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ENGINEERING GROWTH

Abstract

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JEL Classification: O11, O30, N10, I23

Keywords: Engineers, Innovation, Human Capital, technology diffusion, patents, growth, structural transformation, Development, History

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Engineering Growth[*]

William F. Maloney[†] Felipe Valencia Caicedo[‡]

July 25, 2020

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"You have all the elements, but you cannot make steel"

—Andrew Carnegie (1900)[1]

1 Introduction

Carnegie's taunt to the owners of the Birmingham Steel Company suggests the difficulties the American South faced in absorbing the knowledge required to establish dynamic industries and converge to the North (Wright, 1986). This remains the case in today's developing regions—a vast literature now puts barriers to technological adoption at the center of explanations of the distribution of income globally.[2] Most recently, Comin et al. (2008); Comin & Mestieri (2018) argue that the diverging use of new technologies plausibly explains observed TFP differentials and can drive simulations that closely track the magnitudes of the Great Divergence of the last two centuries (e.g. Pritchett, 1997; Galor & Weil, 2000; Galor, 2011).

That human capital is a critical ingredient in technology adoption already enjoys a substantial supporting literature. There is no consensus, however, on what type of human capital is most important and, in particular, the role of the upper tails of the education distribution, including higher order technical skills. Endogenous growth theory (Romer, 1990), empirical studies of technological transfer and innovation, as well as historical accounts put the engineer and associated scientific institutions at the center of the growth process, especially during the Second Industrial Revolution (1870-1914) (Mokyr, 1998). Yet, despite recent empirical work rigorously documenting the importance of some of these factors, there is no systematic evidence on the historical prevalence of allegedly *the* central actor in modern economic growth, or even the relative importance of the upper educational tails for growth and hence, their plausible importance to explaining the patterns of development that we see today.

In this paper we first make this very basic contribution. We establish the stylized facts surrounding the relative density (labor share) of engineers during the Second Industrial Revolution at the national level for the Western Hemisphere and representative benchmark countries of Europe, and at the sub-national level for six countries in the Americas. The engineering data collection is done in a systematic way drawing on graduation records, membership in

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[1] Cited in Wright (1986) p.171.

[2] See also, Parente & Prescott (1994); Eaton & Kortum (1999, 2001); Galor & Moav (2006); Caselli & Coleman (2001); Keller (2004); Klenow & Rodriguez-Clare (2005).

professional societies, and census data. We see our estimates as capturing indigenous *innovative capacity* defined as the ability to absorb new technologies as well as eventually invent during the second wave of the Industrial Revolution, a period when science became more formalized and technological adoption required higher level and more specific skills.[3] We document the extraordinary variance in engineering density across countries of very similar income levels in 1900—for instance, Argentina, Chile, Denmark, Sweden and the US South—that correlates well with their divergent income positions today (see Figure 1).

To empirically establish the importance of engineers and innovative capacity as a determinant of income, we construct a rich data set for the United States at the *county* level. The increased degrees of freedom allow controlling for an extensive set of geographical, growth related, and human capital variables that may be confounded with engineering. We further instrument for the possible endogeneity of engineering using the 1862 Morrill Land Grant Colleges program. This program had an important long-run impact on establishing engineering training institutions, however, this was not its initial intent, and the location of these colleges was largely independent of demand considerations—as we show empirically. We then demonstrate plausible mechanisms through which technical human capital worked, by looking at technology adoption and structural change at intervals across the following century, as well as the incidence of high-tech industries and within-industry technical upgrading today.

We further incorporate geo-located patenting density collected by Acemoglu et al. (2018) as a measure of innovative output, but also of a particular kind of scientific human capital. Patenting appears partly explained by county engineering density, and many growth and innovation related variables are more affected by engineers than patenting. Hence, it appears that the two measures are capturing different things: patenting human capital or even institutions more dedicated to *invention* (Griliches, 1990; Sokoloff, 1988) while engineering more *adoptive* innovative capacity (see Mokyr, 1992).

Both innovation variables show an important and robust effect on income: a one standard deviation in engineering density in 1880 accounts for a 10-15% rise in county-level income today, and patenting capacity another 10%. Further, we find very similar coefficients at the "state" level both for the US—suggesting migration issues among geographical units are

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[3] While economic historians have long debated about whether the First Industrial Revolution was a deskilling process (see, most recently De Pleijt et al. (2020)), the Second Industrial Revolution was decidedly skilled. See Gordon (2016) for a discussion of the centrality of this period to US and world growth.

not critical—and for a broader sample of countries in the hemisphere. Applying the well-estimated US county-level coefficient to the national level data, a one standard deviation in engineering density in 1900 accounts for approximately a 30% difference in income today, enough to partially explain the Great Divergence in the Americas. We then use historical evidence to validate our ranking of innovative capacity and, through case studies document how, consistent with the dynamics of the Second Industrial Revolution, technological progress and positive development outcomes require the more professional engineering and scientific capabilities that we quantify. Finally, before concluding, we present some suggestive findings on the historical determinants of innovative capacity.

1.1 Literature and Conceptual Framework

The economics literature has postulated several types of human capital that may be important for growth. Literacy, and accumulated years of schooling or enrollment have received the most attention (Krueger & Lindahl, 2001; Glaeser et al., 2004; Barro & Lee, 2015), although as Vandenbussche et al. (2006); Aghion et al. (2009); Gennaioli et al. (2013) note, the composition among levels of education matter as well, depending on distance from the frontier. Other dimensions figure importantly as well: Lucas (1993); Young (1993), among others, stress the importance of accumulated "learning by doing"; Ben Zeev et al. (2017); De la Croix et al. (2018) focus on apprenticeship; and Baumol (1990) on entrepreneurial skills and orientation. In in his classic article on endogenous growth Romer (1990) highlights the *research engineer* and Mokyr (2005), the minority of "trained engineers, capable mechanics and dexterous craftsmen on whose shoulders the inventors could stand" (pg.16, see also Meisenzahl & Mokyr (2011)). Rosenberg (2000) and Nelson (2005) stress the accumulated ability and scientific institutions to manage new ideas for innovation and invention, and Cohen & Levinthal (1989); Griffith et al. (2004), the capacity for research and development needed for technological transfer.

Several authors including Mokyr (1998), and Howitt & Mayer-Foulkes (2005) stress that higher-order human capital and the institutions that generated and housed it may have had an even more determinant role at the dawn of the Second Industrial Revolution, which saw an increased emphasis on more structured scientific inquiry such as laboratory-based R&D. This scientifically oriented human capital, and a technologically savvy entrepreneurial class were necessary to tap into the expanding and increasingly sophisticated global stock of knowledge and convert it into local growth. The technological leap forward also meant an erosion in the efficacy of existing levels of human capital and innovative capacity, relative to that needed to continue to adopt (see Howitt (2000); Aghion et al. (2005)). Building on this Schumpeterian insight, Howitt & Mayer-Foulkes (2005) argue for multiple equilibria in innovation where countries whose human capital evolved with the frontier at the time of the technological leap forward could innovate or adopt, but those whose frontier-adjusted human capital did not keep up, slipped to an equilibrium where even the adoption of technologies was difficult, and stagnation followed. See Appendix A for our sketch of this model.

Among empirical attempts to document the impact of even very basic measures of human capital, similar in spirit to the present work, Hanushek et al. (2017) find that differences in human capital account for 20-35 percent of the current variation in GDP per capita among US states (see also Hsieh et al. (2019)). However, there have been relatively few efforts to systematically capture what kind of human capital matters, or even to document the stocks of different types of capital. At the most basic level Valencia Caicedo (2018) shows how Jesuit missionaries improved literacy, positively impacting modern incomes. Goldin & Katz (2011); Goldin (1999); Goldin & Katz (1999) have famously traced the evolution of secondary and tertiary education in the context of US growth. Judson (1998), Castelló-Climent & Mukhopadhyay (2013) attempt to assess whether tertiary education matters more or less than primary education. Perhaps closest to this work, Murphy et al. (1991) document that countries with a higher proportion of engineers grow faster relative to those with more law concentrators. Drawing and expanding on their data sources, Figure 2 offers suggestive evidence that for the present period, there exists as well a high correlation between income and the density of engineers, though at this stage causality remains elusive.

Historically, Voigtländer & Squicciarini (2014) show that mid-18th century French cities with more subscriptions to the *Encyclopédie*—proxying for higher order human capital—grew faster after the dawn of the First Industrial Revolution. Becker et al. (2011) and Cinnirella & Streb (2017) show that this was the case too for later Prussian innovation. Universities, as generators of higher order human capital, have also been shown historically to contribute to growth (Cantoni & Yuchtman, 2014; Valero & Van Reenen, 2016; Kantor & Whalley, 2019). Yuchtman (2017) shows that during early 20th century China, engineers enjoyed massive wage premia over all other classes of higher education, and that modern Western education and engineers in particular were critical for China's ability to adopt Western technologies. Waldinger (2016) shows that the dismissal of scientists in Nazi Germany led to a permanent decrease in growth, while Moser et al. (2014) and Nunn et al. (2020) show that foreign immigration to the US substantially increased invention there.

To date, however, neither the historical prevalence of Romer's research engineers or Mokyr's "engineers and mechanics" have been quantified in a globally comparable form, in particular during periods of intense technological change—such as the Second Industrial Revolution—in the United States and the Americas at large. We seek to remedy this gap as well as offer estimates of their importance to the growth process.

2 Data

2.1 Measuring Engineering / Innovative Capacity

For the US county level data, we use the census of 1880 to generate measures of literacy, and density of engineers, lawyers and medical doctors.[4] Our primary measure of innovative capacity at the national level across all countries is the number of engineers with domestically emitted university degrees per 100,000 male workers. Unlike literacy data, which countries sometimes collect as part of the census, countries do not tabulate such information in a uniform fashion. Hence, we construct these country series using three sources of data.

Engineering Graduates: To the degree possible, calculations are done with actual graduates of engineering colleges and universities within the country. Clearly, many engineers even in the US acquired valuable training on the ground, or may have had partial degrees from some type of technical program. However, such skills are difficult to capture with any degree of commonality across geographical units. As a more consistent metric across countries, we take the number of degrees awarded. Though most countries also employed foreign engineers, we are interested in broader indigenous technical capacity, local university engineering training and research programs, so we focus on domestically trained engineers.[5] Since the

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[4] As an interesting historical note, the 1880 US Census data was collected under Francis Walker as superintendent, the first President of the American Economic Association. We are grateful to a referee for bringing this to our attention.

[5] For Argentina and Chile we have data on both foreign and domestic engineers and including the former leaves the results unchanged. We also control for the number of foreigners in the Appendix Table A12 and

working life of an engineer is roughly 40 years, we begin accumulating the stock in 1860, discounting it in each period by .983 as the rate of annual death / attrition. In some cases, we have a long series of graduation records which make this procedure straightforward. In Bolivia, Denmark, Mexico, New York, Peru, Spain, Sweden, Venezuela, or Mexico, the flow of graduated engineers is available for the 1860-1900 period.[6] In other cases, for instance, Argentina, Brazil, Chile, Colombia, Ecuador, and the US as a whole, the information is less complete and we bring other sources of data to bear to fill in the gaps in the series.

Membership in Engineering Societies: Data on membership in Engineering societies or official registries validate broad orders of magnitude of our generated stocks. In some cases, such as Brazil, registry with the government was required to be a practicing engineer. What is considered an engineer, however, is less clear and hence these measures are less definitionally tight. In other countries, such as Colombia or Argentina, membership in Engineering associations was not required so registration likely underestimates.

Census Data: Census data on engineers are also available for several countries. Census data have the advantage of being collected over time by several countries and across sub-national units. However, here also, it is the individual respondent who is deciding whether he / she is an engineer or not with limited institutional confirmation, or detail on the actual level of education. This is reasonable for within country analysis but less reliable for cross-country comparisons. To address this, we include state and country fixed effects in our (US and international) specifications. Sub-national data derive from the Argentine census of 1895, Mexican National Census of 1895, Chilean Census of 1907, Colombian census of 1912, Venezuelan Census of 1926, and US Census of 1900. Appendix B discusses how these three sources of data were employed for each country in detail, and Appendix D.1 provides evidence that our estimates are consistent with other historical data.

2.2 Patenting

For the US, we also construct a measure of average patenting activity from 1890-1910–during the immediate aftermath of our engineering variable—drawing on patents granted by the United States Patent and Trademark Office (USPTO), again at the county level, provided by

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find no significant impact on the results.

[6] We refer to Ahlström (1982)'s estimates for Germany and France, the frontier countries, which are generated in a virtually identical manner.

Acemoglu et al. (2018). This is likely to capture the more structured scientific inquiry at the frontier, which began to assume a central role in the Second Industrial Revolution, in addition to its direct interpretation as new ideas. Akcigit et al. (2017) relate historical U.S. patents to state and county-level aggregates between 1880 and 1940 and identify a causal relationship between patented inventions and long-run economic growth. In our work, we show that patenting does not appear fully driven by engineers or the other human capital variables and hence we interpret it as capturing a distinct type of human capital (see Sokoloff, 1988) or alternatively as a measure of institutions that promote it (see Khan, 2005). Comparable patent data is not available for the Latin American countries and hence the variable only enters in the county-level US analysis.

2.3 Sub-national Income per Capita

Income in 2005 PPP US Dollars is drawn from a highly disaggregated spatial data set on population, income and poverty built on the basis of national census data by the World Bank (2009) for the World Development Report on *Reshaping Economic Geography.*[7] Modern county level US income in dollars is mean household income taken from the 2000 US Census.

2.4 Control Variables

As control variables we use: literacy, secondary schooling, higher level non-engineering human capital, railroads, mining, manufacturing output, population density in 1880, pre-colonial population density, slavery, a US South dummy, foreigners, agricultural intensity, religion, and a set of geographic and weather controls including temperature, altitude, rainfall, agricultural suitability, river density, distance to coast and ruggedness. Appendix C offers detail on the construction and description of these measures.

2.5 Mechanisms

As intermediate historical outcomes we look at various measures of technological progress and structural change, among them: value added in manufacturing, horsepower per manufacturing establishment, and number of retail and financial establishments in 1930, as well

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[7] For further detail see Maloney & Valencia Caicedo (2016).

as numerous present-day high-tech industry measures from the County Business Patterns (2012), Cermeño (2019) and Lexis/Nexis Ci Technology Database (2016).

Table 1 presents the summary statistics at the US county level and Table 2 at the state level for the Americas.

3 Empirical Results

3.1 Establishing the Importance of Engineering and Patenting Capacity: US County Level Data

To establish the link between historical innovative capacity and present day income, we employ our engineering and patenting density data for the US at the county level.[8] Table 3 presents the OLS estimates including the groups of controls (in bold, below) for geography, economic activity and other human capital measures. All specifications have robust errors and are clustered at the state level, and include both OLS and fixed effect estimators. In particular, we estimate:

$$Y_{2000,i} = \alpha + \gamma_E Eng_{1880,i} + \gamma_P Pat_{1880,i} + \mathbf{Geo_i}\gamma_{\mathbf{Ge}} + \mathbf{Y_{1880,i}}\gamma_{\mathbf{Gr}} + \mathbf{HC_{1880,i}}\gamma_{\mathbf{H}} + \mu_{state} + \epsilon_i \tag{1}$$

To be consistent with the other samples, we begin with an OLS specification of engineering density along with a vector of geographical controls. As we will use these estimates for inference out of the US sample, we standardize the data and report (beta) coefficients capture impact of a one standard deviation change, which also eases interpretation. In Column 1, engineering emerges strongly significantly and of expected positive sign in the OLS specification. Temperature and distance from the coast both enter negatively and significantly. Column 2 replicates the specification but with the smaller sample, limited by slavery and education, and results in only a minor change in significance and magnitude.

Column 3 then includes the set of income related controls that together work to reduce the correlation that may occur simply because historically denser, richer areas with more infrastructure and in particular manufacturing and railroads (as in Hornbeck & Rotemberg (2019)), may be correlated both with engineers in 1880 and also with income today through

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[8] A small number of counties change their borders in the last century and we drop them. This and missing observations leave us with 1905 observations. Our baseline results also hold without controls, not shown.

non-innovation related channels. We further include a measure of slavery as an institutional variable that may be correlated with low human capital, but also provides other institutional channels to present income. Population density, our measure of lagged economic activity (manufacturing output), and railroads enter positively and significantly and will remain so throughout the analysis. Slavery, which enters significantly and negatively with just geographical controls (not shown) loses significance. As a measure of agricultural activity, farms per capita never enter significantly.

The next 3 columns seek to ensure that the engineering measure is not simply a proxy for human capital more generally. Column 4 includes literacy, which enters positively and significantly, as expected, and reduces the engineering coefficient by just over 10%. Column 5 then includes a proxy for secondary education, whose importance across the next century Goldin (1999); Goldin & Katz (2011) have stressed, and which enters significantly and positively. Goldin & Katz (1999) also discuss the importance of the expansion in higher education across the earlier 1890-1940 period, and in Column 6 we include several variables to ensure that engineers is not picking up higher order human capital more generally: the share of individuals who report attending at least one year of college, the density of lawyers, and density of physicians. The first two enter significantly and positively. That physicians do not is confirming that there are types of human capital whose density is associated with income, but whose effect on it is more tenuous,[9] while the significant relationship we find between engineering and income, is conceptually more direct.

Finally, Column 7 includes all the human capital variables together. Literacy and lawyers remain significant although now neither secondary education, the college proxy, nor physicians do.[10] Either literacy or college attendance can eliminate secondary education suggesting that, at this point in history, the latter is broadly proxying for literacy, or perhaps college readiness. The same remains true in Column 8 which includes state fixed effects, which effectively control for more local unobservables. We test formally for the role of such factors using Altonji et al. (2005) ratios, finding that the role of unobservables would have to be larger than the one of observables to explain away our result. We further explore this later when we employ LASSO techniques to select our control set, which suggest that at this point

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[9] For physicians, this time is also before the 1910 Flexner report, which revolutionized the discipline.

[10] Heterogeneous results reveal a higher impact of engineers on above the median literacy counties, not reported.

we might be over controlling in the full OLS specification.

In all cases, engineering retains its significance at the 1% level although losing some of its magnitude from the initial specification, as we progressively control for unobserved correlates. The relative robustness of engineering vs. secondary education suggests that a small well-educated technological class was, at this time, more important than broad based post-literacy skills. The consolidation of higher education in engineering occurred well before the major expansion of secondary education which Goldin & Katz (2011); Goldin (1999) document rose from only 18% in 1910 to 71% in 1940. Across our period, the corresponding average for the country is 7% with a maximum of 26%. Literacy—at the lower tail—is critical to growth, but beyond it, a high level engineering capital (technical capacity) was also necessary.

The positive effect of lawyers may arise, as posited by Cantoni & Yuchtman (2014) because in earlier periods they were factors complementary to scientific human capital—critical to the establishment of institutions and economic rules of the game.If we divide the sample into that above and below the median level of laywers (Table A2), it appears that a higher density of lawyers may enhance the effect of engineers. The negative effect of lawyers found by Murphy et al. (1991) may arise because as institutions firmed up over time, the social value of lawyers fell as they became more oriented towards unproductive activities. The now positive impact of slavery suggests that its earlier negative effect could have worked through the human capital channel, though we can not make any causal claims at this point.

We next explore the interaction of the engineering term with patents. Table 4 suggests that engineering density is significantly correlated with patenting, providing a mechanism through which the engineering variable is acting. Still, in the complete specification including all measures of formal human capital, we only explain 50% of the variance. This suggests that, as in Sokoloff (1988); Mokyr (1992); Aghion et al. (2015); Bell et al. (2019); Sarada et al. (2019) there may be a particular entrepreneurial or inventive human capital *not* captured by our engineering term. Columns 1 and 2 of Table 5 repeat the last two full OLS specifications but replace engineering density with patenting density as the innovation capacity measure. Patenting enters significantly at 1% again in all specifications and both remain significant at least at the 5% level with and without fixed effects. The coefficient is also remarkably close to that found by Akcigit et al. (2017) using an alternative approach. Columns 3 an 4 combine the two measures. Both coefficients decline 15-20% in magnitude suggesting that one channel through which engineering density operates is through patenting (as suggested by Table 4) and that some of the effect of patenting is perhaps working through non-patenting channels.[11] A more formal Sobel-Goodman decomposition test shows that only 15% of the effect of engineers on income works via patents. However, that each continues to enter very significantly and independently suggests that they are capturing *different* types of human capital or other factors: namely, technological adoption in engineering and inventive activity in patenting (see again Mokyr, 1992). We fully accept the argument of Moser (2013) that much innovation including patentable invention is done outside the patent system and hence such distinctions cannot be drawn too sharply.

3.2 Instrumental Variables Results

Our engineering variable is already lagged a century, and in addition, we have included numerous controls for other plausible channels through which it may be correlated with present income, besides the capacity to manage and generate new technologies. We also show later that there is no correlation of engineers in 1880 with manufacturing in 1860, suggesting that locational economic activity is not driving engineering density. Nonetheless, for econometric identification, we instrument our engineering measure with the log distance to the nearest Morrill Land Grant colleges and universities. The Morrill Program was introduced in 1862 precisely to remedy the perceived shortfalls in technical assistance in agricultural and mechanical innovation in the abstract. Its motivation was driven by both democratic ideals of educating the working man, and by the observation that the US had none of the agricultural and technical schools found in Europe (Nevins et al., 1962; Nienkamp, 2010). However, it was not locally demand driven hence, as an instrument, it is unlikely to capture pre-existing economic activity, as we test empirically later. As Johnson (1981) argues, "On the contrary, a case could be made that the new colleges were created by reformers, not practitioners, and for an ideal, not for an established need" and under-subscription remained the rule for decades.[12] This weak revealed demand is further reflected by the lack of clarity, in the early

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[11] Griliches (1998) notes the limitations of patenting as capturing innovative activity when he says that "Not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in quality, in the magnitude of inventive output associated with them."

[12] "Reaching out to sons, and later daughters, of farmers and artisans, to indigent students, and to whomever the existing system passed by was a noble egalitarian ideal that remained just that-an ideal-for decades, with laborious progress toward its realization. Dormancy or decline in enrollments had actually set in, with

years, over what form that education should take, as well as the precarious finances of the institutes, both suggesting little initial impulse from the private sector.[13]

Further, the channel through which the Land Grant colleges is likely to affect growth is precisely through the generation of higher order technical human capital. Though the promoters of the Morrill Program did not envisage it as fomenting engineering per se, it would eventually finance the first engineering departments in the West, Midwest and the South, and would become a central driver in developing the higher order scientific and engineering capacity of the country. Nienkamp (2010) in *Land-Grant Colleges and American Engineers* argues that, especially the Mid-Western schools "provided the foundation, both in training and number, for twentieth-century American professional engineering" and were critical in defining their identity and ushering in the modern scientific, laboratory-based approach to technical education (as in Aghion et al. (2005)). Nevins et al. (1962) argues that the Morrill Program "promoted the emergence of the most effective engineering schools on the globe." Goldin & Katz (1999) note that while the majority of new universities of the time were privately started and Morrill cannot explain the expansion of higher education, it was central to engineering. As of 1908 they note that 60% of the nation's engineering students were found in public universities and the "geographical dispersion of engineering students came mainly from those enrolled in public schools "the rise of which they attribute to the Morrill Program (Goldin, 1999). Seely (2005) confirms that by 1900, the majority of engineers were graduating from land grant colleges: 76% of mechanical engineers, 63% of civil engineers, and 63% of electrical engineers. Hence there is a tight link from the land grant colleges instrument to engineering density.[14]

Consistent with the historical narrative, the first stage of a basic 2SLS (Table 6) reveals a strong positive correlation between engineering density and the Morrill proxy with very high Cragg-Donald F-tests (1% level) and acceptable F-tests suggesting a strong instrument.

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surprising results in the new colleges" [46, p. 486; 13, pp. 66-68]. When Ohio's Land-Grant college opened, its public predecessor, Miami University of Ohio, was forced to close its collegiate department for want of enrollment, to resume only a dozen years later [26, pp. 54, 56]."

[13] Prior to the Civil War, the South had actively opposed the bill, fearing greater interference in matters such as universal primary education and only the withdrawal of the Confederate States from the US Congress allowed the bill to be passed. However, during Reconstruction, recognizing its technological lag, the South started privately institutes such as Georgia Tech, and actively embraced the Morrill Program.

[14] In a complementary paper, Kantor & Whalley (2019) find that the channel to growth through agricultural research stations affiliated with Land Grant Collegess increasing agricultural productivity was also important, but dissipated after 20 years. We explore empirically the role of agriculture later on.

However, to exclude other possible channels through which it might be working, we undertake several additional exercises. Table 6, first row, shows that there is no significant correlation with the other measures of higher education: lawyers and physicians. In this sense, our interpretation differs with Moretti (2004) who uses a similar instrument for general higher education–we are likely capturing a channel through technical human capital, not generic higher education.

Additionally, as mentioned before, there is little evidence of the instrument being correlated with pre-existing trends. Tables A3 and A4 show that Land Grant Colleges are not correlated with the contemporaneous value of production, employment, capital invested, or the value of home production in manufacturing in 1850 and with additional measures in 1860, right before the passing of the Morrill Act. Table 6 also shows that none of the human capital measures for 1880 are correlated with the second wave of land grant universities established in 1890, as might be expected if the location of the universities were driven by economic factors that engendered higher order human capital independently. Confirming this, as a placebo, in Table A5 we run our core second stage regression but using the 1890 instrument, revealing insignificant results throughout.

Columns 5 and 6 of Table 5 present the second stage results for the complete specification. Engineers enters again at the 1% level with a modest increase in value to .11 in the fixed effect specification, both with and without patents. We do not present all previous specifications simply because, as with the OLS specifications, both engineering and patenting retain their significance and broad magnitudes throughout.[15] The IV estimates are only slightly larger than the OLS, perhaps reflecting a modest reduction in bias due to measurement error in our proxy for technical human capital. It is possible, for example, that “engineer” in 1880 included people who did not have advanced technical education and hence our instrument will mitigate such misreporting. Still, we view the stability between the OLS and IV coefficients positively. Overall, it appears that the saturation of the OLS specification with numerous controls for economic activity may have also reduced any residual unobserved correlation with engineers. We repeat our exercises dropping the counties where the Land Grant Colleges are located, to mitigate the impact of the university and associated activities per se, leaving the

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[15] We also explore controlling for potential bias resulting from selection into being a zero in the instrument stage. It is thus similar to the standard Heckman selection regression. The results using a Buchinsky estimator remain significant and are of slightly higher order of magnitude, not reported.

results essentially unchanged (Table A6). Our county level estimates are also consistent for sub-samples of regions such as the South, New England and non-Rust-Belt areas (consistent with Franck & Galor (2019)).

As a further exercise to mitigate any possible selection bias the Land Grant Colleges, we follow Andrews (2019) in restricting the sample to only those counties that were formally in consideration for one such school.[16] This guarantees that the comparison group is more similar to the Land Grant Colleges receivers along the unobservables correlated with selection of sites, although it substantially reduces the sample. Table 7 shows that OLS regressions with this reduced sample show very similar results to those above, while the instrumented regressions confirm the significant, positive impact of engineers. The effect is not present for lawyers or doctors, consistent withe the baseline findings in the full sample.

For robustness, Table 8, Columns 1 and 2 use LASSO regression (Belloni et al., 2014) to impose additional discipline on variable selection, offering a more parsimonious representation of the most important explanatory variables. Column 1 presents the results for OLS and Column 2 for IV estimation. The LASSO procedure sets virtually all geographical controls, slavery, secondary education and physicians to zero. However, core structural variables—manufacturing output, railroad infrastructure, farms per capita—as well as basic literacy and higher order human capital variables: engineers, share with tertiary education, and lawyers, remain critical. The magnitude of the engineers variable remains fairly unchanged.

To make our international comparisons more valid, we replicate the exercise for the 1900 5% Census subsample at the state level, with the number of covariates reflecting the reduced degrees of freedom.[17] This higher level of aggregation allows for more labor mobility among units of analysis, as discussed by Aghion et al. (2009). Though, a high degree of mobility among counties could reduce the impact of our instrumented engineering variable, again, it does not seem to prevent the emergence of a very robust and significant coefficient. It also allows introducing a measure of mining activity which is available at the state, but not county level. The OLS and IV estimates at .1 and .2 (Appendix E, Tables A7 and A8) are significant and very close to the corresponding county level estimates respectively.

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[16] We thank Michael Andrews for sharing with us the data of his ongoing project and a referee for suggesting this point. Andrews (2019) shows the impact of colleges on local innovation and we can think of this exercise as tracing the intermediate impact through engineering / technical capacity per se and then on to income. This sub sample of counties is richer, more educated and innovative to start with, consistent with the findings in Andrews (2019).

[17] We thank Ufuk Akcigit for suggesting this exercise.

Taken together, the US data suggests that innovative capacity, spanned by engineering and patenting density, has a strong and independent effect on future income levels. The results suggest that a one standard deviation rise in engineering density leads to an 11% increase in income. Though not instrumented, patenting capacity leads to another 11%. Hence, higher level human capital plausibly accounts for important differences in income per capita. This does not imply the unimportance of lower level human capital. A one standard deviation increase in literacy (again uninstrumented) accounts for 51%. A comparable increase in secondary schooling leads to only a 4.5% increase although, again, the High School movement began substantially later and the variance in 1880 is very small. As a final back-of-the-envelope exercise, taking the coefficient from the well-saturated US regressions and applying it to the international data in Figure 1, a one standard deviation rise in engineers in 1900 leads to a difference of a third of 2000 income. We present estimates with international data in Section 5. It appears then, that differences in the stock of engineers at the beginning of the Second Industrial Revolution substantially contributed to the subsequent divergence observed across the 20th century. We analyze next possible mechanisms of transmission of this sizable effect next.

4 Mechanisms of Influence

What are the mechanisms through which engineering or technical capabilities affect income today? We approach this question in several ways. Table 8 explores whether the effect is somehow limited to higher order human capital as an input, or whether as a proxy for innovative capability, it has spillovers beyond the impact on engineers per se. Column 3, offers a first approximation showing that engineering density has a similar impact on income when incomes of engineers are *excluded*, suggesting our results are not merely compositional. Column 4, for instance, shows a similar impact on the incomes of managers as a class, suggesting there is broad-based rising of the profitability of firms in higher engineering density areas. Column 5 shows that the channel is *not* through a trivial correlation of historical engineering density with modern engineering density which drives today's income. The coefficient on engineers falls only slightly, when controlling for its modern-day counterpart.[18] This suggests

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[18] Table A9 reports the estimates without state fixed effects, which are slightly larger.

that there is something else about engineers historically. Together these results suggest that the engineering density is in fact capturing a innovative capacity at the turn of the 20th century that would have long-lasting impacts on the broader economy, as explored next.

Perhaps the primary mechanism through which engineering or technical capabilities more generally drive higher incomes across the long run is the adoption of new technologies, which leads both to increased productivity in existing sectors, and structural evolution of the economy into new sectors. At the highest level of aggregation, Alfaro & Comin (2019) show that our country level engineering densities are negatively correlated with technological adoption lags for the sample in Figure 1 (see Table A10). At the state level, engineering shows a significant positive correlation with several celebrated technology adoption measures (Griliches, 1957; Skinner & Staiger, 2007): the adoption rates of hybrid corn; rates of mechanization in agriculture proxied by the introduction of tractors; and, in the digital age, the percentage of homes with personal computers in 1993 (Figures 3A, 3B and 3C).

As an illustration of the time path of influence, Figure 4 plots the coefficient of engineering density on county level manufacturing value added at 20 year intervals from 1860 to our midpoint of 1940, after which the censuses do not tabulate this information in a comparable fashion. We see that, the 1880 engineering density measure has an insignificant impact in 1860, alleviating concern about pre-trends. But from 1880 to the 1920, its coefficient grows steadily in magnitude and significance. The final 1940 point, while decreasing slightly in value, is statistically of the same magnitude.[19] Hence, we have an enduring influence of 1880 engineering density on manufacturing growth well into the 20th century.

Table 9 presents seven indicators drawn from the 1930 manufacturing census, one of the earliest and most complete, undertaken 50 years after our engineering measure—roughly half way through our historical span. Three are measures of industrialization: manufacturing value added per capita and manufacturing establishments per capita capture structural transformation, while horsepower per firm is more likely to capture increasing technological intensity of production. Second, following the association made by Murphy et al. (1991) of engineering with entrepreneurship and industry-related services, we employ as a proxy the number of retail stores per capita and value of net wholesale transactions per capita (see also Glaeser et al. (2015)).[20] Finally, we have two measures of financial depth, bank deposits and

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[19] Data for 1930, used in Table 9, show the same pattern and we exclude it only for simplicity in the graph.

[20] Drawing the share of managers in the population from the 1990 census, we find that, in fact, engineering

banks per capita, which may capture how technological upgrading gave impetus to a service industry to finance it (Jaremski, 2014; Fulford, 2015).[21] In all cases, engineers emerge as statistically significant with the full controls set, highlighting the importance of innovative capacity for structural transformation and transition into more advanced sectors.

Though the census will not permit carrying this exercise to the present, recent specialized data sets confirm the long run cumulative impact of engineering capacity. Using the County Business Patterns (2012) data set collected by the US Census Bureau, in Table 10, Columns 1-3 confirm the correlation of 1880 engineering density with the number of high-tech industries in a county, as well as payroll and employment in these sectors. This measure is also correlated with the incidence of Knowledge Intensive Business Services (KIBS) as drawn from Cermeño (2019) in 2010 and 1980 (Columns 5 and 6), but also historically—as early as 1930 (in Column 4). Across this 80 year span, the coefficient on 1880 engineering density remains remarkably constant. Finally, using the Lexis/Nexis Ci Technology Database (2016), which provides technology marketers an insight into the installed technology and purchase plans for 120,000 US businesses, we are able to document the importance of technology investments at the intensive margin, within firms. Columns 7-9 shows that 1880 engineering density is significantly correlated with the number of personal computers per firm, the number of servers, and the budget allocated by factories for information technology, 130 years later.

As a final check that the correlations with hybrid seeds and tractor adoption above are not pointing to the engineering variable picking up some more generic modernizing factor affecting all sectors—and analogous to the discussion of lawyers above—Appendix Table A2 considers the interaction of engineers with agricultural activity (see Kantor & Whalley (2019); Fiszbein (2017)). When we split the sample (using the median number of farms per capita in 1880), the effect of engineers in both OLS and IV estimates on long-term income is concentrated in *less* agricultural areas. Though technical change in agriculture was an important precursor for growth and engineering capabilities facilitated that, taken together, our engineering measure appears to have worked more through structural transformation, developing manufacturing and perhaps associated services,as well as within industry productivity.

Section 5 revisits the relationship between historical engineering density and present income using international data, both at the sub-national and national levels. Section 6 then

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density in 1880 is correlated with management today, consistent with the results in Table 8.

[21] Results also hold using 1920s finance data.

draws on historical case studies as another means to document the channels through which engineering density affected growth. Section 7 explores the drivers of innovative capacity.

5 International Data

5.1 International Sub-national Engineering Data

We undertake similar analyses at the sub-national (state) level for Argentina, Chile, Colombia, Mexico, Venezuela and the US, for which census data are available. To give a feel for the disparities, Figure 5 maps this data for the US and Mexico by decile of engineering density and strikingly confirms that the border divided worlds apart. Perhaps predictably, the advanced New England states and the heavily mining dependent and generally less populated Western states show the highest density, while the emerging industrial centers of the Midwest are close behind. The South is concentrated in the lower ranks with South Carolina, Georgia, Arkansas and Alabama in the bottom deciles—the lowest density in the US. What is striking, however, is that the country that was the principal mining center of the Spanish empire (Mexico) is almost entirely concentrated in the first and second quintiles with Sonora and the two Baja Californias appearing in the third and fourth deciles. Taking out Mexico City and the border states, Mexico is almost uniformly below even the American South in density of engineers. As we discuss next, despite four centuries of mining, this country had not acquired a corpus of trained professionals in the field compared to relative newcomer, the American West. The other Latin American countries show similar patterns.

Table 11 presents the results from the sub-national panel and comes to similar conclusions to those previous. Namely, we estimate:

$$Y_{2005,ij} = \alpha + \gamma_E Eng_{1900_{ij}} + \gamma_{pop} Pop_{1900,ij} + \gamma_L Lit_{1900,ij} + \mathbf{Geo_i}\gamma_{\mathbf{Ge}} + \mu_j + \epsilon_{ij} \tag{2}$$

The only difference is that now we take country, instead of state fixed effects. Engineering density enters persistently significantly and very close to the magnitude of the OLS estimates from the US county and state level samples. In Column 3, Literacy again enters positively and significantly and reduces the coefficient on engineering by 30%, again, broadly consistent with the US results in both effect and overall magnitude of the final engineering coefficient.

Though we cannot control for a more complete set of human capital measures, the county level exercises shown before suggest that, in fact, engineering is capturing innovation related human capital and not human capital accumulation more generally. In sum, the estimates suggest that our county level US findings resonate internationally: *both* literacy and higher order human capital related to engineering, science and technology are important determinants of long-run income.

5.2 Cross-Country Data

At the highest level of aggregation, Figure 1 plots our measure of national engineering density against GDP per capita, both in 1900. First, there is substantial variance in the stock of engineers that is weakly related to income in 1900. The Northern United States with a density of 160 is the highest in our sample, roughly double the average for the country as a whole, 84, while the US South shows roughly a third of the engineering density of the North at 60, consistent with the historical evidence Wright (1986). Lagging as it was, the American South was miles ahead of the Latin American countries who average under 20. What is most striking is that countries that we tend to associate with a declining relative position across the previous century, especially Argentina and to a lesser degree Chile and Mexico, show densities a fraction of countries of very similar levels of income (such as Denmark or Sweden) who would converge to the frontier.[22] Arguably, in Latin America, natural resource rents, while elevating income, were not being deployed as they were in the US or Scandinavia for the development of innovative capacity that would prepare them for the next phase of industrialization. In the framework of Howitt & Mayer-Foulkes (2005) we have countries with similar levels of Schumpeterian backwardness, but with radically different levels of absorptive capacity.

Second, the dominance of the US in the Western Hemisphere is clearly not being driven by some idiosyncratic US data issue that would exaggerate its density. The US average is broadly in the same league as Denmark and Sweden, and even the North is below the calculations by Ahlström (1982) for France (200) and Germany (250), the frontier countries of the era. This not seem to be driving the consistently low scores of Latin America either,

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[22] Figure A1 illustrates this point for two industrial manufacturing centers in our sample: Antioquia (Colombia's industrial hub) and New York to which it would catch up only a century later. In this case, it would take Antioquia (Colombia's industrial hub) a hundred years to catch up with NY.

as all countries cluster very near each other and the colonial mother countries. Appendix D and Table A1 shows that these differences in engineering densities for 11 countries are indeed correlated with present income, although the coefficient is an order of magnitude higher than that emerging from the US and international sub national panel, suggesting engineers is picking up other correlated factors at this level. As a back of the envelope calculation, applying a coefficient of .1 as a rough consensus value from the US and international sub-national exercises can account for roughly 30% of the cross country variation in incomes.

6 Support from History: Case Studies

To flesh out our understanding of the mechanisms further, the next section presents several case studies from the American South and Latin America, which document stunted long-run within-sector productivity growth and frustrated structural transformation as a result of deficient innovative capacity.

6.1 The American South

The US started relatively early and energetically in the training of engineers. The first institution of engineering education emerged from the Revolutionary War at West Point—established in 1802—trained engineers for both military and civilian purposes, and by 1862 there were roughly a dozen engineering schools in the East, but there were also schools as far west as Michigan and south as Maryland.[23] The passage of the Morrill Land Grant Act in 1862 led to an acceleration in the establishment of engineering programs, roughly sextupling the number in the decade after passage.[24] The period also saw a deepening, as the profession

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[23] Subsequently the American Literary, Scientific and Military Academy at Norwich, Vermont awarded its first Civil Engineering degrees in 1837, and Rensselaer School in New York, in 1835. The Polytechnic College of the State of Pennsylvania, founded in 1853 granted degrees in Mechanical Engineering in 1854, and Mining Engineering in 1857.

[24] The Act led to the establishment of the Columbia School of Mines in 1864, Worcester Polytechnic in 1868, Thayer School of Civil Engineering at Dartmouth College in 1867, Cornell University as well as new universities in Iowa, Nebraska, Ohio, and Indiana. It also gave impetus to the foundation and consolidation of engineering schools in the South. As early as 1838 the University of Tennessee was teaching courses in Civil Engineering, but in 1879 it began awarding doctorate degrees in Civil and Mining Engineering. Texas A&M awarded its first degree in Civil Engineering in 1880, Virginia Tech in 1885 in Mining Engineering, and the University of Kentucky, although having an engineering program dating from 1869, graduated their first civil engineer in 1890. Auburn University in Alabama began its engineering program in 1872, and North Carolina State in 1887.

in the U.S. diversified further into sub-branches. The establishment of professional societies in Civil Engineering (1852), Mining (1871), Mechanical (1880) and Electrical (1884), testifies the the consolidation of a process of specialization and diversification. By 1890, a modern and world-class engineering profession was firmly established in the US.

An extensive literature deals with southern development and we present only a brief summary to draw the parallel with other cases. The training of engineers began seriously only after the Civil War with special impetus from the Morrill program, and this late start had lasting implications for technology adoption and convergence of the region with the North. The emblematic failure was the Birmingham Steel industry referred to in the introduction. Central was that the low iron, high phosphorous nature of Alabama red hematite required substantial adaptations of technology to the southern context, which the local innovative capacity was not able to engineer. Nor was it able to develop southern versions of new inventions in the paper and textile industries. In lumbering and iron making, as well, southern producers of the 1920s were not only *not* innovative, they were using methods phased out decades earlier elsewhere. Wright (1986) further argues that "Having missed the formative phases of the 'American System', the South was lacking a machine-tools and capital-goods sector almost entirely and therefore was bypassed by the kind of adaptive, dynamic, path-breaking series of technological breakthroughs that made the 'American System' distinctive"(p. 124-125).

6.2 Latin America vs. the US

The lack of technological capacity just described extended south of the US border. The data for Latin America are consistent with the observation by Safford (1976) in his classic *Ideal of the Practical* that "Latin American societies in general, and the upper classes in particular, have been considered weak in those pursuits that North Americans consider practical, such as the assimilation, creation, and manipulation of technology and business enterprise in general"(p 3). Graham (1981) argues that Brazil, consistent with our estimates, lagged far behind the American South in every aspect of industrialization, transportation and agricultural technology. A long literature has focused on Argentina's weakness in innovation effort in comparison to countries such as Australia and Canada seen as similarly endowed (see, for example Diaz Alejandro, 1985; Duncan & Fogarty, 1986; Campante & Glaeser, 2018). As Appendix D.1 documents, the national scientific establishments and professional training of civil engineers appeared much later and on a smaller scale. As an example, perhaps the richest country in Latin America at the time, Argentina, began graduating engineers only in 1870, and Peru, one of the premier mining centers of the hemisphere, in 1880, roughly on the same timeline as Alabama. General engineering associations were set up in many countries around the same time that US associations in individual sub-fields were established.

The potentially catastrophic impact of this late start is nowhere more in evidence than in the industry in which Latin America for centuries had had a true comparative advantage, yet by the turn of the 20th century had lost: mining, which the Second Industrial Revolution had radically transformed. Chile saw its world market share of copper fall from 40% to under 4 percent by 1911 (See Appendix Figure A2), and even as early as 1884 the *Sociedad de Minería* (Mining Association) wondered openly whether Chile's copper mines would survive at all (Collier & Sater, 1996). Chilean historians date this technological slippage to the beginning of the nineteenth century, when "the work of mining was not very systematic" and the "receipt of industrial innovations [from abroad] was slow and without visible influence"(Villalobos et al., 1990, p. 95-96).[25] Only with the purchase of the mines by UK and US firms did Chilean mining modernize, reaching new production highs. By 1918, American interests controlled 87% of Chilean copper output (O'Brien, 1989).

In Mexico, local entrepreneurs lost share in the mining industry they had dominated for centuries precisely due to lacking the capacity to master emerging technologies (Ruiz Larraguivel, 2004; Brading, 1971; Marichal, 1997). As Figure 5 shows, in Mexico, even when including Zacatecas, San Luis de Potosí, and Guanajuato—long centers of mining—density was at low levels compared to the newcomers in the US West. Around 1900, abandoned, underexploited and newly discovered mines fell to foreign hands that could bring new global technologies to bear and the US grew to control close to 80% of investments in the sector, much as occurred throughout the region.[26]

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[25] Charles Lambert, a representative of a British mining company in La Serena who was trained in the *École Polytechnique in Paris*, noted in 1819 the primitive mining practice, scarce knowledge of minerals, and inefficient smelting, all of which represented poor technique relative to that employed in Europe. See also Maloney (2002). One of Chile's most venerated historians, Francisco Encina noted that "from the point of view of capital and of technical and administrative aptitude, the copper industry is as demanding as the most complicated manufacturing industry" (Encina, 1972, p. 62). However, his studies revealed "an extraordinary economic ineptitude in the national population consequence of an education completely inadequate to meet the demands of contemporary life."(Idem, p. 17).

[26] See Maloney (2015) for ownership details. As an example, the Guggenheim interests opened smelters in Monterrey (1892) and Aguascalientes (1894) purchased the largest Mexican Smelting and Refining company in 1906, introduced modern methods of extracting and refining silver ores and in addition, started the production

The eventual American dominance of the Chilean copper and Mexican mining industries strikingly illustrates the road that could have been taken with the same homogeneous product. Not only does Wright (1999) argue that the US in the 19th century "parlayed its [natural] resource-based industrial prosperity into a well-educated labor force, an increasingly sophisticated science-based technology, and world leadership in scientific research itself" (Wright, 1987, p. 665), but he uses precisely the US copper industry as an example of national learning and of innovation as a network phenomenon. In the post-Civil War period, the US became the foremost location for education in mining engineering and metallurgy. It was the revolution in metallurgy (e.g. the Bessemer process and the introduction of electrolysis on a commercial scale for the refining of copper), that propelled the copper industry during the last decades of the 19th century and laid the groundwork for much subsequent industrialization. The transference of these technologies by US firms to their mines and smelters in Chile and Mexico revolutionized the antiquated industries in both countries, dramatically increased production, and left them dominant in both cases.[27]

7 Drivers of Innovative Capacity

Having documented the importance of engineers and patents for long-term growth, we explore their prevalence in the US, using our county level data. In Table 12, we include as a predetermined measure of agglomeration or economic activity, population density prior to colonization. We further introduce slavery as well as a southern dummy, along with geographical controls.

Somewhat strikingly, pre-colonial population enters strongly significantly and positively in all specifications with both engineers and patents. This offers a channel through which agglomerations and arguably economic activity persist over time (see Maloney & Valen-

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of lead and zinc mining (Bernstein, 1964; O'Brien, 1989). This phenomenon was visible throughout the continent. In Upper Peru (now Bolivia), the decline of silver production in some of the most famous mines, like those at Potosí, arose from the "failure to apply new mining techniques, heavy mortality among Indian laborers and the exhausting of previous rich veins" (Scobie, 1964, p. 59). In Ecuador, Hurtado (2007) argues that the discovery of new mineral deposits was hindered by a resistance to scientific methods.

[27] The Guggenheim's El Teniente mine was the first in the world to apply the flotation process in concentrating low-grade ores. Mechanizing digging made Chuquicamata in the North the largest open pit mine and, again, a new concentration process was introduced using sulfuric acid and electrolytic precipitation to treat the mine's ore. From 1912-1926, copper production in Chile quintupled as a result, reversing a 25 year period of stagnation (O'Brien, 1989).

cia Caicedo (2016) for a discussion). Slavery enters negatively and very significantly in all specifications confirming that reduced investment in higher level human capital is a channel through which slavery had a depressing impact on future incomes. The southern dummy continues to enter significantly in all specifications, suggesting an impact beyond the set of factors associated with slavery. Of the geographical controls, perhaps the most consistent with the literature is that innovation falls with distance to the coast and, significantly so, in the case of patents. Appendix Table A11 further introduces a measure of church density per capita and density of foreigners. Both enter significantly although prevalence of religious institutions seems to deter patenting, consistent with Bénabou et al. (2015a,b); Squicciarini (2019).[28] The findings for foreigners are also in line with Bandiera et al. (2019); Nunn et al. (2020) who find that migrants were instrumental to pass compulsory schooling legislation, and led to higher income through increased innovation at the upper end.

Though we lack the data to undertake a similar global analysis, related to the cross-country discussion, it is striking that Spain's own development path shows the exact same issues of inability to manage new technologies and external dominance characterizing Latin America (Tortella Casares, 2000) suggesting a high degree of commonality in underlying factors. For example, the evolution of the Spanish mercury mining industry precisely foreshadows the subsequent experience in Latin America discussed earlier.[29] Though our data do not permit further inference, these suggestive findings offer some guidance for future research.

8 Conclusion

Much of the growth literature stresses differences in the capacity to generate, import, and apply new technologies as central to explaining relative growth performance. To date, however, there has been little data generated on the higher level (technical) human capital, in particular, the central figure of the engineer and none to attempt to verify its impact on

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[28] Our core results are not altered with the introduction of these controls (see Appendix Table A12).

[29] Though Spanish mines were rich, and mercury had been worked for a millenium, the lack of technical capacity, capital, and the slow growth of domestic metallurgical know-how led Spanish entrepreneurs to work close to the surface and sell out to foreigners once easy veins had been exhausted. In 1873, a UK / German led conglomerate purchased the mines on the Rio Tinto river in Andalucia, introduced new technologies, and from 1877-1891, became the world's largest producer of copper, contributing the to fall in Chile's global share in Figure A2. As (Tortella Casares, 2000, pp. 96, 213-215) summarizes: "extraction and processing constitute a classic example of the failure of Spanish entrepreneurs to confront the problems of developing an industrial sector with complex technology, intensive use of capital, [and] a fast-expanding horizon."

income differentials. This paper collects data at various levels of aggregation to remedy that.

It begins employing county-level data from the US and establishes the robust explanatory power of engineering density and patenting, controlling for a variety of economic and geographic variables; measures of secondary and tertiary education, as well as attempting to control directly for possible endogeneity using the 1862 Morrill Land Grant Colleges. We then explore the impact of engineering density through several intermediate mechanisms across the next century at various intervals. Looking 50 years after—using the 1930 manufacturing census—we find a robust impact on manufacturing expansion, technological intensification, and structural transformation, and show that the impact on manufacturing value added increased steadily from 1860 to 1940. Engineering density is also correlated with the adoption of celebrated technologies such as hybrid corn and mechanization in agriculture. Its effects continue to the present day with high-tech sectors and technological intensity within sectors, with computer adoption, number of servers, and IT budget being positively correlated.

The paper then uses cross country and 'state' level data to explore the relationship internationally. It repeats the US exercises with a multi-country panel working at the sub-national level, revealing similar orders of magnitude. Finally, it generates national level engineering data for the Americas in 1900, which suggests that differences in innovative capacity can plausibly explain up to a third of of the disparate development trajectories of countries which—at the time—had very similar levels of income.

Lastly, we conduct preliminary explorations of the determinants of innovative capacity. We show that for the US data, slavery had a negative impact on engineering density suggesting that human capital accumulation is a channel through which the institution negatively affected growth. Consistent with recent work, religion enters negatively as well. In the international data, the similarity of engineering density in Spain and Portugal to that of Latin America, and the commonality of experiences with, for example, mining, suggests important inherited determinants of low capacity for technological absorption. Given the large impact we establish of higher order technical human capital and innovative capacity on income, further investigation of their determinants yield promise for the growth research agenda (e.g. Akcigit et al. (2017) and Bell et al. (2019)).

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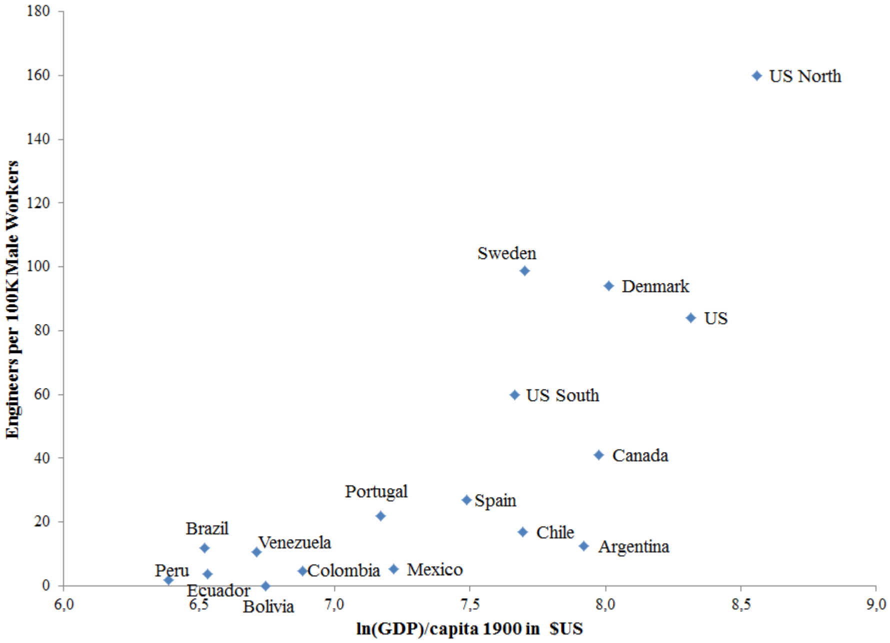
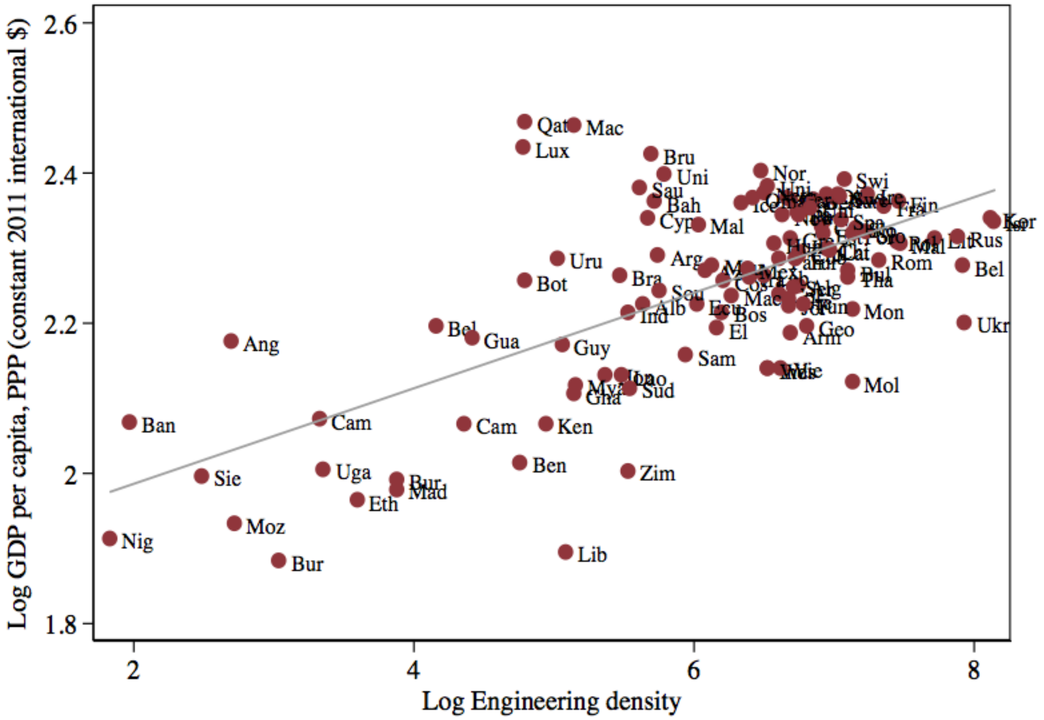
9 Figures and Tables

Figure 1: Income 1900 and Engineering Density 1900



Note: Plot of GDP per capita in 1900 from Maddison. Engineering Density is accumulated graduates of engineering programs per 100,000 male workers around 1900 as described in Appendix B.

Figure 2: Contemporary GDP vs. Engineering Graduate Density



Engineering density: (graduates from engineering, manufacturing and construction)*1000/Population

Note: Plot of GDP per capita in 2012 vs Engineering density. Engineering Density is average graduates of tertiary graduates in Engineering, Manufacturing and Construction programs from 1999 to 2015 per 100,000 inhabitants as tabulated by UNESCO, available at: http://data.uis.unesco.org/index.aspx?queryid=163. .

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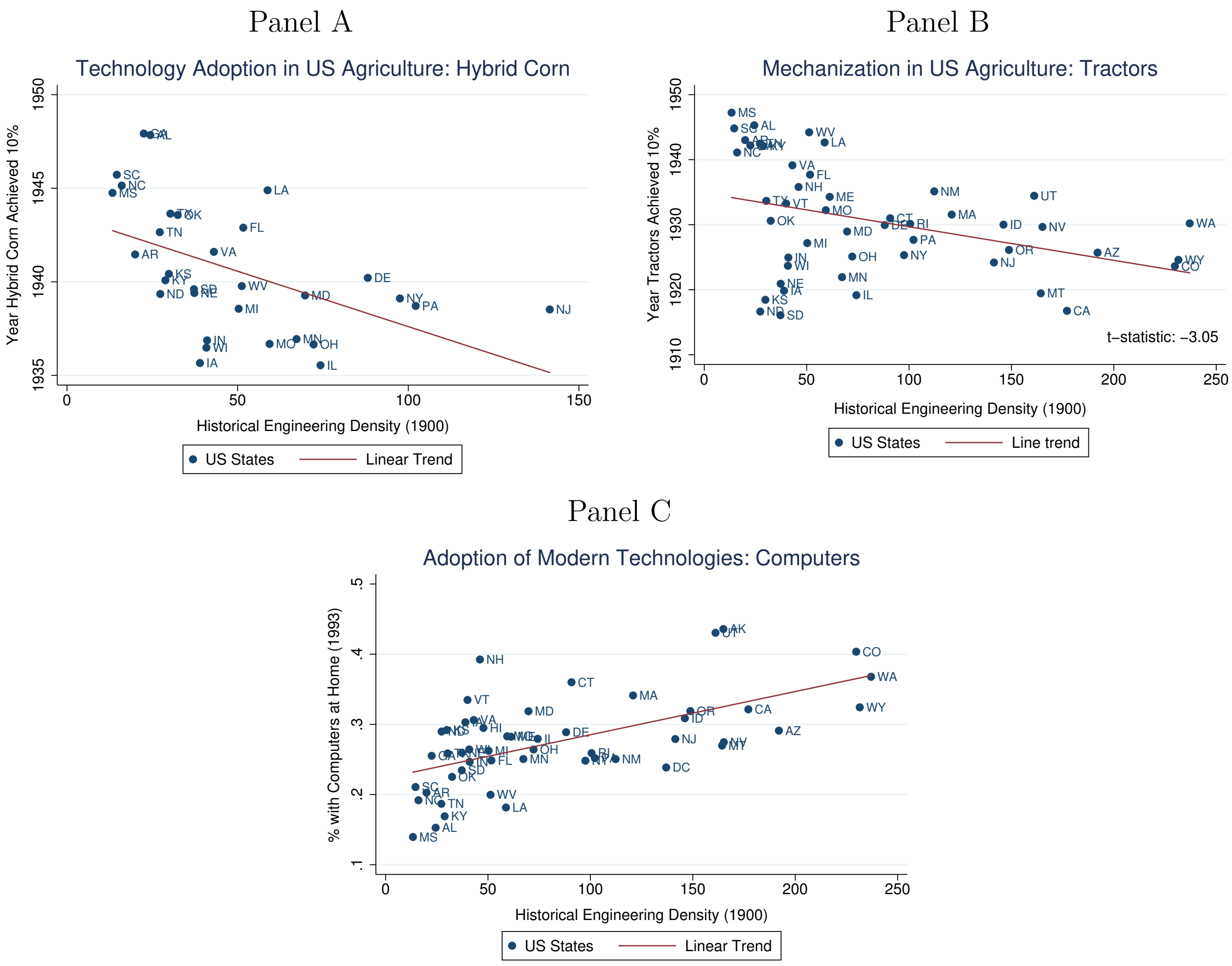
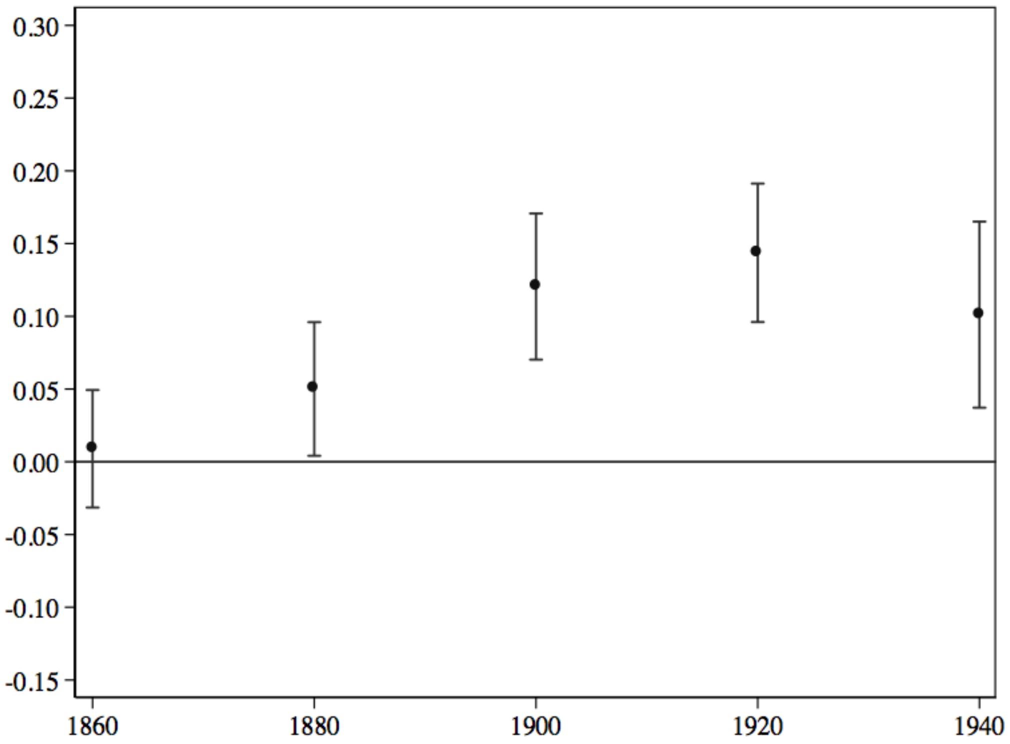
Figure 3: Engineering Density and Adoption of Different Technologies (US States)


Panel A
Panel B
Panel C

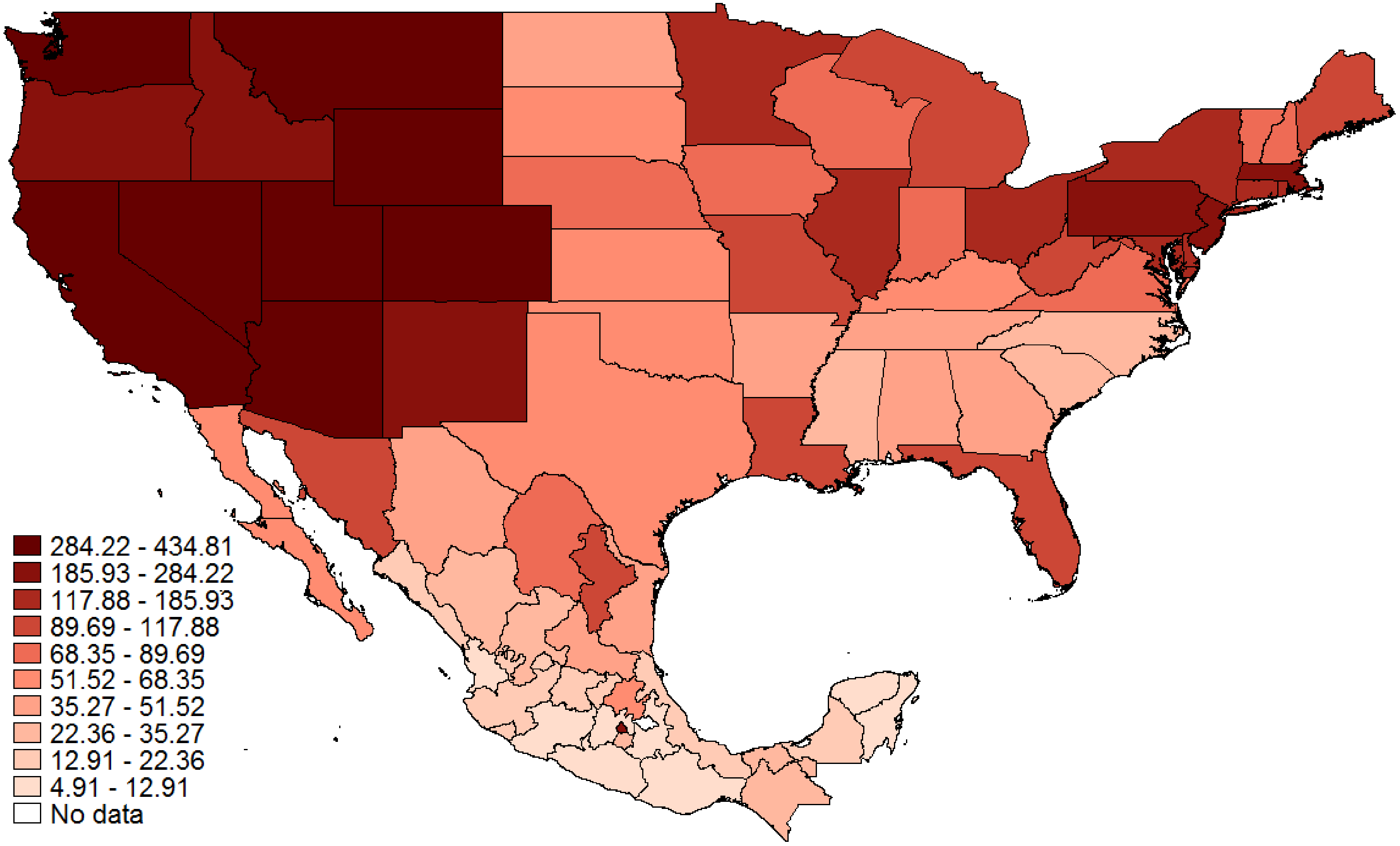
Note: US state level Engineering density in 1900 vs. A) Year in which hybrid corn cropland reached 10% B) Year in which tractor use achieved 10%, and C) Percentage of population living in homes with personal computer in 1993. All data is from Skinner and Staiger (2007).

Figure 4: Engineering Density on US Manufacturing Value 1860-1940



Note: The figure plots the coefficient of engineering density on manufacturing value added at 20 year intervals from 1860 to 1940, at the county level, for the US. Controls included are mentioned then. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Beta coefficients. Robust and clustered SE reported. Lines mark 95% confidence intervals.

Figure 5: Sub-national Engineering Density, US and Mexico, in 1900



Note: Engineering Density at the subnational level for North America. Derived from census reported engineers per 100,000 male workers around 1900.

Table 1: Summary Statistics (County Level, US)

Variable	**mean**	**p50**	**sd**	**min**	**max**	**obs**
Ln Income	10.043	10.032	0.219	9.165	11.360	1905
Engineers	0.022	0.000	0.038	0.000	0.299	1905
Patents	0.453	0.274	0.602	0.000	6.041	1905
Ln LGC distance	0.176	0.281	0.683	-5.450	1.765	1905
Rainfall	0.077	0.076	0.042	0.009	0.393	1905
Altitude	0.025	0.023	0.019	0.000	0.175	1905
Ruggedness	0.005	0.003	0.006	0.000	0.043	1905
Distance to river	0.017	0.014	0.014	0.000	0.141	1905
Average Temperature	-0.002	-0.006	0.061	-0.160	0.188	1905
Dist. from Coast	0.027	0.023	0.020	0.000	0.102	1905
Population Density	0.003	0.001	0.049	0.000	2.055	1905
Manufacturing GDP	0.042	0.018	0.066	0.000	0.576	1905
Slavery	0.153	0.019	0.215	0.000	0.925	1905
Farms per capita	0.105	0.110	0.038	0.000	0.698	1905
Railroads	0.584	1.000	0.493	0.000	1.000	1905
Literacy	0.759	0.829	0.203	0.151	1.000	1905
School Assistance 12-17	0.051	0.055	0.018	0.000	0.090	1905
Educational Score	0.073	0.073	0.019	0.035	0.168	1905
Lawyers	0.001	0.001	0.001	0.000	0.005	1905
Physicians	0.002	0.002	0.001	0.000	0.004	1905

Notes: Log Income per capita in 2000. Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 habitants. Dist. to LGC is distance to Land Grant College measured by distance between the near LGC and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Literacy share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Slavery to county level is taken from Nunn (2008). Lawyer density measured by lawyers per 100.000 individuals. Physicians density measured by physicians per 100.000 individuals. Mining is total mining output in 1860 in hundred thousand dollars. Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees celsius; Altitude measures the elevation of the capital city of the state in kilometers; and Rainfall captures total yearly rainfall in meters. Dist. to Coast is distance between the coast and the county centroid; Ruggedness of Terrain from Nunn & Puga (2012). Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS.

Table 2: Summary Statistics (State Level, Americas)

Variable	**mean**	**p50**	**sd**	**min**	**max**	**obs**
Ln Income	9.03	8.92	0.91	7.13	11.18	377
Engineers	23.38	11.00	30.08	0.00	84.00	275
Engineers (sub)	82.07	39.68	105.70	0.00	472.59	170
Population Density (1900)	41.06	4.44	243.20	0.00	3319.27	235
Population Density (1500)	8.88	2.00	26.13	0.00	392.34	365
Literacy	40.85	34.00	23.95	11.30	86.70	337
Literacy (sub)	49.06	39.96	30.10	4.60	98.31	175
Railroads	3.15	1.80	2.71	0.30	9.30	377
Railroads (sub)	65.12	48.54	57.46	5.16	309.20	49
South	0.15	0.00	0.36	0.00	1.00	111
Slavery	20.67	3.28	25.16	0.00	72.66	83
Lawyers	218.92	139.22	210.93	1.64	1156.44	114
Mine Output	0.47	0.12	1.06	0.00	6.49	45
Spain	0.81	1.00	0.39	0.00	1.00	390
Land Suitability	0.56	0.58	0.28	0.00	1.00	384
River Density	3.28	3.29	1.23	0.00	6.92	386
Average Temperature	19.97	20.40	5.83	2.38	29.00	332
Rainfall	1.28	1.10	0.95	0.00	8.13	332
Altitude	0.66	0.19	0.92	0.00	4.33	332
Dist. from Coast	0.87	0.91	0.12	0.45	1.00	383
Ruggedness	126.89	99.33	103.53	0.00	474.34	378

Notes: Log Income per capita in 2000 (PPP 2005 US dollars). Engineering density measured by engineers per 100.000 male workers. Engineering density measured by engineers per 100.000 male workers, sub-national. Engineering density measured by engineers per 100.000 male workers, sub-national, scaled by national estimates of engineering stock. Population density is number of individuals per square kilometer in 1900. Pre-colonial population density measures the number of natives per square kilometer in 1492. Literacy share of the population that is literate in 1900. Literacy share of the population that is literate in 1900, sub-national. Railroad density measured as miles of track per 1000 square kilometers. Railroad density measured as miles of track per 1000 square kilometers, sub-national. South is a dummy variable for whether the US state is a southern state according to the US census. Slavery is measured as a fraction of the population and is taken from Bergad (2008) and Nunn (2008). Lawyer density measured by lawyers per 100.000 individuals. Mining is total mining output in 1860 in hundred thousand dollars. Spain is a dummy for whether the country was a Spanish colony: Argentina, Chile, Mexico and Venezuela. Agriculture Suitability is an index of probability of cultivation given cultivable land, climate and soil composition, from Ramankutty, Foley and McSweeney (2002). Rivers captures the density of rivers as a share of land area derived from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees celsius; Altitude measures the elevation of the capital city of the state in kilometers; and Rainfall captures total yearly rainfall in meters, all are from Bruhn and Gallego (2011). Distance from the Coast from (Gennaioli et al., 2013); Ruggedness of Terrain from Nunn & Puga (2012)

Table 3: Engineering Capacity as a Determinant of Income (County Level, US)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS
Engineers	0.224***	0.288***	0.190***	0.148***	0.184***	0.126***	0.117***	0.0931***
	(0.0335)	(0.0403)	(0.0350)	(0.0287)	(0.0329)	(0.0284)	(0.0269)	(0.0248)
Rainfall	0.0263	0.0332	0.0298	0.0553	0.0290	0.0720	0.0816	0.135
	(0.0646)	(0.0741)	(0.0695)	(0.0707)	(0.0700)	(0.0640)	(0.0713)	(0.0807)
Altitude	-0.00452	-0.0183	0.0347	0.00555	0.0425	0.0186	-0.00955	-0.0698
	(0.0323)	(0.0758)	(0.0730)	(0.0784)	(0.0737)	(0.0714)	(0.0747)	(0.0691)
Ruggedness	-0.0810	-0.0825	-0.104	-0.0298	-0.115	-0.0770	-0.0335	-0.0204
	(0.0828)	(0.106)	(0.0911)	(0.0850)	(0.0894)	(0.0783)	(0.0788)	(0.0775)
River Dist.	0.0234	0.0142	0.0210	0.0181	0.0183	0.0329	0.0282	0.0291
	(0.0323)	(0.0311)	(0.0296)	(0.0271)	(0.0285)	(0.0286)	(0.0268)	(0.0278)
Temperature	-0.281***	-0.311***	-0.122*	-0.0101	-0.0787	-0.120*	-0.0314	-0.0750
	(0.0492)	(0.0501)	(0.0624)	(0.0534)	(0.0661)	(0.0663)	(0.0658)	(0.134)
Coast Dist.	-0.172***	-0.237***	-0.171***	-0.130**	-0.175***	-0.185***	-0.135***	-0.0730
	(0.0556)	(0.0489)	(0.0473)	(0.0527)	(0.0479)	(0.0467)	(0.0483)	(0.0895)
Pop. Density			0.0930***	0.0952***	0.0934***	0.0830***	0.0895***	0.0993***
			(0.00725)	(0.00671)	(0.00735)	(0.00882)	(0.00780)	(0.00832)
Manuf. Output			0.197***	0.176***	0.213***	0.185***	0.171***	0.120***
			(0.0443)	(0.0395)	(0.0430)	(0.0446)	(0.0416)	(0.0386)
Slavery			-0.1000	0.180	-0.0418	-0.0149	0.163	0.178**
			(0.0757)	(0.109)	(0.0770)	(0.0840)	(0.109)	(0.0681)
Railroad			0.162***	0.113***	0.144***	0.131***	0.110***	0.0949***
			(0.0343)	(0.0320)	(0.0327)	(0.0313)	(0.0306)	(0.0197)
Farms per capita			0.0100	0.00698	0.00230	0.0401	0.0259	-0.00261
			(0.0616)	(0.0441)	(0.0589)	(0.0596)	(0.0475)	(0.0349)
Literacy				0.462***			0.393***	0.502***
				(0.103)			(0.104)	(0.0723)
Secondary					0.119**		0.00151	0.0361
					(0.0516)		(0.0529)	(0.0486)
Tertiary						0.143***	0.0481	0.0572
						(0.0524)	(0.0434)	(0.0398)
Lawyers						0.136***	0.115***	0.119***
						(0.0389)	(0.0371)	(0.0343)
Physicians						-0.00169	-0.0464	0.0181
						(0.0438)	(0.0396)	(0.0301)
Observations	2,380	1,904	1,904	1,904	1,904	1,904	1,904	1,904
R-squared	0.192	0.241	0.318	0.366	0.323	0.351	0.377	0.490
FE	No	No	No	No	No	No	No	Yes

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Literacy is share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. Beta coefficients. Robust and clustered SE in parenthesis. State level fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Engineering Density as a Determinant of Patents (County Level, US)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	OLS	OLS	OLS	OLS	OLS	OLS	OLS
Engineers	0.318***	0.305***	0.181***	0.181***	0.182***	0.125***	0.124***
	(0.0423)	(0.0409)	(0.0294)	(0.0290)	(0.0295)	(0.0252)	(0.0250)
Rainfall		-0.181	-0.197	-0.196	-0.198	-0.142	-0.150
		(0.155)	(0.160)	(0.162)	(0.160)	(0.138)	(0.136)
Altitude		0.206*	0.207**	0.207**	0.205**	0.212**	0.210**
		(0.120)	(0.0921)	(0.0923)	(0.0926)	(0.0800)	(0.0773)
Ruggedness		-0.179	-0.182*	-0.181*	-0.178*	-0.165*	-0.173**
		(0.118)	(0.103)	(0.101)	(0.103)	(0.0896)	(0.0837)
River Dist.		-0.0195	0.0364	0.0363	0.0370	0.0376	0.0403
		(0.0469)	(0.0361)	(0.0363)	(0.0364)	(0.0324)	(0.0324)
Temperature		0.00860	0.00837	0.0113	-0.000773	0.0497	-0.0111
		(0.168)	(0.148)	(0.148)	(0.147)	(0.152)	(0.144)
Coast Dist.		-0.238**	-0.175**	-0.175**	-0.172**	-0.203***	-0.209***
		(0.0978)	(0.0780)	(0.0779)	(0.0785)	(0.0733)	(0.0750)
Pop. Density			0.0187**	0.0187**	0.0187**	0.0102	0.00850
			(0.00827)	(0.00828)	(0.00829)	(0.00726)	(0.00722)
Manuf. Output			0.493***	0.493***	0.488***	0.458***	0.450***
			(0.0684)	(0.0693)	(0.0672)	(0.0671)	(0.0672)
Slavery			-0.0945***	-0.0915***	-0.106***	-0.0713**	-0.140***
			(0.0327)	(0.0269)	(0.0299)	(0.0303)	(0.0319)
Farms per capita			-0.0595	-0.0597	-0.0540	-0.0260	-0.00967
			(0.0379)	(0.0385)	(0.0404)	(0.0325)	(0.0340)
Railroad			-0.0489	-0.0495	-0.0452	-0.0804**	-0.0689**
			(0.0332)	(0.0323)	(0.0320)	(0.0300)	(0.0293)
Literacy				0.00750			-0.141**
				(0.0451)			(0.0638)
Secondary					-0.0455		-0.0860**
					(0.0400)		(0.0353)
Tertiary						0.130***	0.166***
						(0.0359)	(0.0370)
Lawyers						0.189***	0.191***
						(0.0538)	(0.0521)
Physicians						-0.00601	0.0171
						(0.0349)	(0.0366)
Observations	1,904	1,904	1,904	1,904	1,904	1,904	1,904
R-squared	0.344	0.369	0.506	0.506	0.506	0.540	0.545
FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Dependent Variable is patents per 100 inhabitants (1900). Engineering density measured by engineers per 100,000 male workers. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Railroad is a identifier variable if the county has railroad. Literacy share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals.Engineers instrumented using log distance to nearest Land Grant College measured by distance between the near LGC and the county centroid, estimated by 2SLS. Beta coefficients. Robust and clustered SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In Column 5, the F statistic of the instrument's relevance is 14.023 with robust standard errors and 7.755 with robust and clustered to state level standard errors. Cragg-Donald F statistical is 20.34.

Table 5: Engineering and Patenting Capacity as Determinants of Income: Patents & IV (County Level, US)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) IV	(6) IV
Engineers			0.0989***	0.0789***	0.112***	0.108***
			(0.0257)	(0.0228)	(0.0255)	(0.0200)
Patents	0.137***	0.127***	0.116***	0.113***	0.131***	
	(0.0383)	(0.0363)	(0.0377)	(0.0353)	(0.0360)	
Rainfall	0.0864	0.149*	0.0804	0.149*	0.153*	0.132***
	(0.0754)	(0.0856)	(0.0743)	(0.0832)	(0.0829)	(0.0551)
Altitude	-0.0394	-0.0990	-0.0371	-0.0952	-0.108**	-0.0806*
	(0.0736)	(0.0635)	(0.0749)	(0.0662)	(0.0547)	(0.0431)
Ruggedness	-0.000979	0.00261	-0.00915	-0.000504	-0.00560	-0.0278
	(0.0755)	(0.0695)	(0.0773)	(0.0732)	(0.0669)	(0.0389)
River Dist.	0.0295	0.0267	0.0254	0.0247	0.0315	0.0372*
	(0.0267)	(0.0265)	(0.0254)	(0.0260)	(0.0272)	(0.0217)
Temperature	-0.0306	-0.0817	-0.0368	-0.0809	-0.0690	-0.0715
	(0.0654)	(0.131)	(0.0624)	(0.129)	(0.151)	(0.0770)
Coast Dist.	-0.120**	-0.0510	-0.124**	-0.0498	-0.0372	-0.0658
	(0.0501)	(0.0844)	(0.0496)	(0.0841)	(0.0846)	(0.0445)
Pop. Density	0.0888***	0.0985***	0.0889***	0.0985***	0.0949***	0.0961***
	(0.00738)	(0.00784)	(0.00774)	(0.00818)	(0.00834)	(0.0131)
Manuf. Output	0.128**	0.0719	0.123**	0.0695*	0.0632	0.124***
	(0.0489)	(0.0439)	(0.0471)	(0.0408)	(0.0452)	(0.0292)
Slavery	0.176	0.188**	0.177	0.193***	0.172**	0.153***
	(0.114)	(0.0707)	(0.111)	(0.0688)	(0.0693)	(0.0439)
Railroad	0.117***	0.103***	0.119***	0.103***	0.0880***	0.161***
	(0.0304)	(0.0200)	(0.0302)	(0.0196)	(0.0189)	(0.0435)
Farms per capita	0.000461	-0.0221	0.0275	-0.00204	-0.0315	-0.0368
	(0.0476)	(0.0352)	(0.0481)	(0.0348)	(0.0318)	(0.0243)
Literacy	0.409***	0.516***	0.399***	0.518***	0.514***	0.495***
	(0.107)	(0.0726)	(0.107)	(0.0732)	(0.0718)	(0.0548)
Secondary	0.0142	0.0484	0.0115	0.0472	0.0341	0.0233
	(0.0540)	(0.0494)	(0.0531)	(0.0488)	(0.0539)	(0.0340)
Tertiary	0.0324	0.0437	0.0251	0.0383	0.0399	0.0633**
	(0.0416)	(0.0379)	(0.0425)	(0.0383)	(0.0360)	(0.0321)
Lawyers	0.112***	0.113***	0.0937**	0.0980***	0.106***	0.135***
	(0.0399)	(0.0366)	(0.0385)	(0.0350)	(0.0389)	(0.0269)
Physicians	-0.0493	0.0166	-0.0440	0.0162	0.0146	0.0170
	(0.0390)	(0.0299)	(0.0383)	(0.0298)	(0.0293)	(0.0244)
Observations	1,904	1,904	1,904	1,904	1,904	1,904
R-squared	0.377	0.492	0.383	0.496		
FE	No	Yes	No	Yes	Yes	Yes
F statistical (robust)					13.75	13.75
F Cragg-Donald					19.95	19.95

Notes: Dependent Variable is log subnational income per capita (2000). Standardized Beta coefficients. Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from Univ.of Virginia Library.Railroad is a identifier variable if the county has railroad. Literacy share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. Engineers instrumented using log distance to nearest Land Grant College measured by distance between the near LGC and the county centroid, estimated by 2SLS. Beta coefficients. Robust and clustered SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In Column 5, the F statistic of the instrument's relevance is 13.75 with robust standard errors and 7.62 with robust and clustered to state level standard errors. State level fixed effects. Cragg-Donald F statistic is 19.99.

Table 6: Correlates of distance to Land Grand College: First Stage (County Level, US)

	Engineers	*Lawyers*	*Physicians*
Distance LGC 1862	-0.103***	-3.18e-05	0.0120
	(0.0370)	(2.74e-05)	(0.0417)
Observations	1,905	1,905	1,905
R-squared	0.011	0.003	0.000
Distance LGC 1890	-0.0461	7.85e-06	0.0344
	(0.0348)	(2.74e-05)	(0.0405)
Observations	1,905	1,905	1,905
R-squared	0.002	0.000	0.001

Notes: Engineering density measured by engineers per 100,000 male workers. Lawyer and Physician density measured per 100 individuals. *Distance LGC 1862 (1890)* is the log of distance between the near Land Grand College in 1862 (1890) and the county centroid. Robust and clustered SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Andrews (2017) Colleges and Losing Finalists (County Level, US)

	(1) OLS	(2) First Stage Engineers	(3) First Stage Lawyers	(4) First Stage Physicians	(5) IV
Engineers	0.136*				0.623*
	(0.0695)				(0.362)
Rainfall	-0.140	-0.0671	-0.125	0.0402	-0.110
	(0.100)	(0.177)	(0.100)	(0.0488)	(0.141)
Altitude	-0.787**	0.414	0.644***	0.230**	-0.974**
	(0.331)	(0.363)	(0.233)	(0.0969)	(0.406)
Ruggedness	0.319*	0.0790	-0.0746	-0.0507	0.284
	(0.167)	(0.147)	(0.0959)	(0.0373)	(0.183)
River Dist.	0.721	-1.533	-1.382*	0.175	1.422
	(1.173)	(1.003)	(0.715)	(0.254)	(1.340)
Temperature	0.0992	0.708***	0.368***	0.102***	-0.233
	(0.136)	(0.140)	(0.0854)	(0.0278)	(0.279)
Coast Dist.	-0.0806	0.350**	0.245***	0.162***	-0.241
	(0.101)	(0.144)	(0.0863)	(0.0307)	(0.181)
Pop. Density	-0.368***	-0.115	-0.0298	0.0393***	-0.283***
	(0.0389)	(0.0849)	(0.0391)	(0.0129)	(0.0835)
Manuf. Output	0.0722	0.132	-0.0433	-0.0129	-0.00464
	(0.0625)	(0.0844)	(0.0404)	(0.0146)	(0.0904)
Slavery	0.0556	0.0318	0.241**	0.0602	0.0560
	(0.210)	(0.167)	(0.119)	(0.0432)	(0.215)
Railroad	0.0646	0.109	0.0910*	0.0546***	-0.000860
	(0.107)	(0.0900)	(0.0541)	(0.0205)	(0.118)
Farms per capita	-0.401***	-0.601***	-0.434***	-0.0239	-0.115
	(0.115)	(0.113)	(0.0718)	(0.0262)	(0.254)
Literacy	0.587**	0.499**	0.630***	0.236***	0.362
	(0.245)	(0.229)	(0.158)	(0.0592)	(0.313)
Secondary	-0.299*	0.128	-0.00307	0.00595	-0.350*
	(0.171)	(0.141)	(0.0929)	(0.0402)	(0.191)
LGC 1862		0.0746**	0.00624	0.00487	
		(0.0305)	(0.0144)	(0.00558)	
Observations	202	202	204	204	202
R-squared	0.420	0.469	0.458	0.377	0.267

Notes: Dependent Variable is log subnational income per capita (2000). Standardized Beta coefficients. Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Literacy share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Engineers instrumented using a dummy for whether the county had a Land Grant college or not, estimated by 2SLS. Robust and clustered SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8: LASSO, Non-Engineers Income and Modern Engineers (County Level, US)

	(1) LASSO	(2) LASSO IV	(3) OLS	(4) OLS	(5) OLS
Engineers	0.0881***	0.107***	0.104***	0.0943***	0.0823***
	(0.0219)	(0.0203)	(0.0308)	(0.0267)	(0.0278)
Rainfall			0.0446	0.0945	0.127
			(0.100)	(0.0863)	(0.0908)
Altitude			-0.455**	-0.207	-0.187
			(0.189)	(0.147)	(0.142)
Ruggedness			0.0546	-0.0891	-0.0108
			(0.0884)	(0.0813)	(0.0781)
River Dist.			0.0375	-0.238	0.509
			(0.261)	(0.226)	(0.334)
Temperature			-0.0422	0.0391	-0.0360
			(0.176)	(0.180)	(0.144)
Coast Dist.			-0.261	-0.218	-0.0687
			(0.165)	(0.160)	(0.118)
Pop. Density			0.0239***	0.0152**	0.0957***
			(0.00489)	(0.00651)	(0.00656)
Manuf. Output	0.140***	0.145***	0.0629**	0.109***	0.0657*
	(0.0338)	(0.0344)	(0.0304)	(0.0277)	(0.0372)
Slavery			0.0985	0.0199	0.148**
			(0.0635)	(0.0522)	(0.0629)
Railroad	0.136***	0.118***	0.0863***	0.119***	0.0505***
	(0.0211)	(0.0214)	(0.0234)	(0.0251)	(0.0173)
Farms per capita	-0.0141	-0.0476*	0.00613	-0.0414	-0.0198
	(0.0256)	(0.0248)	(0.0326)	(0.0262)	(0.0371)
Literacy	0.390***	0.390***	0.299***	0.210***	0.426***
	(0.0482)	(0.0484)	(0.0630)	(0.0493)	(0.0722)
Secondary			0.0312	0.0406	0.0241
			(0.0497)	(0.0462)	(0.0482)
Tertiary	0.0867**	0.0921***	0.0145	0.0228	0.0157
	(0.0337)	(0.0336)	(0.0264)	(0.0242)	(0.0201)
Lawyers	0.118***	0.130***	0.0236	0.0259	0.211***
	(0.0265)	(0.0268)	(0.0537)	(0.0580)	(0.0517)
Physicians			-0.0251	0.0492	0.0221
			(0.0942)	(0.104)	(0.0944)
Modern Engineers					0.391***
					(0.0367)
Observations	1,904	1,904	1,699	1,751	1,751
R-squared			0.130	0.159	0.390
FE	Yes	Yes	Yes	Yes	Yes

*Notes: Dependent Variables are: log subnational income per capita (2000) (Columns (1), (2), and (5)), log subnational mean income for non engineers in 2010 (Column (3)) and and log subnational mean income for managers in 2010 (Column (4)). Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Literacy is share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. Modern Engineers is the proportion of employed in architecture and engineering in a county from 2010 census. Beta coefficients. Robust and clustered SE in parenthesis. *** p<0.01, ** p<0.05, * p<0.1*

Table 9: Intermediate Mechanisms through which Engineering affects GDP (1930, County Level, US)

	(1) *Value manuf. per capita*	(2) *Horsepower in manuf.*	(3) *Establishment per capita*	(4) *Retail stores per capita*	(5) *Wholesale sales per capita*	(6) *Bank Deposits per capita*	(7) *Banks per capita*
Engineers	0.0688**	0.0464**	0.0611**	0.0794**	0.0937***	1.559**	0.0145**
	(0.0258)	(0.0214)	(0.0271)	(0.0344)	(0.0298)	(0.687)	(0,00702)
Observations	1,745	1,722	1,745	1,884	1,761	1951	1951
R-squared	0.490	0.514	0.486	0.470	0.419	0,153	0,199
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Dependent Variable is log of: Value of Manufactured Products (Column 1), Horsepower in Manufacturing (rated capacity of prime movers of electric motors) (Column 2), Manufacturing Establishments (Column 3), Retail Distribution Stores (Column 4) and Net Sales of Wholesale Establishments in Thousands of Dollars (Column 5). Bank Deposits per capita and Bank Branches in Columns 6 and 7. Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Railroad is a identifier variable if the county has railroad. Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Literacy share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals.

Table 10: Modern Mechanisms through which Engineering affects GDP (County Level, US)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	High-tech Sectors			Knowledge Intensive Business Sectors			Investments in Technology		
	Payroll	Employment	Establishments	1930	1980	2010	PCs	Servers	IT budget
Engineers	82.87*	0.917**	0.995**	0.000762***	0.00137***	0.000800**	0.0525***	0.00857**	22.40***
	(44,83)	(0,43)	(0,37)	(0,0002)	(0,0003)	(0,0003)	(0,017)	(0,003)	(7,11)
Observations	1.754	1.754	1.754	1.854	1.799	1.853	1954	1954	1954
R-squared	0,132	0,158	0,192	0,162	0,189	0,195	0,106	0,09	0,084
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Independent Variable is: Engineering density measured by engineers per 100,000 male workers. Data on High-tech Sectors is from the County Business Patterns (2012). We use data on Payroll, Employment and number of Establishments in these sectors (Columns 1 to 3). Knowledge Intensive Business Sectors (KIBS) for 1930, 1980 and 2010 in Columns 4 to 6 are taken from Cermeño (2019). Investments in Technology are taken from the Ci Technology Database (2016). We use the number of Personal Computers, Servers and IT budget per capita (Columns 7 to 9).

Table 11: Innovative Capacity as a Determinant of Income (State Level, Americas)

	(1)	(2)	(3)	(4)	(5)	(6)
Engineering	0.1***	0.1***	0.07***	0.10***	0.1***	0.05**
	(0.04)	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)
Pop Density		0.07**	0.06***		0.1***	0.06***
		(0.03)	(0.02)		(0.04)	(0.01)
Literacy			0.4***			0.4***
			(0.13)			(0.10)
Area				-0.03	0.08	-0.04
				(0.06)	(0.05)	(0.04)
Ruggedness				-0.03	-0.06	-0.04*
				(0.05)	(0.04)	(0.02)
Rainfall				-0.1*	-0.1	-0.09
				(0.06)	(0.08)	(0.06)
Altitude				-0.03	-0.07	-0.03
				(0.05)	(0.06)	(0.05)
Landlocked				-0.02	-0.003	-0.02
				(0.03)	(0.02)	(0.04)
Constant	0.6	0.6	0.6**	0.5	0.5	0.6**
	(0.42)	(0.40)	(0.28)	(0.39)	(0.37)	(0.23)
N	170	166	166	160	156	156
N Countries	6	6	6	6	6	6
R^2	0.11	0.18	0.37	0.19	0.29	0.48

Notes: Dependent Variable is log subnational income per capita (2000). Data for Argentina, Chile, Colombia, Mexico, US and Venezuela. Engineering density measured by engineers per 100,000 male workers. Population density is log number of individuals per square kilometer in 1900. Literacy is share of the population that is literate in 1900. Beta coefficients. Bootstrapped clustered SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 12: Innovation Capacity Determinants (County Level, US)

	Engineers (1)	Patents (2)
Pop. Density	0.02***	0.3***
	(0.004)	(0.06)
South	-0.02***	-0.2***
	(0.004)	(0.05)
Slavery	-0.02***	-0.7***
	(0.005)	(0.07)
River distance	-0.09	-2.0
	(0.08)	(1.3)
Temperature	0.09***	0.3
	(0.03)	(0.6)
Rainfall	-0.08*	-1.2*
	(0.04)	(0.7)
Altitude	-0.09	3.9*
	(0.10)	(2.1)
Coast Distance	-0.06	-4.7***
	(0.06)	(0.9)
Ruggedness	0.5*	-16.7***
	(0.3)	(5.2)
N	1912	1907
R^2	0.140	0.231

Notes: Dependent Variable is innovative capacity measured by engineers per 100,000 male workers and patents per 100 inhabitants. Pre-colonial population density measures the number of natives per square kilometer in 1492. South a dummy capturing southern US states; slavery as tabulated from the 1860 Census as compiled in Nunn (2008). Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Geographical controls include river density, average temperature, rainfall, altitude, distance from a coast, and ruggedness of terrain. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Engineering Growth
Online Appendix: Electronic Supplementary Material

William F. Maloney & Felipe Valencia Caicedo

A Modeling the Microeconomics of Technological Adoption

Numerous models exist for modeling the micro economics of adoption. Comin et al. (2010b); Comin & Hobijn (2010); Comin et al. (2010a) for instance are closely aligned with the opening stylized facts about divergence at the intensive margin. Human capital shortfalls are embedded in a scalar that reflects barriers to adoption for the agent that adapts the technology to the idiosyncrasies of the country or for individual producers that find a profitable use for the technology. Howitt & Mayer-Foulkes (2005) further unpack this parameter and investigate the effects that introducing a new technology of scientific inquiry, such as happened in the Second Industrial Revolution, can have in generating convergence clubs of advancing and lagging countries or regions. To briefly sketch their argument, the probability that an entrepreneur innovates is

$$\mu_t = \lambda S_t^{\eta} z_t^{1-\eta} / \bar{A}_{t+1} \tag{1}$$

where λ represents the productivity of the innovation technology; S_t the skill level of the entrepreneur broadly construed; z_t the quantity of material inputs to the innovation process; and η the Cobb-Douglas exponent in the innovation technology. As in Howitt (2000); Aghion et al. (2005), the division by $\bar{A}_{t+1}$ represents a crucial "fishing out" effect where the more advanced the technological frontier, the more difficult it is to innovate. In turn $S_t = \xi A_t$ where ξ is the "effective education time," the product of schooling years and quality, and the multiplication by the local level of technological advance reflects an externality that in more advanced countries, teachers will be better versed in modern techniques, classrooms, curricula etc. are up to date and this will lead to more educational output per unit of effective education time.

$$\mu_t = \frac{\mu \frac{A_t}{\bar{A}_t}}{1+g} \tag{2}$$

which states that μ_t, the innovation rate, is function of overall competitiveness μ (which is in turn a function of policy distortion, incentives to innovate, overall profits, the incentive to save, and education.) The "normalized productivity", $A_t/\bar{A}_t$ captures increasing absorptive capacity with proximity to the frontier arising from the fishing out and education externalities. Finally, the denominator (1+g) captures the growth rate of the frontier and reflects that local skills are proportional to productivity this period, whereas the skill level required to innovate depends on the global frontier next period. Hence, the faster the growth of the frontier, the larger the effort necessary to maintain a constant innovation rate.[1]

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[1] μ is a measure of the country's "competitiveness" in the sense that a higher value of μ means more innovation for any given relative distance from the frontier and world growth rate.

$$\mu = \lambda^{\frac{1}{\eta}} \left[\frac{1-\eta}{1-\phi} \beta \pi \right]^{(\frac{1}{\eta})-1} \xi \tag{3}$$

where ϕ is a proxy for distortions and policies that impinge on the incentive to innovate and π is a profit parameter that suggests that in countries where geography, policies and institution make productivity higher, competitiveness rises, even if they do not affect the innovation process directly. Hence, μ is increased by the incentive to innovate, the profitability of innovation; the productivity of the innovation process, λ, the incentive to save β, and the quantity or quality of education ξ.

For our purposes, there are two key results. First, as the global technology frontier advances and becomes more complex, a country needs to increase its skill levels to prevent the erosion of its absorptive capacity and the offsetting of Schumpeterian gains from backwardness. Second, the introduction of a new method of technological change, loosely termed "modern R&D" such as culminated in the late 19th century with the modern R&D laboratory (the rise of institution such as government research agencies, scientific academies, universities with close to industry etc.) gives rise to the possibility of an important and discrete shift in $\lambda > \lambda$. However, only countries with with a threshold level of skill could undertake this "modern R&D"' and Howitt & Mayer-Foulkes (2005) show that this results in the emergence of three equilibria. Countries with a skilled enough labor force to undertake modern R&D immediately start growing faster. Countries with skills too low to do R&D but not too far behind will have the absorptive capacity to continue to implement foreign technologies, and will follow a growth path parallel to the first country, but with a magnified initial gap in level. Countries with even lower absorptive capacity will grow less than the common growth rate of the first two countries and diverge.[2]

B Construction of the Engineering Data

B.1 Argentina

The principal source is *Historia de la Ingeniería Argentina* (Centro Argentino de Ingenieros, 1981). At the end of the 19th century, there were three universities that granted the title of civil engineer which was their omnibus term for engineers- Buenos Aires, Cordoba and La Plata as well as a school of mining engineers in San Juan. The CAI documents that from 1870, the year when the first engineers graduated in the country, until 1900, 250 engineers received their diplomas. We do not know the distribution of these degrees across years so we impute uniform graduation rates after which the attrition adjustment leaves 196 or a density of 12.[3]

B.2 Bolivia

In Bolivia, the first engineering school, the Escuela Nacional de Ingenieria in Oruro, began in 1917 and hence Bolivia has 0 locally trained engineers by 1900. As late as 1937, 84% of engineers in the Patiõ Tin mines (accounting for 10 of world production) were foreign (Contreras, 1993).

B.3 Brazil

Telles (1994) *Historia da Engenharia no Brasil, Seculos XVI a XIX* is the principal source. In 1858 the Royal Academy of Artillery, Fortification and Drawing, established in Rio de Janeiro in 1792, dedicated itself to civil engineering for the first time, studying steam engines and railroads, and in 1874 it became independent of the Military and became the Polytechnical

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[2] Howitt (2000) offers a similar result of complete stagnation.

[3] A later data point is offered by Almada & Zalduendo (1962), which, when adjusted to be compatible with our data, yields a density of 41.25 in 1925. Given the rapid increase in output of engineers in the beginning decades of the 20th century in most countries, this supports our 1900 estimate.

School of Rio (today the School of Engineering of the Federal University of Rio de Janeiro). This was the dominant institution for training engineers. Brazil's second engineering school was founded around Mining in Ouro Preto. However, the low motivation for technical teaching of the time the school's isolation, among other social factors, made it difficult to recruit students and it graduated few. From 1894 to 1896 four new schools were started in Saõ Paolo, Pernambuco, Porto Alegre and Salvador. Telles (1994) suggestion that these schools would eventually end the Polytechnical School of Rio's monopoly confirms the dominance of the latter in the production of engineers up to that point. We do not, however, have a long time series on graduates from any program. Telles reports the average annual number of domestic engineering graduates in Brazil as a whole for the period after 1890 at 45 per year, half of them produced in Rio by 1900. To estimate graduation rates for the 1860-1890 period, we rely on evidence from reported stocks. Telles tabulates the number of engineers in Rio as reported in *Almanaque Laemmert*, a periodical dealing with governance, commerce and industry in Rio, for 1854, 1870, 1883 and from the official *Almanak dos Engenheiros* an official publication of the government for the whole country in 1906. In Rio in 1854, there were 6 engineers and in Saõ Paolo, the other principle locus of engineering talent, in 1857, there were 5. We therefore set 11 as our initial stock for the country in 1860. In 1870, the *Almanaque Laemmert* notes that Rio had grown to 28 engineers and by 1883, 126 (page 593). Given the rough earlier parity of Rio and Saõ Paolo in 1854-57, we double the Rio numbers figures to get national figures for these periods. While the Almanak may be overstating the stock by including non degreed engineers, the implicit graduation rate leading up to 1883 is roughly 15 per year which is substantially below Telles' documented graduation rate of 45 beginning in 1890. On the other hand, the consolidation of the Ouro Preto School of Mines and the new schools established after 1890 doubled whatever Rio's capacity was and that was likely substantially more in 1890 than prior. Hence, a three-fold increase over the last two decades seems plausible. We interpolate an average value between the known values of 1883-1890. Together, these lead to a total stock in 1900 of 786. If we extrapolate at the same graduation rate, the terminal stock in 1906 is 968 or slightly above the value reported by the official Almanak (941) suggesting that we may, again, be overstating the stock somewhat. Density 12.

B.4 Canada

McInnis (2004) is perhaps the most complete of a thin literature. Substantial engineering curricula had been introduced at King's College (UNB), at McGill College, and the University of Toronto in the 1850s although demand for engineering education gained traction only in the 1870s. McGill offered a full diploma course by 1863 although the first five students graduated only in 1874. Four year courses were implemented in Civil Engineering, Mechanical Engineering, Practical Chemistry and Mining by 1878, Electrical engineering in 1891, Chemical Engineering and Metallurgical Engineering in 1908. The University of Toronto School of Practical Science opened in 1878 and offered the degree of civil engineer in 1885. In 1874, Laval University established an Ecole Polytechnique which emitted its first graduates in 1877. Other smaller programs also emerged at the same time. Also of importance, The Royal Military College in Kingston Ontario, established in 1876, with West Point as a model, explicitly had the dual object of providing scientific training to military officers as well as producing civilian engineers.[4] If we take the discounted sum of the licensed graduates plus half the military graduates [5] by 1900 we reach a total density of about 41. This is relatively low by US standards especially given the number of institutions offering engineering courses, as well as the articulation of the different fields of engineering at a relatively early phase. The development of, for instance, mechanical engineering as a separate course about 20 years after in the US, Electrical Engineering 10-15 years after, but still far ahead of any of the Latin Universities in the sample. Electrical engineering appears more or less at the same time as in the US. It is worth noting, however, that the four principle Canadian Universities emitting graduates lay within a circle of 350 mile radius with Cornell at its center and including many of the principle US universities of the time. Density: 41

B.5 Chile

As Serrano (1993) notes in *Universidad y Nación: Chile en el Siglo IX*, training at the *Universidad de Chile* (University of Chile), the principal source of engineers in the 19th century, began in the mid-1850s. Prior to this, there were effectively no schools in Chile and those engineers trained abroad were very few. From 1846-50 there had been 2 fellowships to study abroad with uneven results. Serrano notes (p. 216) that between 1856 and 1879, 100 geographical engineers (surveyors/geographers), 61 mining engineers and 4 civil engineers plus 11 general assayers graduated. This gives us a graduation rate for the first 20 years of our exercise. To anchor the subsequent 20 years, Villalobos et al. (1990) collaborating with Serrano in *Historia de la Ingeniería en Chile*, offers that “in the 19th century there were 130 Chilean engineers and toward 1938, the country had a list of 270 professionals graduating from the University of Chile. They created, in 1930, the Institute of Mining Engineers of Chile ” (p. 198). The context may be taken to suggest that we are talking exclusively about mining engineers, although in personal communication, Serrano confirms that it is total graduated engineers. This is consistent with the fact that the implicit graduation rates from the pre -1879 period, 2.3 mining engineers per year, respectively accumulates to only half of the 130 number cited by Villalobos at end century. Clearly, this gap could be made up by a rapid expansion in number of graduates from 1879 on, but as Serrano notes, in 1867 the government expressed concern that the numbers of graduates in physical studies and mathematics was actually decreasing (page 212) so this would have represented a reversal in trend. Geographical engineers translate broadly as surveyors/geographers which are not generally treated as engineers per se and hence, to the degree that they are included in the 130 number, this overstates installed capacity. Density: 17.

B.6 Colombia

As Safford (1976) notes in his *The Ideal of the Practical: Colombia’s Struggle to Form and Technical Elite*, the process of establishing a technical class was undermined by recurrent civil wars which often whipsawed the ideological foundations of the schools when they were not closing them, and perennial shortages of funding. The *Universidad Nacional* (National

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[4] http://www.warmuseum.ca/education/online-educational-resources/dispatches/the-royal-military-college-of-canada-1876-to-the-present

[5] our thanks to Marvin McInnis for discussions on this

University), founded in 1867, was the dominant source of degreed engineers. It was built on the *Colegio Militar* (Military College) which operated over two brief periods, 1848-1854, and then in 1861. In the early 1880s, the Congress also authorized the creation of mining schools in Antioquia, Rionegro, Popayan and Ibague but most were aborted by the civil war of 1885. Safford (1976). The exception was the *Escuela Nacional de Minería* (National Mining School) in Antioquia set up in 1887 to 1895, that would eventually close due to a lack of financing, among other factors, and become part of the *Escuela de Ingeniería de la Universidad de Antioquia* (Engineering School of the University of Antioquia).[6] Poveda Ramos (1993) in *Historia Social de la Ciencias en Colombia: Ingeniería e Historia de las Técnicas* summarizes "By the end of the century, there were only three schools of engineering in Colombia: the *Universidad Nacional*, the *Escuela Nacional de Mineria*, and the *Universidad Republicana* (Republican University) in Bogota. The number of students was small, so much so that the National University, the largest of all, the number of students fluctuated from one year to another between 25 and 50."(p.55). The *Universidad Republicana* (now the *Universidad Libre* Free University) was begun in 1890 but it nearly collapsed financially by 1910 and its contribution to our accumulated stock is likely to be small. Facultad de Ingeniería (2011) tabulates that from 1868-1870 enrollments in the National University averaged 35 per year, yet graduates in the 1871-1875 period average about 4 per year. Though the authors note that their tabulations may not be complete, the virtual absence of graduates from 1876 to 1888 is plausible as from 1876 to 1884 the school was again taken over by the military and oriented away from industry related training. In 1880, despite 56 enrolled, higher mathematics and engineering classes contained only 4 students. (p. 195). In the National School of Mines, from 1887 to 1890 average enrollment was 25 students. Safford notes 63 alumnai of the 1888-1894 period, which is confirmed by Santa-Maria Alvarez (1994) as the number of "egresados" (exiters) of the program. However the same text notes that only five of these had graduated with thesis across the period (in 1893 and 1894) and none again until 1906 (Annex 5 page 103). Poveda Ramos (1993) confirms the lower numbers noting that the first 3 degrees of Mining Engineer were granted in 1893. The two schools together yield an accumulated stock of 75 Engineers by 1900. This is broadly consistent with Safford's finding of "more than 200 Colombian engineers and surveyors "in 1887 derived from the *Anales de Ingeneiría* (Annals of Engineering), the organ of the Colombian Engineering Association Safford (1976) page 219) which, again does not discriminate by whether or not the inscribed had completed a degree, nor separate out surveyors. However, we also know that both the University of Cauca as well as the Republican University in Bogota were generating some unknown quantity of graduates. We round to 100 as number that would incorporate these and missing graduates from Antioquia and the National University. Density: 5.

B.7 Denmark

The Polyteknisk Laereanstalt was founded in 1829 as the first university level technical school in Copenhagen and was one of the first of its kind in Europe and was heavily influenced by the French Ecole Polytecnique. Harnow (1997) in his study of the impact of engineers in Denmark only focuses on this school, arguing that from 1850 to 1920 it was by far the most important Danish technical institution. He tabulates the number of graduates across the period 1832-69 and then for roughly 10 year periods after. Taking the yearly graduation rate

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[6] Data also comes from the Consejo Prfesional de Ingenierìa https://www.copnia.gov.co/

as the average of each period and then applying the usual discounting yields a density of 92.

B.8 Ecuador

The *Escuela Politécnica Nacional* (National Polytechnical School) was founded in 1869 by the President Gabriel García Moreno with the aim of establishing a center for research and training of engineers and scientists at a high level. German Jesuits were brought for the purpose but the school was closed in 1876 for political reasons and was only reopened in 1935. This trajectory is not so different from that of Colombia's School of Mines, although that country had two other universities for more or less three times the population. We can't know the number of graduates of the program, over these seven years, but the density would have to be less that than of Colombia, including that until 1935 there was effectively no local training capacity which is part of what we're trying to capture here. `http://www.epn.edu.ec/index.php?option=com_content&view=article&id=1129&Itemid=378.` We assign a value of 2.

B.9 Mexico

The earliest technical training in Mexico was the *Colegio de Mineria* formerly the *Real Seminario de Mineria* (College of Mining, Royal Seminary of Mining) in Mexico city which opened in 1792 and was perhaps the most secular and highest quality technical institution in the hemisphere at the time. Bazant de Saldaña (1993) in her *Historia de la Educación Durante el Porfiriato* has best documented the subsequent evolution. Wars of independence, foreign invasion, and perilous fiscal situations led to a steady decline and by the time it was transformed into the into the *Escuela Nacional de Mineria* (National School of Mines) in 1867 under Benito Juarez, the number of students was so low that the government considered closing it and sending the 8-10 students abroad. Porfirio Diaz would subsequently put great emphasis on engineering as part of his modernization compaign. Despite this, by 1902, still only 18 engineers were graduating per year. Flows from the National School of Mines from 1876-1901 total 327. From 1876 to 1880 (41); 1881-1890 (106); 1891-1901 (180). Most other universities in other areas contributed very few. Allowing for another 16 years prior at the 1877 rate, which likely overstates the case, gives a total stock in 1900 of 336 or a surprisingly low density of 5. Other figures broadly corroborate. The census reports 884 engineers for Mexico city or roughly half the total that it reports for the entire country. Applying that ratio to the stock above gives 159. By comparison, Bazant cites the *Massey Blue Book*, an English language director of Mexico (City) as giving a total of 91 engineers and the *Directorio de Vecinos de la Ciudad de Mexico* as 183, both including some unspecified number of foreigners. The *Association de Ingenieros* (Engineering Association) in 1910 counted 255 members which, again, is not clear on the level of education of its members and may also include both the acceleration in graduation at the turn of the century in many countries. In all, the magnitudes do not suggest that our stocks are importantly underestimated. Density of 5.

B.10 Peru

Although there were institutions teaching technical skills in various parts of the country, modern engineering began in Peru in 1852 two French and one Polish engineer to design and undertake public works of engineering. The need to import talent for these tasks, as was the case elsewhere in Latin America, testifies to the dearth of locally generated qualified human capital. The first school of engineers was discussed in the early 1850s, but only became reality when the Peruvian sbtate in 1876 invited Polish engineer, Edward John Habich, to advise on irrigation, railways and other projects as well as the founding of a school of mines. Lopez Soria (2012) in *Historia de la Universidad Nacional de Ingenieria, los Años Fundamentales, 1876-1909* notes that the resulting School of Civil Construction and Mining Engineers (now the National Engineering University-Universidad National de Ingenieria) opened in 1876 and graduated its first class of 4 in 1880. The school was heavily damaged when used by the invading Chilean forces in 1880 and took several years to rebuild, only graduating one more student by 1882. Lopez Soria (2012) tabulates annual list of graduates going forward, disaggregated by specialty and allowing us to take out surveyors and include only industrial, mining and civil engineers, giving a total net of attrition of 100. This broadly confirms the statement by the *Sociedad de Ingeneiros Del Perù*(Peruvian Engineering Society) (established 1898) of "more than 80" engineers in the country. This gives us a density of 5.

B.11 Portugal

Formal training of non military engineering in Portugal did not begin until the turn of the 20th century with the Instituto de Lisboa (Institute of Lisbon) which started training industrial engineers in 1903 (Heitor et al), and the *Instituto Superior Técnico* (Higher Technical Institute) founded in 1917 Diogo (2007)). Hence, we are unable to generate a stock of graduates as in many of the other cases. Diogo argues, however, that military engineers were responsible for most civil engineering projects and hence military engineers should be counted in this case. The *Associação dos Engenheiros Civis Portuguezes - AECP* (Portuguese Association of Civil Engineers) also did register the majority of those who considered themselves non-military engineers. Though registration in the AECP was not mandatory to be a practicing engineer, it was mandatory in the organization that followed, the *Ordem dos Engenheiros (OE)* (Order of Engineers). In 1870 the AECP reports 150 inscribed; in 1926, 733. We take the average growth rate between the two points and impute the value for 1900. After 1900, we are able to compare the rates between the AECP and the mandatory OE: in 1930, there were 845 members (AECP) and in 1936, 1127 members (OE). Imputing the same growth rate between 1930 and 1936 as previous suggests that the AECP is understating the stock of practicing engineers by roughly 20%. We apply this to the stock value generated using the AECP data for 1900 to yield 579 or a density of 22. This is likely to be an overstatement since we do not know what fraction of these had any higher educational training.

B.12 Spain

We offer two estimates of the stock of Spanish engineers derived from Riera i Tuebols (1993) from 1867 *Industrialization and Technical Education in Spain, 1850-1914* and López et al. (2005) *Estadisticas Históricas de España: Siglos XIX-XX* from 1857. The estimates differ in scope. Riera i Tuebols reports graduates of *escuelas de ingeniería* engineering schools as such, starting with Spain's first, founded in Barcelona in 1867, to train industrial engineers (see also Riera, 2008). He also offers data from mining and civil engineer graduates primarily from institutions in Madrid. Though Riera's tabulations are the most accurate count of certifiably degreed engineers from university programs available, the resulting stock, 892, may be a lower bound. López et al. (2005) casts a broader net, including information from all technical schools (including *Escuelas Nacionales, Escuelas Superiores, Escuelas Especiales, Escuelas Centrales, Escuelas Profesionales and Escuelas Elementales*). Although this compendium is more comprehensive geographically, the estimates include graduates from other technical disciplines potentially miscategorized as engineers as well as including graduates of indeterminate level of training. We treat the resulting estimate of 3,089 as an upper bound. The Riera number is roughly half of the number of engineers and architects combined reported in the 1900 census. The Lopez is about 50% higher, which makes it the only case among our countries where the accumulated estimate is above that reported in the census. Since, as noted, self-reported census definitions are looser than documented degrees conferred, we find this improbable. Density either 12 or 42 respectively and we plot the average of the two. In our regressions, the Spanish influence is accounted for by a dummy so our results are unaffected by these estimates.

B.13 Sweden

The reference here is Ahlström (1993) who tabulates graduates of the two principal engineering programs. The Kungl Tekniska Högskolan (KTH) or Royal Technical University in Stockholm has roots in the Laboratorium Mechanicum founded in 1697, which later became the Mechanical school (1798). The Chalmers Institution in Gothenburg, founded in 1829, provided technical education equal to that of the KTH. Ahlström argues that in the mid 19th century, "...anyone in Sweden who sought an internationally reputable technical education could find it in these institutions." Density is 99.

B.14 United States

B.14.1 National Data

We draw on several sources for the US engineering numbers. First, Mann (1918), in his *Study of Engineering Education* done for the Joint Committee on Engineering Education, tabulated graduates from US schools until 1915. As of 1900 this gives a total of 14,679, which gives a density per 100,000 workers of 50. However, as Adkins (1975) in *The Great American Degree Machine: An Economic Analysis of the Human Resource Output of Higher Education* notes, before 1940, the Office of Education made no effort to maintain comparability across years or completeness of coverage of educational institutions. It is not clear how they identified the universe of relevant institutions and, if an institution did not respond to their survey two years in a row, it was dropped from the interview rolls. Hence, Mann's estimates underestimate the true stock by a potentially significant amount. To bring to bear other sources of information, we use more reliable graduation data in select states or periods to calibrate the Census numbers, and then impute engineering stocks for the country in 1900. First, Adkins' tabulations for the US in 1930 yield a stock that is .53 of the census declaration of occupations in engineering at that time. Second, Edelstein (2009) in *The Production of Engineers in New York Colleges and Universities, 1800-1950* offers a full and comprehensive stock accounting for the state of New York for our time period 1900. His tabulations yield a density of 179 which is .67 of the US census number corresponding to New York that year. It is likely that New York's number may have a higher density of fully degreed engineers self-reporting in the census than the country as a whole so this number may be somewhat high.

Similarly, Adkins' estimates for the whole country in 1930 may reflect that, in the ensuing 30 years, a higher share of self-declared engineers actually had degrees. Mann's numbers yield a ratio of .39 which we expect to be too low for the reasons outlined above. Hence, we take an intermediate value of .5 as the national ratio of actual graduates to Census declared engineers in 1900 and the data for the South and the North are projections based on this ratio. This yields a density of 84 for the entire country, 160 for the North, and 60 for the South.

B.14.2 County Data

Innovative capacity: As elsewhere we calculate density by engineers per 100.000 male workers. We use OCC1950 variable of IPUMS USA for 1880 census and we aggregate all categories for set up engineers: Engineering, chemical engineers, civil engineers, electrical engineers, industrial engineers, mechanical engineers, metallurgical and metallurgists engineers, mining engineers, and other engineers.[7] We use as proxy of male workers the 40% of population because there are inconsistencies in labor force variable. Patenting is the collected number of patents between 1890 and 1910 like proportion to 1880 population. Number of patents was collected from Akcigit et al. (2013) and include all patents granted by the USPTO.

Sub-national Income in 2005 US Dollars is the household mean income drawn from 2000 USA Census.

Geographical Controls: we include temperature, altitude and rainfall taken from Worldcrim. We use distance to river (distance between the county centroid to the near medium or big size river) derived from HydroSHEDS (USGS 2011). We employ a measure of distance to the coast calculated like distance between centroid and the near coast similar to Gennaioli et al. (2013). We further include a measured of ruggedness of terrain from Nunn & Puga (2012).

Growth variables: Population Density in 1880 as a measure of agglomeration is taken from the 1880 census data. As a measure of lagged economic activity, we calculate two measures using manufacturing output, taken from the 1870 NHGIS. Per capita yields a measure of structural transformation, per manufacturing output a measure of productivity. The extreme values and high variance of manufacturing employment suggests some lack of confidence in the 1880 labor allocation data so we report only the first measure. However, the results do not change appreciably using the other. We use slavery as a measure of institutions taken from the 1860 Census as well as Nunn (2008). For railroads, we employ two variables from the Nebraska-Lincoln University railroads data. An identifier variable if the county has railroad or a railroad density variable.

Human capital: Aggregate literacy rates we take from 1880 Census. As with engineers, we measured lawyers and physicians density per 100.000 habitants. We use the OCC1950 variable of IPUMS USA for 1880 census. Lawyers and Physicians categories are used from OCC1950.

Instrument: we compute the distance between the county centroid to the near the 57 1862 Land Grant Colleges.

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[7] Detailed at: `https://usa.ipums.org/usa/resources/volii/Occupations1950.pdf`

B.15 Venezuela

Mendez (2013) in *Historia de la Tecnología en Venezuela* notes that the *Universidad Central de Venezuela (UCV)* (Central University of Venezuela), as it would eventually be known, become the primary source of engineering graduates from 1867 on: 8 from 1867 to 1879 ; 80 from 1880 to 1889; 102 from 1890 to 1899. Other universities that graduated engineers were la *Universidad del Zulia* (University of Zulia) (1 in 1892) and the *Universidad de Valencia* (University of Valencia) (4 between 1892 y 1904); *Colegio Federal de Maracaibo* (Federal College of Maracaibo) 1886 (5) who submitted their these to the UCV for approval. To fill in the 1860-1866 period, we take the average of graduates from *Academia de Matemáticas de Caracas* (Academy of Mathematics of Caracas)from 1831 to 1872 (97 graduates) perhaps half of which were employed in civil or industrial work. Applying our usual discounting gives about 185 engineers. The engineering association gives 196 although this may include foreigners and members of undetermined educational attainment. Density: 11.

C Details on controls

C.1 Controls

As controls in our regressions, we also employ data on:

Literacy: Aggregate literacy rates we take from (Mariscal & Sokoloff, 2000; Núñez, 2005). Sub-national literacy rates for Argentina, Chile, Mexico, Venezuela, and the US taken from same census data as above. County level from 1880 census.

Secondary Schooling: Similar to Goldin & Katz (2011); Goldin (1999) for the US we construct a proxy for secondary schooling by the share of 14-17 years olds who report that they are attending school (1880 US census).

Higher Level Non-Engineering Human Capital: For the US, this is measured as number of lawyers and medical doctors per 100,000 inhabitants (US Census 1880). We also aggregate across occupational categories the EDSCOR50 measure that indicates the percentage of people in the respondent's occupational category who had completed one or more years of college. Together these allow us to ensure that our engineering measure is not proxying for the availability of higher order human capital in general.

Railroads: At the national level, we employ the density of railroads measured as kilometers of track per 1000 square kilometers in 1900 (Pachón & Ramírez, 2006; Thorp, 1998). At the sub-national level, we employ the Interstate Commerce Commission's data on miles of track per 100 square miles converted to the same units above for consistency in 1899 (ICC, 1899). Individual country sub-national data is not available for Latin America. At the county level we use an indicator variable showing the presence, or not, of a railroad.

Mining: For the US state level it is the total mining output in 1880 in $US 100,000.

Manufacturing output per capita: The value of manufactured products and labor in manufacturing in 1870 taken from NHGIS to compute the per capita and per unit of labor labor manufacturing product.[8]

Population Density in 1900: These are collected from census data from the individual countries. Argentina (1895), Brazil (1900), Chile (1907), Colombia (1912), Mexico (1895), Peru (1876), Venezuela (1926), and the US (1900).

Pre-colonial Population Density: This measures the estimated number of indigenous people per square kilometer just before colonization. See Maloney & Valencia (2016) for more detail.

Slavery: As a measure of institutions that is available for the United States sample, we used the 1860 Census as well as the data compiled in Nunn (2008).

Foreigners: Total foreign born people per capita taken from the 1880 census and University of Virginia Historical Census Browser (UVCB).

Agriculture: Total number of farms normalized by county population, taken from the 1880 census (UVCB).

Religion: Total churches at the county level, taken from the 1860 census. These censuses also distinguish by faith, including: Roman Catholic, Presbyterian, Methodist, Baptist, Christian, Union, Jewish and Episcopal. (UVCB)

Geographical Controls: in addition to the set of sub-national geographical variables collected by Bruhn & Gallego (2011) including temperature, altitude, and annual rainfall, we add a measure of agricultural suitability and river density as developed in Maloney & Valencia (2016). Distance to the coast as calculated by Gennaioli et al. (2013). We further include a measured of ruggedness of terrain from Nunn & Puga (2012).

C.2 Intermediate Mechanisms of Influence

The 1930 census allows us to generate several proxies for structural change, technological upgrading and entrepreneurship.

Structural change and technological upgrading: manufacturing value added per inhabitant, manufacturing establishments per capita, and horsepower per manufacturing firm. We follow value added from 1860 to 1930 using the corresponding censuses.

Entrepreneurship: Number of wholesale and retail stores per capita, net wholesale sales per capita.

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[8] `https://www.nhgis.org/documentation/gis-data`

C.3 Modern Mechanisms of Influence

Data for modern mechanisms comes from the County Business Patterns (2012), the Lexis/Nexis Ci Technology Database (2016), Cermeño (2018), and Skinner and Staiger (2007).

High-tech Sectors: Data on payroll, Employment and Number of Establishments is from the the County Business Patterns (2012).

Knowledge Intensive Business Sectors: For 1930, 1980 and 2010 are taken from Cermeño (2018). We thank Alexandra for sharing this data with us.

Technology Adoption: We use three indicators from Skinner and Staiger (2007).These are the year in which tractor use achieved %10, the year in which hybrid corn cropland reached 10% and the percentage of population living in homes with personal computer in 1993. We thank Diego Comin for granting us access.

Investments in Technology: Are taken from the Lexis/Nexis Ci Technology Database (2016). We use the number of Personal Computers, Servers and IT budget per capita.

C.4 Land Grant Colleges and Losing Finalists

Data on Land Grant Colleges along with losing finalists comes from Andrews (2019). Please refer to the paper for more details. More than any additional variable, what we do with his data is to restrict our sample to counties that eventually received Land Grant Colleges with their runner ups.

D Aggregate National Correlations

As a quick check of the relationship depicted in Figure 1, basic correlations suggest that these differences in engineering densities for 11 countries are indeed correlated with present income. Since we have population density and income variables at the subnational level, we run a simple regression as a panel and bootstrap the clustered SEs at the country level (the results also hold with simple OLS):

$$Y_{2005,ij} = \alpha + \gamma_E Eng_{1900_i} + \gamma_{pop} Pop_{1900,ij} + \gamma_R Rail_{1900_i} + \beta_L Lit_{1900,i} + \mu_i + \epsilon_{ij} \qquad (4)$$

where the variables are defined as above for country i and sub-national unit j: the dependent variable is income per capita today; the explanatory variables are Literacy, Engineering density in 1900, Railroad density in 1900, Population density in 1900, and a set of geographical controls. Table A1 shows that engineering in 1900 appears positive and significantly in explaining today's income per capita despite controlling sequentially and then together for population density and railroad density. Were we to include Denmark and Sweden, whose density we have confidence in, not to mention France and Germany, the results would be even stronger. Columns 4 suggests that with few observations, it is impossible to separate the impact of engineering and literacy although clearly in the US county level exercises, we do.

D.1 Consistency with Historical Evidence

Our engineering estimates are consistent with historical evidence. France and Germany were acknowledged leaders in the sciences and engineering. The relative positions of the two peripheral areas- Scandinavia vs. the Iberian peninsula correspond closely to the characterization of Landes (1998) and Bénabou et al. (2015) of their respective attitudes towards science and the Enlightenment. Both Sweden and Denmark's institutions of higher technical learning date from the 1700s and Sweden's high density is consistent with the characterization by Sandberg (1979) of the country as the "Impoverished Sophisticate."[9]

The US started relatively early and energetically in the training of engineers. The first institution of engineering education emerged from the Revolutionary War at West Point, established in 1802, which trained engineers for both military and civilian purposes and by 1862 there were roughly a dozen engineering schools in the East, but there were also schools as far west as Michigan and south as Maryland.[10] The passage of the Morrill Land Grant Act in 1862 led to an acceleration in the establishment of engineering programs, roughly sextupling the number in the decade after passage.[11] The period also saw a deepening, as the profession in the U.S. diversified further into sub-branches.The establishment of professional societies in Civil Engineering (1852), Mining (1871), Mechanical (1880) and Electrical (1884), testifies the the consolidation of a process of specialization and diversification. By 1890, a modern and world-class engineering profession was firmly established in the US.

Canada's innovative capacity is higher than that suggested by the density numbers since it was part of the greater New England scientific community. The four principal Canadian Universities emitting graduates- McGill, University of Toronto, *Ecole Polytechnique* in Montreal, and Queen's University in Kingston Ontario- lay within a circle of 350 mile radius with Cornell University at its center, and that includes many of the principal US departments of

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[9] The overproduction of engineers led many to emigrate to the US and 19^{th} century Swedish engineers are credited with inventing the blowtorch, ball bearings, ship propellers, the safety match, the revolver, the machine gun, dynamite, and contributing to the development of bicycles, steam turbines, early calculators, telephony (Ericsson) among others. We control for foreign immigration in Annex Table A14

[10] Subsequently the American Literary, Scientific and Military Academy at Norwich, Vermont awarded its first Civil Engineering degrees in 1837, and Rensselaer School in New York, in 1835. The Polytechnic College of the State of Pennsylvania, founded in 1853 granted degrees in Mechanical Engineering in 1854, and Mining Engineering in 1857.

[11] The Act led to the establishment of the Columbia School of Mines in 1864, Worcester Polytechnic in 1868, Thayer School of Civil Engineering at Dartmouth College in 1867, Cornell University as well as new universities in Iowa, Nebraska, Ohio, and Indiana. It also gave impetus to the foundation and consolidation of engineering schools in the South. As early as 1838 the University of Tennessee was teaching courses in Civil Engineering, but in 1879 it began awarding doctorate degrees in Civil and Mining Engineering. Texas A&M awarded its first degree in Civil Engineering in 1880, Virginia Tech in 1885 in Mining Engineering, and the University of Kentucky, although having an engineering program dating from 1869, graduated their first civil engineer in 1890. Auburn University in Alabama began its engineering program in 1872, and North Carolina State in 1887.

the time.[12]

The data for Latin America are consistent with the observation by Safford (1976) in his classic *Ideal of the Practical* that "Latin American societies in general, and the upper classes in particular, have been considered weak in those pursuits that North Americans consider practical, such as the assimilation, creation, and manipulation of technology and business enterprise in general"(p 3). Graham (1981) argues that Brazil, consistent with our estimates, lagged far behind the American South in every aspect of industrialization, transportation and agricultural technology. A long literature has focused on Argentina's weakness in innovation effort in comparison to countries such as Australia and Canada seen as similarly endowed (see, for example Diaz Alejandro, 1985; Duncan & Fogarty, 1986; Campante & Glaeser, 2009). The determined efforts of both these countries to achieve widespread literacy in the prairies had no analogue in Latin America, nor did the extensive expansion in the form of experiment stations and technical assistance. As Annex II documents, the national scientific establishments and professional training of civil engineers appeared much later and on a smaller scale. As an example, perhaps the richest country in Latin America at the time, Argentina, began graduating engineers only in 1870, and Peru, one of the premier mining centers of the hemisphere, in 1880, roughly on the same time line as Alabama. General engineering associations were set up in many countries around the same time that, in the US, associations in individual sub-fields were established.

E The US at the State Level

We now look more closely at the US sub-sample alone since the 1900 census offers several other correlates that allow us to test the robustness of the engineering results (Table A9). The cost of these additional covariates is the reduced number of observations (51). The geographic variables for this sample are not significant as a block and we drop them to preserve degrees of freedom.[13] The magnitudes of the remaining coefficients are not sensitive to this omission. In Columns 1-3, Engineering enters significantly freestanding, with population density, and literacy included sequentially and entering significantly and positively as before.

We test the robustness of this result in two ways. First, the US sample allows progressively adding a richer group of controls. Following Murphy et al. (1991) for the present day, in Column 4 we include the density of lawyers. This does not alter the magnitude of the engineering variable suggesting that we are not picking up simply higher order human capital. In Column 5 we add state-level measures of railroad density and mining activity which, again, capture infrastructure or industrial activity that engineering may be proxying for. The former enters significantly and positively although mining does not and engineering continues to remain significant and of similar magnitude.

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[12] Although the first graduates were in the 1870s, substantial engineering courses were in place by the 1850s. Further, the articulation of the different fields of engineering occurred later than in the US but not much. The development of, for instance, mechanical engineering as a separate course occurred about 20 years after in the US, and Electrical Engineering 10-15 years after.

[13] Given the small number of observations, we also bootstrap the standard errors. The results remain unchanged.

It is also possible that engineering is proxying for the institutional differences across states, and in particular, the legacy of slavery. We employ slavery data from Nunn (2008) which reduces our sample to 38 observations. Consistent with Nunn (2008), slavery alone (not shown) enters negatively and significantly. However adding engineering eliminates its importance, while engineering density itself remains strongly significant (Column 6). This suggests that weak engineering capacity is one possible channel through which the institution of slavery depressed southern incomes.[14]

Including all variables (Column 7) renders many insignificant although engineering prevails. Though we are pushing the data hard given the limited degrees of freedom, engineering retains its significance after controlling for agglomeration effects, other higher order human capital, sectors using engineers that may have an independent effect, and institutions.

Second, though we have controlled for the two activities most related to engineering, we also attempt to instrument engineering density using the number of Morrill Land Grant colleges and universities found in each state. As discussed earlier, the Morrill program was introduced in 1868 precisely to remedy the perceived shortfalls in regional technical assistance in agricultural and mechanical innovation. In practice, this program financed the first engineering departments in the emerging West and Midwest and especially in the South. It was to an important degree supply driven. Prior to the Civil War, the South had actively opposed the bill, fearing greater interference in matters such as universal primary education. The withdrawal of the Confederate States from the US Congress allowed the bill to be passed. However, during Reconstruction, recognizing its technological lag, the South started privately some universities such as Georgia Tech, and actively embraced the Morrill Program.

The first stage reveals a strong and negative correlation between engineering density and the Morrill uptake, suggesting the role of the program as a remedial supply side effort.[15] As discussed earlier, Morrill financed programs in Texas, Virginia, Kentucky, and North Carolina began awarding degrees in the 1880s and 1890s which means that their accumulated engineering stock would still be low in 1900. Table A10 presents the second stage results. Though we have few degrees of freedom, engineering enters significantly in all specifications despite sequential addition of agglomeration, literacy and lawyers as controls. The coefficient is significantly higher in all specifications suggesting that the instrument is, in fact, helping to overcome an important downward bias.

In sum, the various estimations offer support to the idea that higher order human capital and institutions related to engineering and science and technology at the turn of the 20th century plausibly are important to explaining present prosperity.

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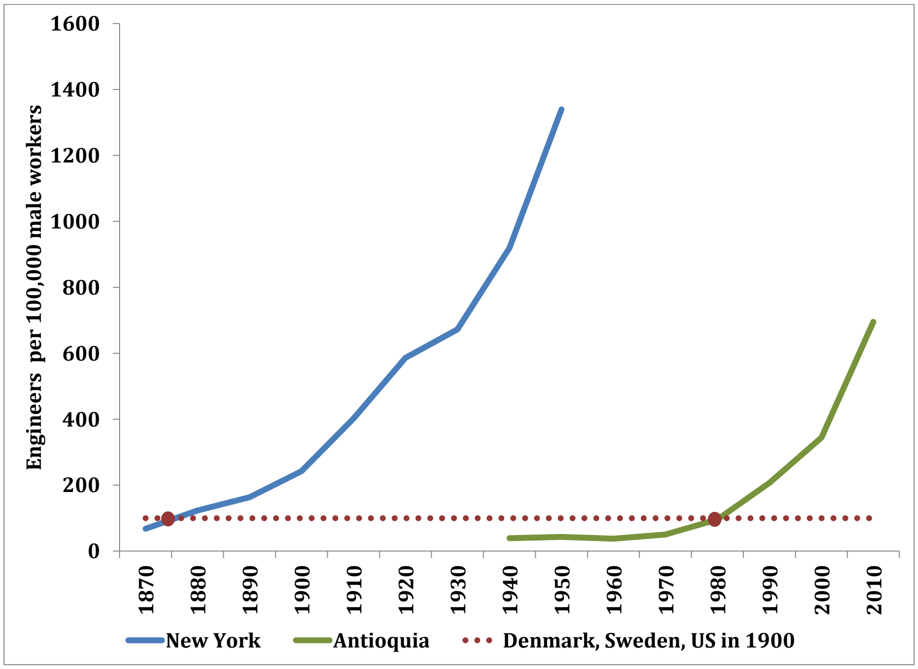
[14] Taking the parameter value on engineering from the most complete specification (Column 7), the difference in engineering density between the North and the South could account for a log difference of .12 or roughly 13 percent which is, in fact, larger than the difference that currently exists between the two regions.

[15] With 51 observations, this exercise is somewhat heroic and diagnostics should be taken as suggestive. Both the first stage Cragg-Donald F test and Anderson-Rubin test of joint significance of regressors are marginally acceptable suggesting that attempting to instrument is informative. Using the second wave 1890 Morrill grants yields stronger diagnostics although there is less clarity on the selection criteria and hence we prefer using the 1868 wave. Both yield similar second stage results.

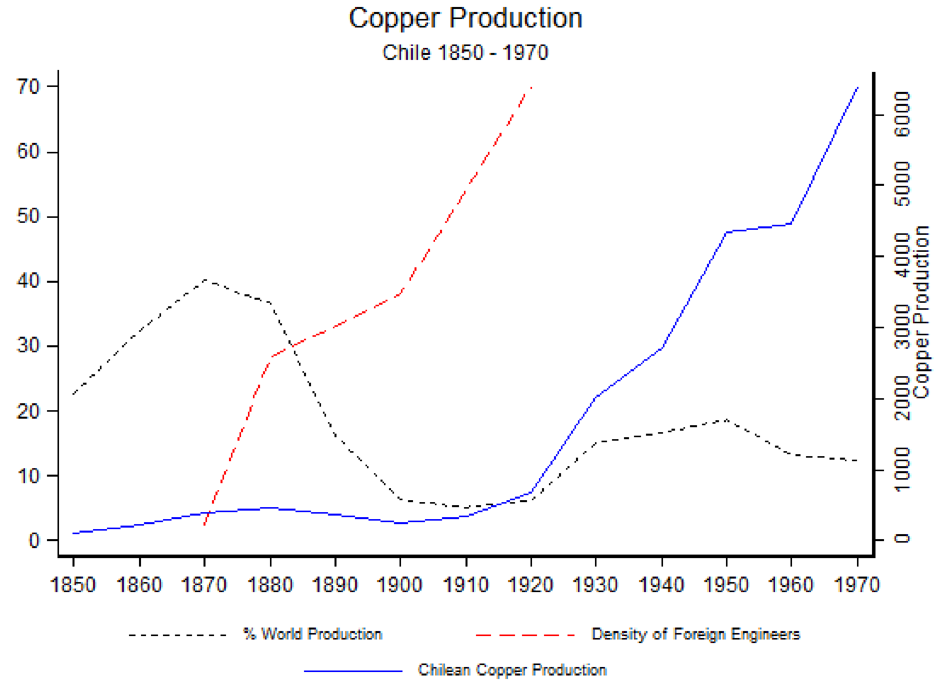
F Figures

Figure A1: Evolution of Engineering Density in Two Textile Producing Regions: New York and Antioquia, Colombia



Note: Estimates for the stock of engineering graduates in New York State and Antioquia in blue and green, respectively. Denmark, Sweden and US average for reference in a dashed red line, following our national sources as in Appendix B. Data is from Blank et al. (1957) and the Consejo Nacional Profesional de Ingenierìa, or Colombian National Engineering Association.

Figure A2: Copper Production in Chile and Foreign Engineers



Note: The figure shows the decline in Chilean production and share of the world market for Copper approaching 1900 and then the sharp recovery with the entrants of foreign mining companies and engineers in 1905. Engineering density per 100,000 male workers calculated from National Censuses available until 1920 when Chile ceased to divide by profession-origin.

G Tables

Table A1: Summary Regressions
Innovation Capacity (1900) vs Income per capita (2000)
National Level, Americas

	(1)	(2)	(3)	(4)	(5)
Engineering	0.9***	0.9**	0.9***	0.7	0.9***
	(0.35)	(0.36)	(0.30)	(0.61)	(0.31)
Pop Density		0.06*			0.06**
		(0.03)			(0.03)
Railroads			0.2		0.2*
			(0.16)		(0.14)
Literacy				0.2	
				(0.41)	
N	273	248	273	273	248
N Countries	11	11	11	11	11
R^2	0.82	0.82	0.88	0.83	0.88

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per 100,000 male workers. Population density is number of individuals per square kilometer in 1900. Railroad density measured as miles of track per 1000 square kilometers. Literacy share of the population that is literate in 1900. Beta coefficients. Robust and clustered SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A2: Heterogeneity of Impact of Engineering across Agriculture and Lawyers (County Level, US)

	(1)	(2)	(4)	(5)	(7)	(8)	(10)	(11)
	Lawyers				Agriculture			
	Below		Above		Below		Above	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Engineers	0.0932**	0.0870**	0.0647***	0.110***	0.0961***	0.115***	0.00567	0.0347
	(0.0390)	(0.0381)	(0.0236)	(0.0330)	(0.0267)	(0.0421)	(0.0214)	(0.0332)
Rainfall	0.0470	0.0579	0.131	0.135	0.178*	0.143*	0.0434	0.0615
	(0.137)	(0.128)	(0.0959)	(0.102)	(0.0907)	(0.0799)	(0.0840)	(0.105)
Altitude	0.0549	0.0373	-0.161**	-0.168***	-0.146**	-0.143***	0.0928	0.0853
	(0.0679)	(0.0712)	(0.0605)	(0.0546)	(0.0569)	(0.0447)	(0.0729)	(0.0705)
Ruggedness	-0.0607	-0.0637	0.0124	0.00723	0.0323	0.0212	-0.0767	-0.0917
	(0.0824)	(0.0879)	(0.106)	(0.103)	(0.101)	(0.0869)	(0.0635)	(0.0752)
River Dist.	0.0215	0.0341	0.00922	0.00947	0.0313	0.0395	0.00927	0.0119
	(0.0398)	(0.0445)	(0.0283)	(0.0278)	(0.0400)	(0.0397)	(0.0264)	(0.0287)
Temperature	-0.0335	-0.0259	-0.143	-0.132	-0.0638	-0.0361	-0.0635	-0.0676
	(0.211)	(0.204)	(0.120)	(0.125)	(0.179)	(0.156)	(0.128)	(0.145)
Coast Dist.	-0.182	-0.166	-0.00269	0.0109	-0.125	-0.0914	-0.0826	-0.0871
	(0.114)	(0.104)	(0.0751)	(0.0862)	(0.110)	(0.0774)	(0.0923)	(0.110)
Pop. Density	6.653*	0.179**	0.0973***	0.135***	0.0871***	0.107***	25.57***	0.339***
	(3.439)	(0.0890)	(0.0103)	(0.0151)	(0.0115)	(0.0146)	(4.853)	(0.0650)
Manuf. Output	0.0754	0.0589	0.00545	0.0114	0.0285	0.0193	0.166**	0.0729**
	(0.0688)	(0.0671)	(0.0560)	(0.0636)	(0.0434)	(0.0556)	(0.0683)	(0.0287)
Slavery	0.134*	0.135*	0.354***	0.261***	0.247**	0.246**	0.122*	0.105*
	(0.0671)	(0.0786)	(0.0723)	(0.0543)	(0.111)	(0.120)	(0.0669)	(0.0586)
Railroad	0.0633**	0.0528*	0.135***	0.128***	0.116***	0.0845***	0.0592*	0.0675*
	(0.0243)	(0.0272)	(0.0291)	(0.0268)	(0.0299)	(0.0237)	(0.0292)	(0.0358)
Farms per capita	0.0896*	0.0495	-0.0349	-0.0651	-0.0241	-0.0589	0.0129	0.00840
	(0.0514)	(0.0418)	(0.0388)	(0.0465)	(0.0678)	(0.0406)	(0.0230)	(0.0179)
Literacy	0.557***	0.574***	0.445***	0.360***	0.519***	0.516***	0.324***	0.350***
	(0.105)	(0.108)	(0.0867)	(0.0696)	(0.141)	(0.136)	(0.0666)	(0.0694)
Secondary	0.0478	0.0393	0.0131	0.00723	-0.00427	-0.00890	0.00596	0.00227
	(0.0629)	(0.0728)	(0.0559)	(0.0495)	(0.0705)	(0.0649)	(0.0449)	(0.0512)
Tertiary	-0.0130	-0.00591	0.0749	0.0624	0.0392	0.0348	-0.0211	-0.0222
	(0.0409)	(0.0373)	(0.0547)	(0.0460)	(0.0610)	(0.0520)	(0.0497)	(0.0556)
Lawyers	0.206***	0.0865***	0.0803**	0.0826**	0.200***	0.207***	-0.0292	-0.0302
	(0.0727)	(0.0334)	(0.0391)	(0.0372)	(0.0525)	(0.0552)	(0.0360)	(0.0375)
Physicians	0.0384	0.0503	0.0137	0.00462	0.0145	0.0102	-0.0187	-0.0219
	(0.0457)	(0.0421)	(0.0325)	(0.0313)	(0.0543)	(0.0478)	(0.0376)	(0.0464)
Patents	-0.000642	0.0155	0.156***	0.200***	0.107***	0.140***	0.182*	0.120*
	(0.0781)	(0.0504)	(0.0348)	(0.0421)	(0.0317)	(0.0370)	(0.0971)	(0.0625)
Constant	0.439***	0.00996*	-0.0268	-0.0242***	-0.0802	-0.0238***	1.175***	0.0191*
	(0.150)	(0.00512)	(0.0618)	(0.00506)	(0.0678)	(0.00668)	(0.240)	(0.0101)
Observations	952	952	952	952	952	952	952	952
R-squared	0.500		0.503		0.553		0.489	
FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Literacy is share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. To compute heterogeneous effects, Lawyers and Agriculture are divided by above and below the median. Beta coefficients. Robust and clustered SE in parenthesis. State level fixed effects. $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A3: Manufacturing in 1850 as correlate of distance to Land Grand College (County Level, US)

	Value of products...	How many Employed...	Capital Invested...	Value of homemade...
	... in manufacturing			
A. Dependent variable is the variable in the column				
Instrument	-4990.4	-7.918	-13605.4	-1214.5
	(57112.1)	(54.1)	(29818.3)	(756.0)
N	1388	1388	1388	1384
R^2	0.730	0.694	0.603	0.361
Controls	Yes	Yes	Yes	Yes
B. Dependent variable is the variable in the column per capita				
Instrument	0.571	-0.000576	-0.531	-0.0516
	(1.6)	(0.0009)	(0.4)	(0.03)
N	1388	1388	1388	1384
R^2	0.079	0.256	0.441	0.481
Controls	Yes	Yes	Yes	Yes

Notes: Dependent Variables are Value of Products in Manufacturing, Number of People Employed in Manufacturing, Capital Invested in Manufacturing and Value of Homemade Manufacturing. Variables in Panel A are the raw numbers and in Panel B, divided by population. Data is from the 1850 Census. The independent variable is the log distance to the nearest Land Grant College in 1862. Geographic and Weather controls as elsewhere. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A4: Manufacturing in 1860 as correlate of distance to Land Grand College (County Level, US)

	Value of products...	Cost of labor...	How many Employed...	Cost of raw materials...	Capital invested...	Num Establishments...
	... in manufacturing					
A. Dependent variable is the variable in the column						
Instrument	13997.1	14362.2	26.58	-17370.4	17876.2	-1.990
	(80579.9)	(18351.8)	(58.5)	(40716.0)	(47121.0)	(4.6)
N	1593	1593	1905	1593	1593	1593
R^2	0.692	0.633	0.583	0.728	0.564	0.513
Controls	Yes	Yes	Yes	Yes	Yes	Yes
B. Dependent variable is the variable in the column per capita						
Instrument	0.0757	0.572	0.000616	-0.956***	1.100	0.0000176
	(0.8)	(0.3)	(0.0008)	(0.3)	(1.2)	(0.0001)
N	1593	1593	1905	1593	1593	1593
R^2	0.505	0.308	0.439	0.542	0.190	0.198
Controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Dependent Variables are Value of Products in Manufacturing, Cost of Labor in Manufacturing, Number of People Employed in Manufacturing, Cost of Raw Materials in Manufacturing, Capital Invested in Manufacturing and Number of Manufacturing Establishments. Variables in Panel A are the raw numbers and in Panel B, divided by population. Data is from the 1860 Census. The independent variable is the log distance to the nearest Land Grant College in 1862. Geographic and Weather controls as elsewhere. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A5: First Stage using Instrument 1890 (County Level, US)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS	(9) OLS
LGC distance	-0.00751	-0.0613	-0.0409	-0.0193	-0.0212	-0.0162	-0.0157	-0.0174	-0.00237
	(0.05)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Rainfall		-0.0494	-0.0585	-0.0354	-0.0178	-0.0358	0.0479	0.0497	-0.0625
		(0.07)	(0.05)	(0.05)	(0.03)	(0.04)	(0.05)	(0.05)	(0.08)
Altitude		0.198^{***}	0.0406	0.102	0.0799	0.106	0.0477	0.0416	-0.00412
		(0.06)	(0.09)	(0.09)	(0.07)	(0.09)	(0.09)	(0.09)	(0.09)
Ruggedness		0.00982	0.0962^{*}	0.0185	0.0675^{*}	0.0126	0.0454	0.0566	0.0157
		(0.07)	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.06)	(0.08)
River Dist.		0.0170	0.0174	0.0119	0.00938	0.0100	0.0369	0.0365	0.0206
		(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Temperature		-0.00278	-0.0516	0.196^{*}	0.267^{**}	0.221^{*}	0.148	0.156	0.0542
		(0.08)	(0.08)	(0.1)	(0.1)	(0.1)	(0.10)	(0.1)	(0.2)
Coast Dist.		-0.182^{***}	-0.159^{**}	-0.0486	-0.0206	-0.0521	-0.0454	-0.0364	-0.0932
		(0.05)	(0.07)	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.06)
Pop. Density				0.0151	0.0161	0.0153	-0.00217	-0.00122	-0.000679
				(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)
Manuf. Output				0.346^{***}	0.324^{***}	0.357^{***}	0.266^{***}	0.260^{***}	0.218^{***}
				(0.04)	(0.04)	(0.05)	(0.03)	(0.04)	(0.05)
Slavery				-0.156^{**}	0.0365	-0.121^{**}	-0.0450	-0.0209	-0.0746^{*}
				(0.07)	(0.04)	(0.06)	(0.04)	(0.04)	(0.04)
Railroad				0.0732^{**}	0.0383	0.0640^{**}	0.0166	0.0152	0.0291
				(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Literacy					0.311^{***}			0.0735	-0.0761
					(0.07)			(0.05)	(0.06)
Secondary						0.0678		-0.0243	-0.0434
						(0.07)		(0.05)	(0.06)
Tertiary							0.167^{***}	0.153^{***}	0.133^{**}
							(0.05)	(0.05)	(0.06)
Lawyers							0.276^{***}	0.272^{***}	0.266^{***}
							(0.05)	(0.05)	(0.04)
Physicians							-0.0593	-0.0637	-0.00808
							(0.05)	(0.05)	(0.05)
N	2471	2471	1905	1905	1905	1905	1905	1905	1905
R^2	-0.000	0.080	0.038	0.169	0.191	0.170	0.264	0.264	0.310
State FE	No	No	No	No	No	No	No	No	Yes

Notes: Dependent Variable is Engineering density, measured by engineers per 100,000 male workers. The independent variable is the log distance to the nearest Land Grant College in 1890. Engineering density measured by engineers per 100,000 male workers. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Literacy share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A6: Excluding counties with any Land Grant College in 1862 (County Level, US)

	(1)	(2)	(3)	(4)	(5)
	OLS	OLS	OLS	OLS	IV
Engineers			0.0950***	0.0801***	0.111***
			(0.0266)	(0.0242)	(0.0311)
Patents	0.121***	0.108**	0.102**	0.0956**	0.115***
	(0.0441)	(0.0404)	(0.0419)	(0.0385)	(0.0388)
Rainfall	0.0861	0.145*	0.0815	0.146*	0.147*
	(0.0769)	(0.0849)	(0.0753)	(0.0816)	(0.0844)
Altitude	-0.0345	-0.0958	-0.0352	-0.0945	-0.106*
	(0.0743)	(0.0601)	(0.0765)	(0.0639)	(0.0548)
Ruggedness	-0.00321	0.00218	-0.0108	-0.000102	-0.00695
	(0.0769)	(0.0694)	(0.0795)	(0.0740)	(0.0682)
River Dist.	0.0324	0.0275	0.0293	0.0265	0.0340
	(0.0262)	(0.0266)	(0.0248)	(0.0262)	(0.0275)
Temperature	-0.0246	-0.0720	-0.0375	-0.0770	-0.0519
	(0.0659)	(0.161)	(0.0620)	(0.161)	(0.153)
Coast Dist.	-0.120**	-0.0539	-0.119**	-0.0490	-0.0365
	(0.0493)	(0.0870)	(0.0486)	(0.0868)	(0.0863)
Pop. Density	0.0904***	0.0988***	0.0905***	0.0988***	0.0940***
	(0.00758)	(0.00792)	(0.00793)	(0.00826)	(0.00855)
Manuf. Output	0.134***	0.0910*	0.116**	0.0794*	0.0836*
	(0.0458)	(0.0455)	(0.0455)	(0.0436)	(0.0441)
Slavery	0.177	0.187**	0.177	0.190***	0.172**
	(0.113)	(0.0693)	(0.112)	(0.0684)	(0.0669)
Railroad	0.114***	0.103***	0.111***	0.100***	0.0925***
	(0.0297)	(0.0201)	(0.0299)	(0.0200)	(0.0198)
Literacy	0.414***	0.516***	0.407***	0.520***	0.511***
	(0.105)	(0.0721)	(0.106)	(0.0726)	(0.0710)
Secondary	0.0185	0.0452	0.0186	0.0474	0.0246
	(0.0537)	(0.0527)	(0.0526)	(0.0518)	(0.0547)
Tertiary	0.0352	0.0486	0.0252	0.0401	0.0507
	(0.0414)	(0.0378)	(0.0425)	(0.0382)	(0.0361)
Lawyers	0.111***	0.115***	0.0902**	0.0971***	0.112***
	(0.0399)	(0.0357)	(0.0386)	(0.0339)	(0.0375)
Physicians	-0.0493	0.0126	-0.0440	0.0135	0.0126
	(0.0394)	(0.0301)	(0.0391)	(0.0301)	(0.0292)
Constant	-0.00538	-0.00528***	-0.00487	-0.00477***	0.00107***
	(0.0544)	(0.000787)	(0.0542)	(0.000816)	(0.000230)
Observations	1,872	1,872	1,872	1,872	1,872
R-squared	0.368	0.484	0.374	0.488	
FE	No	Yes	No	Yes	Yes

Notes: Dependent Variable is log subnational income per capita (2000). Standardized Beta coefficients. Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Literacy share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. Engineers instrumented using log distance to nearest Land Grant College measured by distance between the near LGC and the county centroid, estimated by 2SLS. Beta coefficients. Robust and clustered SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. In Column 5, the F statistic of instrument's relevance is 13.75 with robust standard errors and 7.62 with robust and clustered to state level standard errors. State level fixed effects. Cragg-Donald F statistical is 19.99.

Table A7: Innovative Capacity as a Determinant of Income (US, State Level)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Engineering	0.06***	0.09***	0.05***	0.04**	0.07***	0.1***	0.1***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.05)	(0.04)
Pop Density		0.1***					-0.02
		(0.03)					(0.06)
Literacy			0.1*				0.4
			(0.06)				(0.32)
Lawyers				0.04			-0.05
				(0.05)			(0.05)
Railroads					0.1***		0.08
					(0.02)		(0.05)
Mining					-0.02		-0.03***
					(0.01)		(0.01)
Slavery						-0.004	0.2
						(0.06)	(0.14)
South						-0.001	-0.02
						(0.04)	(0.03)
N	51	51	51	51	44	38	34
R^2	0.14	0.40	0.17	0.17	0.47	0.41	0.60

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per 100,000 male workers. Population density is log number of individuals per square kilometer in 1900. Literacy share of the population that is literate in 1900. Lawyer density measured by lawyers per 100.000 individuals. Institutional Controls: Slavery and South; Railroad density measured as miles of track per 1000 square kilometers. Mining is total mining output in 1880 in US 100,000 dollars. Beta coefficients. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A8: Innovative Capacity as a Determinant of Income (US State Level, Instrumented)

	(1)	(2)	(3)	(4)	(5)
Engineering	0.1***	0.1***	0.09**	0.1**	0.2***
	(0.03)	(0.03)	(0.04)	(0.05)	(0.07)
Pop Density		0.1***			0.2***
		(0.03)			(0.05)
Literacy			0.08		-0.06
			(0.07)		(0.10)
Lawyers				-0.005	-0.05
				(0.07)	(0.05)
N	51	51	51	51	51
R^2	0.02	0.29	0.12	0.01	0.11

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per male workers. Population density is log number of individuals per square kilometer in 1900. Literacy share of the population that is literate in 1900. Lawyer density measured by lawyers per 100.000 individuals. Engineers instrumented using the number of Land Grant colleges in a state, estimated by 2SLS. Beta coefficients. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A9: LASSO, Non-Engineers Income and Modern Engineers (County Level, US, without FEs)

	(1)	(2)	(3)	(4)	(5)
	LASSO	LASSO IV	OLS	OLS	OLS
Engineers	0.117***	0.145***	0.149***	0.119***	0.111***
	(0.0244)	(0.0224)	(0.0322)	(0.0246)	(0.0267)
Rainfall			0.0338	0.0710**	0.0580*
			(0.0383)	(0.0346)	(0.0320)
Altitude			-0.231**	-0.0624	-0.0940
			(0.108)	(0.0847)	(0.0844)
Ruggedness			0.0844*	-0.0593	-0.0174
			(0.0483)	(0.0433)	(0.0387)
River Dist.			0.0822	-0.231	0.476*
			(0.285)	(0.240)	(0.279)
Temperature			0.102**	0.196***	-0.0224
			(0.0402)	(0.0347)	(0.0399)
Coast Dist.			-0.358***	-0.292***	-0.0797**
			(0.0419)	(0.0370)	(0.0326)
Pop. Density			0.0226***	0.0127**	0.0926***
			(0.00369)	(0.00602)	(0.00713)
Manuf. Output	0.212***	0.203***	0.106***	0.137***	0.109***
	(0.0289)	(0.0300)	(0.0250)	(0.0204)	(0.0238)
Slavery			0.122***	0.0333	0.133***
			(0.0443)	(0.0390)	(0.0398)
Railroad	0.141***	0.107***	0.0785***	0.119***	0.0687***
	(0.0215)	(0.0217)	(0.0236)	(0.0219)	(0.0202)
Farms per capita	-0.0502*	-0.0930***	-0.0117	-0.0364	0.00612
	(0.0283)	(0.0295)	(0.0362)	(0.0252)	(0.0266)
Literacy	0.224***	0.229***	0.328***	0.156***	0.341***
	(0.0337)	(0.0342)	(0.0511)	(0.0466)	(0.0461)
Secondary			-0.0129	-0.00349	0.0153
			(0.0393)	(0.0351)	(0.0336)
Tertiary	0.0467	0.0573*	0.0263	0.0230	0.00890
	(0.0334)	(0.0331)	(0.0245)	(0.0221)	(0.0216)
Lawyers	0.0669***	0.0944***	0.0584	0.0260	0.203***
	(0.0250)	(0.0254)	(0.0502)	(0.0444)	(0.0483)
Physicians			-0.183**	-0.0539	-0.231***
			(0.0855)	(0.0801)	(0.0742)
Modern Engineers					0.412***
					(0.0257)
Observations	1,904	1,904	1,699	1,751	1,751
R-squared			0.273	0.268	0.475
State FE	No	No	No	No	No
F statistical		13.75			
F Cragg-Donald		19.95			

*Notes: Dependent Variables are: log subnational income per capita (2000) (Columns (1), (2), and (5)), log subnational mean income for non engineers in 2010 (Column (3)) and and log subnational mean income for managers in 2010 (Column (4)). Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Literacy is share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. Modern Engineers is the proportion of employed in architecture and engineering in a county from 2010 census. Beta coefficients. Robust and clustered SE in parenthesis.*** p<0.01, ** p<0.05, * p<0.1*

Table A10: Mechanisms through which Engineering in 1900 Drives Income in 2000 (Country Level)

	All Countries	New World
Inputs		
R&D/GDP	0.94	0.96
Firm Innovative Capacity	0.94	0.94
Modern Management	0.93	0.93
Outputs		
Patents	0.95	0.98
Technological Adoption	0.84	0.94

Notes: Table reports the correlation between engineering density in 1900 and three inputs and two outputs in the 2000. Inputs: 1. R&D expenditures as a share of GDP. 2. Firm capacity for innovation ranging from pure licensing to pioneering their own new products and processes. "In your country, how do companies obtain technology? [1 = exclusively from licensing or imitating foreign companies; 7 = by conducting formal research and pioneering their own new products and processes]. 3. A globally consistent measure of management quality from Bloom & Van Reenen (2010) and in particular, the sum of the scores on the two the questions dealing with how firms identify new production processes to adopt. On the output side, we have 1. Comin & Hobijn (2010); Comin & Ferrer (2013); Comin et al. (2008)'s measure of technological adoption at the extensive margin, averaging their industrial and sectoral scores and 2. patent applications filed under the Patent Cooperation Treaty (PCT) per million population as tabulated by the World Economic Forum (2008-9)(World Economic Forum et al., 2012).

Table A11: Innovation Capacity Determinants (County Level, US)

	Engineers (1)	Patents (2)
Population Density	0.01***	0.2**
	(0.004)	(0.07)
South	-0.010***	-0.1**
	(0.004)	(0.06)
Slavery	-0.02***	-0.6***
	(0.006)	(0.08)
River distance	0.02	-0.3
	(0.09)	(1.3)
Temperature	0.1***	1.3*
	(0.04)	(0.7)
Rainfall	-0.04	-0.6
	(0.06)	(0.8)
Altitude	-0.2	1.3
	(0.1)	(2.7)
Coast Distance	0.04	-3.1***
	(0.06)	(0.9)
Ruggedness	0.7**	-9.5
	(0.3)	(6.0)
Foreigners	0.001***	0.01***
	(0.0002)	(0.003)
Churches	-1.9	-52.7***
	(1.2)	(11.5)
N	1659	1662
R^2	0.220	0.292

Notes: Dependent Variable is innovative capacity measured by engineers per 100,000 male workers and patents per 100 inhabitants. Pre-colonial population density measures the number of natives per square kilometer in 1492. South a dummy capturing southern US states; slavery as tabulated from the 1860 Census as compiled in Nunn (2008). Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Foreigners is born people per capita taken from the 1880 census and University of Virginia Historical Census Browser (UVCB). Churches per capita at the county level, taken from the 1860 census. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A12: Additional Controls for Religion and Immigration (County Level, US)

	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS	(7) OLS	(8) OLS
Engineers	0.223***	0.291***	0.156***	0.129***	0.150***	0.102***	0.103***	0.0866***
	(0.0370)	(0.0363)	(0.0357)	(0.0315)	(0.0357)	(0.0345)	(0.0322)	(0.0269)
Rainfall		0.0116	0.0199	0.0403	0.0217	0.0538	0.0622	0.145*
		(0.0820)	(0.0694)	(0.0737)	(0.0717)	(0.0679)	(0.0732)	(0.0731)
Altitude		-0.0393	-0.0200	-0.0349	-0.0232	-0.0275	-0.0382	-0.0731
		(0.0940)	(0.109)	(0.109)	(0.108)	(0.104)	(0.104)	(0.0794)
Ruggedness		-0.0299	-0.0364	0.0188	-0.0400	-0.0132	0.00642	-0.0220
		(0.116)	(0.108)	(0.0950)	(0.105)	(0.0926)	(0.0892)	(0.0897)
River Dist.		0.0229	0.0289	0.0186	0.0249	0.0364	0.0272	0.0290
		(0.0294)	(0.0305)	(0.0291)	(0.0286)	(0.0300)	(0.0287)	(0.0265)
Temperature		-0.307***	-0.0854	0.0105	-0.0328	-0.0692	0.00158	0.00253
		(0.0615)	(0.0704)	(0.0580)	(0.0698)	(0.0670)	(0.0651)	(0.154)
Coast Dist.		-0.275***	-0.183***	-0.149**	-0.179***	-0.195***	-0.154***	-0.0615
		(0.0444)	(0.0549)	(0.0611)	(0.0564)	(0.0527)	(0.0556)	(0.0835)
Pop. Density			0.0898***	0.0930***	0.0893***	0.0800***	0.0873***	0.0937***
			(0.00827)	(0.00774)	(0.00843)	(0.0105)	(0.00950)	(0.0111)
Manuf. Output			0.161***	0.154***	0.180***	0.163***	0.160***	0.0996**
			(0.0543)	(0.0478)	(0.0525)	(0.0527)	(0.0492)	(0.0464)
Slavery			-0.115	0.130	-0.0477	-0.0243	0.128	0.182**
			(0.0752)	(0.122)	(0.0874)	(0.0940)	(0.125)	(0.0707)
Railroad			0.140***	0.100***	0.128***	0.117***	0.0935***	0.0800***
			(0.0348)	(0.0325)	(0.0331)	(0.0323)	(0.0313)	(0.0204)
Farms per capita			-0.0148	-0.00504	-0.0148	0.0345	0.0238	0.0241
			(0.0613)	(0.0499)	(0.0607)	(0.0588)	(0.0537)	(0.0457)
Churches per capita			-0.0196	-0.0190	-0.0126	-0.000975	-0.00473	-0.0207
			(0.0443)	(0.0343)	(0.0433)	(0.0386)	(0.0346)	(0.0248)
Foreigners per capita			0.0917	0.0662	0.111	0.107	0.0741	0.134
			(0.0846)	(0.0746)	(0.0854)	(0.0880)	(0.0852)	(0.0869)
Literacy				0.406***			0.335***	0.500***
				(0.111)			(0.108)	(0.0808)
Secondary					0.127**		0.0231	0.0819
					(0.0604)		(0.0622)	(0.0570)
Tertiary						0.119**	0.0356	0.0696
						(0.0532)	(0.0458)	(0.0448)
Lawyers						0.116***	0.111***	0.124***
						(0.0403)	(0.0408)	(0.0406)
Physicians						0.0247	-0.0297	0.0419
						(0.0539)	(0.0484)	(0.0320)
Observations	2,380	1,656	1,656	1,656	1,656	1,656	1,656	1,656
R-squared	0.077	0.274	0.345	0.379	0.351	0.371	0.388	0.501
FE	No	No	No	No	No	No	No	Yes

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per 100,000 male workers. Patents density measured by patents per 100 inhabitants. Rainfall captures total yearly rainfall in meters; Altitude measures the elevation of the capital city of the state in kilometers; Ruggedness of Terrain from Nunn & Puga (2012); Rivers captures the distance between the near river and the county. Rivers taken from HydroSHEDS (USGS 2011). Temperature is a yearly average in degrees Celsius; Dist. to Coast is distance between the coast and the county centroid. Population density is number of individuals per 100 square kilometers in 1880. Manuf. Output is the manufacturing output per capita in 1880 taken from NHGIS. Slavery to county level is taken from Nunn (2008). Farms per capita is the number of farms per capita retrieved from University of Virginia Library. Railroad is a identifier variable if the county has railroad. Foreigners is born people per capita taken from the 1880 census and University of Virginia Historical Census Browser (UVCB). Churches per capita at the county level, taken from the 1860 census. Literacy is share of the population that is literate in 1880. Secondary is share of 14-17 years olds who report that they are attending school. Tertiary is percentage of workers who report completing one or more years of college. Lawyer and Physician density measured per 100 individuals. Beta coefficients. Robust and clustered SE in parenthesis. State level fixed effects. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

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