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Engineers, Innovative Capacity and Development in the Americas

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Abstract

Using newly collected national and sub-national data, and historical case studies, this paper argues that differences in innovative capacity, captured by the density of engineers at the dawn of the Second Industrial Revolution, are important to explaining present income differences, and, in particular, the poor performance of Latin America relative to North America. This remains the case after controlling for literacy, other higher order human capital, such as lawyers, as well as demand side elements that might be confounded with engineering. The analysis then finds that agglomeration, certain geographical fundamentals, and extractive institutions such as slavery affect innovative capacity. However, a large effect associated with being a Spanish colony remains suggesting important inherited factors.

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Engineers, Innovative Capacity and Development in the Americas*

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

—Andrew Carnegie[1]

1 Introduction

Carnegie's taunt to the owners of the Birmingham Steel Company in Alabama highlights the complexity of technological transfer to lagging regions. As Wright (1986) documents, shortfalls in management, learning by doing, and the R&D capacity necessary to adapt technologies to local conditions all impeded the establishment of a dynamic steel (and textile and lumber) industry in the American South, and hence slowed catch-up to the North. The issue of differential technological transfer remains central to the more general convergence debate.[2] Most recently Comin et al. (2008); Comin & Ferrer (2013) argue that the diverging measured intensity of use of new technologies (as a share of economic activity) 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). That human capital is a critical ingredient in technology adoption also enjoys a substantial supporting literature.[3]

The nature of the relevant human capital has been less clear. Literacy and accumulated years of schooling/enrollment have received the most attention, although other dimensions figure importantly in the literature as well: Lucas (1993); Young (1993) and Foster & Rosenzweig (1995), among others, stress the importance of accumulated "learning by doing"; Baumol (1990) and Murphy et al. (1991), entrepreneurial skills and orientation;Mokyr (2005), the minority of "trained engineers, capable mechanics and dexterous craftsmen on

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

[2]See also, Parente & Prescott (1994); Eaton & Kortum (1999, 2001); Caselli (2001); Comin & Hobijn (2004); Keller (2004); Klenow & Rodriguez-Clare (2005); Comin et al. (2008, 2010a); Comin & Hobijn (2010); Comin et al. (2012)

[3]See, for example, Nelson & Phelps (1966); Foster & Rosenzweig (1996); Cohen & Levinthal (1989); Benhabib & Spiegel (1994); Basu & Weil (1998); Temple & Voth (1998); Howitt (2000); Acemoglu & Zilibotti (2001); Caselli (2001); Comin & Hobijn (2004); Benhabib & Spiegel (2005); Aghion et al. (2005); Howitt & Mayer-Foulkes (2005); Ciccone & Papaioannou (2009); Goldin & Katz (2009)

whose shoulders the inventors could stand" (pg.16); Rosenberg (2000) and Nelson (2005), the accumulated ability and scientific institutions to manage new ideas for innovation and invention; 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 generate and housed it may have had an even more determinant role at the dawn of the Second Industrial Revolution (cerca 1870-1914), which saw an increased emphasis on more structured scientific inquiry such as laboratory-based R&D.[4] This scientifically oriented human capital, and a technologically savvy entrepreneurial class,[5] 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 insight, Howitt & Mayer-Foulkes (2005) argue for multiple equilibria in innovation where countries whose human capital/innovative capacity 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.[6]

Empirically, documenting the impact of even very basic measures of human capital on growth or relative incomes has proved surprisingly complex.[7] Further, there have been few

[4]Rosenberg (2000) and Nelson (2005) stress the incremental and cumulative nature of technological progress and related institutions more generally as a central dynamic of industrialization.

[5]As numerous authors have stressed from Schumpeter (1934) to the present, technological progress without entrepreneurs to take it to market does not lead to growth (See Aghion & Howitt, 1992; Baumol, 1990, 2010; Glaeser, 2007; Glaeser et al., 2009, 2010; Braunerhjelm et al., 2010). Over the longer term this reflects the accumulation of a specific kind of human capital, at the very least, suited to the evaluation and management of risk, but extending to skills for managing people, credit, and technologies which need to be learned.

[6]See also Gancia et al. (2008) for related discussion of convergence clubs resulting from education-technology complementarities.

[7]For overviews see Krueger & Lindahl (2001); Sianesi & VanReenen (2003); Stevens & Weale (2004)

efforts to systematically capture what kind of human capital matters, or even to document the stocks of different types of capital. Judson (1998), Wolff & Gittleman (1993), Self & Grabowski (2004) Castelló-Climent & Mukhopadhyay (2013) attempt to document whether tertiary education matters more or less than primary education. Murphy et al. (1991) document that countries with a higher proportion of engineers grow faster relative to those with a higher proportion of law concentrators. The problem is exacerbated when a longer historical perspective is taken, and even more so at the sub-national level. Related to the present work, Acemoglu & Dell (2010) in their analysis of sub-regional differences in incomes in the Americas, stress technological know-how, efficiency of production, and human capital as determinants of both within and across country productivity differences, but lack specific measures of human capital. Campante & Glaeser (2009) argue that the "lion's share" of the differences in long run income level between the cities of Buenos Aires and Chicago is human capital, but they lament that literacy remains the primary, albeit coarse, measure (see, for example, Mariscal & Sokoloff (2000)). However, neither the historical prevalence of Mokyr's engineers and mechanics, nor Rosenberg's and Nelson's systems of innovation are documented in a globally comparable form.[8]

This paper, first, makes a very basic contribution: it establishes the stylized facts surrounding the relative density of engineers at the end of the 19th century at the national level for the Western Hemisphere and representative countries of Europe. It does the same at the sub-national level for a five country panel: the US, Argentina, Chile, Mexico and Venezuela. This is done in a systematic way drawing on graduation records, membership in professional societies, and census data. We see these estimates, in the first instance, as a measure of what they are: the stock of higher level scientifically oriented human capital

and Acemoglu & Zilibotti (2001); Pritchett (2001); Easterly (2002); Benhabib & Spiegel (1994). A recent literature has sought to explain the often small measured impact by incorporating measures of the quality of human capital (see, for example Hanushek & Woessmann, 2007; Behrman & Birdsall, 1983; Hanushek & Woessmann, 2012)

[8]Collected articles in Fox & Guagnini (1993) have examined the evolution of engineering capacity in several advanced countries although the comparability of the measures across countries is not always clear, and there is no attempt to establish a link to economic performance.

directly linked to productive activity available at the beginning of the Second Industrial Revolution. Second, because our national measures are based on graduates of domestic engineering schools, it also proxies for the universities and institutions that support them, and for which data are more elusive (see Nelson, 2005). Further, we are sympathetic to the use in Murphy et al. (1991) of engineering density as a proxy for "good entrepreneurship," perhaps more specifically the advancement of the long-run cumulative process of developing entrepreneurial technological depth. In sum, we see it as a broad proxy for innovative capacity.

The paper then shows that our measure of engineering in 1900 has an impact on present income beyond the customary measure of literacy and even after controlling for plausibly correlated factors such as railroad construction, agglomeration levels, and a host of locational fundamentals. We document that countries at very similar distances from the technological frontier as measured by income per capita in 1900– for instance Sweden and Argentina– had enormous differences in innovative capacity and that, consistent with Howitt & Mayer-Foulkes (2005) this could drive the resulting clubs they find themselves in today. The paper then looks in depth at the US case where detailed sub-national data are available for engineering, literacy and other types of higher order human capital, such as lawyers. We broadly confirm the findings in Murphy et al. (1991) by showing that engineering's positive effect strengthens once we control for the negative impact of lawyers. We also attempt to control for the remaining endogeneity of engineering capacity using uptake of the Morrill Land Grant program, an initiative that affected the supply of technical talent, often in the absence of local demand and including opposition by the target beneficiaries. Statistically, engineering capacity appears to have been an important part of the growth story.

We then develop several historical examples to support the conclusions of the estimations. First, we provide corroborating historical evidence for the relative ranking of innovative capacity generated by our data. Lagged as the American South was relative to the North, as

Carnegie suggests above, it appears substantially ahead of Latin America. Second, through the lens of the mining industry, we show how Latin America managed to lose its technological edge and autonomy around the period we study while the US used the industry precisely to further leverage its innovative capacity, much as predicted by Howitt & Mayer-Foulkes (2005).

Finally, we ask what determined engineering capacity in 1900. We find that existing population agglomerations and some geographical fundamentals, such as temperature or rainfall, have an impact, and institutions, such as slavery, appeared to have a negative effect in the American South, providing an additional channel through which that institution may have negatively affected growth.[9] However, controlling for all these factors leaves a broad similarity between colonizer and colony innovative capacity. This suggests, consistent with recent work, that substantial explanatory weight should be put on the human capital, productive structures, values and institutions imported during the colonial period through migration that retained their influence in the interaction with the local environment.[10]

2 Data

2.1 Measuring Engineering/Innovative Capacity

Our measure of innovative capacity 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 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

[9]As numerous authors have noted (see North, 1990; Pritchett, 2001; Murphy et al., 1991; Acemoglu & Dell, 2010), how individuals allocate their talents among activities and their eventual rates of return depends partly on the institutional environment.

[10]See McCleary & Barro (2006); Putterman & Weil (2008); Spolaore & Wacziarg (2009); Becker & Woessmann (2009); Galor & Michalopoulos (2009); Comin et al. (2010a); Spolaore & Wacziarg (2012); Easterly & Levine (2012).

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 consistent metric across countries, we take the number of degrees awarded.[11] Though most countries employed substantial numbers of foreign engineers, we are interested in indigenous technical capacity and the institutional structure to generate it, so we focus on domestically trained engineers. Some nationals studied abroad, however the historical evidence from Argentina, Chile, Colombia and Mexico suggests the numbers are small and difficult to document. Since the working life of an engineer is roughly 40 years, we begin accumulating the stock in 1860, discounting the stock in each period by .983 as the rate of death/attrition in each year. In some cases, we have a long series of graduation records which make this procedure straightforward. In Denmark, Mexico, New York, Perú, Spain, Sweden, Venezuela, or México, the flow of graduated engineers is available for the 1860-1900 period. We refer to Ahlström (1982)'s estimates for Germany and France, the frontier countries, which are generated in a virtually identical manner, yet we do not have access to his data and these are not our calculations.[12] In other cases, for instance, Argentina, Brazil, Chile, Colombia, 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.

[11] Fox & Guagnini (1993) tabulate for several advanced countries the number of students enrolled. However, we find often that the difference between students enrolled and eventual graduates can differ greatly so enrollment rates are not as reliable.

[12] In fact, he calculates the stock for France, Germany as well as Sweden for which we do have the raw underlying data and hence can verify that we are doing the calculations in a virtually identical fashion.

Census Data: Census data are also available in 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 is an engineer or not with limited institutional confirmation, or detail on the actual level of education. As numerous local historians have noted (Serrano (1993) in Chile, Bazant de Saldaña (1993) in Mexico) and in the case for which we have the best information, the US, censuses are often substantially higher than the actual graduates of engineering programs. Sub-national data derive from the Argentine census of 1895, Mexican National Census of 1895, Chilean Census of 1907, the Venezuelan Census of 1926, and the US Census of 1900.

Annex I discusses how these three sources of data were combined for each country in detail.

2.2 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 constructed on the basis of national census data by the World Bank (2009) for the World Development Report on *Reshaping Economic Geography*.[13]

[13] These "poverty maps" combine household level data sets with limited or non representative coverage with census data to generate income maps for much of the hemisphere (see Elbers et al., 2003). This is important since in some cases, for instance Mexico, household income surveys are not representative at the "state" level at which we are working. We expand the sample to include Canada and the United States. We thank Gabriel Demombynes for providing the data. See original study for methodological details. We expect that while somewhat more complete, our data is similar to the census based data used by Acemoglu & Dell (2010). For Argentina, Colombia and Venezuela, the study uses the inverse of the basic needs index as a proxy for household income which we then scale by national income. Such household level data is arguably preferable as a measure of regional prosperity to national accounts data for two reasons. First, in the case of natural resource rich regions, income may or may not accrue to the locality where it is generated and hence may provide a distorted measure of level of development. As an example, the revenues from oil pumped in Tabasco and Campeche, Mexico, are shared throughout the country, although they are often attributed entirely to the source state in the National Accounts.(See Aroca et al. (2005)). This is a broader issue wherever resource enclaves are important. For instance, from a national accounts point of view the richest sub national units in Argentina, Colombia, Chile and Peru respectively are Tierra del Fuego (oil), Casanare (oil), Antofagasta (copper), Moquegua (copper) all of which, with the exception of the last, are average or below average in household survey measured income. Further, the geographical inhospitability of these locales ensured and continues to ensure relatively little human habitation: Antofagasta is in the middle of the driest desert in the world, Tierra del Fuego the closest point in the hemisphere to Antarctica. Since this combination can give rise to a negative, although relatively uninteresting, correlation of initial population density with present income, our household survey numbers are more suitable for better tests of institutional hypotheses.

2.3 Other Controls

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

Literacy: Aggregate literacy rates we take from (Mariscal & Sokoloff, 2000). Sub-national literacy rates were gleaned from census data from Argentina, Chile, Mexico, Venezuela, and the US.

Higher Level Non-Engineering Human Capital: This is measured as number of lawyers per 100,000 inhabitants (US Census 1900).[14]

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 level data was not available for Latin America.

Population Density in 1900: These are collected from census data from the individual countries. Argentina (1895), Brazil (1900), Chile (1907), Colombia (1905), 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. We expand the sample further using analogous data on Canada from Ubelaker (1988), and Nicaragua from Newson (1982). Though the project of estimating populations half a millennium past is necessarily speculative, the estimates synthesize the most recent available geographical, anthropological, and archaeological findings. In particular, they draw on documentary evidence such as reports

[14]We thank Adriana Camacho for suggesting the use of lawyers as a control.

by Europeans, actual counts from church and tax records, as well as contemporary and recollected native estimates and counts.[15]

Institutions: As controls for institutional quality, Bruhn & Gallego (2011) collect data on economic activities performed in different regions during the colonial period for 16 countries in the Americas. Each region is assigned three dummy variables summarizing whether it had predominantly good, bad or no colonial activities. They first identify the main economic activity using history books for each country and then classify the activities in good and bad activities following Engerman & Sokoloff (1994). Bad activities include mining, rice, sugar and tobacco cultivation. Good activities include all other agricultural activities, cattle, livestock, sherry, trade, naval stores, ports, textiles, and wine production. None of the above is the omitted category in our regressions.

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).

Mining: For the US, we collect separate data on mining, based on the 1880 census and Hewes (1883).[16] The variable measures total mining output in millions of US dollars and is used as a control for one of the pre-eminent engineering activities, as discussed later in the case studies section. Comparable data is not available for Latin America for the same time period.

Geographical Controls: in addition to the set of sub-national geographical variables collected by Bruhn & Gallego (2011) including temperature, altitude, landlocked and annual rainfall, we add a measure of agricultural suitability and river density as developed in

[15] Depending on the country, projections across similar geographic areas, regional depopulation ratios, age-sex pyramids, and counts from sub-samples of the population (such as warriors, adult males, tribute payers) are used, as well as backward projections from the time of contact with Europeans. These are corroborated by evidence including archaeological findings, skeletal counts, social structure, food production, intensive agricultural relics, carrying capacity, and environment. See Maloney & Valencia (2012)

[16] We thank Christian Dippel for pointing us to this source.

Maloney & Valencia (2012).

Table 1 presents the summary statistics.

3 The Impact of Innovative Capacity

3.1 The Engineering Data

Figure 1 plots our measure of innovative capacity against GDP per capita, both in 1900.[17] The availability of data means that our effective sample going forward is restricted to the relatively larger countries depicted here. Several facts merit note.

First, there is broadly a positive relationship between the stock of engineers and income in 1900. The United States, at 84, and in particular the Northern United States with an engineering density of 160, the US at 84 is slightly below Sweden and Denmark, and the US South shows under a third of the engineering density of the North and just over a third of the income. Somewhat surprisingly, Canada enters at a density of 41 or roughly the level of the US South.

Second, lagging as it is, the American South is miles ahead of the Latin American countries. Their engineering densities of under 20 in most cases puts them at a third of the US South and under half of Canada. What is most striking is that countries that we tend to associate with declining relative position across the previous century, especially Argentina and to a lesser degree Chile and Mexico, show densities below countries of similar level of income: Argentina and Chile had roughly the same level of income as the American South,

[17]Maddison does not tabulate a separate series for the American South, but Mitchener & McLean (2003) estimates place the US South roughly 50% below the national average and New England 50% above. Imposing these differentials on Maddison's data, places the South roughly 15% higher than Spain and the North roughly triple. Clearly, issues can be taken with even Maddison's Herculean effort, however, the available alternatives do not suggest that the picture would change much. Prados de la Escosura (2000) PPP based estimates with the OECD correlate .89 with those of Maddison, and do not significantly change the level of Spain relative to the US, although they move Portugal up perhaps 40%, now above Mexico but still 20% below Spain.

Sweden and Denmark yet had roughly a third of its engineering capacity of the South, and a fifth of the Scandinavian countries. Even if the number of engineers were underestimated by a factor of two, the lag with the US and Scandinavia would still be dramatic. A plausible interpretation would be that natural resource rents, while elevating income, were not being deployed as they were in the US or Scandinavia to the development of innovative capacity that would prepare them for the next phase of industrialization. In Howitt & Mayer-Foulkes (2005)'s framework, we have countries with similar levels of Schumpeterian backwardness, but with radically different levels of absorptive capacity.

Third, 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. In fact, in comparison to all of the Northern European countries, the US is absolutely and conditionally low: 84 compared to roughly 100 for Denmark and Sweden, and by Ahlström (1982)'s calculations, 200 for France, and 250 for Germany, all of which have lower levels of income. Again, we have confidence in the Scandinavian estimates and given that France and Germany were considered the frontier at the time we expect that their densities were in fact, higher than the Scandinavian. Nor is some sort of idiosyncratic data issue driving the consistently low scores of Latin America. These cluster very near the colonial mother countries, both around 20. Broadly speaking the Latin countries are of the same order of magnitude as the southern European colonies, the US and Canada closer to the levels found in Northern Europe.

3.2 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 Landes (1998)' characterization of their attitudes towards science and the enlightenment. Both Sweden and Denmark's institutions of higher technical learning date from the 1700s. Sweden's high density is consistent with the characterization by Sandberg (1979) of the country as the

"Impoverished Sophisticate." 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.

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. 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. By 1862 there were roughly a dozen engineering schools in the East, but also as far west as Michigan and south as Maryland. The Polytechnic College of the State of Pennsylvania, founded in 1853 granted degrees in mechanical engineering in 1854, and mining engineering in 1857.

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. 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 AM 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 sum, the post-Civil War period saw the expansion of engineering education throughout the country.

It also saw a deepening, with the profession in the U.S. diversified further into sub-branches. For example, the University of Missouri established both Civil and Military Engineering departments in 1868, and the first department of Electrical Engineering in 1886. 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 degree of sophistication is probably higher than that suggested by the density numbers. 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.[18] It is also the case that 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 the time. Hence, Canada was likely part of the greater New England scientific community.

In Latin America 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, and the third richest in our sample at the time, Argentina, began graduating engineers only in 1870, and Peru, one of the mining centers of the hemisphere, in 1880, roughly on the same time line as Alabama. Further, in countries like Colombia and Mexico, political instability undermined programs begun relatively early leading to very low levels of graduation. In addition, the process of diversification and specialization was not as

[18] 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.

advanced as was the case, for example, in Missouri. General engineering associations were set up in many countries around the same time that, in the US, associations in individual sub-fields were established. In sum, the broad stylized facts about the relative innovative capacity of the US North vs the US South, and then both with relation to Latin America seem supported by the historical evidence.

3.3 Aggregate Correlations

We first begin by documenting that, using aggregate engineering densities for 9 countries, there is evidence that our engineering measures are correlated with income.

$$Y_{2005,ij} = \alpha + \beta_L Lit_{1900,i} + \gamma_E Eng_{1900_i} + \gamma_R Rail_{1900_i} + \gamma_{pop} Pop_{1900,ij} + \gamma GEO_{ij} + \epsilon_{ij} (1)$$

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. Errors are clustered at the country level.

Columns 1 and 2 of Table 2 show that with or without geographical controls, engineering in 1900 appears strongly significantly in explaining today's income per capita. We lose Canada and fall to 8 countries in columns 2 on because it lacks geographical controls. Columns 3 to 6 sequentially include additional controls. Column 3 adds sub-national population density in 1900 as a way of controlling for agglomeration effects which engineering may be proxying for. It enters positively but it does not affect the magnitude or significance of the engineering variable. Column 4 adds literacy which does not enter with significance and does not affect engineering in either magnitude or significance. Column 5 adds railroad density to avoid conflating the effects of engineering capacity with the infrastructure it is often instrumental in creating. Again, significant but without reducing the impact of engineering. Column 6 tests any conflation of engineers with institutions by adding the Bruhn & Gallego (2011) institutional controls. They do not enter significantly nor diminish the importance or significance of engineering. Finally, column 7 combines all variables. Engineering remains significant and positive, as does population density and railroads. Literacy becomes counterintuitively negative although this does not remain a robust result going forward. Both good and bad institutions enter negatively and significantly, a result which we will discuss further later.

These results are not driven entirely by the US. Canada shows a density that is low by US standards, but high by Latin standards. Its income in 2000, like the American South, was roughly 10-20% below the aggregate US income level and with similarly intermediate engineering densities in 1900. Further, 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.

3.4 Sub-national Engineering Data from Argentina, Chile, Mexico, the US, and Venezuela

We are able to collect engineering data at the sub-national level for Argentina, Chile, Mexico, Venezuela and the US. To give a feel for the disparities, Figure 2 maps this data for the US and Mexico by decile of engineering density and strikingly confirms that the border divided worlds apart. In fact, the data likely understate the true difference since our calculated stocks in Figure 1 suggest substantial overstatement in the Mexican census data. 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 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. Despite four centuries of mining, it had not acquired a corpus of trained professionals in the field compared to relative newcomer, the American West. The other countries show similar patterns.

Table 3 employs the sub-national data and comes to similar conclusions to those previous. We estimate:

$$Y_{2005,ij} = \alpha + \beta_L Lit_{1900,ij} + \gamma_E Eng_{1900_{ij}} + \gamma_{pop} Pop_{1900,ij} + \gamma GEO_{ij} + \mu_i + \epsilon_{ij} (2)$$

Engineering density is persistently significant, although of lower magnitude reflecting that it is only capturing the within effect whereas the previous results were capturing an average of the within and between. The finding of continued significance even after controlling for a measure of population density (column 2) is consistent with Comin et al. (2010a). In column 3, Literacy now enters positively and significantly and reduces the coefficient on engineering by over 50%. The Bruhn & Gallego (2011) controls for institutions (column 4) do not enter significantly although their inclusion reduces the coefficient on engineering by 25%.

Column 5 combines all variables. Although none enter significantly, we also include geographical controls. The previous results are preserved: Engineering, Agglomerations (Pop Density), and Literacy all have a significant positive effects of magnitudes similar to those identified in previous columns. Overall, our sub-national regressions appear to confirm the previous finding of the importance of higher level human capital as well as now permitting lower level- literacy- to enter significantly and positively as well.[19] Despite

[19]We also run these regressions standardizing the regional data by our aggregate estimates in addition to employing fixed effects. The results do not change substantially.

the modest degrees of freedom, differing sources of data, and ambitious specifications, engineering density emerges in all specifications as significant at conventional levels.

3.5 The US in Detail

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 5). 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.[20] 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.

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

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

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.[21]

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, in the spirit of Moretti (2004), 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.[22] As discussed earlier, Morrill financed programs in Texas, Virginia, Kentucky, and

[21]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.

[22]With 51 observations, this exercise is somewhat heroic and diagnostics should be taken as suggestive.

North Carolina began awarding degrees in the 1880s and 1890s which means that their accumulated engineering stock would still be low in 1900. Table 5 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.

4 Support from History: Case Studies

This section offers historical evidence that confirms that innovative capacity was a critical barrier to taking advantage of the advances of the Industrial Revolution. The interaction of lost learning by doing, weak higher level human capital, and underdeveloped technical institutions emerges in explanations of the lag of the US South as well as Latin America. However, it also offers support for more complex view of how innovative capacity affects steady state growth.

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 (theirs) 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

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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.

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

$$\mu_t = \lambda S_t^{\eta} z_t^{1-\eta} / \bar{A}_{t+1} \tag{3}$$

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. The resulting equilibrium innovation rate is shown to be

$$\mu_t = \frac{\mu \frac{A_t}{\bar{A}_t}}{1+g} \tag{4}$$

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.[23]

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.[24]

Our data do not permit testing explicitly for convergence clubs, and we must be satisfied with a correlation with present income. However, the historical case studies do suggest the importance of these dynamics and the model helps organize that happened around 1900 in the US South and Latin America vs the US North in particular. The

[23] 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.

$$\mu = \lambda^{\frac{1}{\eta}} \left[\frac{1-\eta}{1-\phi} \beta\pi \right]^{(\frac{1}{\eta})-1} \xi \tag{5}$$

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.

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

initial conditions in terms of skills broadly defined allowed the latter to fully adopt modern R&D technologies, while in the former, they did not. In the South they were unable in some cases to undertake the necessary R&D to adapt some new technologies to local conditions, for instance, in Steel. In Latin America, the erosion of their frontier adjusted human capital was so severe when faced with new technologies in metallurgy and chemistry that they were forced to abandon critical industries, in our case mining, altogether.

4.1 The American South

Wright (1986) casts much of his work explaining the US South's persistent lag exactly in terms of an innovative capacity framework. "The fundamental reason for [protracted lack of uptake of technologies] is that early industrialization is a matter of learning in the broadest sense of that term: in management, in technology, in marketing and certainly-though this is often underestimated- in learning on the part on the part of the labor force"(pp. 124-125). The South came relatively late to industrialization and lacked the indigenous technical capacity necessary for rapid catch up.[25] The emblematic failure was of the Birmingham Steel industry, which Carnegie referred to. The problems were manifold-high labor costs, product quality and marketing- all of which reflect the low level of collective, accumulated learning by doing. But also 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. By way of contrast, Japan also initially imported technology and processes, but over time it generated distinctive technologies and, by the 1920s, was making its own textile machinery. 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. Arguably, the big push by the

[25]Wright (1986) 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).

federal government, ranging from the Land Grant colleges to selective location of advanced industries, and migration of higher order human capital, raised innovative capacity toward the frontier and permitted catch up.

4.2 Latin America

This dearth of collective learning by doing and ability to adapt new technologies finds an amplified resonance in Latin America. Safford (1976), in his *Ideal of the Practical* notes 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 (p. 634). In agriculture, there was little use of plows, scrapers, cultivators or mechanical seeders until the 20th century, partly because the low level of literacy rendered pointless the agricultural journals found commonly in the American South. In Brazilian industry, Baer (1969) and Rogers (1962) argue that despite a tradition of iron smelting dating from the mid-sixteenth century, the techniques used at the end of the nineteenth century were primitive. While particularly the northern US colonies engaged in a sustained process of learning by doing and innovation in both iron and steel (Swank, 1965) from the early 18th century on, from 1830 to 1880 Brazil actually experienced a "retrogression in technique," or for our purposes, stagnation.(Rogers, 1962, p. 183). Unable to innovate, Brazilian firms instead lobbied for protection from cheaper iron imports.[26] The critical innovation for the development of the native steel industry was the foundation in 1879 of the *Escola de Minas* (Mining School) at Ouro Preto, Minas Gerais, which led to the

[26]Of the thirty ironworks in the headwater region of the Rio Doce in 1879, only seven used Italian forging methods, while the rest used the old African cadinho (crucible) technique. Graduates of the *Escola de Engenharia do Exercito* (Military Engineering School) established in 1930 led the steel industry as it developed through the 1960s.

establishment of the first new blast furnace since the failures at the beginning of the century.[27]

A long literature has focused on weakness in managing knowledge to understanding why Argentina fared so much worse than similarly endowed areas (see, for example Diaz Alejandro, 1985; Duncan & Fogarty, 1986; Campante & Glaeser, 2009). The absence of innovative infrastructure was recognized by contemporary Argentines as key to explaining the lagging performance of the wheat industry compared to that in Canada and Australia. The determined efforts in both the latter 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, seed testing services, and technical assistance.[28] More generally, Di Tella (1985) argues that Argentina proved unable to move beyond a state of exploiting the pure rents of a frontier or extraction of mineral riches, and beyond the "collusive rents" offered by state-sanctioned or otherwise imposed monopolies to tap the "unlimited source of growth" found in exploiting the quasi-rents of innovation, as the US, Canada and Australia were able to do. They remained in an adoption or, perhaps, stagnation equilibrium.

However, the potentially catastrophic impact of a dearth of innovative capacity is nowhere more in evidence than in the industry in which the region for centuries had a true comparative advantage, yet by the turn of the 20th century had completely stagnated: mining. The engineering data in Figure 1 supports the historical evidence that in Mexico local entrepreneurs lost share in the industry they had dominated for centuries precisely due to lacking the capacity to master emerging technologies (Ruiz Larraguivel, 2004; Brading, 1971; Marichal, 1997). Even in Zacatecas, San Luis de Potosí, and Guanajuato, long centers of mining, engineering density was at low levels compared to the newcomers in the US West. Around 1900, abandoned, underexploited and newly discovered mines fell to foreign

[27]A similar complementarity is suggested in Colombia by the emphasis both present and contemporary observers put on the impact of engineering schools, such as the *Escuela de Minas de Antioquia* (Antioquia School of Mines) as providers of talent for emerging industry (Safford, 1976; Murray, 1994).

[28]Fogarty et al. (1985) attributes to weak innovative capacity the outcome of a quasi-experiment whereby the Spanish Merino sheep were introduced into New South Wales, Australia, and Argentina's River Plate region in the same year and had the same access to European capital, but by 1885 showed yields of only half the wool per sheep in Argentina.

hands that could bring new global technologies to bear. 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 of lead and zinc mining (Bernstein, 1964; O'Brien, 1989). By the early 20th century, the Americans absolutely dominated the industry.[29]

Close observation by numerous historians offers a particularly compelling window on how a similar inability to adapt new technologies in the face of declining ore quality nearly destroyed the Chilean mining industry as well. Chile saw its world market share fall from one-third to under 4 percent by 1911, 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).[30] 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."(p. 17). Another prominent historian, Pinto Santa Cruz (1959) argued that Chileans failed to take advantage of opportunities for learning by doing and to evolve the innovative capacity required to confront the technological revolution in mining and hence became dependent on foreign firms.[31] As in Mexico, and consistent with

[29]See Maloney (2012) for data on nationality of owners.

[30]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).

[31]"The technological demands of the period, in contrast to what is occurring today in some areas of mining or industry, were relatively modest and thus not too costly. What could and had to be done in the national

Howitt & Mayer-Foulkes (2005)'s education externality, both the quantity and the quality of the engineering graduates produced by local universities were thought inferior to the talent imported from Europe and the US (Serrano, 1993; Bazant de Saldaña, 1993). Increasing frustrated by the creeping influence of foreigners across the major industries, it is perhaps not surprising that Chileans developed a self-perception that they were perhaps "unfit for the modern era"(Monteón, 1982, p. 62 and 35).[32] By 1918, American interests controlled 87% of Chilean copper output (O'Brien, 1989). Similar stories of an inability to exploit new technologies leading to decline in the mining industry can be found throughout the region.[33]

The US eventual dominance of the Chilean copper and Mexican mining industries strikingly illustrates the road that could have been taken. Not only does Wright (1987) argue that 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. Wright stresses that 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) overwhelmingly an American achievement, that propelled

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mining companies and in agriculture was perfectly compatible with the resources accumulated in the long periods of bonanza. If the process had been initiated and maintained adequately, without doubt it would have created the means to confront more challenging tasks, such as those posed by copper mining when it was necessary to exploit less rich veins. However, faced with the technological revolution, the local mining companies did not have either sufficient accumulated resources or organizational and administrative capacity- both of which were indispensable. In these circumstances, there was no other option but the introduction of foreign capital and expertise." Pinto Santa Cruz (1959)(p 71)

[32]Prominent intellectual Tancredo Pinochet Le-Brun(1909), granting that Chileans were inferior to Europeans, still wondered, "Don't we have minds in this country that can go to Europe to learn what professors, whom we have imported and continue importing, have studied? Are we truly incapable of steering our own ship?" *La Conquista de Chile en el Siglo XX*, Santiago, La Ilustracion, page 81 cited in Monteón (1982)).

[33]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.

the copper industry during the last decades of the 19th century. 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.[34]

In line with Howitt & Mayer-Foulkes (2005) view, the US reaped high growth dividends from inventing new technologies in mining, and its engineering and scientific capital became the best in the world. At the same time, and with exactly the same goods, Latin America's declining human capital relative to the expanding technological frontier left it unable even to adapt new technologies, and the domestic industries stagnated.

4.3 Potemkin Industrialization?

The sheer disparity of our innovative capacity numbers poses the question: If it was so hard for the American South to start competitive industries with its innovative capacity captured by 60 engineers per 100,000 individuals, how did Latin America's industry expand so quickly at the turn of the 20th century with an average of 10? The answer may lie in the Potemkin nature of much of Latin American industrialization. Blocks in the input-output table were rapidly filled in but, as Haber (2005, 2006) notes, these industries were not modern in the sense of being at the technological frontier or being able to export to other countries. Much as Wright notes in the American South, Mexico and Chile relied heavily on foreign technology imports, and were sluggish in developing an indigenous local machine and capital goods industry, a result attributed to low innovative capacity.[35] The fact that

[34]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).

[35]"Since... capital goods industries now required well-developed scientific and engineering capabilities, Mexico had little choice but to import its capital equipment. The blast furnaces and rolling mills came from the United States, the high-speed cigarette machinery from France, the paper-making machinery from Switzerland, the textile looms, spindles, and other equipment from England, Belgium, the United States, or Germany." Haber (1997), p. 18

Latin America evolved the highest levels of tariffs in the world prior to World War I –on average five times the rates in Europe– is arguably the result of the need to protect an industry erected on weak foundations of entrepreneurship, accumulated learning by doing, and higher level human capital.[36] This supports Haber's theory that the standard view of protectionism stimulating industrialization is potentially backwards. An emerging, but technologically backward and uncompetitive industry demanded protection.

These case studies offer evidence that the lack of an ability to identify new opportunities or manage new technologies was important in explaining the weaker progress in both the American South and Latin America relative to the leaders at the time. In turn, a weakness in the supply of higher level human capital, of entrepreneurial capacity, and of ongoing, collective learning by doing emerge as missing elements of innovative capacity that plausibly underlies the impact of our engineering variable.

4.4 Mechanisms of Influence Today

Table 6 offers some suggestive mechanisms through which these engineering densities in 1900 could continue to affect output today. We collect five indicators that broadly capture modern day innovation-related inputs and outputs and calculate the simple correlation. The first is the dynamism of the system of research and development measured as total R&D expenditures as a share of GDP. The second asks about firm capacity for innovation ranging from pure licensing to pioneering their own new products and processes.[37] These two, arguably, correspond most closely to Howitt & Mayer-Foulkes (2005)'s R&D model. The third draws from a globally consistent measure of management quality from Bloom & Van Reenen (2010) and in particular, the sum of the scores on the two questions dealing with how firms identify new production processes to adopt. On the output side, we have Comin

[36] Coatsworth and Williamson and Clemson and Williamson, cited in Haber (2005).

[37] "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].

& Hobijn (2010); Comin & Ferrer (2013); Comin et al. (2008)'s measure of technological adoption at the extensive margin, averaging their industrial and sectoral scores[38], and finally patent applications filed under the Patent Cooperation Treaty (PCT) per million population as tabulated by the World Economic Forum (World Economic Forum et al., 2012). Together, these give an impression of measure of national absorptive and inventive capacity in the present. In virtually every case, the correlation between our engineering numbers in 1900 and these indicators today is above .9.[39]

5 Determinants of Innovative Capacity

Pursuing the determinants of innovative capacity in a comprehensive way is beyond the scope of this paper. However, some attempt is in order to address why it is that these differences in innovative capacity exist. While not restricting ourselves to their framework, Howitt & Mayer-Foulkes (2005) offer a suggestively wide range of factors, both working through profitability generally, and directly through the technology of innovation, process of generating human capital (broadly construed), and the level of effort dedicated to innovation.

5.1 Local and inherited determinants of innovative capacity

Innovative capacity has been postulated to emerge as a function of local conditions, but also effectively exogenous pre-existing imported or inherited factors. For the former, Acemoglu et al. (2002) and Engerman & Sokoloff (1994) have argued that a large indigenous populations, or particular factor endowments might lead to extractive institutions. Such institutions could clearly dampen innovative capacity through the restriction of the population allowed access to education of any kind. On the other hand, Maloney & Valencia (2012) have argued that, at the sub-national level, large indigenous populations may have provided the kernel of an agglomeration that would increase the productivity of engineers,

[38] Their data on the arguably more relevant intensive margin is not yet available

[39] While it may be interesting to compare engineering densities, the available UNESCO data is on flows and suffers from very important differences in definition across countries.

entrepreneurs, and other innovation related factors and hence foment their replication in line with Howitt & Mayer-Foulkes (2005)'s externality. Geographical factors, such as an agreeable climate, may repulse or attract talent. Few would argue that the geographical fundamentals of the San Francisco Bay area are not attractors of high level human capital, as was the case of Florida in the early 20th century (Cobb, 1993). Likewise, engineers are unlikely to remain in the inhospitable areas where mines are often found after the industry loses profitability.

It is also likely that institutions, human capital and attitudes brought by the colonists affected the evolution of innovative capacity. The education level of the immigrants, and how steeped they were in the scientific project radiating from England–the quality of the stock planted in the local soils– is relevant. In fact, the striking similarity of both engineering levels and histories between countries and former colonial masters suggests that these larger forces may be found in the often mutually reinforcing production structures, institutions, and values brought with the settlers themselves. A recent literature has attempted to put the influence of such inherited characteristics on a firmer empirical basis.[40]

Table 7 presents, first, the results for the US sub-sample. Column 1 suggests that

[40]Spolaore & Wacziarg (2009) have found that the distance from the technological frontier captured by genetic characteristics, proxying for "customs, habits, biases, conventions etc. that are transmitted across generations-biologically and/or culturally-with high persistence" is correlated with economic performance (p. 471). Putterman & Weil (2008) demonstrate that backgrounds of the ancestors migrating to a country are correlated with economic performance. Weber's assertion of a link between religious belief or religiosity and entrepreneurial qualities is re-argued by McCleary & Barro (2006); Becker & Woessmann (2009) have argued the "very long-lived (centuries) economic consequences of the emergence of Protestantism," although through its impact of human capital accumulation (literacy) rather than through work effort and thrift. Easterly & Levine (2012) argue that European origins can account to as much as half of global development and that European colonizers where important, even when they were relatively few in number. Maloney (2012) documents that the majority of industries, particularly in more technically advanced areas, were started by immigrants in Argentina, Mexico, Baranquilla, Colombia, and Chile. Within countries, Rocha et al. (2012) and Droller (2012) show how infusions of immigrant human capital were important for, respectively the development of Sao Paulo, Brazil and Las Pampas, Argentina. Ashraf and Galor (2012) in turn argue that cultural diversity, measured by distance from Africa, is a strong determinant for subsequent growth. Similarly, Spolaore & Wacziarg (2012) have shown that genetic distance matters for development and innovation. Galor & Michalopoulos (2009) take a genetic point of view, arguing that the failure of the landed aristocracy to lead the risky process of industrialization could be attributed to Darwinian selection reducing the representation of entrepreneurial, risk tolerant individuals within the landed gentry, and the prevalence of risk tolerant individuals among the middle and even the lower classes.

pre-colonial densities enter positively. This contrasts somewhat with Comin et al. (2010a) who find a negative effect of population. Column 2 introduces a dummy for the American South and shows it to be very significant. Column 3 adds explicit measures of institutions, the presence of slavery, and the Good and Bad institutional variables. In both cases slavery emerges with a strong and negative sign and the Good and Bad institutions have no effect either on slavery's influence or any other covariate and South loses significance. Though we are certainly pushing 37 observations too hard, including the geographical results in column 4 suggests that rainfall enters negatively and significantly. Column 5 combines all covariates. That initial population's effect is preserved even after adding geographical controls suggests that it is the agglomeration itself, and not geographical factors that may initially have spurred it, such as agricultural suitability, which attract engineers. Slavery continues to hurt the development of engineering capacity. Rainfall and Landlocked now both enter significantly suggesting that engineers prefer to be dry and on a coast.

Table 8 presents the results for the full panel including Argentina, Chile, Mexico, Venezuela and the US. Column 1 again includes colonial population density. This variable retains its significance in all specifications although with a value substantially below that found for the US. Either agglomerations in the US are more effective in stimulating engineering capacity, or the orders of magnitude difference in density between the US and, for instance, Mexico, do not map linearly to engineering capacity. Column 2 introduces the proxies for Good and Bad institutions. Both variables enter negatively and significantly both with and without geographical controls leaving the impact of these measures somewhat ambiguous. In all likelihood, the categorization of activities thought to have bad institutional effects may not correspond well to sectors encouraging or discouraging the generation of innovative capacity. In particular, given the definitions as based on types of agricultural activity and mining, it may be the case that the omitted category, no activities, corresponds to urban areas which our population density variable suggests attract engineers.[41]

[41] "Bad" activities include mining, rice, sugar and tobacco cultivation. But, as discussed earlier, mining is engineering intensive and in the US was a major contributor to national innovative capacity. However,

Column (3) adds a dummy for having been a Spanish colony including the states which are now part of the US (dropping fixed effects and clustering only by country). The dummy shows a very strong negative effect that suggests that, with a coefficient of -92.5 these regions have roughly half the density of the US. Clearly, this includes such innovative states as California. If we think the relatively modest Spanish presence in North America and the subsequent population by US settlers may have led to a weaker long run impact of Spanish colonization, a dummy for Spanish colonization that includes Latin America only rises to -120 (not shown).

Column (4) introduces the geographical controls, none of which enter significantly although the signs are largely consistent with those from the US. Column (5) combines all variables except the Spanish dummy and confirms the previous results. Column (6) introduces the effect of Spanish colonization, this time explicitly allowing for differing effects in Latin America and the US by introducing a separate dummy for the latter. Pre-Colonial population density and the institutional variables retain the same sign as before. The Spanish colonial dummy maintains its negative sign and significance consistent with the unconditional correlations found in Figure 1. Despite having averaged in the more generous estimate of Spain's engineering capacity, the mother country falls within the Latin cluster, and were we to have taken Riera's estimate alone, it would be average for that cluster. Portugal, while above Brazil, is similarly low. On the other hand, the US-Spanish colonial dummy is strongly positive reflecting the high density of engineers, for instance, in California. More profoundly, it suggests either that the Spanish colonial heritage is not responsible for Latin America's low engineering density or that the subsequent Anglo

combined with the other traditional agricultural activities, we may have a strong negative effect. Similarly, "Good" activities include all other agricultural activities, cattle, livestock, sherry, trade, naval stores, ports, textiles, and wine production which, perhaps with the exception of textiles, has less of a demand for engineering capacity. In short, both variables maybe simply picking up colonial activities and even rural economies in contrast to the pre-colonial densities which are more correlated with urban agglomerations and manufacturing over the long run.

dominance more than offset it.[42]

There is a substantial literature supporting the interpretation that the innovative apples did not fall far from the colonial tree. Coatsworth (2008)'s observation that "Much of recent work on the political economy of the Americas concludes that Iberian colonialism failed to create dynamic societies that could independently generate technological or organizational innovation"(p. 550). Spain and Portugal, confronted with the Industrial Revolution in England, failed to develop a scientific vocation nor the complementary innovation promoting institutions essential to industrialization. In both countries, literacy lagged even the black (often freed slave) population in the American South, and is of similar magnitude to that of the corresponding American colonies.[43] Further, higher education was largely religiously based, focused on law, philosophy, and theology, and resistant to attempts to introduce enlightenment-informed technical curricula.[44]

Arguably, because of this dearth of innovative capacity, Spain shows the same symptoms of the disease documented above: problems with entrepreneurship and managing technological progress, domination by foreign firms across industries, and a similar penchant for monopolistic structures and trade protection (Tortella Casares, 2000). In particular, the Spanish experience with mining tightly parallels that of the Latin case studies above.

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[42]Repeating the exercise with innovative capacity adjusted by our aggregate stock estimates again preserves the results on the institutional variables, the Spanish dummy, cultivable land, and agglomeration although there is some loss of significance of the last when geographical controls are added.

[43]Tortella (1994) notes that in 1900 Spain had a literacy rate of 44%. This is slightly below that of Argentina (48 %) and blacks in the American South (49%) (Collins & Margo, 2006)), and not dramatically ahead of Peru (38%), Chile (37%), Colombia (32 %), or Mexico (22%). Portugal's low level of literacy, 22%, is essentially identical to that of its colony Brazil (20%).

[44]In Portugal, the flagship university at Coimbra briefly established a more technical curriculum in 1759 under the Marquis of Pombal in the context of radical political, education and ecclesiastical reform to modernize the state and energize the economy. However, in 1777 there was a reaction against the reforms and the emphasis on natural science was abandoned and civil law regained its ancient prestige. The Spanish enlightenment in the same period saw the establishment of groups of autonomous sociedades económicas (economic societies) that sought to diffuse technology from abroad and establish libraries throughout the country, as well as some Royal Societies emphasizing applied science. But Spain began training engineers seriously only in the 1850s, and by 1867 the country had only one functioning School of Industrial Engineers, located in Barcelona (Riera i Tuébols, 1993).

Spanish mines were rich, and some minerals, mercury for example, had been worked for a thousand years. However, lack of technical capacity and capital, and slow growth of domestic metallurgical know how led Spanish entrepreneurs to work close to the surface and then sell out to foreigners once easy veins had been exhausted. As Tortella Casares (2000) 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" (p. 96, 213-215).[45]

Second, the Peninsular legal-theological focus of education carried through to Latin America, exacerbated by mechanisms of colonial control.[46] Portugal prohibited the printing press in Brazil until 1808 as well as the establishment of local universities seeing them as a step toward independence (Carvalho, 1982). Spanish America saw universities established from the moment of conquest, yet they were largely committed to the training of ministers to convert Indians, and lawyers to staff the empire (Benjamin, 1965). As Will documents for Chile, although it applies with greater generality "With the exception of the inadequate facilities provided by a few religious organizations, there did not exist before the middle of the eighteenth century an institution capable of furnishing the youth of the colony with the barest essentials of a secular education" (Will, 1957, p.17).[47] Across the region,

[45]By contrast, Sandberg (1979)'s explanation for Sweden's educational excesses are much closer to the US case and less so the Latin. Near universal literacy by 1850 arose from the mandate of orthodox Lutheranism that all subjects read combined with a surprisingly inclusive political system that channeled the peasantry's tendencies in the same direction. Higher order human capital was a result of the country's heavy engagement with mining and metallurgy combined with the inheritance of a set of institutions and a bureaucratic class and tradition arising from the period of empire.

[46]"The Latin American upper classes have been noted for their devotion to the study of law, the humanities, and the arts and their lack of interest in the natural sciences and technology. In the hands of the upper classes, Latin America's educational systems, at least in times past, have been dedicated to forming and maintaining the political elite and have been only mildly effective in furthering such economically practical aims as the broad diffusion of literacy and technical capacities." (Safford p. 3.)

[47]The majority of the relatively few university educated members of the Brazilian elite at independence trained at Coimbra in the reinstated legal theological tradition (Carvalho, 1982). In Ecuador, Hurtado (2007) argues that education quality even among the elite was poor and unfocused on practical elements. Again, he cites the American ambassador to Quito in the 1850s who found "convents instead of presses, barracks in place of schools" (p. 115). See comparable accounts in Will (1957) for Chile; Safford (1976) for Colombia; and Lopez Soria (2012) for Peru.

particularly after Independence, the lack of technical capacity was understood by some as a barrier to growth; conscious, but generally unsuccessful attempts were made to establish engineering or other more scientifically based schools.[48] Further, the commitment was never wholehearted. The most basic measure of progress - literacy rates- remained low into the 20th century, curricula and quality lagged even for the elites, and the attitude toward US pragmatism and materialism remained distinctly ambivalent (Lipset, 1967).

6 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. In particular, Aghion et al. (2005) document that different frontier adjusted endowments of human capital broadly construed dictate very distinct growth trajectories and Howitt & Mayer-Foulkes (2005) argue that at the time of a radical shift in technological progress, such differences lead to convergence clubs of high growth and stagnant economies. To date, however, there has been little data generated on the higher level human capital and institutions required to make this possible, especially in a historical context, and none to attempt to verify its impact on income differentials.

This paper generates a data set on innovative capacity in the Americas as measured by the density of engineers in 1900. This measure, compiled using graduates of local engineering universities, professional associations and censuses, is arguably the first to offer international comparability for this key period around the Second Industrial Revolution. We see it as a measure of higher level scientifically oriented human capital per se and supporting institutions, as well as arguably a more general measure of technological sophistication of the entrepreneurial class. We show that engineering density has an effect

[48]See Safford (1976) for Colombia; Villalobos et al. (1990) and Greve (1938) for Chile; and Baer (1969) for Brazil,and Lopez Soria (2012) for Peru.

beyond literacy or other measures of higher order human capital, such as lawyers, as well as beyond confounding measures such as railroads, mining, and agglomerations. Instrumenting engineering preserves its significance and effect in the US.

We then provide historical evidence that broadly confirms the ranking of countries emerging from our engineering data. Further, it suggests that precisely an inability to manage the new technologies emerging from the Second Industrial Revolution slowed growth in the Southern US, and led to a loss of competitiveness in a sector long an area of comparative advantage in Latin America– mining. The fact that the US was able to leverage this sector into a well-educated workforce, and world leadership in scientific research while Latin America lost the industry confirms the importance of innovative capacity, and the persistent effect of early human capital investments. It also lends support to the idea of multiple equilibria arising from differences in innovative capacity.

Finally, we also attempt to identify the determinants of innovative capacity in existing agglomerations, certain locational fundamentals, and extractive institutions such as slavery. Pre-colonial densities have an overall strong positive effect which we attribute to their constituting the kernel of large population densities over the long run. However, a large effect remains associated with being a Spanish colony which we see as operating both through an effect intrinsic to peninsular society and the colonial institutions imposed. Overall, the results suggest the importance of not only human capital, but historical investments in it, beyond literacy. They also suggest the importance of inherited cultural and institutional factors in determining such investments, perhaps reducing the role of local conditions in determining growth trajectories.

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7 Appendix: Construction of Engineering Data

7.1 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.[49]

7.2 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 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 Sao 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 Sao 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 Sao 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

[49] 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.

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.

7.3 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.[50] If we take the discounted sum of the licensed graduates plus half the military graduates [51] 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

7.4 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

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

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

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.

7.5 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 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 Mineria* (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). 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.

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

7.7 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.

7.8 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 state 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.

7.9 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.

7.10 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.

7.11 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.

7.12 United States

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

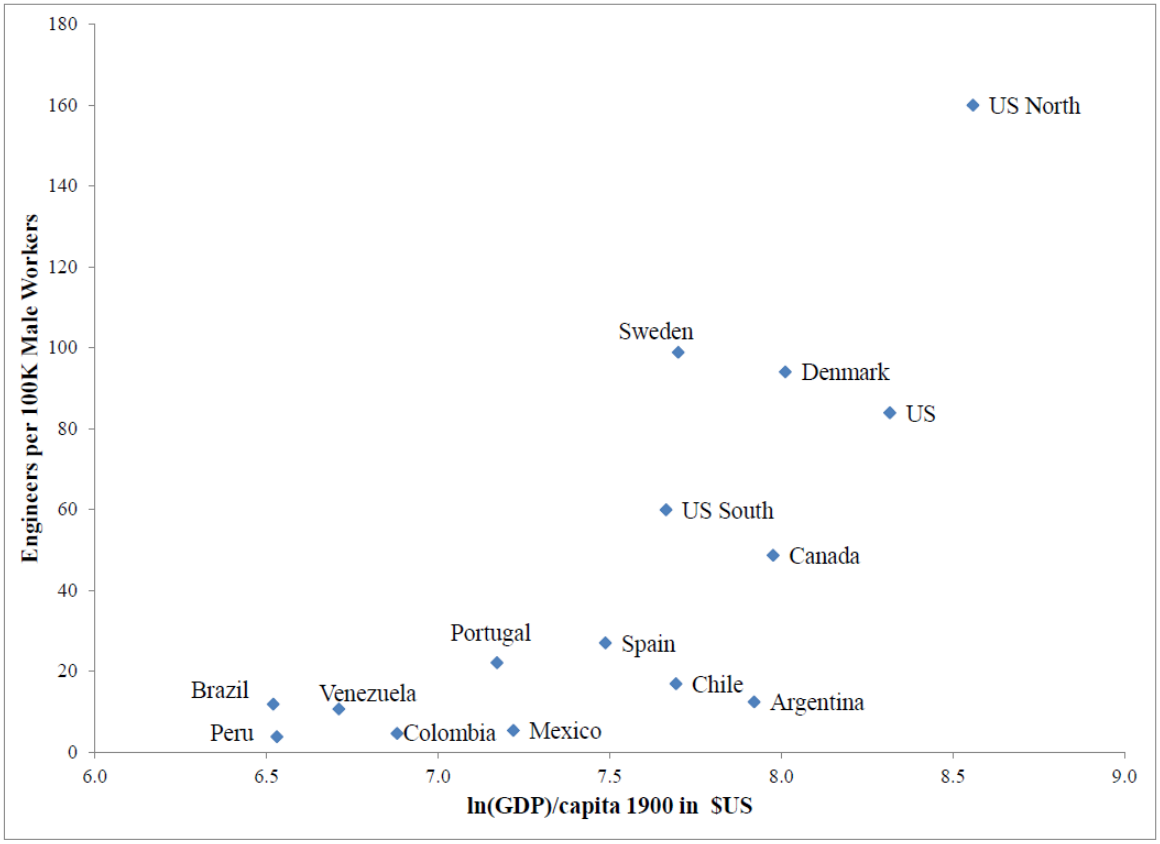
South.

7.13 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.

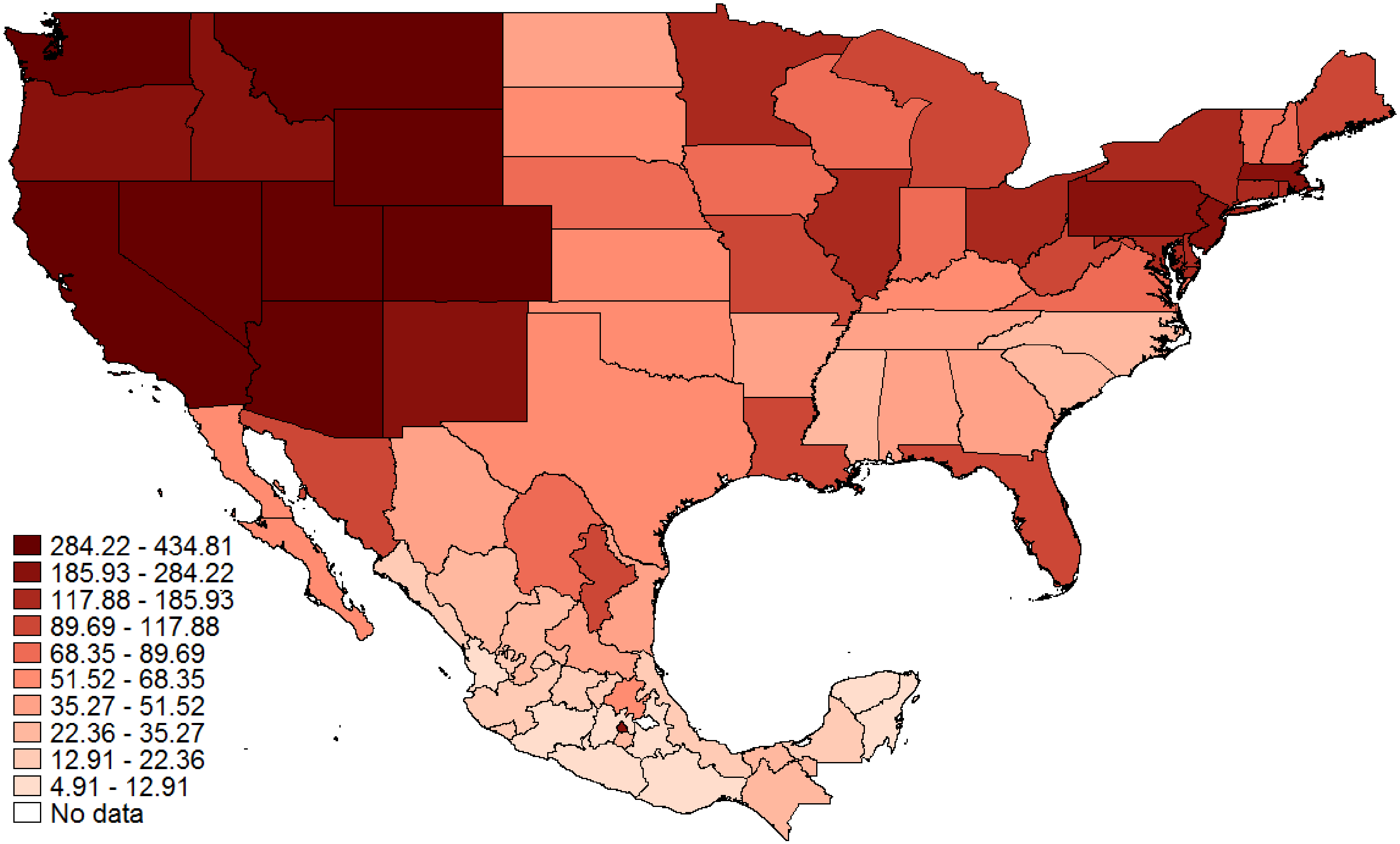
8 Figures and Tables

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 the Annex.

Figure 2: 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**

Variable	mean	p50	sd	min	max
Ln Income	9.03	8.92	0.91	7.13	11.18
Engineers	25.34	11.00	31.49	5.00	84.00
Engineers (sub)	88.30	44.81	108.69	0.00	472.59
Engineers (sub Stdzed)	37.52	12.20	53.27	0.00	237.05
Population Density (1900)	42.78	4.54	248.42	0.00	3319.27
Population Density (1500)	8.88	2.00	26.13	0.00	392.34
Literacy	41.93	34.00	24.41	11.30	86.70
Literacy (sub)	53.86	46.57	30.97	7.64	98.31
Railroads	3.15	1.80	2.71	0.30	9.30
Railroads (sub)	65.12	48.54	57.46	5.16	309.20
Good Institutions	0.62	1.00	0.49	0.00	1.00
Bad Institutions	0.22	0.00	0.41	0.00	1.00
South	0.15	0.00	0.36	0.00	1.00
Slavery	20.67	3.28	25.16	0.00	72.66
Lawyers	218.92	139.22	210.93	1.64	1156.44
Mine Output ($)	.466	.123	1.06	.000075	6.49
Spain	0.81	1.00	0.39	0.00	1.00
Land Suitability	0.56	0.58	0.28	0.00	1.00
River Density	3.28	3.29	1.23	0.00	6.92
Average Temperature	19.97	20.40	5.83	2.38	29.00
Rainfall	1.28	1.10	0.95	0.00	8.13
Altitude	0.66	0.19	0.92	0.00	4.33
Landlocked	0.57	1.00	0.50	0.00	1.00

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 100 square kilometers 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. Colonial Good and Bad Institutions as generated by Bruhn and Gallego (2011); none is excluded category. 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). Landlocked is a dummy variable for whether the state has access to a coast or not; 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).

Table 2: Innovative Capacity as a Determinant of Income per Capita (Aggregate Engineering Measure, Random Effects, Pooled)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Engineering	26.0***	20.1***	19.0***	29.2***	21.0***	20.2***	25.4***
	(4.75)	(1.17)	(1.70)	(6.38)	(0.58)	(1.17)	(1.37)
Pop Density			0.03**				0.05***
			(0.01)				(0.01)
Literacy				-0.01			-0.010***
				(0.01)			(0.00)
Railroads					0.09***		0.09***
					(0.03)		(0.02)
Institutions (Good)						-0.03	-0.1**
						(0.07)	(0.06)
Institutions (Bad)						-0.2	-0.3**
						(0.13)	(0.14)
Constant	8.8***	9.7***	9.7***	10.2***	8.9***	9.7***	9.3***
	(0.16)	(0.22)	(0.24)	(0.43)	(0.12)	(0.25)	(0.17)
Geo Control	No	Yes	Yes	Yes	Yes	Yes	Yes
N	242	216	207	216	216	216	207
N Countries	9	8	8	8	8	8	8
R^2	0.77	0.90	0.90	0.92	0.94	0.90	0.96

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per 100.000 male workers at the national level (coef. scaled X 1000). Population density is log number of individuals per 100 square kilometers in 1900. Literacy is share of the population that is literate in 1900. Railroad density measured as miles of track per 1000 square kilometers. Colonial Good and Bad Institutions as generated by Bruhn and Gallego (2011); none is excluded category. Geographical Controls include agricultural suitability, river density, average temperature, rainfall, altitude and landlocked. More detailed data sources and descriptions in the text. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Innovative Capacity as a Determinant of Income (Fixed Effect, Subnational)

	(1)	(2)	(3)	(4)	(5)
Engineering	0.8*	1.0**	0.3*	0.6*	0.3*
	(0.33)	(0.31)	(0.14)	(0.25)	(0.13)
Pop Density		0.03*			0.04*
		(0.01)			(0.02)
Literacy			0.01*		0.01***
			(0.01)		(0.00)
Institutions (Good)				-0.007	0.04
				(0.08)	(0.03)
Institutions (Bad)				-0.09	0.02
				(0.08)	(0.05)
Constant	9.7***	9.7***	9.1***	9.8***	9.4***
	(0.03)	(0.03)	(0.26)	(0.05)	(0.14)
Geo Control	No	No	No	No	Yes
N	137	137	137	130	130
N Countries	5	5	5	5	5
R^2	0.06	0.10	0.30	0.05	0.47

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per 100.000 male workers (coef. scaled X 1000). Population density is log number of individuals per 100 square kilometers in 1900. Literacy is share of the population that is literate in 1900. Colonial Good and Bad Institutions as generated by Bruhn and Gallego (2011); none is excluded category. Geographical Controls include agricultural suitability, river density, average temperature, rainfall, altitude and landlocked. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Innovative Capacity as a Determinant of Income (US)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Engineering	0.5***	0.8***	0.4***	0.4**	0.6***	1.2***	1.2***
	(0.15)	(0.15)	(0.14)	(0.18)	(0.11)	(0.40)	(0.33)
Pop Density		0.04***					-0.008
		(0.01)					(0.03)
Literacy			0.003*				0.01
			(0.00)				(0.01)
Lawyers				0.2			-0.2
				(0.21)			(0.23)
Railroads					0.002***		0.001
					(0.00)		(0.00)
Mining					-14.7		-23.1***
					(10.58)		(7.12)
Slavery						-0.0002	0.006
						(0.00)	(0.00)
South						-0.004	-0.05
						(0.10)	(0.07)
Constant	10.6***	10.4***	10.4***	10.6***	10.5***	10.6***	9.3***
	(0.02)	(0.06)	(0.15)	(0.07)	(0.03)	(0.06)	(0.91)
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 (coef. scaled X 1000). 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 (coef. scaled X 1000). 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. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Innovative Capacity as a Determinant of Income (US, instrumented)

	(1)	(2)	(3)	(4)	(5)
Engineering	0.9*	1.6***	0.8**	0.9**	2.1**
	(0.50)	(0.51)	(0.36)	(0.40)	(1.06)
Pop Density		0.07***			0.08**
		(0.02)			(0.03)
Literacy			0.002		-0.002
			(0.00)		(0.00)
Lawyers				-0.02	-0.3
				(0.25)	(0.34)
Constant	10.6***	10.3***	10.4***	10.6***	10.5***
	(0.08)	(0.11)	(0.16)	(0.08)	(0.25)
N	51	51	51	51	51
R^2	0.02	0.06	0.09	0.02	.

Notes: Dependent Variable is log subnational income per capita (2000). Engineering density measured by engineers per male workers (coef. scaled X 1000). 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 (coef. scaled X 1000). Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. $R^2 inspecification 5 is close to 1 but not calculated$.

Table 6: Mechanisms through which Engineering in 1900 Drives Income in 2000.

	All	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 7: Determinants of Innovative Capacity (US)

	(1)	(2)	(3)	(4)	(5)
Pre-colonial Density	57.0**				25.7*
	(23.44)				(14.88)
South		-108.7***	-41.3		18.9
		(24.94)	(26.11)		(22.57)
Slavery			-1.3**		-4.1***
			(0.51)		(0.69)
Good Institutions			24.6		-18.9
			(33.98)		(37.14)
Bad Institutions			20.0		26.7
			(31.36)		(24.77)
Cultivable land				-110.2	-41.3
				(85.33)	(75.67)
River Density				-18.9	-10.5
				(16.06)	(9.74)
Temperature				-2.7	4.9
				(2.72)	(3.56)
Rainfall				-176.3***	-76.9*
				(47.76)	(44.37)
Altitude				37.1	40.8
				(46.92)	(67.45)
Landlocked				-55.3	-73.1**
				(48.02)	(31.85)
Constant	128.2***	190.3***	135.9***	492.0***	260.0**
	(20.12)	(20.53)	(33.31)	(73.05)	(120.59)
N	48	51	37	48	37
R^2	0.07	0.20	0.31	0.54	0.77

Notes: Dependent Variable is innovative capacity measured by engineers per 100,000 male workers. Pre-colonial population density measures the number of natives per square kilometer in 1492. Institutional controls: Colonial Good and Bad Institutions as generated by Bruhn and Gallego (2011), and slavery as tabulated from the 1860 Census as compiled in Nunn (2008). South a dummie capturing southern US states. Geographical Controls include agricultural suitability, river density, average temperature, rainfall, altitude and landlocked.

Table 8: Determinants of Innovative Capacity (Subnational sample, Fixed Effects)

	(1)	(2)	(3)	(4)	(5)	(6)
Pre-colonial Density	0.4***				0.4***	0.4***
	(0.01)				(0.04)	(0.04)
Good Institutions		-50.5***			-45.5**	-42.2**
		(10.67)			(11.97)	(12.74)
Bad Institutions		-80.3**			-84.1**	-72.5**
		(25.13)			(24.94)	(17.42)
Spanish Colony			-92.5***			-92.5**
			(17.55)			(26.91)
Spanish Colonized US						204.3***
						(13.06)
Cultivable land				-23.3	-43.8	-29.6
				(20.97)	(31.24)	(28.09)
River Density				-9.5	-3.9	1.8
				(21.27)	(18.91)	(16.79)
Temperature				-2.1	0.3	-0.6
				(1.44)	(1.26)	(1.33)
Rainfall				-25.0	-15.5	-15.2**
				(20.98)	(11.26)	(3.64)
Altitude				22.3	31.7	11.9
				(36.29)	(34.77)	(15.65)
Landlocked				-11.1	-26.0	-20.5
				(34.15)	(28.88)	(25.62)
_cons	73.1***	120.7***	140.5***	173.7**	157.8**	200.7**
	(0.04)	(8.80)	(0.00)	(40.66)	(45.78)	(71.19)
N	130	130	137	130	130	130
N Countries	5	5		5	5	
R^2	0.02	0.09	0.18	0.09	0.19	0.52

Notes: Dependent Variable is innovative capacity measured by engineers per 100,000 male workers. Full sample is Argentina, Chile, Mexico US and Venezuela. Pre-colonial population density measures the number of natives per square kilometer in 1492. Institutional controls: Colonial Good and Bad Institutions as generated by Bruhn and Gallego (2011). Geographical Controls include agricultural suitability, river density, average temperature, rainfall, altitude and landlocked. Columns 3 and 6 are pooled (no fixed effects) to identify the impact of the Spanish dummy. Robust SE in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.