and Human-Capital Returns and Investments: Evidence from the Green Revolution," *American Economic Review*, 1996, *86* (4), 931–953.

French, Jacob, "Technological Change, Inequality, and Intergenerational Mobility: The Case of Early 20th Century Agriculture," 2026. Working Paper.

Frey, Carl Benedikt, *The Technology Trap: Capital, Labor, and Power in the Age of Automation*, Princeton University Press, 2019.

Goldin, Claudia and Lawrence F. Katz, "The Origins of Technology-Skill Complementarity," *The Quarterly Journal of Economics*, 1998, *113* (3), 693–732.

_ and _ , "Human Capital and Social Capital: The Rise of Secondary Schooling in America, 1910–1940," *The Journal of Interdisciplinary History*, 1999, *29* (4), 683–723.

_ and _ , "Education and Income in the Early Twentieth Century: Evidence from the Prairies," *The Journal of Economic History*, 2000, *60* (3), 782–818.

_ and _ , *The Race between Education and Technology*, The Belknap Press of Harvard University Press, 2008.

_ and _ , "Mass Secondary Schooling and the State: The Role of State Compulsion in the High School Movement," in Dora L. Costa and Naomi R. Lamoreaux, eds., *Understanding Long-Run Economic Growth: Geography, Institutions, and the Knowledge Economy*, University of Chicago Press, 2011, pp. 275–310.

Gollin, Douglas, Casper Worm Hansen, and Asger Mose Wingender, "Two Blades of Grass: The Impact of the Green Revolution," *Journal of Political Economy*, 2021, *129* (8), 2344–2384.

Gross, Daniel P., "Scale versus Scope in the Diffusion of New Technology: Evidence from the Farm Tractor," *The RAND Journal of Economics*, 2018, *49* (2), 427–452.

Haines, Michael, Price Fishback, and Paul Rhode, "United States Agriculture Data, 1840–2012," Inter-university Consortium for Political and Social Research [distributor] 2018. ICPSR 35206, Version 4.

Herrendorf, Berthold, Richard Rogerson, and Ákos Valentinyi, "Growth and Structural Transformation," in Philippe Aghion and Steven N. Durlauf, eds., *Handbook of Economic Growth*, Vol. 2, Amsterdam: Elsevier, 2014, pp. 855–941.

Heyman, Fredrik and Martin Olsson, "Long-Run Effects of Technological Change: The Impact of Automation on Intergenerational Mobility," RFBerlin Discussion Paper 047/26, ROCKWOOL Foundation Berlin 2026.

Hobijn, Bart and Robert S. Kaplan, "Occupational Switching during the Second Industrial Revolution," *Economics Letters*, 2024, *238*, 111682.

Hornbeck, Richard, "The Enduring Impact of the American Dust Bowl: Short- and Long-Run Adjustments to Environmental Catastrophe," *American Economic Review*, 2012, *102* (4), 1477–1507.

_ **and Suresh Naidu**, "When the Levee Breaks: Black Migration and Economic Development in the American South," *American Economic Review*, 2014, *104* (3), 963–990.

Jaworski, Taylor, Carl T. Kitchens, and Luke P. Rodgers, "Skill Formation, Child Labor, and the Schooling Consequences of the World War I Agricultural Boom," Working Paper 35032, National Bureau of Economic Research 2026.

Kantor, Shawn and Alexander Whalley, "Research Proximity and Productivity: Long-Term Evidence from Agriculture," *Journal of Political Economy*, 2019, *127* (2), 819–854.

Keynes, John Maynard, "Economic Possibilities for Our Grandchildren," in "Essays in Persuasion," London: Palgrave Macmillan, 2010, pp. 321–332. Originally published 1930.

Koch, Michael, Ilya Manuylov, and Marcel Smolka, "Robots and Firms," *The Economic Journal*, 2021, *131* (638), 2553–2584.

Lee, Jong-Wha and Hanol Lee, "Human Capital in the Long Run," *Journal of Development Economics*, 2016, *122*, 147–169.

Lleras-Muney, Adriana, "Were Compulsory Attendance and Child Labor Laws Effective? An Analysis from 1915 to 1939," *The Journal of Law and Economics*, 2002, *45* (2), 401–435.

Manuelli, Rodolfo E. and Ananth Seshadri, "Frictionless Technology Diffusion: The Case of Tractors," *American Economic Review*, 2014, *104* (4), 1368–1391.

Margo, Robert A., "Race and Schooling in the South: A Review of the Evidence," in "Race and Schooling in the South, 1880–1950: An Economic History," University of Chicago Press, 1990, pp. 6–32.

McKibben, Eugene G. and R. Austin Griffin, "Changes in Farm Power and Equipment: Tractors, Trucks, and Automobiles," Studies of Changing Techniques and Employment in Agriculture A-9, Works Progress Administration, National Research Project on Reemployment Opportunities and Recent Changes in Industrial Techniques, Philadelphia, PA 1938.

Mokyr, Joel, Chris Vickers, and Nicolas L. Ziebarth, "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?," *Journal of Economic Perspectives*, 2015, *29* (3), 31–50.

Mrema, Geoffrey C., Doyle Baker, and David Kahan, "Agricultural Mechanization in Sub-Saharan Africa: Time for a New Look," Agricultural Management, Marketing and Finance Occasional Paper 22, Food and Agriculture Organization of the United Nations, Rome 2008.

Nelson, Lowry, "The Agricultural Labour Situation in the United States," *International Labour Review*, 1938, *37* (6), 754–763.

Olmstead, Alan L. and Paul W. Rhode, "Reshaping the Landscape: The Impact and Diffusion of the Tractor in American Agriculture, 1910–1960," *The Journal of Economic History*, 2001, *61* (3), 663–698.

Parman, John, "Good Schools Make Good Neighbors: Human Capital Spillovers in Early 20th-Century Agriculture," *Explorations in Economic History*, 2012, *49* (3), 316–334.

Porzio, Tommaso, Federico Rossi, and Gabriella Santangelo, "The Human Side of Structural Transformation," *American Economic Review*, 2022, *112* (8), 2774–2814.

Reese, William J., *The Origins of the American High School*, Yale University Press, 1999.

Restrepo, Pascual, "Automation: Theory, Evidence, and Outlook," *Annual Review of Economics*, 2024, *16*, 1–25.

Roser, Max, "Employment in Agriculture," *Our World in Data*, 2023. https://ourworldindata.org/employment-in-agriculture.

Ruggles, Steven, Matt A. Nelson, Matthew Sobek, Catherine A. Fitch, Ronald Goeken, J. David Hacker, Evan Roberts, and J. Robert Warren, "IPUMS Ancestry Full Count Data: Version 4.0 [dataset]," IPUMS, Minneapolis, MN 2024.

_ , Nesile Ozder, Catherine A. Fitch, Matthew Sobek, Julia A. Rivera Drew, J. David Hacker, Jonas Helgertz, Cheyenne Lonobile, Matt A. Nelson, Evan Roberts, and John Robert Warren, "IPUMS Multigenerational Longitudinal Panel: Version 2.0 [dataset]," IPUMS, Minneapolis, MN 2025.

Schroeder, Jonathan, David Van Riper, Steven Manson, Katherine Knowles, Tracy Kugler, Finn Roberts, and Steven Ruggles, "IPUMS National Historical Geographic Information System: Version 20.0 [dataset]," IPUMS, Minneapolis, MN 2025.

Schultz, Theodore W., *Transforming Traditional Agriculture*, New Haven: Yale University Press, 1964.

_ , "The Value of the Ability to Deal with Disequilibria," *Journal of Economic Literature*, 1975, *13* (3), 827–846.

Steckel, Richard H. and William J. White, "Engines of Growth: Farm Tractors and Twentieth-Century U.S. Economic Welfare," Working Paper 17879, National Bureau of Economic Research 2012.

Timmer, Marcel P., Gaaitzen J. de Vries, and Klaas de Vries, "GGDC 10-Sector Database," Groningen Growth and Development Centre, University of Groningen 2015. 2014 release.

United States Department of Agriculture, *Yearbook of Agriculture, 1932*, Washington, DC: Government Printing Office, 1932. 72nd Congress, 1st Session, House Document No. 241.

U.S. Bureau of the Census, "United States Census of Agriculture: 1959, Volume II: General Report, Chapter III: Farm Facilities, Farm Equipment," Technical Report, U.S. Department of Commerce 1962. Table 13, pp. 214–215.

— , *Historical Statistics of the United States, Colonial Times to 1970, Bicentennial Edition, Part 1*, Washington, DC: U.S. Government Printing Office, 1975. Chapter K: Agriculture, Series K 184–191, p. 469.

Washburn, R. S. and Delia Merrick, "Tillage, Planting, and Harvesting Equipment on Grain Farms and Rates of Doing Field Work with These Implements When Drawn with Horse and with Tractor Power, Northern Great Plains and Pacific Northwest," Technical Report, United States Department of Agriculture, Bureau of Agricultural Economics, Washington, DC 1936.

Welch, Finis, "Education in Production," *Journal of Political Economy*, 1970, *78* (1), 35–59.

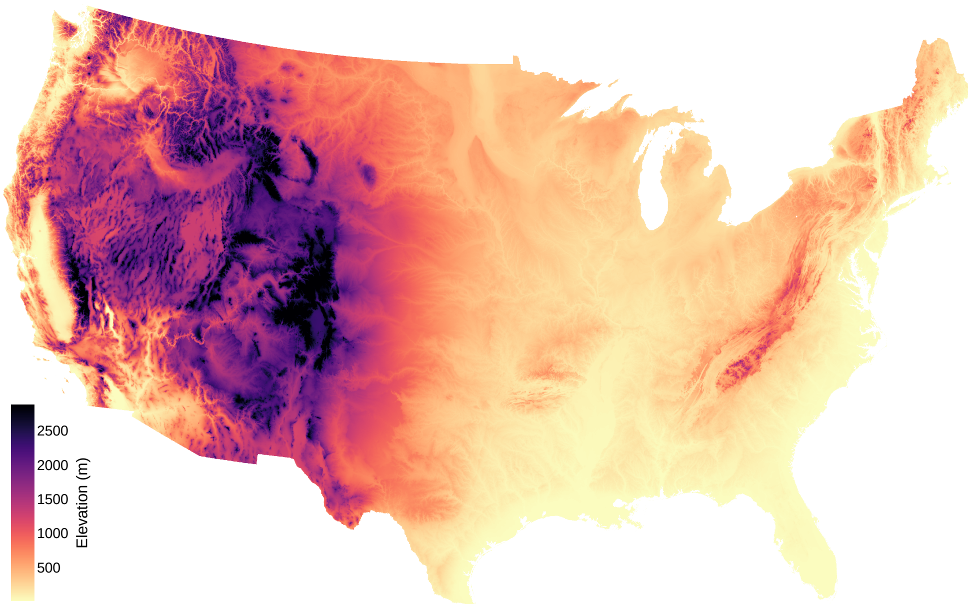
White, William John III, "An Unsung Hero: The Farm Tractor's Contribution to Twentieth-Century United States Economic Growth." PhD dissertation, The Ohio State University, Columbus, OH 2000.

Appendix

Wheels of Change: Agricultural Automation and Human Capital in the 20th Century

A Context

A.1 Additional Figures and Tables



(A) Elevation

(B) Elevation in Example Counties

Figure A1: U.S. Elevation

Notes: This figure displays elevation across the contiguous U.S. in Panel A and within Greene County, Iowa, Winneshiek County, Iowa, and Trempealeau County, Wisconsin, in Panel B. Elevation data are from the USGS digital elevation model described in the main text. The color scales differ across panels.

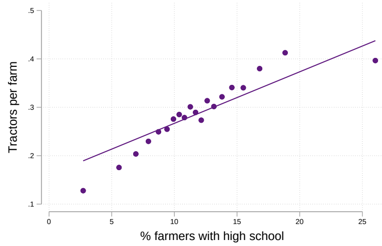
A.2 Human Capital and Agricultural Modernization in 1940

This section uses data from the 1940 full-count population census obtained through IPUMS (Ruggles et al., 2024) together with county-level agricultural census data from Haines et al. (2018), aggregated to the county level, to document a positive association between the share of farmers that had attained at least high school and agricultural modernization, as captured by measures of technology adoption, farm size, and agricultural productivity.

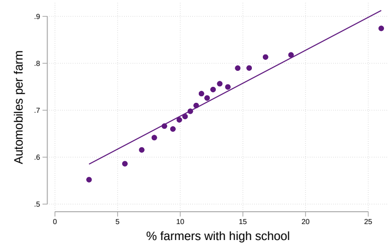
The technology-adoption outcomes are tractors per farm, automobiles per farm, motortrucks per farm, the log value of implements and machinery per farm, the share of farms with electricity, and the share with telephone. The farm-size outcomes are log average acres per farm and log farm laborers per farm. The productivity outcome is log total farm product value per acre.

Appendix Table A1 presents county-level OLS regressions that relate farmer schooling to a broader set of modernization outcomes while controlling for log county population and the urban share, with state fixed effects and standard errors clustered by state. The table expands the descriptive evidence beyond tractors to include farm vehicles, on-farm electrification, telephones, farm scale, labor intensity, and productivity. Because the outcomes remain in natural units, the coefficients can be read directly as changes in per-farm quantities, log outcomes, or farm shares associated with a one-standard-deviation increase in farmer high-school attainment. The final productivity column adds standardized tractors per farm as a control and therefore isolates how the productivity association with farmer schooling changes once county tractor intensity is held fixed.

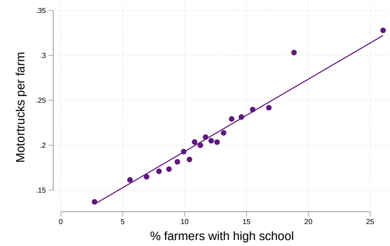
Appendix Figure A2 displays the corresponding residualized binscatters after netting out state fixed effects, log county population, and the urban share. Taken together, these cross-sectional patterns show that counties where a larger fraction of farmers had a high-school education also differed systematically along technology-adoption, size, and productivity margins. While these associations are merely suggestive, they are consistent with the idea of a complementarity between human capital and agricultural modernization.



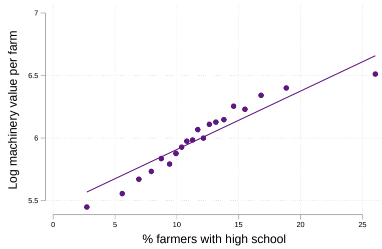
(A) Tractors/Farm



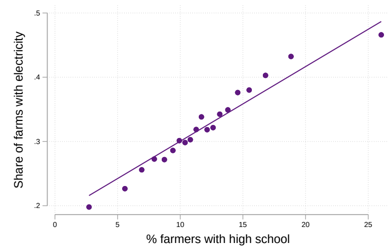
(B) Autos/Farm



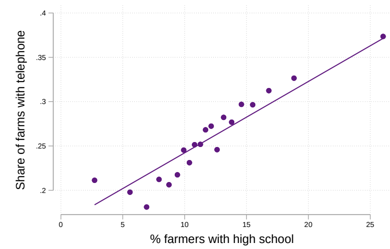
(C) Trucks/Farm



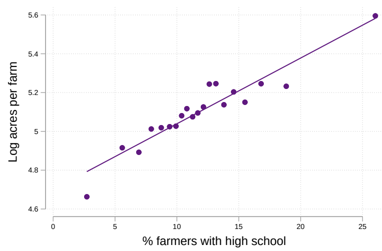
(D) ln(machinery/farm)



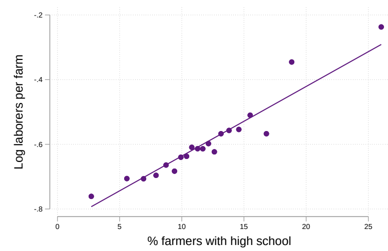
(E) % Electricity



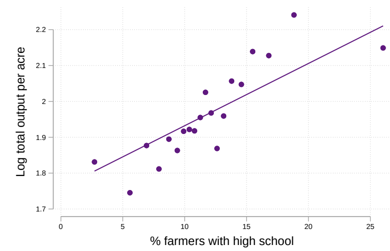
(F) % Phones



(G) ln(acres/farm)



(H) ln(laborers/farm)



(I) ln(output/acre)

Figure A2: Farmer Schooling and Modernization Binscatters

Notes: This figure displays county-level binned scatterplots relating the share of farmers with at least a high school degree to nine measures of agricultural modernization in 1940, based on population-census data from Ruggles et al. (2024) and agricultural-census data from Haines et al. (2018). The sample includes 3,068 counties. The nine panels correspond, in order, to the outcomes in columns 1 to 9 of Appendix Table A1. Each panel residualizes both variables with respect to state fixed effects, log county population, and urban share. The farmer-schooling share is expressed in percentage points, while the outcomes remain in their natural units.

Table A1: Farmer Schooling and Modernization

	Technology adoption						Farm size		Productivity	
	Tractors/farm	Autos/farm	Trucks/farm	ln(machinery/farm)	% electricity	% phones	ln(acres/farm)	ln(laborers/farm)	ln(output/acre)	ln(output/acre)
% farmers with HS (std.)	0.083***	0.110***	0.063***	0.366***	0.091***	0.063***	0.265**	0.168***	0.136**	0.083
	(0.012)	(0.014)	(0.009)	(0.040)	(0.009)	(0.010)	(0.105)	(0.030)	(0.067)	(0.065)
Tractors per farm (std.)										0.167***
										(0.042)
State FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean outcome	0.287	0.715	0.209	5.999	0.323	0.258	5.105	-0.596	1.966	1.966
Counties	3068	3068	3068	3068	3068	3068	3068	3068	3068	3068

Notes: County-level OLS regressions. Columns 1 to 6 report technology-adoption outcomes: tractors per farm, automobiles per farm, motortrucks per farm, the log value of implements and machinery per farm, the share of farms with electricity, and the share with telephone. Columns 7 and 8 report log average acres per farm and log farm laborers per farm. Columns 9 and 10 report log total farm product value per acre. The sample includes 3,068 counties in 1940. The main regressor is the county share of farmers with at least a high school degree, standardized to mean zero and SD one. Column 10 additionally includes tractors per farm, standardized to mean zero and SD one. All outcomes remain in their natural units, and share outcomes are proportions. County controls are log county population and urban share. All specifications include state fixed effects. The row labeled Mean outcome reports the estimation-sample mean for each dependent variable. Standard errors clustered at the state level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

B Individual-Level Results

Table B1: Linked-Census DiD Estimates: Post-1900 Cutoff

	Outcome: high school (=1)				
	Farm (F)		Nonfarm (NF)		F vs. NF
	(1)	(2)	(3)	(4)	(5)
Tractors, 1940 (std.) × Post-1900 (=1)	1.641***	1.949***	-0.174	-0.194	
	(0.303)	(0.404)	(0.538)	(0.438)	
Tractors, 1940 (std.) × Post-1900 (=1) × Farm (=1)					2.089***
					(0.307)
Childhood county FE	Yes	Yes	Yes	Yes	No
Childhood state × cohort FE	Yes	Yes	Yes	Yes	No
County controls × cohort FE	No	Yes	No	Yes	No
Childhood county × farm FE	No	No	No	No	Yes
Cohort FE × farm FE	No	No	No	No	Yes
Childhood county × cohort FE	No	No	No	No	Yes
Mean outcome	22.361	22.355	42.889	42.879	34.077
Cohorts	1880–1920	1880–1920	1880–1920	1880–1920	1880–1920
Counties	2782	2772	2788	2777	2798
Observations	263342	262114	349648	348912	612284

Notes: Individual-level OLS and triple-difference regressions based on Equations 2 and 3, respectively. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940 with known schooling, assigned to a linked childhood census record closest to age 15 among ages 0 to 20. The main regressor is tractors per farm in 1940 interacted with an indicator for cohorts after 1900. The tractor measure is standardized to mean zero and SD one. Columns 1 and 2 report farm-origin estimates, columns 3 and 4 report nonfarm-origin estimates, and column 5 reports the farm-versus-nonfarm triple-difference estimate. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects where indicated. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B2: Linked-Census DiD Estimates: Tractors Assigned at Age 15

	Outcome: high school (=1)				
	Farm (F)		Nonfarm (NF)		F vs. NF
	(1)	(2)	(3)	(4)	(5)
Tractors at age 15 (std.)	0.962***	0.917***	0.671	1.190***	
	(0.267)	(0.299)	(0.421)	(0.285)	
Tractors at age 15 (std.) × Farm (=1)					1.341***
					(0.277)
Childhood county FE	Yes	Yes	Yes	Yes	No
Childhood state × cohort FE	Yes	Yes	Yes	Yes	No
County controls × cohort FE	No	Yes	No	Yes	No
Childhood county × farm FE	No	No	No	No	Yes
Cohort FE × farm FE	No	No	No	No	Yes
Childhood county × cohort FE	No	No	No	No	Yes
Mean outcome	22.361	22.355	42.889	42.879	34.077
Cohorts	1880–1920	1880–1920	1880–1920	1880–1920	1880–1920
Counties	2782	2772	2788	2777	2798
Observations	263342	262114	349647	348912	612284

Notes: Individual-level OLS and triple-difference regressions based on Equations 2 and 3, respectively. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940 with known schooling, assigned to a linked childhood census record closest to age 15 among ages 0 to 20. The tractor measure is tractors per farm in the census year closest to the calendar year in which an individual turned 15, with exposure set to zero in 1900 and 1910, standardized to mean zero and SD one. Columns 1 and 2 report farm-origin estimates, columns 3 and 4 report nonfarm-origin estimates, and column 5 reports the farm-versus-nonfarm triple-difference estimate using the interaction between tractor exposure at age 15 and farm origin. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects where indicated. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B3: Linked-Census DiD Estimates: Assigned Ages 14–18

	Outcome: high school (=1)				
	Farm (F)		Nonfarm (NF)		F vs. NF
	(1)	(2)	(3)	(4)	(5)
Tractors, 1940 (std.) × Post-1895 (=1)	0.969**	1.884***	0.349	0.042	
	(0.414)	(0.550)	(0.631)	(0.567)	
Tractors, 1940 (std.) × Post-1895 (=1) × Farm (=1)					1.488***
					(0.480)
Childhood county FE	Yes	Yes	Yes	Yes	No
Childhood state × cohort FE	Yes	Yes	Yes	Yes	No
County controls × cohort FE	No	Yes	No	Yes	No
Childhood county × farm FE	No	No	No	No	Yes
Cohort FE × farm FE	No	No	No	No	Yes
Childhood county × cohort FE	No	No	No	No	Yes
Mean outcome	21.424	21.425	42.132	42.116	33.046
Cohorts	1880–1920	1880–1920	1880–1920	1880–1920	1880–1920
Counties	2757	2747	2724	2716	2770
Observations	118433	117872	150337	150048	267169

Notes: Individual-level OLS and triple-difference regressions based on Equations 2 and 3, respectively. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940 with known schooling, assigned to a linked childhood census record closest to age 15 among ages 14 to 18. The main regressor is tractors per farm in 1940 interacted with an indicator for cohorts after 1895. The tractor measure is standardized to mean zero and SD one. Columns 1 and 2 report farm-origin estimates, columns 3 and 4 report nonfarm-origin estimates, and column 5 reports the farm-versus-nonfarm triple-difference estimate. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects where indicated. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B4: Representativeness of the Linked 1940 Sample

	Universe of 1940 men	Retained linked sample			Reweighted linked sample		
	Mean	Mean	Difference	p-value	Mean	Difference	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Adult-county tractor exposure (std.)	0.000	-0.011	-0.011**	(0.012)	0.000	0.000	(0.961)
Age	37.02	34.94	-2.07***	(0.000)	36.91	-0.11***	(0.000)
Birth year	1902.98	1905.06	2.07***	(0.000)	1903.09	0.11***	(0.000)
Completed high school	32.28	34.14	1.86***	(0.000)	33.18	0.90***	(0.000)
Years of schooling	9.45	9.62	0.17***	(0.000)	9.56	0.11***	(0.000)
Lives on a farm	26.44	27.89	1.45***	(0.000)	26.73	0.29***	(0.001)
Urban residence	49.25	47.24	-2.01***	(0.000)	48.92	-0.32*	(0.053)
In labor force	93.75	93.81	0.07***	(0.010)	93.81	0.06***	(0.004)
Industry reported	92.54	92.46	-0.08**	(0.012)	92.57	0.03	(0.223)
Agricultural employment	23.05	24.04	0.99***	(0.000)	23.43	0.38***	(0.000)
Industrial employment	37.23	37.01	-0.22***	(0.000)	36.67	-0.56***	(0.000)
Service employment	39.72	38.95	-0.77***	(0.000)	39.91	0.19***	(0.008)
Occupation reported	94.33	94.22	-0.11***	(0.000)	94.36	0.03	(0.158)
Farmer	15.11	15.34	0.23***	(0.000)	15.50	0.39***	(0.000)
Wage farm laborer	4.69	5.08	0.38***	(0.000)	4.64	-0.06**	(0.017)
Unpaid family farm laborer	1.93	2.27	0.35***	(0.000)	1.95	0.02***	(0.003)
Log wage income	6.740	6.688	-0.052***	(0.000)	6.734	-0.006***	(0.002)

Notes: This table reports selected 1940 characteristics for the eligible universe of men and the retained linked sample. The eligible universe includes White native-born men with native-born parents observed in the 1940 MLP extract, birth cohorts 1880–1920, known schooling, an identifiable 1940 county, and observed 1940 county tractor exposure. The retained linked sample is the subset used in the linked individual-level analysis. Columns 1, 2, and 5 report sample means. Columns 3 and 6 report differences from the eligible universe, while columns 4 and 7 report p-values based on standard errors clustered at the 1940-county level. Reweighted linked means use inverse-probability weights based on predicted linkage probabilities estimated in the eligible universe using birth year, 1940 farm status, 1940 urban status, 1940 state fixed effects, and 1940 adult-county tractor exposure. Percentage variables are reported in percentage points. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B5: Linked-Census DiD Estimates: Linkage-Probability Weights

	Outcome: high school (=1)				
	Farm (F)		Nonfarm (NF)		F vs. NF
	(1)	(2)	(3)	(4)	(5)
Tractors, 1940 (std.) × Post-1895 (=1)	1.303***	1.714***	-0.230	-0.241	
	(0.301)	(0.404)	(0.549)	(0.472)	
Tractors, 1940 (std.) × Post-1895 (=1) × Farm (=1)					1.974***
					(0.323)
Childhood county FE	Yes	Yes	Yes	Yes	No
Childhood state × cohort FE	Yes	Yes	Yes	Yes	No
County controls × cohort FE	No	Yes	No	Yes	No
Childhood county × farm FE	No	No	No	No	Yes
Cohort FE × farm FE	No	No	No	No	Yes
Childhood county × cohort FE	No	No	No	No	Yes
Mean outcome	21.660	21.652	41.722	41.712	33.126
Cohorts	1880–1920	1880–1920	1880–1920	1880–1920	1880–1920
Counties	2782	2772	2787	2776	2797
Observations	261886	260736	348577	347874	609748

Notes: Individual-level OLS and triple-difference regressions based on Equations 2 and 3, respectively. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940 with known schooling, assigned to a linked childhood census record closest to age 15 among ages 0 to 20. The main regressor is tractors per farm in 1940 interacted with an indicator for cohorts after 1895. The tractor measure is standardized to mean zero and SD one. Linkage probabilities are estimated in the eligible 1940 universe using birth year, 1940 farm status, 1940 urban status, 1940 state fixed effects, and 1940 adult-county tractor exposure. Regressions weight observations by the product of the Ferrara fractional childhood-county weight and the stabilized inverse-probability weight based on predicted linkage probabilities, trimmed at the first and 99th percentiles among linked men. Columns 1 and 2 report farm-origin estimates, columns 3 and 4 report nonfarm-origin estimates, and column 5 reports the farm-versus-nonfarm triple-difference estimate. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects where indicated. Observations report fractional linked men before applying linkage-probability weights. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B6: Linked-Census DiD Estimates: Farm-Origin Sons of Farmer Fathers

	Outcome: high school (=1)	
	Farm origins	
	(1)	(2)
Tractors, 1940 (std.) × Post-1895 (=1)	2.053***	2.311***
	(0.333)	(0.446)
Childhood county FE	Yes	Yes
Childhood state × cohort FE	Yes	Yes
County controls × cohort FE	No	Yes
Mean outcome	22.404	22.393
Cohorts	1880–1920	1880–1920
Counties	2770	2760
Observations	208850	207802

Notes: Individual-level OLS regressions based on Equation 2. The outcome is an indicator for high-school completion by 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940 with known schooling, assigned to a linked childhood census record closest to age 15 among ages 0 to 20, and restricted to boys whose father is recorded as a farmer in the assigned childhood census year. Because that restriction leaves only a small nonfarm-residence group, the table reports farm-origin specifications only. The main regressor is tractors per farm in 1940 interacted with an indicator for cohorts after 1895. The tractor measure is standardized to mean zero and SD one. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects where indicated. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

C County-Level Results

Table C1: Rosenwald Schools and Attendance

	Outcome: High school attendance (std.)	
	Boys	Girls
	(1)	(2)
Tractors per farm (std.)	-0.073	-0.044
	(0.064)	(0.070)
Tractors per farm (std.) × Rosenwald (=1)	0.050	-0.022
	(0.067)	(0.074)
County FE	Yes	Yes
State × year FE	Yes	Yes
County controls × year FE	Yes	Yes
Mean outcome	Std. (0/1)	Std. (0/1)
Observations	7730	7467
Counties	1773	1721

Notes: County-level OLS regressions. The outcomes are the high-school attendance rates among Black farm boys and girls ages 14 to 18. The regressors of interest are tractors per farm and its interaction with an indicator equal to one if a 1900 county ever contained Rosenwald school territory by the end of the program. Tractors per farm and the outcomes are standardized to mean zero and SD one. All specifications include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Standard errors clustered at the county level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table C2: Alternative Tractor Exposure Measures

	Outcome: High school attendance (std.)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tractors per acre (std.)	0.131***	0.059***	0.060***						
	(0.013)	(0.013)	(0.013)						
Tractors per farm pop. (std.)				0.109***	0.132***	0.117***			
				(0.016)	(0.018)	(0.019)			
Tractors per 1900 farm (std.)							0.039***	0.028***	0.019**
							(0.010)	(0.011)	(0.009)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Time-varying county controls	No	No	Yes	No	No	Yes	No	No	Yes
Mean outcome	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)
Observations	13185	13185	13185	13185	13185	13185	13185	13185	13185
Counties	2637	2637	2637	2637	2637	2637	2637	2637	2637

Notes: County-level OLS regressions. The outcome is the high-school attendance rate among White farm boys ages 14 to 18. Columns 1 to 3 measure tractor exposure as tractors per acre, columns 4 to 6 as tractors divided by farm population, and columns 7 to 9 as tractors divided by the number of farms in 1900, with the denominator held fixed across years. All three tractor measures are standardized to mean zero and SD one across county-years; the outcome is standardized within each census year. All specifications include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects where indicated. Time-varying controls are AAA grants per capita, non-AAA New Deal grants and loans per capita, and the county shares in medium and high Dust Bowl erosion zones, where indicated. Standard errors clustered at the county level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table C3: Attendance Rates in Levels

	Outcome: High school attendance (level)						
	Farm (F)			Nonfarm (NF)			F vs. NF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Tractors per farm (std.)	0.012***	0.011***	0.009***	0.000	0.005**	0.004*	
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	
Tractors per farm (std.) × Farm (=1)							0.009***
							(0.001)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	No
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	No
County controls × year FE	No	Yes	Yes	No	Yes	Yes	No
Time-varying county controls	No	No	Yes	No	No	Yes	No
County × year FE	No	No	No	No	No	No	Yes
County × farm FE	No	No	No	No	No	No	Yes
Year × farm FE	No	No	No	No	No	No	Yes
Mean outcome	0.594	0.594	0.594	0.626	0.626	0.626	0.610
Observations	13185	13185	13185	13185	13185	13185	26370
Counties	2637	2637	2637	2637	2637	2637	2637

Notes: County-level OLS and stacked triple-difference regressions based on Equations 4 and 5, respectively. The outcome is the high-school attendance rate among White boys ages 14 to 18, reported as a proportion rather than standardized. The tractor measure is tractors per farm, standardized to mean zero and SD one. Because census attendance definitions vary somewhat across years, the table is best read as a magnitude translation rather than the preferred specification. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects where indicated. Standard errors clustered at the county level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table C4: Exposure to Tractors and School Attendance by Census Region

	Outcome: High school attendance (std.)							
	Northeast		Midwest		South		West	
	Farm (1)	Nonfarm (2)	Farm (3)	Nonfarm (4)	Farm (5)	Nonfarm (6)	Farm (7)	Nonfarm (8)
Tractors per farm (std.)	0.128	0.031	0.134***	0.035	0.101**	0.086	0.144***	-0.006
	(0.080)	(0.080)	(0.026)	(0.027)	(0.043)	(0.056)	(0.048)	(0.056)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	910	910	4890	4890	5960	5960	1425	1425
Counties	182	182	978	978	1192	1192	285	285

Notes: County-level OLS regressions. The outcome is the high-school attendance rate among White boys ages 14 to 18. Tractors per farm and the outcome are standardized to mean zero and SD one. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Standard errors clustered at the county level are reported in parentheses. The table reports the number of counties in each sample. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table C5: Exposure to Tractors and School Attendance by County Structure

	Outcome: High school attendance (std.)					
	Urban share		Farm share		Agriculture share	
	High	Low	High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. White boys: farm						
Tractors per farm (std.)	0.091***	0.135***	0.124***	0.093***	0.102***	0.117***
	(0.029)	(0.024)	(0.026)	(0.026)	(0.027)	(0.025)
Panel B. White boys: nonfarm						
Tractors per farm (std.)	0.004	0.048*	0.043	0.030	0.006	0.060**
	(0.030)	(0.028)	(0.038)	(0.026)	(0.039)	(0.025)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5000	8175	6565	6595	6570	6595
Counties	1000	1635	1313	1319	1314	1319

Notes: County-level OLS regressions. Panels A and B report estimates for White farm and nonfarm boys, respectively. The outcome is the high-school attendance rate among boys ages 14 to 18. Tractors per farm and the outcome are standardized to mean zero and SD one. High groups are above the relevant 1900 median, and low groups are at or below it. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Standard errors clustered at the county level are reported in parentheses. Observations and counties are reported once because the counts are identical across panels. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

D County-Level IV Results

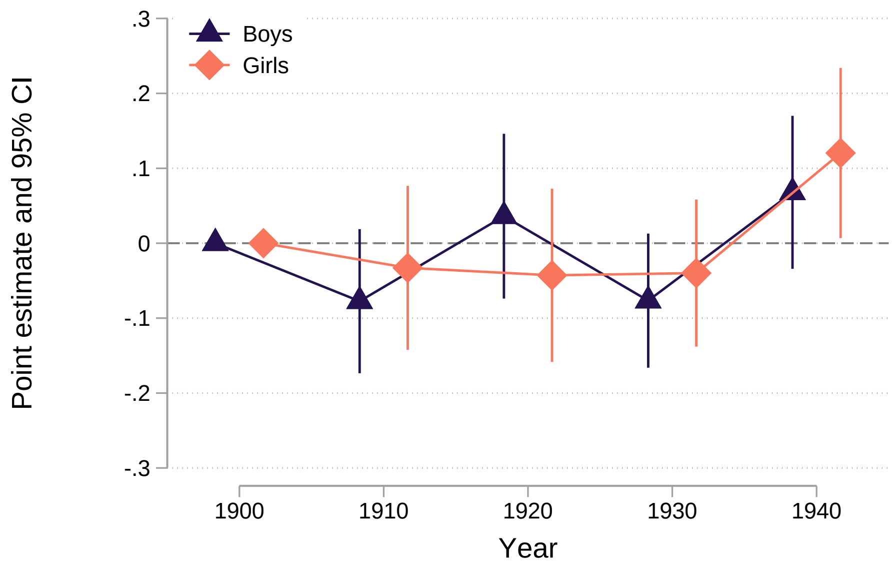


Figure D1: Placebo Reduced Form

Notes: This figure displays decade-specific reduced-form coefficients from county-level regressions of high-school attendance among White farm boys and girls on terrain smoothness interacted with year indicators, restricting the sample to counties with fewer than 0.05 tractors per farm in 1940. Terrain smoothness and high-school attendance are standardized to mean zero and SD one. All specifications include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Vertical bars denote 95% confidence intervals based on standard errors clustered at the county level.

Table D1: IV Exclusion Samples

	Outcome: White farm boys' high school attendance (std.)						
Excluded:	Northeast	Midwest	South	West	Major mountains	Urban counties	Nonagr. counties
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Tractors per farm (std.)	0.627***	0.606***	0.422***	0.485***	0.511***	0.771***	0.551***
	(0.109)	(0.157)	(0.079)	(0.104)	(0.106)	(0.171)	(0.095)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First stage F-statistic	20.81	12.49	16.95	27.47	20.83	12.52	24.57
Observations	12275	8295	7225	11760	12550	8180	13185
Counties	2455	1659	1445	2352	2510	1636	2637

Notes: County-level 2SLS regressions. The outcome is the high-school attendance rate among White farm boys ages 14 to 18. The endogenous regressor is tractors per farm, instrumented with terrain smoothness interacted with year indicators. Tractors per farm, terrain smoothness, and the outcome are standardized to mean zero and SD one. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Standard errors clustered at the county level are reported in parentheses. The table reports the first-stage Kleibergen-Paap rk Wald F-statistic. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table D2: Alternative Terrain IVs

	Outcome: High school attendance (std.)								
	Mean slope			Elevation SD			Share slope > 5%		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Tractors per farm (std.)	0.661***	0.558***	0.626***	0.737***	0.614***	0.644***	0.496***	0.274***	0.364***
	(0.067)	(0.094)	(0.118)	(0.164)	(0.164)	(0.188)	(0.049)	(0.052)	(0.069)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Time-varying county controls	No	No	Yes	No	No	Yes	No	No	Yes
First stage F-statistic	64.92	24.59	19.03	7.99	4.36	4.18	118.94	83.49	55.72
Mean outcome	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)
Observations	13185	13185	13185	13185	13185	13185	13185	13185	13185
Counties	2637	2637	2637	2637	2637	2637	2637	2637	2637

Notes: County-level 2SLS regressions. The outcome is the high-school attendance rate among White farm boys ages 14 to 18. The endogenous regressor is tractors per farm. Columns 1 to 3 use mean slope as the excluded instrument, columns 4 to 6 use elevation SD, and columns 7 to 9 use the share of county land with slope above 5%; each instrument is interacted with year fixed effects. Tractors per farm, the excluded instruments, and the outcome are standardized to mean zero and SD one. All specifications include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects where indicated. Time-varying controls are AAA grants per capita, non-AAA New Deal grants and loans per capita, and the county shares in medium and high Dust Bowl erosion zones, where indicated. Standard errors clustered at the county level are reported in parentheses. The table reports the first-stage Kleibergen-Paap rk Wald F-statistic. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

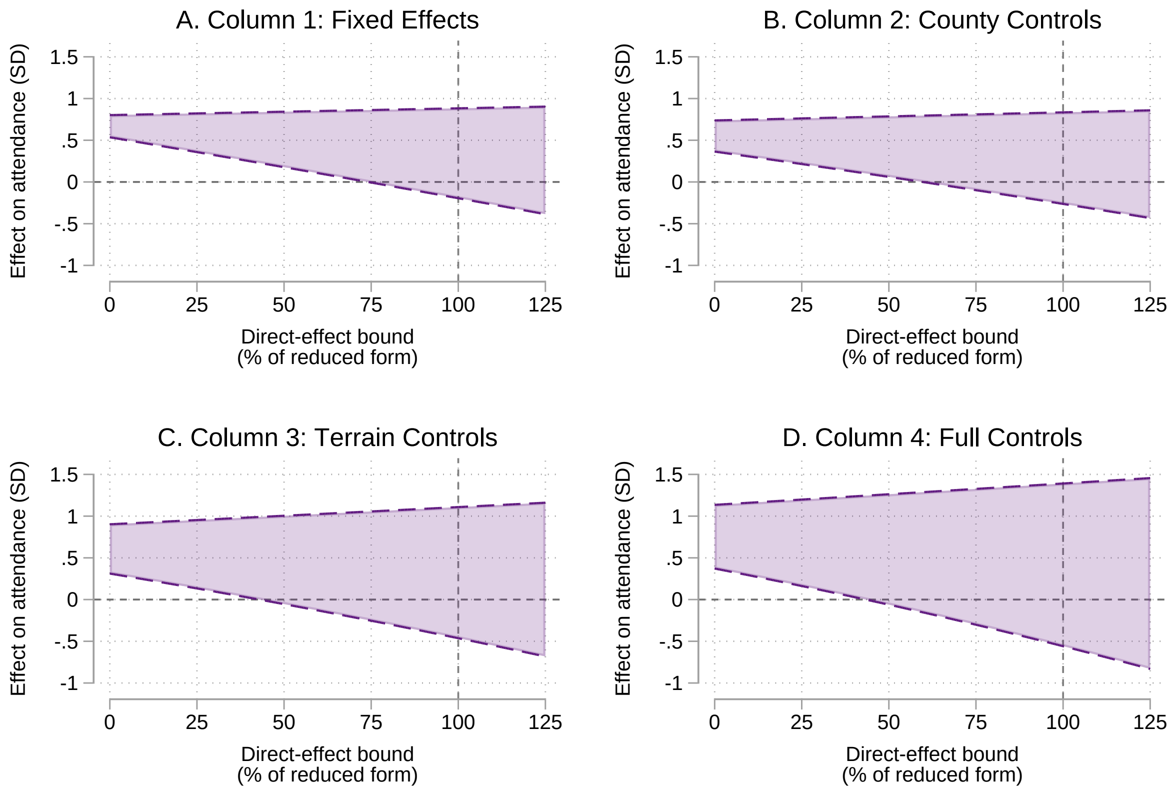


Figure D2: Terrain IV Exclusion Sensitivity

Notes: This figure displays joint 95% union confidence sets following Conley et al. (2012). Panels A–D correspond to columns 1–4 of Table 4. The outcome is high-school attendance among White farm boys ages 14 to 18; the endogenous regressor is tractors per farm. Both are standardized to mean zero and SD one. Each panel retains its table column's sample, controls, county fixed effects, and state-by-year fixed effects. Let $\hat{\rho}_\tau$ denote the reduced-form coefficient on standardized terrain smoothness interacted with the indicator for year $\tau \in \{1910, 1920, 1930, 1940\}$, relative to 1900, estimated jointly on the same sample with the same controls. At horizontal-axis value $100s$, the direct effects satisfy $\gamma_\tau = \lambda_\tau \hat{\rho}_\tau$, with each λ_τ varying independently over $[0, s]$. Shading shows the union of conventional 95% 2SLS confidence intervals over all simultaneous direct-effect combinations, using county-clustered standard errors and normal critical values. The dashed vertical line marks 100%; the horizontal line marks zero.

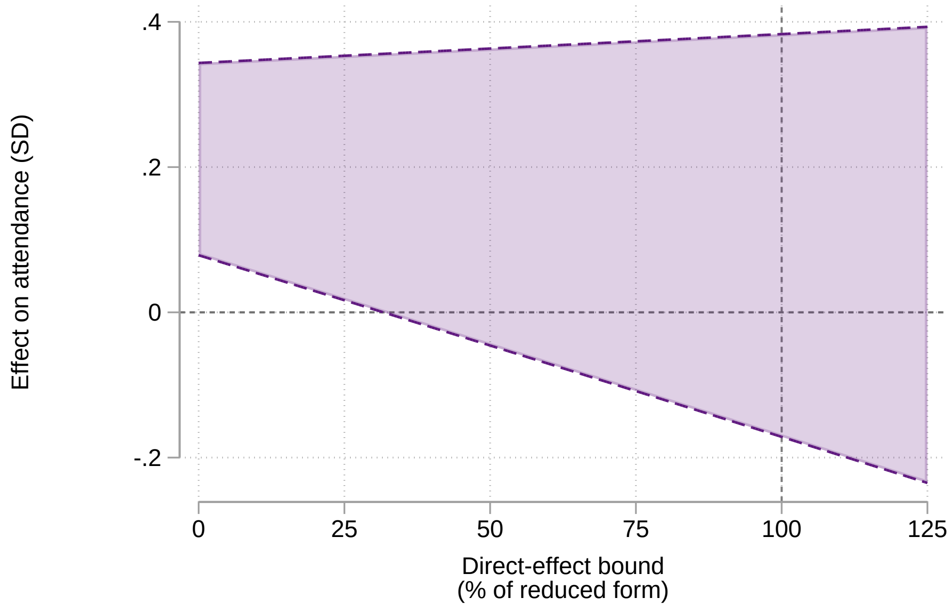


Figure D3: Triple-Difference IV Exclusion Sensitivity

Notes: This figure displays joint 95% union confidence sets following Conley et al. (2012) for the stacked farm-versus-nonfarm specification in column 5 of Table 4. The outcome is standardized high-school attendance among White boys ages 14 to 18, and the endogenous regressor is standardized tractors per farm interacted with farm status. The specification retains the table's sample and county-by-year, county-by-farm-status, and state-by-year-by-farm-status fixed effects. The four excluded instruments interact standardized terrain smoothness with farm status and the 1910, 1920, 1930, and 1940 indicators, relative to 1900. At horizontal-axis value $100s$, each instrument's direct effect varies independently between zero and s times its own reduced-form coefficient, estimated jointly with the same fixed effects on the same sample. Shading shows the union of conventional 95% 2SLS confidence intervals over all simultaneous direct-effect combinations, using county-clustered standard errors and normal critical values. The dashed vertical line marks 100%; the horizontal line marks zero.

E Mechanisms Results

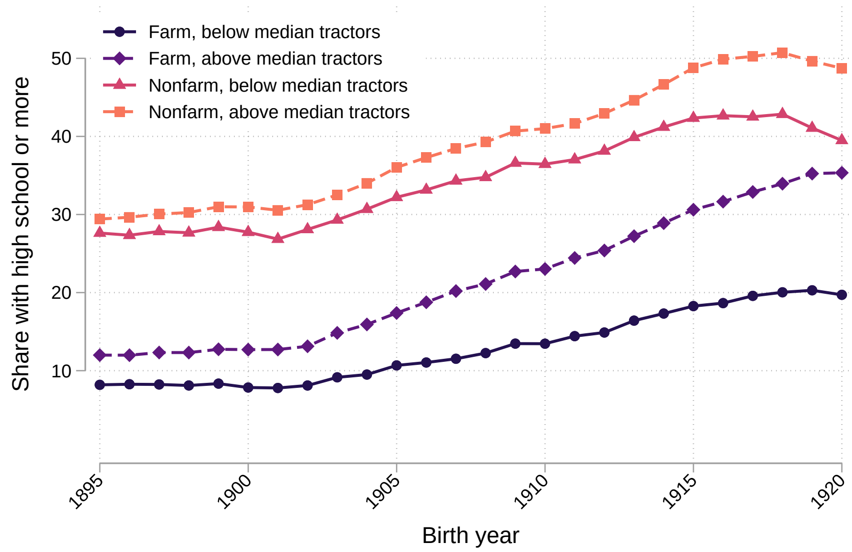


FIGURE E1: HIGH SCHOOL ATTAINMENT BY COHORT

Notes: This figure displays the share with at least a high school degree by birth cohort for White native-born men born between 1895 and 1920 with reported industry, known schooling, farm status, and an identifiable county in the 1940 census. The series are reported separately for farm and nonfarm men in counties below and above the national median tractors per farm in 1940.

Table E1: High School Attainment by Household Type and Occupation

Household type or occupation family	Counties by tractor intensity (quintiles) All (1)	Q1 (2)	Q2 (3)	Q3 (4)	Q4 (5)	Q5 (6)	**Q5 vs. Q1 (%)** (7)	Observations (8)
Household type								
Farm	13.9	8.4	11.4	15.6	17.0	16.7	**197.8**	4,249,329
Nonfarm	34.1	28.4	32.3	35.8	34.5	34.3	**120.9**	14,985,669
Agriculture								
Agricultural occupations	12.2	6.6	9.4	13.6	14.9	15.3	**234.1**	3,523,995
Farmers (Owners and Tenants) (100)	12.6	6.6	9.7	14.4	16.1	16.2	**247.0**	2,550,003
Farm Laborers, Wage Workers (820)	9.7	4.6	6.5	10.5	11.0	11.7	**255.9**	745,301
Farm Laborers, Unpaid Family Workers (830)	13.6	9.1	11.3	14.2	15.7	16.9	**186.4**	192,905
Manufacturing								
Manufacturing occupations	22.1	18.9	20.3	24.9	21.9	21.7	**114.5**	1,839,813
Machinists (544)	19.8	17.4	18.3	23.4	19.2	18.5	**106.4**	287,978
Electricians (515)	30.1	29.4	28.7	32.9	28.8	29.8	**101.3**	153,526
Compositors and Typesetters (512)	32.7	43.9	30.4	36.9	31.5	30.8	**70.1**	98,043
Welders and Flame Cutters (685)	20.1	19.8	18.9	23.4	19.0	19.7	**99.5**	87,842
Cranemen,Derrickmen, and Hoistmen (513)	13.7	12.3	13.6	14.7	13.5	13.6	**110.5**	76,813
Stationary Firemen (680)	14.0	9.6	12.4	15.2	14.6	14.1	**146.1**	57,248
Bakers (500)	19.3	19.5	16.5	20.7	18.6	20.6	**105.7**	53,275
Tool Makers, and Die Makers and Setters (592)	23.3	19.3	16.3	27.5	23.2	22.0	**113.9**	49,482
Filers, Grinders, and Polishers, Metal (635)	14.4	10.9	12.1	15.3	14.6	13.9	**127.4**	49,234
Tinsmiths, Coppersmiths, and Sheet Metal Workers (591)	19.4	17.3	15.9	25.7	17.8	17.0	**98.7**	48,389
Services								
Service and white-collar occupations	54.5	53.3	52.1	56.3	55.3	53.5	**100.4**	6,810,837
Bookkeepers (310)	73.9	77.6	71.9	76.8	73.6	71.7	**92.5**	276,445
Insurance Agents and Brokers (450)	65.4	64.4	62.9	67.3	65.8	65.0	**101.0**	146,993
Lawyers and Judges (55)	96.8	94.1	95.9	96.9	97.3	97.6	**103.7**	111,331
Shipping and Receiving Clerks (342)	30.5	39.3	31.0	34.8	29.7	25.8	**65.7**	109,184
Policemen and Detectives (773)	27.7	32.4	24.6	32.6	26.9	25.0	**77.0**	106,999
Barbers, Beauticians, and Manicurists (740)	19.8	15.4	16.8	20.7	20.5	22.3	**144.3**	105,604
Janitors and Sextons (770)	15.7	12.4	14.4	17.6	15.3	15.0	**120.9**	92,657
Guards, Watchmen, and Doorkeepers (763)	15.5	10.7	13.5	17.9	16.3	15.1	**142.1**	90,754
Physicians and Surgeons (75)	97.8	98.0	97.8	97.8	97.7	97.8	**99.8**	90,086
Mail Carriers (335)	40.2	39.5	38.6	43.7	39.5	38.5	**97.4**	82,221

Notes: This table reports the share with at least a high school degree by household type and occupation for White native-born men ages 25 to 54 in 1940 with reported industry, known schooling, and an identifiable county. Shares are reported in percentage points. Rows based on occupations additionally require a reported OCC1950 occupation. Column 1 reports the national share. Columns 2 to 6 report the corresponding shares in counties in the first through fifth national quintiles of tractors per farm in 1940. Column 7 reports the ratio of column 6 to column 2 multiplied by 100, and column 8 reports the number of observations in each row. Agricultural occupations are OCC1950 farmers, farm managers, farm foremen, farm laborers, farm-service laborers, and unpaid family farm laborers. Manufacturing occupations are production craft and operative occupations (OCC1950 500–690) after excluding construction, repair, transport, mining, utilities, and broad or ambiguous operative categories. Service and white-collar occupations are professional and technical, managerial/proprietor, clerical, sales, and service-worker occupations (OCC1950 0–99, 200–490, and 700–790). The detailed agriculture rows report farmers and the two farm-laborer categories. The detailed manufacturing rows and the detailed service and white-collar rows report the ten most common well-defined occupations in each occupational group after excluding broader catch-all categories. The OCC1950 code is reported in parentheses.

Table E2: Adult Outcomes for Farmer Sons

	Place of residence			Industry			Occupation		
	Urban	Migrant	On farm	Agriculture	Industrial	Services	Farmer	Wage laborer	Family laborer
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A. High school attainment									
High school (=1)	15.003***	6.503***	-15.806***	-18.641***	-7.017***	25.657***	-11.632***	-5.590***	-1.265***
	(0.257)	(0.251)	(0.301)	(0.312)	(0.260)	(0.295)	(0.280)	(0.143)	(0.115)
Panel B. Tractor exposure									
Tractors per farm (std.)	-1.121***	-0.921***	1.552***	1.041***	-0.269	-0.772***	-0.274	0.434**	0.650***
	(0.256)	(0.336)	(0.306)	(0.352)	(0.295)	(0.299)	(0.326)	(0.206)	(0.166)
Panel C. Tractor exposure and high school attainment									
Tractors per farm (std.)	0.366	0.193	-0.159	-0.026	-1.025***	1.051***	-2.152***	1.118***	0.751***
	(0.273)	(0.338)	(0.331)	(0.367)	(0.310)	(0.293)	(0.343)	(0.232)	(0.184)
High school (=1)	14.945***	6.462***	-15.741***	-18.575***	-6.964***	25.540***	-11.502***	-5.633***	-1.276***
	(0.254)	(0.251)	(0.299)	(0.309)	(0.257)	(0.283)	(0.274)	(0.145)	(0.117)
Tractors (std.) $\times$ HS (=1)	-3.918***	-2.784***	4.463***	3.138***	2.016***	-5.154***	4.818***	-1.434***	-0.195
	(0.228)	(0.226)	(0.278)	(0.291)	(0.232)	(0.265)	(0.258)	(0.189)	(0.164)
Childhood county FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Childhood state $\times$ cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls $\times$ cohort FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean outcome	22.744	58.438	54.663	46.684	27.626	25.690	31.790	8.458	4.925
Observations	218616	218585	218616	206995	206995	206995	209877	209877	209877
Counties	2770	2770	2770	2767	2767	2767	2768	2768	2768

Notes: Individual-level OLS regressions based on Equation 9. The outcomes are indicators for place of residence, industry, and occupation in 1940, multiplied by 100 so the coefficients are expressed in percentage points. The sample includes White native-born men observed in 1940, assigned to a linked childhood census record closest to age 15 among ages 0 to 20, and restricted to men whose father is recorded as a farmer in the assigned childhood census. Panels A and C additionally require known schooling. Panel A reports estimates for the high-school indicator. Panel B reports estimates for tractor exposure at age 15. Panel C includes tractor exposure, high-school completion, and their interaction. The tractor measure is standardized to mean zero and SD one. Birth cohorts are five-year bins, with the 1920 birth year merged into the 1915 bin. Columns 4 to 6 condition on reported 1940 industry, and columns 7 to 9 condition on reported 1940 occupation. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with cohort fixed effects. Standard errors clustered at the county-of-origin level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table E3: Child Labor-Force Participation

	Children in Labor Force (%)							
	Ages 10–14				Ages 14–18			
	All sectors		Agriculture		All sectors		Agriculture	
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. All White Boys								
Tractors per farm (std.)	0.208	-2.216**	0.198	-2.573***	-0.072	0.694	-0.223	0.428
	(0.171)	(1.018)	(0.159)	(0.991)	(0.226)	(1.271)	(0.203)	(1.217)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First stage F-statistic		24.57		24.57		24.57		24.57
Mean outcome	12.417	12.417	10.566	10.566	42.994	42.994	28.896	28.896
Observations	13185	13185	13185	13185	13185	13185	13185	13185
Counties	2637	2637	2637	2637	2637	2637	2637	2637
Panel B. White Farm Boys								
Tractors per farm (std.)	0.236	-2.259*	0.242	-2.406**	-0.190	-0.739	-0.059	1.275
	(0.221)	(1.191)	(0.206)	(1.190)	(0.277)	(1.422)	(0.282)	(1.509)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First stage F-statistic		24.57		24.57		24.57		24.57
Mean outcome	15.159	15.159	14.306	14.306	47.023	47.023	41.337	41.337
Observations	13185	13185	13185	13185	13185	13185	13185	13185
Counties	2637	2637	2637	2637	2637	2637	2637	2637
Panel C. White Nonfarm Boys								
Tractors per farm (std.)	0.026	0.114	0.022	-0.266	0.317	3.561***	0.039	0.525
	(0.121)	(0.754)	(0.096)	(0.633)	(0.241)	(1.301)	(0.175)	(0.915)
County FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First stage F-statistic		24.57		24.57		24.57		24.57
Mean outcome	6.755	6.755	3.454	3.454	35.201	35.201	10.593	10.593
Observations	13185	13185	13185	13185	13185	13185	13185	13185
Counties	2637	2637	2637	2637	2637	2637	2637	2637

Notes: County-level OLS and 2SLS regressions of labor-force participation rates (percentage points). Panels A–C cover all White boys and White farm and nonfarm boys, respectively. The 2SLS columns instrument tractors per farm with terrain smoothness interacted with year indicators. Tractors per farm is standardized to mean zero and SD one. Specifications include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. County-clustered standard errors are reported in parentheses. The reported first-stage statistic is the Kleibergen-Paap rk Wald F-statistic. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table E4: Part-Time and Full-Time Attendance

	Outcome: High school attendance (std.)			
	Farm boys		Nonfarm boys	
	OLS	2SLS	OLS	2SLS
Panel A. Part-Time				
Tractors per farm (std.)	0.064***	0.457***	0.129***	0.770***
	(0.022)	(0.119)	(0.030)	(0.136)
Panel B. Full-Time				
Tractors per farm (std.)	0.047***	0.373***	-0.018	0.112
	(0.018)	(0.106)	(0.021)	(0.119)
First stage F-statistic		24.57		24.57
County FE	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes
Observations	13185	13185	13185	13185
Counties	2637	2637	2637	2637

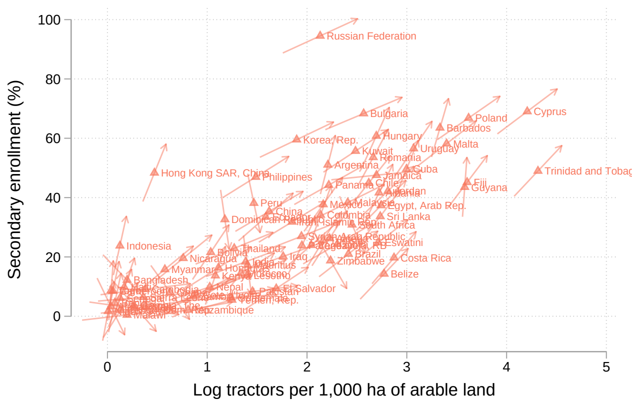
Notes: County-level OLS and 2SLS regressions. Panel A reports part-time attendance, while Panel B reports full-time attendance. Columns 1 and 2 report estimates for White farm boys, while columns 3 and 4 report estimates for White nonfarm boys. The outcome is the high-school attendance rate among boys ages 14 to 18. In the 2SLS columns, the endogenous regressor is tractors per farm, instrumented with terrain smoothness interacted with year indicators. Tractors per farm and the outcome are standardized to mean zero and SD one. All specifications include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Standard errors clustered at the county level are reported in parentheses. The table reports the first-stage Kleibergen-Paap rk Wald F-statistic. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table E5: Tractor Adoption and Teacher Supply

	Teachers					
	Per resident		Per child, ages 5–18		Per child, ages 14–18	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Levels (std.)						
Tractors per farm (std.)	0.0266*	0.0692	0.0165	0.0772	0.0077	-0.0103
	(0.0154)	(0.0639)	(0.0147)	(0.0591)	(0.0141)	(0.0585)
Panel B. Log of corresponding outcome (std.)						
Tractors per farm (std.)	0.040***	0.065	0.027***	0.082	0.023**	0.022
	(0.011)	(0.060)	(0.009)	(0.050)	(0.010)	(0.052)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
State × year FE	Yes	Yes	Yes	Yes	Yes	Yes
County controls × year FE	Yes	Yes	Yes	Yes	Yes	Yes
First stage F-statistic		24.57		24.57		24.57
Mean outcome	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)	Std. (0/1)
Observations	13185	13185	13185	13185	13185	13185
Counties	2637	2637	2637	2637	2637	2637

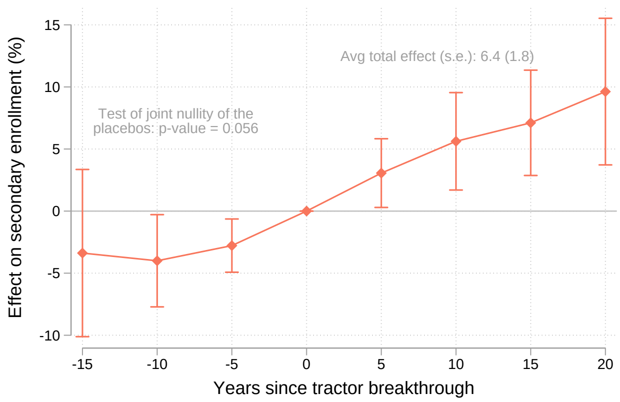
Notes: County-level OLS and 2SLS regressions. Panel A reports teacher counts per resident, per child ages 5 to 18, and per child ages 14 to 18, while Panel B reports the corresponding log measures. All outcomes are standardized to mean zero and SD one. In the 2SLS columns, the endogenous regressor is tractors per farm, instrumented with terrain smoothness interacted with year indicators. The tractor measure is standardized to mean zero and SD one. All specifications include county and state-by-year fixed effects. County controls are 1900 log population, log county area, longitude, latitude, urban share, farm share, Black share, immigrant share, prime-age literacy share, teachers per capita, the prime-age industrial employment share, log average farm size, log average farm value, log implements-and-machinery value per farm, wheat acreage share, and the school-attendance rate of White farm boys ages 14 to 18, each interacted with year fixed effects. Standard errors clustered at the county level are reported in parentheses. The table reports the first-stage Kleibergen-Paap rk Wald F-statistic. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

F Cross-Country Results



(A) Trajectories

(B) Residualized Binscatter



(C) Event Study

Figure F1: Tractors and Secondary Enrollment: Girls

Notes: This figure displays the girls' counterparts to Figure 11, with country trajectories added in Panel A. Variable definitions, specifications, and confidence intervals follow that figure.

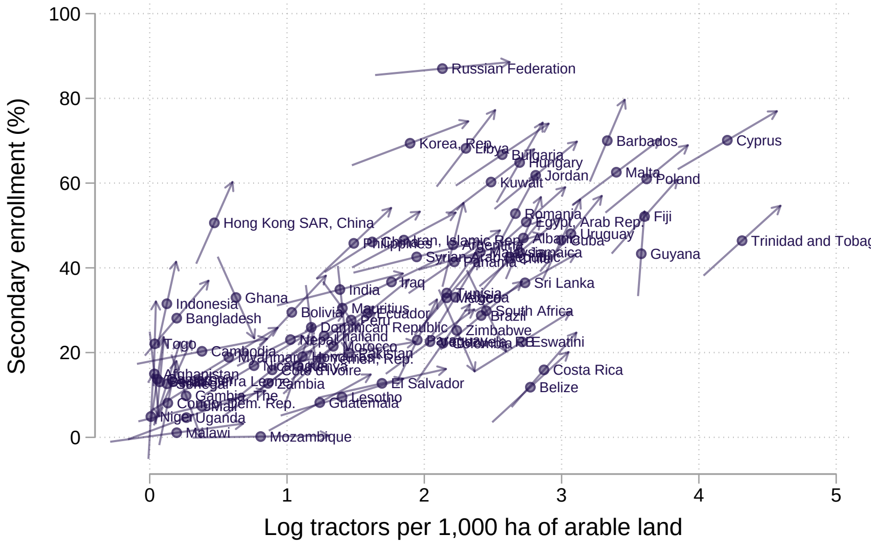


Figure F2: Tractors and Secondary Enrollment: Boys' Trajectories

Notes: This figure displays country-level trajectories relating tractor intensity to boys' secondary-school enrollment across 81 non-advanced countries from 1960 to 2000. Each circle denotes the country mean, and each arrow denotes the direction and slope of the within-country association between tractor intensity and boys' secondary-school enrollment. Tractor intensity is measured as log tractors per 1,000 hectares of arable land.

Table F1: Tractors and Secondary Schooling

	Outcome: enrollment (%)							
	Secondary							Tertiary
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Boys								
Tractors per 1,000 ha arable land (std.)	3.919***	3.965***	3.518***	3.758***	2.311**	7.828***	3.826**	-0.670
	(1.001)	(1.170)	(1.272)	(1.301)	(1.046)	(2.505)	(1.842)	(0.592)
ln GDP p.c. (std.)			2.837	2.739	2.699	1.731	6.059*	3.087**
			(2.626)	(2.541)	(2.283)	(4.038)	(3.221)	(1.262)
Mean outcome	33.796	33.578	33.578	33.578	33.578	40.648	36.444	9.329
Panel B. Girls								
Tractors per 1,000 ha arable land (std.)	5.491***	5.000***	3.902***	3.989***	2.674***	2.434	4.499***	-0.297
	(0.872)	(0.785)	(0.922)	(0.978)	(0.795)	(3.263)	(0.904)	(0.937)
ln GDP p.c. (std.)			6.978**	6.913**	7.163***	4.366*	6.656**	2.799*
			(2.804)	(2.795)	(2.427)	(2.393)	(2.650)	(1.568)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Primary enrollment control	No	No	No	Yes	Yes	No	No	No
Region × year FE	No	No	No	No	Yes	No	No	Yes
Population weights	No	No	No	No	No	Yes	No	No
At least one official tractor observation	No	No	No	No	No	No	Yes	No
Mean outcome	28.842	28.991	28.991	28.991	28.991	31.355	32.183	7.881
Observations	627	525	525	525	525	525	310	525
Countries	81	67	67	67	67	67	63	67

Notes: Country-panel OLS regressions. Columns 1 to 7 use secondary-school enrollment as the outcome, while column 8 uses tertiary-school enrollment; both outcomes are measured in percentage points. The sample covers non-advanced countries from 1960 to 2000. Panel A reports estimates for boys, while Panel B reports estimates for girls. The main regressor is tractors per 1,000 hectares of arable land, standardized to mean zero and SD one. Column 2 restricts column 1 to the estimation sample used in column 3, which requires nonmissing GDP per capita. Columns 4 and 5 additionally control for primary-school enrollment, and column 5 replaces year fixed effects with region-by-year fixed effects. Column 6 re-estimates column 3 using country-population weights. Column 7 re-estimates column 3 after restricting the sample to country-periods with at least one official FAOSTAT tractor observation within the five-year period. All specifications include country fixed effects and either year or region-by-year fixed effects, as indicated. Standard errors clustered at the country level are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

References

Conley, Timothy G., Christian B. Hansen, and Peter E. Rossi, "Plausibly Exogenous," *The Review of Economics and Statistics*, 2012, *94* (1), 260–272.

Haines, Michael, Price Fishback, and Paul Rhode, "United States Agriculture Data, 1840–2012," Inter-university Consortium for Political and Social Research [distributor] 2018. ICPSR 35206, Version 4.

Ruggles, Steven, Matt A. Nelson, Matthew Sobek, Catherine A. Fitch, Ronald Goeken, J. David Hacker, Evan Roberts, and J. Robert Warren, "IPUMS Ancestry Full Count Data: Version 4.0 [dataset]," IPUMS, Minneapolis, MN 2024.