# The origins of American industrial success: Evidence from the US portland cement industry

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26 June 2008

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†This paper began while visiting UCLA. Additional work was done at Lehigh University and the author is most appreciative of the hospitality of both universities. The author is also grateful to Naomi Lamoreaux and Jean-Laurent Rosenthal whose suggestions got this paper off the ground and gave it direction. The paper has also benefited from comments from Lionel Frost, Gary Magee, Simon Ville, Gavin Wright and from participants at seminars at Deakin University, La Trobe University, Lehigh University and the Universities of Melbourne and Sydney.

**Abstract**

The contributions of innovations, factor endowments and institutions to American industrialization are examined through analysing the rise of the American portland cement industry. Minerals abundance contributed in multiple ways to the spectacular rise of the industry from the 1890s. However, the results of a structural econometric analysis of entry suggests geological surveys, institutions highlighted by David and Wright, played a contributing rather than critical role in the American portland cement industry overcoming incumbent European portland cement and American natural cement producers.

# 1 Introduction

The origins of American industrial success have long been debated. While early work emphasized the effects of the US Civil War, subsequent research focussed on the interaction between innovation, factor endowments, and other characteristics of the American economy (Engerman and Sokoloff, 2000). The distinctively capital intensive and standardized American production technology was explained as resulting from relative labor scarcity and a relatively even distribution of income. The rate of innovation was encouraged by the increasing scale of markets due to immigration and falling transportation and communication costs. Most recently Wright (1990) argues that the origins of the rise of the United States to international industrial leadership lay in its abundant mineral resources rather than scarce labor relative to capital or exogenous innovations. This abundance resulted not from a more extensive endowment but from a more extensive exploration and exploitation of that endowment. This resulted, argues David and Wright (1997), from a combination of liberal property rights, public geological research and extensive university-industry links. How these institutions (and to a lesser extent the factors highlighted by the earlier literature) created a competitive advantage for American firms, when competing with European firms, beyond presuming they lowered costs for American firms, has not been directly examined.

The American portland cement industry is an excellent case for such an examination. It is a minerals-intensive industry. Portland cement is manufactured by burning, using mineral fuels, limestone and clay in large kilns. Secondly, the industry rose to prominence during the 1890s — the decade Wright identifies as the beginning of international leadership. Finally, despite its highly visible role, in the form of concrete, in construction and urbanization, with the exception of Marchildon (1994), the cement industry is relatively neglected by economic historians.

The first step in our analysis is to review the development of the cement industry. We find the successful commercialization and rapid diffusion of the rotary kiln was the main development that enabled American manufacturers to replace the previously dominant natural and imported portland cement. It was the temporary abundance of fuel oil that enabled the experimentation to solve the operating problems of the rotary kiln that had previously prevented its commercialization by its English inventors. Hence, this industry is another example of an industry which achieved industrial success based on mineral abundance. However, the institutions highlighted by David and Wright were not directly involved in these developments, though there is anecdotal evidence of their playing other significant roles in the development of the industry.

In the second step of our analysis we econometrically analyze the contribution of public geological research. Published research on raw materials for cement production would have lowered entry costs. Hence, we estimate a structural model of entry, at the county level, in the portland cement industry to determine if entry was more likely in counties with more information on raw materials, and in states where geological surveys had been active for longer. We find, at best, a weak systematic relationship between entry and these controls for the contributions of geological surveys. This suggests that for the cement industry, public geological research played a contributing rather than a systematic critical role in its rise to industrial success. This does not rule out though that these institutions, as well as other institutions such as universities, transportation improvements and testing laboratories, were critical in different locations depending on the problems that arose there.

## 2 Testing the institutional origins of industrial success

In three papers Wright and David argue the origin of American industrial success was the national ability to locate and develop its abundant mineral resources. These resources were then converted into manufactured goods that were exported (Wright, 1990, 1999; David and Wright, 1997). David and Wright (1997) argue this ability results from three institutional features of the US economy: liberal property rights on minerals; state and federal geological surveys, and; an extensive mining education system with close industry links. Wright (1999) specifically emphasizes the national scale of the learning and the importance of size. David and Wright place the geological surveys around the start of these developments:

> Provision of geological information was perhaps the most important initial step in the collective enterprise of resource discovery and exploitation (David and Wright, 1997, p. 223).

Testing the impact of the institutions as a whole would probably require a cross-country comparison with enormous data requirements. The gradual development of these institutions and their impacts over time also poses problems for determining their impact from time series data. However, two features of the state and federal geological surveys make it more likely that we can identify their impact. First, as their reports identify the location of resources, they potentially have specific local impacts in terms of whether these resources are developed. Secondly, the timing of their operations can be determined and, as demonstrated in Table 1, there is considerable variation across regions in starting dates and periods operated by 1890. Hence, we can analyse if differences in the extent to which the geological surveys identified raw materials suitable for cement production, as well as general differences in the nature of the geological surveys, systematically influenced the development of the Portland cement industry over different locations within the United States.

However, we need to consider if there are other institutions that might have affected the spatial development of the industry. One complementary institution to those identified in David and Wright, mentioned in Wright (1990), is that a transportation network is required before resources can be developed. Meyer (1989) argues the development of the railroad network plays an important role in the industrialization of the Midwest. Calculations from U.S. Department of Interior (1883, 1895) suggest total US railroad mileage constructed doubles between 1870 and 1880 and almost doubles again between 1880 and 1890. In addition Puffert (2000) argues the importance of, during this period, the railroad network adopting a standard gauge. While the factors highlighted by David and Wright are relevant, the rise to success also requires the joining up of the transportation network so the resource intensive exports could be shipped from the midwest where they were made, as in Irwin (2003). This institution is complementary, though, as without US manufacturing having some other advantage, transportation improvements that carried American goods to the world could have just as easily carried European goods to the midwest driving out American manufacturers.

# 3 The rise of the American Portland cement industry

Cement is the powder which is combined with water to make a mortar and combined with sand and aggregate to make concrete. It is manufactured by burning a mixture of limestone and clay, or similar materials, in a large kiln. The burnt material, referred to as clinker, is then ground to make cement. The cement plant is usually built next to the raw materials. Hence, it is a mineral-intensive industry, relying on both minerals for raw materials and mineral fuel for processing. In 1890 there were three sets of sources of supply of cement to the United States. The largest supplier, 77% of consumption, was the domestic natural cement manufacturers, who used raw materials found naturally mixed in roughly the right proportions. The second largest supplier, 20% of consumption, were European manufacturers of portland cement — mainly from England and Germany where portland cement had been developed and all technological innovations had been made til then. Manufacturing portland cement requires combining raw materials, not naturally mixed, in specific proportions and with more extensive processing than natural cement. Portland cement was produced in the United States from around 1873 in the Lehigh Valley, Pennsylvania, and a few other locations, but in 1890 just 3% of cement consumed in the United States was portland cement manufactured there.

Table 2 demonstrates that the American portland cement industry rose to industrial leadership during the 1890s, the critical period identified by Wright. The second column demonstrates an enormous growth in American cement consumption from 2.26 million barrels in 1880 to 90.07 million barrels in 1910. Based on estimates reported in the 1918 Cement chapter, in 1913 the United States was, internationally, the single largest cement producer with 43% of international production, the next largest being Germany with 19%. Column three demonstrates that the price of portland cement fell by more than a half between 1890 and 1913, with most of the fall occurring by 1902. The real fall is even larger if quality improvements are taken into account. Columns four to six demonstrate that how domestic natural cement and imported cement (almost exclusively portland) were replaced by domestic portland cement. Despite almost complete import replacement, column seven shows cement never becomes a large export industry.

While there were forces increasing the demand for domestic cement, as is discussed below, a simultaneous halving of the real price requires a substantial decline in production costs. Contemporary sources and technological histories all highlight the successful commercialization and rapid diffusion of the rotary kiln during the 1890s as reducing costs and increasing quality sufficient to make American manufacture competitive (Marchildon, 1994; Stanger and Blount, 1901) The rotary kiln was first patented in England, in 1877, and improved on there, most notably in 1885 by Frederick Ransome, but had not been commercially successful there (Francis, 1977). So, in 1890 all imported cement and nearly all portland cement produced in the United States was manufactured using English or German-designed vertical kilns. The first successful application of the Ransome kiln was in 1889, also in the Lehigh Valley, by the Atlas Portland Cement Co. Stanger and Blount, English engineers who assisted with the unsuccessful attempts to develop the rotary kiln, when discussing why successful development happened in the United States and not England state:

> In this task they were much aided by the fact they could use petroleum — a fuel too dear to be employed here. The ease with which the temperature of the kiln could be controlled when a jet of burning petroleum was the source of heat allowed many somewhat crude attempts to reach a qualified success. (Stanger and Blount, 1901, p. 57)

The sources of this abundant and cheap crude oil were recent discoveries of oil fields at Lima, Ohio, and Los Angeles, California, where the oil contained impurities that made it unusable for illumination so it was used for fuel (Williamson, 1963) The dependence on using crude oil as a fuel initially limited the diffusion of the rotary kiln (Giron, 1893, p. 213). Entrants using the rotary kiln before 1898 mainly occurred in northern Ohio, southern California and the Lehigh and Hudson valleys. Following the adaption in the late 1890s, also at the Atlas Portland Cement Co., of the rotary kiln to use the much cheaper powdered coal as a fuel, the rotary kiln rapidly diffused widely as the Atlas Portland Cement Co. was unable to prevent other companies from inventing around their innovation (Hadley, 1945). The rotary kiln also quickly diffused back to Europe (Francis, 1977; Lathbury and Spackman, 1902). Contemporary sources emphasize substantial savings in labor costs through the mechanization of handling raw materials, output and fuel. They also note an increase in the speed and scale of production. Calculations by Stanger and Blount comparing manufacturing costs between American rotary plants, American rotary technology using English prices and English technology suggest even then that American firms had cost advantage due to lower fuel costs.

Note that the effect on costs is likely to be greater than that suggested by the fall in the price as two forces were increasing demand for cement that would have driven the price up to some extent. First, demand was expanding due to the diffusion, primarily from Europe, of the technology required for construction using reinforced concrete. The 1897 Cement chapter refers to excess demand in Europe as restricting the supply of exports to the United States. Skempton (1963) argues that reinforced concrete, though developed in the 1850s, was not really practical until the 1880s when German portland cements reached a certain strength. Condit (1960) documents the increasing range of applications to which concrete, and then reinforced concrete is applied in the United States from the late 1870s, and particularly from the late 1880s — initially, mainly, in non-building construction such as dams and bridges. The work of Wermiel (2000) suggests increasing urban demand for cement from the 1890s with the requirements by various cities that tall buildings be fireproof. This results in the diffusion of the skeleton frame building, featuring concrete walls around an iron or steel frame.

The second potential factor increasing prices was an increase in effective protection. Effective protection fell from 1861 to 1890 as while tariff rates remained constant, transport costs fell considerably, as documented by Harley (1988). Lesley (1924) note that cement imports came to California, relatively cheaply, as ballast for sailing ships. After 1890, effective protection falls and then rises. In 1890 the ad valorem tariff of 20% is replaced by a tariff of 30.4 cents per barrel, which at 1890 prices is a cut to 15%. But as the price of cement falls, the equivalent tariff rate rises to over 30% by 1904. Furthermore, over the 1890s, transport costs may have risen. The 1894 Cement chapter notes an increase in the transport cost of cement to Chicago. The literature on the transition from sail to steam is suggestive that the use of sail for bulk freights (and therefore the use of solid ballast) ceased by the early 1900s at the latest and, for the Atlantic routes, possibly much earlier (Harley, 1971).

## 3.1 Institutional Origins

Statements by cement manufacturers to the 1883 Tariff Commission refer to claims by importers that portland cement could not be produced in the United States because of a lack of chalk (as used in Europe) though the manufacturers also state suitable raw materials are believed to be widely available. Benjamin Miller also refers to the belief that there was no chalk, or similar materials, as a reason for the slow development of the industry (Tariff Commission, 1883, p. 705-708, p. 2275-2280; Miller, 1930). Both state geological surveys and the United States Geological Survey showed considerable interest in providing information on the raw materials for cement manufacture.

The interest by state geological surveys in supplying information on raw materials for cement manufacturing is demonstrated by the results of searching 30 geological survey reports from 18 states from 1837 to 1878 for references to cement, hydraulic limestone and water-lime. The results of this review are summarized in Table 3. Each column is associated with a different period during which the first entry into cement production using within-state raw materials occurred (if at all). Each row is associated with a different degree of reporting on raw materials for cement, ranging from no reference at all to the results of tests for suitability for cement production being reported. A separate entry is recorded for each report surveyed. This can mean multiple entries for a state. For example, three reports were viewed on Indiana with one having no reference, one having a reference and one including test results. Four reports are reported for Missouri, with three with references and one with test results.

In 17 out of the 30 reports reviewed at least some reference was made to raw materials for cement. Of the 13 reports with no reference, in two cases, references were made in other reports for the same state. In a further seven cases, the state cement industry either did not develop until after 1945 or never developed. While the unsystematic nature of the sample limits the conclusions that can be drawn, it does suggest possibly widespread interest in locating raw materials for cement production during this period.

There is more evidence of State geological survey interest in the rapidly developing industry around 1900. In Arkansas and Alabama, it is claimed such research directly led to firms developing raw materials identified in geological reports. The Indiana State Geologist actively searched for raw materials for the industry, with these searches being referred to in the trade journal, Municipal Engineering. In another trade journal, Stone, Blatchley states he discovered the location of some raw materials used by a new plant.

The United States Geological Survey (USGS) also regularly reported on raw materials for cement production and on the cement industry in general. From 1882, each USGS annual report includes short reports (which expanded over time) on different mineral industries, including the cement industry. In addition, the 1882 and 1887 annual reports contain a substantial chapter on "Useful Minerals of the United States", listing, by state, locations of resources, including cement rock, water-lime and hydraulic limestone. The Cement chapters for 1909-1911, 1914, 1916 and 1923, list USGS and state geological survey publications, as well as other sources, with information on raw materials and the cement industry. These lists include 39 additional USGS reports from between 1902 and 1913 including two large USGS Bulletins in 1905 and 1913 which outline at length (including maps and test results) the location and nature of cement raw materials. Finally, the 1910 Cement chapter extensively discusses cement raw material locations.

There is further evidence of geological survey contributions as well as university-industry links highlighted by David and Wright. John W. Eckert worked on the Pennsylvania Geological Survey, while a student at Lehigh University, Bethlehem Pa, before working for two early Portland cement manufacturers in the Lehigh Valley (Lesley, 1924). Outside of the Lehigh Valley, Professor Lord from Ohio State University, Professor Erasmus Haworth from the University of Kansas, both associated with their state Geological Surveys, were associated with plants in these states. Professor Babcock from the North Dakota State University, as well as that University's President started the first plant in North Dakota in 1899. While a professor at Cornell, S.B. Newberry assisted a nearby cement plant with quality problems and then went to co-found a cement company at Bay Bridge, Ohio (Lesley, 1924). Academics also acted as consultants to the industry. Professor Schaefer, also from Cornell, tested cement at the Howes Cave, New York, plant. Professor R.C. Carpenter also helped in further experiments there (Lesley, 1924). Robert Meade was an instructor in chemistry at Lafayette College at Easton, Pa., who went from assisting local companies in the Lehigh Valley to a nationally known consulting company. Finally, twelve universities (and two academics including Professor Carpenter) are listed in the 1901 edition of a cement directory as available for cement testing (Brown, 1901). However, there is no direct link to the universities and geological surveys with the innovations that enabled the commercialization of the rotary kiln.

The dominance of the natural cement industry in 1890 cannot be attributed to the geological surveys though. In Table 4 we compare, for each state, the starting dates of the natural cement industry with the starting dates of the first geological survey. While the first half of Table 4 demonstrates that in nearly half of the states the industry developed after the geological surveys began operation, 85% of natural cement production in 1890 was in states where the industry developed before the geological surveys, including all of the major producing states of New York, Pennsylvania, Kentucky and Indiana. Of the states that developed afterwards only Kansas, Ohio, Minnesota and Wisconsin had developed sizeable durable natural cement industries by 1890. The second half of Table 4 demonstrates most natural cement in 1890 is from states where entry accompanied the canals.

Contemporary accounts and the experience of plants suggest the transportation network could be important for the development of the industry. Eckel (1905) in discussing the determinants of the value of raw materials, suggests that a plant should be located near at least two transportation routes. Supporting this is the experience of two plants. Distance from a railroad was cited in Burkenroad (1979) as one of the factors contributing to the failure of an early Portland cement works near San Diego. The opening of a plant at Kingsport, Tennessee, is linked directly to the building of a railroad through the area (Cement and Engineering News, 1916, January, p. 21).

Testing laboratories are identified in Lesley (1924) as another institution important to the development of the industry. Lesley (1924) describes testing laboratories as assisting American manufacturers to improve the quality of their cement which was lower than, in particular, German cement. Furthermore, by allowing their conclusions to be used in advertising, these laboratories also enabled local manufacturers to credibly signal their quality improvement. Their credibility could have been established in a resource-abundant economy — most likely during earlier debates about the nature of steel which required extensive chemical testing (Misa, 1995).

# 4 Modelling institutional contributions to competitive entry

The rise of the American portland cement industry featured substantial entry. While from 1870 to 1889 only 19 plants enter in nine states, from 1890 to 1899, 35 plants enter, including entry in eight new states, and between 1900 and 1913, 117 plants enter, including entry in 14 new states. The diffusion of the coal-fired rotary kiln and, to a lesser extent, demand growth, made entry more profitable across all states, but the importance of the additional track and information provided by the surveys is likely to vary by region. So to determine their systematic contribution, we analyze if entry by American portland cement manufacturers was more likely in regions where there was more rapid growth in railroads and where geological surveys provided information on cement raw materials. The variables we use are defined in Table 5, with more detail on their construction in an appendix.

## 4.1 Dependant Variable

To analyze entry we need to identify all possible sites where entry could have taken place, and all entrants between 1889 and 1913. While it is not possible to identify all possible sites with raw materials suitable for cement production, as there have been no major scientific changes in what makes a site useable for cement production, a good approximation is the set of all sites where cement production occurred using local raw materials between 1889 and 2003. This was compiled using Cement chapters, industry directories and other sources.

We consider entry at the county level in part to match the data we have on raw material locations. There are just a few counties where there are multiple entrants within our sample period.

We analyze entry for two periods: 1889 - 1899 and 1900 - 1913. As both demand and technology changes dramatically between 1889 and 1913 it is unlikely that there is a single model for this period. Likelihood ratio tests for a reduced form probit confirm this, always rejecting a single specification to an alternative two period specification. We choose to break the sample period at 1900 as this is when the coal-fired rotary kiln becomes the technological standard and from then entry occurs in a broader set of states than previously.

Hence we define our dependant variable as follows:

$$E = \begin{cases} 1 & \text{if at least one entry in the county occurs} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

If entry does not take place, we construct all variables for the first entrant in a subsequent period e.g. we count the number of competitors that the entrant would have faced at the end of the period, not when they do enter. If all entry occurs before the end of the first period, this county is dropped for the second period. Hence we have 162 counties in the first period and 149 counties in the second period.

## 4.2 Entry Model

The model begins with the idea that entry occurs in a market only if a firm expects positive profits from entry. Following the entry literature from Bresnahan and Reiss (1991) profit is specified as the product of Variable Profit per unit sold and market size less entry costs. Profit per unit sold depends on demand, variable costs and competition. Entry costs include any scale-free costs or benefits of entry. This gives rise to the following equation for a dummy variable for entry, $E$:

$$E = \begin{cases} 1 & \text{if} \quad \text{E}(\Pi) = \text{E}(\text{Variable profit per unit} * \text{Market size} - \text{Entry costs}) > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

As Variable Profit per unit and Entry Costs are typically unavailable to researchers, the literature since Bresnahan and Reiss (1991) replaces each with a set of proxies.

We adopt the functional form for Π used in Dranove et al. (2003):

$$\Pi = \beta_0 + \beta p * ln(Pop_t) + \sum \beta_{vp} X_{vp,t} + \sum \beta_e X_{e,t} \quad (3)$$

where $X_{vp,t}$ and $X_{e,t}$ are sets of variables affecting Variable profit per unit and entry costs for period t. Unlike Dranove et al. (2003) our unit of observation is the county rather than the market, and we focus on initial entry rather than market structure.

Many of the factors highlighted in the previous section affected variable profits and entry costs. Before 1900, being near to crude oil is expected to lower marginal costs and increase variable profit per unit. Public geological research is expected to reduce the costs of locating suitable materials for a plant, and hence lower entry costs. More extensive railroads reduces the costs of shipping fuel in and cement out and increases variable profits.

As Dranove et al demonstrate we solve for the minimum market size required for entry, or entry threshold, by setting Π equal to zero and solving for the population, $Pop*$, that solves the equation:

$$Pop* = exp(-(\beta_0 + \sum \beta_{vp} X_{vp} + \sum \beta_e X_e)) \quad (4)$$

Comparing the entry thresholds to actual market sizes and observing how they change over time provides additional information as well as a check on the validity of our model.

## 4.3 Explanatory Variables

We measure market size, as usually is done in similar entry models, using population within the market area, *Pop*. There is limited information on market areas. In the 1896 Cement chapter Spencer Newberry contrasts mills in Pennsylvania, New York and Ohio that supply large markets and mills in other states that supply only local markets. Lesley (1911) describes how markets for Portland cement firms shrunk from national to regional. We approximate this by including all counties within 200 miles of the plant, as used in Rosenbaum and Sukharomana (2001) and other recent work on the cement industry. Though using one market size may seem not to match the description by Newberry, in practice, as much of the population during this period is concentrated in the northeast, it probably does not make much difference.

The first set of variables we consider are proposed to control for differences in Variable profit per unit. To control for differences in per-capita demand we include measures of the share of the population living in urban areas, *urbshr*, and population growth, *popgrwth*. Regions that are urbanized or rapidly growing are expected to have greater demand for concrete and cement for pavements, sewers and buildings.

To control for differences in competition we control for exposure to imports, *import*, the number of firms producing portland cement, *pc400*, and plants producing natural cement, *nc400*, within 400 miles of the plant. While most firms have one plant, in the natural cement industry during the 1890s there were cartels. However, to treat each cartel as a single plant would be in some cases, because of the numbers involved, misleading as to their effect. Between 1889 and 1899, just over a third of potential entrants would have either one or zero portland cement plants within 400 miles. Hence we include dummy variables for these cases to control for the greater profitability of entering into a monopoly, *pcmon*, or duopoly market, *pcone*.

In the first period, when oil was required for commercial operation of the rotary kiln, we control for the effect of the availability of oil, with a dummy for counties near where fuel oil is produced, *oil*.

To control for the role of the transportation network the growth in railroad mileage, *rrdgr*, is included. Growth rather than the level is used as we are interested in entry rather than firm numbers and the level tends to be highly correlated with population, making estimating a separate effect difficult.

The second set of variables capture the determinants of entry costs. The first variable, *fmh*, is a measure of the information provided by the geological surveys. This variable is a dummy variable indicating if the county has been identified as containing non-magnesian limestone or marl and if these resources were subsequently used, or not. For example, if a county is identified as having limestone but only marl is used, this suggests that the geological survey information was not directly useful so the county is not recorded as having had its raw materials identified. For the first period, we use the information contained in the USGS publication "Useful Minerals of the United States" for 1887. Though stated by the authors to be incomplete, and it may draw on non-geological survey sources, because it was published by the USGS, it is potentially available nationally and is the best source available to us to capture the information known before 1890. For the second period, we use the 1905 USGS Bulletin on the location of Portland cement materials (Eckel, 1905). Though published after 1900, it clearly draws on earlier sources.

We also include the number of years the geological survey had operated continuously before the date of entry to allow for accumulated knowledge and human capital in the geological survey itself, *gsyrc*. If these institutions played important supporting roles, we would expect the coefficients on these variables to be positive and significant.

Finally, we include a set of variables to control for other information that firms may find useful in choosing locations. In the first period, we include dummies for if there is a currently operating portland cement manufacturer within 50 miles, *locpc*. Dummies for if there has previously been a portland cement manufacturer in the county, *prpc*, and if there is or has been natural cement production in the county without portland cement production, *prnc*, are included in both periods. These variables, though, will also capture lagged effects of other causes, such as earlier geological research or growth in railroad density. The number of years since 1780 that a county has been settled, *agectye*, is included to control for other activities, like lime production or quarrying that might also reveal information about raw materials.

With such a specification we can identify if geological survey information increased the likelihood of entry after controlling for differences in demand. This will provide a kind of lower bound of the effect of the institutions highlighted by David and Wright - as spatial variation cannot provide information on those institutions whose effects diffuse nationally. But if we cannot identify a direct effect of these institutions, it provides a serious question as to their importance, and suggests that future work analyzing institutional origins must either be cross-country or use very specific variation in time.

# 5 Econometric evidence

The results from estimating the entry model for the two periods are reported in Table 6. First, we examine the controls for demand, competition and costs. Of the demand variables, population growth, *popgrwth* has a positive significant effect on profitability (therefore reducing the entry threshold) for 1900-1913. Next, examining the competition variables, *import* has a positive effect, significantly after 1899, consistent with this variable picking up demand effects rather than competitive effects. Consistent with expectations, for 1889-1899 there are significant positive coefficients on dummies for limited competition, *pcmon* and *pcone*. Plausibly, the size of the coefficient on *pcmon* is larger than that on *pcone*. The number of competitors of both types of cement significantly affects entry in both periods. Before 1900, low numbers (less than eight) of portland cement manufacturers attracts entry. Toivanen and Waterson (2005) also found that a rival's presence in a market can increase the likelihood of entry. Additional firms beyond eight reduces the expected profit from entry. For natural cement in the first period, the opposite pattern occurs. If a plant is not in range of the large clusters of natural cement plants (Rosendale-Louisville-Lehigh Valley) then additional natural cement plants makes entry less attractive. The effects are largely reversed in the second period. For 115 counties, the effect of additional competition on profitability by portland cement manufacturers is negative. For the remaining counties, mainly in the east and mid-east, the positive effect must be capturing demand effects. For natural cement producers, the effect is switched, with low (less than 6) numbers attracting entry but larger numbers (nearly exclusively in the east) now deterring entry.

Before 1900, the oil dummy has a significant positive and substantial effect on entry. Specifically, this implies that if a plant is near an oil producing area, the required market size is just 74% of what would otherwise be required. This supports the contribution of cheap fuel oil to industry development during this period.

Railroad growth is not close to significant in either period, so we can dismiss this as a systematic influence on the growth of the cement industry. The geological survey variables also do not perform particularly well. For the first period, the coefficient on the dummy for materials identified in the useful materials, *fmh*, is significantly negative. This may be because although areas with materials were known, entry was unprofitable due to other economic factors not captured in our model (such as quality problems). The proxies for the quality of the state organization, *gsyrc* and *gsyrcsq* in total have a negative effect except for those in seven states with current geological surveys that had operated for at least 20 years. In the second period, the results are mixed. While the sign on *fmh* is positive (with a p-value of 0.102) it is not significant. Furthermore as the size of the coefficient is much smaller than that on *oil* in the first period, or *prpc* in the second period, this suggests the effect was relatively small. The combined effect of *gsyrc* and *gsyrcsq* is significantly negative in nearly all cases. Hence, while earlier evidence suggested the importance of geological surveys in Alabama, Arkansas and Indiana, there is, at best, weak evidence that the geological surveys systematically made it easier for initial entry into cement production. This may be because these variables are relatively crude measures of the contribution of these institutions, or that other complementary institutions, such as testing laboratories or helpful local universities, were required for successful entry.

Finally, we consider the effects of previous economic activity on profitability. In both periods, the age of the county has a negative effect for nearly all counties, excluding twenty one in the plains and west in the first period, and a few counties in Oklahoma in the second period. This suggests that previous activity does not so much reveal raw materials as produce other activities that deter entry — perhaps not surprising for an industry requiring large quarries. In the first period, expected profitability is significantly increased by previous natural cement production. The variables capturing previous portland cement production have the expected signs but are not statistically significant. This perhaps reflects the high failure rate of early entrants. In the second period, existing or previous portland cement production has a significant positive effect on expected profitability. In total, it seems, in a finding similar to Toivanen and Waterson, that previous entry has a positive signaling effect, though in this case it is probably more about supply conditions than demand conditions. Furthermore, it suggests that assessing the role different institutions played in early entry, rather than entry in general, might yield additional insights about their importance.

In addition, we examine the predicted entry thresholds in Table 7. In the first panel, for each county, for each period, the predicted entry threshold is compared with the actual market size for the entrant in that county. In the second panel, for each period, whether entry occurred is matched up to whether the market size population exceeded the predicted entry threshold or not. In the first panel, for the period after 1899, the entry thresholds are fairly similar to the actual populations suggesting our model performs fairly well. Before 1900 a substantial proportion of the estimated thresholds are implausibly high. Nevertheless, the second panel of Table 7 shows that in 18 out of 23 cases where entry occurred, population exceeded the estimated entry threshold. As Table 7 suggests entry thresholds were lower (for 128 out of 149 counties) in the second period than the first. These results suggest that there was a general improvement in conditions for entry into the Portland cement industry after 1899. Because we are using proxies, we cannot determine whether this was due primarily to lower entry costs, lower production costs or greater demand. Contributions by institutions whose impacts are less geographically specific, such as greater training of engineers with experience in testing (such as described in Slaton (2001)) may also contribute to this.

# 6 Conclusion

The rise of the American portland cement industry is another example of how minerals abundance combined with innovation led to industrial success. While falling prices and greater output suggest the successful adoption of the rotary kiln, which could only occur in an oil-abundant economy, was the major factor, there is qualitative evidence that suggests that the state geological surveys and university-industry links, institutions highlighted in recent work by David and Wright, were also important contributors. However, an econometric analysis of entry by county, did not find a systematic positive relationship between industry development and resources being identified in two US geological survey publications. There is also no systematic relationship with the growth of railroad density. It may be the case that either better measures of the contributions of these institutions are required, or that complementary institutions such as university-industry links or private testing laboratories were required for exploiting the resources identified by the geological surveys.

# Appendix: Construction of the Dataset

*Plant Sites:*

The primary set of data used is the identities, operating dates and raw materials used by the 323 portland cement plants operating in the continental US between 1870 and 2003. For each year between 1890 and 2003, the Cement chapter reports the number of portland and natural cement plants operating in each state, or group of states. The identity of the plants operating is determined using: accompanying lists of plants for certain years, state reports published by the Bureau of Mines from 1952, and other sources including state geological surveys, company annual reports, industry directories, newspapers and trade journals. For our analysis we exclude plants not using raw materials located at the kiln site, plants producing the specialty product white cement, a few sites in which all entry occurred before 1889 and six sites for which it was difficult to describe their potential market due to their being on the water.

*Cement:* Annual natural, portland and puzzolan (a speciality cement) cement production from 1880-1924 and by decade from 1818-1829 to 1870-1879 is reported in the 1924 Cement chapter. The estimates from 1890 on are based on surveys conducted by the US Geological Survey, with earlier estimates made by chapter authors. Consumption is equal to imports plus domestic production less exports. We follow the contemporary practice of adding barrels unadjusted for differences in barrel sizes (which range considerably from 240 pounds to 400 pounds) in the absence of detailed price data enabling weighting of what were considerably differentiated products.

*Market Size:* Locational coordinates for the towns where the plants were located are collected from the National Atlas of the United States and the US Gazetteer online. For the counties, coordinates for central points, based on 2000 boundaries are collected from the Census 2000 Gazetteer of Locations of Counties. For counties that did not exist in 2000, coordinates for counties that matched according to maps by Thorndale and Dollarhide (1987). Indian Reservations in Oklahoma and South Dakota and Independent Cities in Virginia are similarly treated. Bureau of the Census states that out of 3192 counties and Indian reservations, 2583 have had no significant change from 1880. The remaining 609 counties is an upper bound on the number of problem counties, as mislocation of the centre of the county is only a problem if the county is on the boundary of a market area.

We construct market size as the sum of the populations in all counties within 200 miles. A radius of 200 miles is used because the Census of Transportation in 1977, which is the only comprehensive data on market sizes available, suggests most cement shipments take place within this distance. This distance has been used in other studies including that of Rosenbaum and Sukharomana (2001) and studies cited therein.

*Urbanization:* We define an area within a county as urbanized if it is a town or city and if its population is at least 8000. We compiled all such towns from each of Census of Population and calculated the urban population for each county. The ratio of urban population to total population is used to calculate the urbanization rate.

*Railroad Growth:* We obtain railroad mileage by state from the Statistical Abstract of the United States. State mileage is allocated by county using county population shares. Finally, we aggregate the estimated mileage for all counties within 200 miles of the plant. The estimated growth rate is the exponential growth rate over the previous decade.

*Import* A county is defined to face import competition if on the coast, the Great Lakes, on or near the inland river system up to Kansas City, St. Louis, Cincinatti, Columbus or Indianapolis (as indicated by contemporary reports) or next to a customs district county on the coast, river or lake systems.

*Oil* Two oil fields are identified as producing fuel oil: Los Angeles and Lima (which includes counties in Ohio and Indiana). Counties were identified from Williamson, "American Petroleum", and Oil chapters in USGS reports.

## ENDNOTES

1. All statistics reported in this section are compiled from the chapters on cement found in United States Geological Survey (USGS) and Bureau of Mines publications (hereafter referred to as Cement chapters).

2. This lead was temporary. By 1999, the United States produced about only 5% of cement internationally, with China producing about 35%.

3. The head of the testing laboratory in Philadelphia in 1898 states "The city is using to-day cement over 50 per cent stronger than that used during 1892, and a cost of from 50 to 60 cents per barrel less. Nearly every barrel of this material is American cement" (statement by Richard L. Humphrey in discussion accompanying Lesley (1898).

4. The Atlas Portland Cement Co. is the ultimate name of a series of firms with the same principals that operate from 1885 as extensively described in Hadley (1945).

5. Common terms for materials suitable for cement making.

6. Taff (1902), Municipal Engineering, May, 1902, p. 311.

7. Blatchley (1901), Municipal Engineering, October, 1898, p. 264.

8. Stone, January, 1902, p. 37-38.

9. Though his affiliation is not stated, a Professor R.C. Carpenter was the head of the Department of Experimental Engineering at Cornell University in the 1890s (Selkreg, 1894, Chapter 19).

10. Geological survey starting dates are compiled from Socolow (1988). State natural cement industry starting dates are compiled from USGS and state geological survey reports, the United States Census of Manufactures, and Cummings (1898).

11. Cummings (1898), Lesley (1924) and Hahn and Kemp (1994) have all

made this point.

12. See Brown (1901), where fifteen companies include test results from laboratories, city engineerings and university professors.

13. Rosenberg (1985) also mentions their role in connection with cement and concrete.

14. Standardization, identified by Anderson (1999) as a cause of the rise occurred only after 1904, so is likely to mainly have contributed to the later rise in demand though the discussion of Kelley (1923) suggests it may have broadened the set of usable raw materials too. See Slaton (2001) for further discussion of specifications in cement and concrete.

15. U.S. Bureau of the Census (1996)

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Table 1

STATE GEOLOGICAL SURVEYS

| Census Region | Year Started | | | Operating Years by 1890 | | |
|---|---|---|---|---|---|---|
| | Median | Minimum | Maximum | Median | Minimum | Maximum |
| New England | 1837.5 | 1830 | 1844 | 7.5 | 2 | 19 |
| Middle Atlantic | 1836 | 1835 | 1836 | 36 | 32 | 55 |
| East North Central | 1837 | 1837 | 1853 | 24 | 20 | 35 |
| South Atlantic | 1835 | 1823 | 1907 | 9 | 0 | 40 |
| East South Central | 1843 | 1831 | 1850 | 25.5 | 23 | 57 |
| West North Central | 1864 | 1853 | 1899 | 4 | 0 | 23 |
| West South Central | 1863.5 | 1857 | 1908 | 8 | 0 | 13 |
| Mountain | 1913 | 1866 | 1931 | 0 | 0 | 13 |
| Pacific | 1890 | 1860 | 1911 | 1 | 0 | 26 |

*Note*: Pacific excludes Alaska and Hawaii

*Source*: Socolow(1988)

Table 2

INDUSTRY DEVELOPMENT

| Year | U.S. cement consumption mill. bbls | Portland cement price - real | Portland cement share | Natural cement share | Import cement share | Exports mill. bbls |
|---|---|---|---|---|---|---|
| 1880 | 2.26 | 11.00 | 1.86 | 89.87 | 8.27 | n.a. |
| 1890 | 9.72 | 8.43 | 3.45 | 76.58 | 19.97 | 0 |
| 1902 | 27.38 | 4.86 | 61.70 | 29.38 | 7.17 | 0.34 |
| 1913 | 90.07 | 3.34 | 98.96 | 0.83 | 0.1 | 2.96 |

*Note*: Exports in 1891 used for 1890. Exports unavailable for 1880, 1890.

*Source*: Appendix

Table 3
RESULTS OF REVIEW OF STATE GEOLOGICAL SURVEYS

| Type of report in survey | Industry never develops | First development of the cement industry by state: Industry developed By 1889 | 1890-1899 | post-1913 |
|---|---|---|---|---|
| No reference made | LA,NH, VT | CA(2),MN,WI,IN* | NJ | MS(2),NC(2) |
| Reference made | | IN*,MI,MI*,MO(3)#, OH*,PA(2)*,TN*,WI | AR | |
| Reference includes test results | | IN*,IA#,ME,MO#, OH* | | |

* Cement production already occurring in the state by the time of the survey

\# Unknown if cement production already occurring

*Source*: Text

Table 4
NATURAL CEMENT INDUSTRY AND STATE GEOLOGICAL SURVEYS

| Event | States in 1890: Producing | Non-producing | Production Share: 1890 |
|---|---|---|---|
| *State geological survey(SGS)* | | | |
| Entry before SGS commenced | GA,IL,IN,KY NM,NY,PA,WV | CO,CT,FL, NE,UT,WA | 85% |
| Entry within 10 years of SGS | KS,MD,OH | CA,ND | 6% |
| Entry more than 10 years after SGS commencing | MN,TX,VA,WI | MI,TN | 9% |
| Entry unknown | | IA,MO | 0 |
| *Canals* | | | |
| Entry linked to canals | IL,IN,KY,MD, NY,PA,VA,WV | | 87% |
| Entry after canals | OH | CT | 1% |
| *With no link* | | | |
| No canals | KS,MN,GA NM,TX,WI | CA,CO,FL,IA,MI MO,NE,ND,TN,UT,WA | 12% |

*Source*: Text

TABLE 5
DEFINITIONS OF THE VARIABLES

| Variable | Description |
|---|---|
| Entry | Dummy variable = 1 at least one entrant during the period |
| Pop | State market size in millions |
| *Demand* | |
| urbshr | Ratio of urban population to total population |
| popgrwth | Growth in population over the previous decade. |
| *Competition and Costs* | |
| import | Dummy variable equals 1 if county located on border (including Great Lakes) or on river system accessible by imports (see Appendix for details) |
| pc400 | Number of firms producing portland cement operating within 400 miles |
| nc400 | Number of plants producing natural cement operating within 400 miles |
| pcmon | Dummy variable equals 1 if no portland cement production occurring within 400 miles (Period One only) |
| pcone | Dummy variable equals 1 if one portland cement manufacturer between 50 and 400 miles (Period One only) |
| oil | Dummy variable equals 1 if county or a neighbouring county produces fuel oil (Period One only) |
| *Geological Surveys and Railroads* | |
| fmh | Dummy variable equals 1 if a USGS publication identified raw materials subsequently used (and no previous portland cement production) |
| gsyrc | Number of years the state geological survey operating at the time of entry had been conducted for. |
| rrdgr | Growth in the mileage of railroad over previous decade. |
| *Previous Economic Activity* | |
| prpc | Dummy variable equals 1 if Portland cement production occurred in the county before the current entrant. For period one, excludes currently operating plants |
| prnc | Dummy variable equals 1 if Natural cement production, and no Portland cement production occurred in the county before the current entrant |
| locpc | Dummy variable equals 1 if at least one portland cement manufacturer within 50 miles (Period One only) |
| agectye | Number of years the county (or its predecessor) settled since 1780 |

* Squared versions of these variables are used as well

*Source*: Text and Appendix

Table 6
ENTRY MODEL

| Variables | 1889-1899 | | | 1900-1913 | | |
|---|---|---|---|---|---|---|
| Dependant | entry | | | entry | | |
| Explanatory | Coefficients | | Standard Errors | Coefficients | | Standard Errors |
| constant | -9.481 | ** | 4.357 | -1.654 | | 1.150 |
| lnpop | 1.976 | ** | 0.962 | 0.801 | *** | 0.303 |
| *Demand* | | | | | | |
| urbshr | -10.982 | | 9.907 | 5.363 | | 4.303 |
| urbshrsq | 8.193 | | 15.044 | -7.859 | | 5.919 |
| popgrwth | 40.460 | | 61.952 | 54.870 | ** | 22.341 |
| *Competition and Costs* | | | | | | |
| import | 0.505 | | 0.884 | 0.567 | * | 0.345 |
| pc400 | 1.320 | ** | 0.663 | -0.175 | *** | 0.057 |
| pc400sq | -0.081 | ** | 0.035 | 0.003 | *** | 0.001 |
| nc400 | -0.255 | * | 0.136 | 1.278 | *** | 0.378 |
| nc400sq | 0.011 | *** | 0.004 | -0.124 | *** | 0.043 |
| pcmon | 7.159 | ** | 3.164 | | | |
| pcone | 4.303 | * | 2.380 | | | |
| oil | 4.275 | *** | 1.670 | | | |
| *Geological Surveys and Railroads* | | | | | | |
| fmh | -2.110 | * | 1.102 | 0.472 | | 0.288 |
| gsyrc | -0.122 | | 0.085 | -0.060 | ** | 0.026 |
| gsyrcsq | 0.003 | * | 0.002 | 0.0008 | ** | 0.0004 |
| rrdgr | 6.031 | | 56.591 | -30.688 | | 19.977 |
| *Previous Economic Activity* | | | | | | |
| prpc | 1.884 | | 1.648 | 1.282 | ** | 0.564 |
| locpc | -0.741 | | 1.091 | | | |
| prnc | 5.341 | *** | 2.019 | 0.712 | | 0.484 |
| agectye | 0.167 | ** | 0.075 | 0.024 | | 0.020 |
| agectyesq | -0.002 | ** | 0.001 | -0.0004 | ** | 0.0002 |
| sample | 162 | | | | 149 | |
| Log likelihood | -17.62 | | | | -70.48 | |

***= Significant at the 1 per cent level.

**= Significant at the 5 per cent level.

*= Significant at the 10 per cent level.

Table 7

ENTRY THRESHOLDS

| | 1889-1899 | | | 1900-1913 | | |
|---|---|---|---|---|---|---|
| | First Quartile | Median | Third Quartile | First Quartile | Median | Third Quartile |
| *Counties in which entry occurred* | | | | | | |
| Population | 2.46 | 9.09 | 10.12 | 1.85 | 6.19 | 10.12 |
| Thresholds | 0.34 | 2.14 | 4.72 | 0.70 | 2.12 | 4.68 |
| *Counties in which no entry occurred* | | | | | | |
| Population | 0.73 | 3.93 | 7.88 | 0.83 | 3.83 | 6.71 |
| Thresholds | 5.79 | 24.96 | 175.31 | 1.46 | 7.32 | 21.09 |

| | 1889-1899 | | 1900-1913 | |
|---|---|---|---|---|
| | *Entry* | *No Entry* | *Entry* | *No Entry* |
| Population > Threshold | 18 | 1 | 61 | 18 |
| Population < Threshold | 5 | 138 | 14 | 56 |