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

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THE ORIGINS OF AMERICAN INDUSTRIAL SUCCESS: EVIDENCE FROM THE U.S. CEMENT INDUSTRY

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

The origins of the 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.[1] The distinctively capital intensive and standardised 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 Gavin Wright has argued 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.[2] This abundance resulted not from a more extensive endowment

[1]See Engerman and Sokoloff, "Technology".

[2]Wright,"Origins".

but from a more extensive exploration and exploitation of that endowment. This resulted, argues Wright and Paul David, from a combination of liberal property rights, public geological research and extensive university-industry links.[3] How these insitutions (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 study for such an examination. It is a minerals-intensive industry, being 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. Before the 1890s, American portland cement manufacturers supplied just 3% of the market, with the rest being supplied by American natural cement manufacturers and imports from Europe. By 1913, American portland cement production is the largest in the world and it supplied nearly 99% of a domestic market nearly ten times the size of that in 1890. Thirdly, there is also evidence of public geological research and university-industry links playing a role in the rise of the industry. In addition, despite its highly visible role, in the form of concrete, in construction and urbanisation, the cement industry has been relatively neglected by economic historians.[4]

While there is qualitative evidence that public geological research and university-industry links assisted the development of the American cement industry, a more systematic search by estimating a structural entry model for two periods, 1889 to 1899 and 1900 to 1913, failed to find any statistically

[3] David and Wright,"Increasing Returns".

[4] Marchildon, "Portland" is a notable exception.

significant relationship. This suggests that while the institutions identified by Wright and David played a contributing role, for the cement industry, their contribution was not so large so to be easily detectable using relatively crude measures of their contribution. The successful adoption of the rotary kiln, resulting from a temporary abundance of fuel oil, supported by an increase in demand due to the diffusion of reinforced concrete appear to be the main determinants of the rise. The rotary kiln, though invented in England, increased both the capital intensity and mineral intensity (through increased fuel consumption) of cement production. Hence, the explanation for the development of the cement industry is largely consistent with the general explanation of the rise of American industry that has developed in the literature. However, our close examination of competition between US and European cement producers suggests that as well as reducing costs and improving quality, American producers also had to overcome an asymmetric information problem related to their quality. The endorsements of private testing laboratories, as well as universities, with well established reputations, enabled American firms to credibly signal quality improvements. Such institutions are also a required part of a minerals-intensive economy that is industrialising.

THE ORIGINS OF AMERICAN INDUSTRIAL SUCCESS

In three papers Wright and David arge the origin of American industrial success was the national ability to locate and develop its mineral resources. These resources were then converted into manufactured goods that were exported.[5]

There are two parts to the contribution of Wright and David. First, Wright demonstrates the rise of US manufacturing during the mid 1890s was

[5] Wright, "Origins", David and Wright, "Increasing Returns", and Wright, "Can a Nation".

associated with a rise in the resource intensity of exports rather then product or process innovations. He observes that the rise in resource intensity of exports occurs simultaneously with the rise to world leadership in numerous minerals. The first effect of natural resource abundance is lower input prices. Wright suggests this link for steel products and argues it implicitly for a range of products. Douglas Irwin argues the increase in iron and steel product exports follows the rapid exploitation, from 1892, of the recently discovered non-tradeable Mesabi iron ore deposits, in Minnesota, which led to a dramatic fall in the price of iron ore.[6] In addition, Wright also argues resource abundance encouraged the distinctive American production methods and corporate organization and even the type of goods produced.[7]

Secondly, Wright argues resource abundance resulted not from greater endowments but a greater ability at the time to locate and develop the endowments there. The features of the US economy that lead to this, argue David and Wright are:

1. Liberal property rights on minerals.

2. State and federal geological surveys.

3. Extensive mining education system, with close industry links.

They emphasize the simultaneous contribution of these features, with spillovers across different sectors and developments in each reinforcing the effects of the others. Wright particularly emphasizes the national scale of the learning and the importance of size.[8] David and Wright do, though,

[6] Irwin, "Explaining America's".

[7] Wright, "Origins".

[8] Wright, "Can a Nation".

place the geological surveys around the beginning of these developments:[9]

> Provision of geological information was perhaps the most important initial step in the collective enterprise of resource discovery and exploitation.

Liberal property rights also develop before the Civil War with the mining education system developing shortly after though the United States Geological Survey did not commence until 1879.

In order to test the Wright-David arguments, we need to present an alternative hypothesis. Two possibilities are as follows:

- Resource discoveries did not result from the institutions described by David and Wright.
- Institutions other than those identified by Wright and David were required for industrialization.

One complementary (rather than alternative) institution to those identified in David and Wright, which is mentioned by Wright, is that a transportation network is required before resources can be developed.[10] David Meyer argues the development of the railroad network plays an important role in the industrialization of the Midwest. 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

[9] David and Wright, "Increasing Returns", p223.

[10] Calculations from U.S. Department of Interior, "Agencies of Transportation" and "Transportation Business" suggest total US railroad mileage constructed doubles between 1870 and 1880 and almost doubles again between 1880 and 1890. In addition Douglas Puffert, "Standardization", argues the importance of, during this period, the railroad network adopting a standard gauge.

from the midwest where they were made, as in Irwin's work.[11] Note that the transportation improvements that carried American goods to the world could have just as easily carried European goods to the midwest if there were not other factors, such as resource abundance relative to the rest of the world, present.

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.[12] 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. Just 3% of cement consumed in the United States was portland cement manufactured domestically.

[11] Irwin, "Explaining America's.

[12] 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).

Table 1 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%.[13] Columns five and six demonstrate that while cement never becomes a large export industry, substantial imports are almost completely replaced by the local product. Columns seven and eight demonstrate that the prices of portland and natural cement fall substantially over the period. Finally, columns three to five show how domestic natural cement and imported cement (almost exclusively portland) were replaced by domestic portland cement. It is also important to note that domestic production of portland cement spread right across the United States. From 1870 to 1889 only 19 plants enter in nine states, whereas from 1890 to 1889, 35 plants enter, including entry in eight new states, and between 1900 and 1913, 117 plants enter, including entry in 14 new states.[14]

The enormous expansion of the industry at the same time as the real price shrinking to less than a third (quality adjusted the fall in price is even greater) suggests there must have been a large supply shock (a shift downwards of the supply curve). This is particularly the case when we take into account

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

[14]The geographical diffusion of the industry argues against declining transportation costs being the dominant change. If the existing sites had advantages then declining transportation costs should have led to concentration up to the point where economies of scale are exhausted. It is possible that diffusion could still result if economies of scale and other advantages of incumbent sites are quickly exhausted, but this doesn't seem likely.

two other shocks that were occurring.

The first potential cause for the rise of the cement industry is increased demand. This expansion of demand appears connected with 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. A.W. Skempton argues that reinforced concrete, though developed in the 1850s, was not really practical until the 1880s when German portland cements reached a certain strength.[15] Carl Condit 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.[16] The work of Sara Wermiel 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.[17] However, an increase in demand is unlikely to be the sole explanation as it is not impossible that in the long-run imported portland cement and, to a lesser extent, domestic natural cement could have met these demands.

The effective protection of the American cement industry also changed over this period, though the size of the effect is not clear. Effective protection fell from 1861 to 1890 as while tariff rates remained constant, transport costs fell considerably, as documented by Knick Harley. Robert Lesley et al. note that cement imports came to California, relatively cheaply, as ballast for

[15]Skempton, "Portland".

[16]Condit, "American".

[17]Wermiel, "Fireproof".

sailing ships.[18]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.[19]

The most likely candidate for the supply side shock is the development given greatest prominence in contemporary sources and technological histories. The successful commercialization and rapid diffusion of the rotary kiln during the 1890s.[20] Portland cement had been produced in the United States since around 1873 in the Lehigh Valley, Pennsylvania, and other locations but nearly all entrants up to 1889 used either English or German-designed vertical kilns. 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.[21] The first successful application of the Ransome kiln was in 1889, also in the Lehigh Valley, by the Atlas Portland Cement Co.[22] Following the adaption, also at the Atlas Portland Cement Co., of the rotary kiln to use powdered coal as a fuel, instead of the more

[18]Harley, "Ocean"; Lesley et al., "History".

[19]Harley, "Shift".

[20]Marchildon, "Portland".

[21]Francis, "History".

[22]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, "Magic". One name is used for simplicity.

expensive gas and oil, the rotary kiln rapidly diffused widely as the Atlas Portland Cement Co. was unable to prevent other companies from inventing around their innovation.[23] The rotary kiln also quickly diffused back to Europe. European engineers visited the United States to work and learn about rotary kilns and American engineers built plants in Europe.[24] The rotary kiln was particularly suitable for a resource abundant economy as, compared with vertical kilns, it used much less labor but more fuel and material handling was mechanised. Hence, it increased the capital and resource intensity of cement production, as well as the speed and scale of production.

It is important to note that contemporary sources attribute the successful development of the kiln to abundant supplies of fuel oil. Stanger and Blount, English engineers who assisted with the unsuccessful attempts to develop the rotary kiln state[25]:

> 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.

Similarly, Pierre Giron, a chemist at the Atlas Cement Works states[26]:

> As the matter stands now, however, the Rotary Kiln can be successfully operated only in localities where crude oil is abundant and cheap ...

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[23] Hadley, "Magic".

[24] Francis, "History"; Lathbury and Spackman, "American".

[25] Stanger and Blount, "Rotatory", p57.

[26] Giron, "Burning", p213.

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.[27]

The question remains as to whether the institutions highlighted by David and Wright, particularly the geological surveys, contributed to the rapid geographical diffusion of the industry in the 1900s. The gradual geographical diffusion of the industry is consistent with regions with more extensive surveying developing first. However, it is not unreasonable to suppose that the geological surveys of the period may not have been interested in the location of raw materials for cement manufacturing as limestone deposits were already used to make lime, fertilizer and in iron production. Two statements by cement manufacturers to the 1883 Tariff Commission state suitable raw materials are believed to be widely available. However, both these statements refer to claims by importers that portland cement could not be produced in the United States because of a lack of the type of raw materials used in Europe. Benjamin Miller also refers to this belief as a reason for the slow development of the industry.[28]

However, we demonstrate that at least several state geological surveys reported on cement raw materials. We searched 30 geological survey reports from 18 states from 1837 to 1878 for references to cement, hydraulic limestone and water-lime (these were common terms for materials suitable for cement making). The results of this review are summarized in Table 2. 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,

[27] See Harold Williamson, "American Petroleum".

[28] Tariff Commission, "Report", p. 705-708, p. 2275-2280; Miller, "Contribution".

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 were reported for Missouri, with three having a reference and one including 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.

The United States Geological Survey (USGS) also regularly reported on raw materials for cement production and on the cement industry in general. From 1882, in each USGS annual report, short reports (which expanded over time) on different mineral industries were published, including the cement industry. In addition, the 1882 and 1887 annual reports contain a concluding 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. Included in the additional reports are 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 also evidence of geological survey employees and university professors contributing to the technological development of the industry. John W. Eckert worked on the Pennsylvania Geological Survey, before working for two early Portland cement manufacturers in the Lehigh Valley.[29] While a professor at Cornell, S.B. Newberry assisted with quality problems at a nearby cement plant and then went to co-found a cement company at Bay Bridge, Ohio.[30]There is further evidence that academics acted as consultants to the industry. Professor Schaefer, also from Cornell, is stated to have tested cement at the Howes Cave, New York, plant. Finally, Professor R.C. Carpenter is also stated as helping in further experiments there.[31] Finally, twelve universities (and two academics including Professor Carpenter) are listed in the 1901 edition of a cement directory as available for cement testing.[32] However, there is no direct link to the universities and geological surveys with the innovations that enabled the commercialisation of the rotary kiln.

Finally, we also analyse competition between each of the different types of cement during the 1890s to determine if there were other influential industry specific factors and to assist assessing the importance of each of the potential causes. Graph One demonstrates that between 1892 and 1895, consumption of all types of cement increases. From 1897, domestic portland

[29]Lesley et al., "History". Professor Erasmus Haworth from the University of Kansas, also associated with the Kansas Geological Survey, was associated with a short-lived start-up in the late 1900s in Kansas.

[30]Lesley et al., "History".

[31]Lesley et al., "History". 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, "Landmarks", Chapter 19.

[32]Brown, "Directory".

cement becomes the largest source of portland cement and, by 1900, overtakes natural cement. In 1898, domestic portland cement produced using rotary kilns, exceeds domestic portland produced using vertical kilns. After 1900, all three competing types of cement rapidly decline in relative and, eventually, absolute size.

Note that the dominance of the natural cement industry in 1890 cannot be attributed to the geological surveys. In Table 3 we compare, for each state, the starting dates of the natural cement industry with the starting dates of the first geological survey.[33] While the first half of Table 3 demonstrates that in nearly half of the states the industry developed after the geologicial 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 3 demonstrates most natural cement in 1890 came from states where the first resources were developed during canal construction, the link having been repeatedly argued in earlier literature.[34] Canals provided demand for the initial production and then provided a means of transportation for the cement product itself. This suggests that the rise of the natural cement industry did not result from the factors identified by David and Wright but was rather linked to infrastructure improvements earlier identified as contributing to rise of U.S. manufacturing.

[33]Geological survey starting dates are compiled from Socolow, “State”. State natural cement industry starting dates are compiled from USGS and state geological survey reports, the United States Census of Manufactures, and Cummings, “American”.

[34]Cummings, “American”; Lesley et al.,“History”; and Hahn and Kemp, “Cement”.

The first thing to note when discussing competition with imports is that in the 1880s and early 1890s, as shown in market reports between 1878 and 1887 in the trade journal *Manufacturer and Builder*, and as noted in the Cement chapters of the 1890s, imported portland cement typically trades at a higher price than domestic portland. The combination of higher prices and greater quantities for imported portland, compared with domestic portland, is consistent with the regular references in the cement chapters, and other contemporary sources, to the superiority of imported cements, particularly from Germany. The superiority of German cement seems largely due to the introduction of systematic quality control by trained chemists dating from the 1870s. In the 1880s, official standardised product and testing specifications were also adopted — which did not occur in the United Kingdom or the United States until the 1900s.[35]

There is evidence that American manufacturers did, initially, produce lower quality cement. Miller discusses quality control problems by the first American producer. Frederick Lewis, an engineer at Booth, Garrett & Blair, a testing company, is quoted by Lesley as suggesting that until the 1890s there were quality problems due primarily to a lack of skilled kiln operators.[36] Another early entrant, The Glens Falls Portland Cement Co., which operated German vertical kilns employed German-trained kiln burners to overcome operating problems, as did other firms.[37] Giron and Lesley, in discussion, note problems with quality in American cement produced by both rotary and vertical kilns.[38] However, Lesley et al. note that production us-

[35]Marchildon, "Portland".

[36]Miller, "Contribution"; Lesley et al., "History", p. 134.

[37]Bayle, "History"; Lesley et al., "History".

[38]Giron, "Burning".

ing established European technology was believed to provide an advantage when seeking business in the American market and discusses competition between domestic manufacturers using the two technologies.[39] Even once quality control problems had been overcome, American manufacturers, particularly those using the new rotary kiln technology, face an asymmetric information problem. Consumers cannot distinguish without use the quality (or quality improvements) of American portland cement and hence require a discount before being willing to purchase domestic rather than imported cements, which have well established reputations for quality.

However, two institutions made it easier for the domestic, particularly rotary kiln, cement producers to overcome import competition. First, the publicised specifications for German cement provided a benchmark, in terms of quality, to aim for. Hadley describes how the Atlas Portland Cement Co. consciously strove to surpass the test results of a leading German brand. Second, a set of institutions existed that could credibly certify the quality of American rotary kiln-produced portland cement — private testing laboratories and universities.[40] Lesley et al. state[41]:

> In referring to all this testing of cement as part of the commercial development of the industry, it must be understood that there was required such work as was done by testing laboratories of established reputation before the American cement could acquire merited standing.

[39]This is supported by new vertical kiln plants being built as late at 1897, and new vertical kilns being installed in 1899.

[40]Rosenberg, "Commercial", has stressed the importance of materials testing in this period, including a brief discussion of cement and concrete.

[41]Lesley et al., "History", p. 138.

The efforts of US producers to demonstrate quality control are demonstrated in the company entries in the 1901 edition of Brown's cement industry directory.[42] Fifteen companies (including many of the largest such as Atlas) include test results in their listings. The vast majority of reported test results are for tests performed outside the firm — by users such as city engineers, testing companies such as Booth, Garrett & Blair, Robert W. Hunt Co. and Lathbury & Spackman, and university professors. The asymmetric information problem is overcome through certification of the quality of American cement by credible authorities. Each set of authorities listed above had valuable reputations to be lost if the claims did not turn out to be true, which makes the claims credible.[43] Though David and Wright do not highlight the role played by these firms, it is important to recognise that their credibility could have only been established in a resource-abundant economy.[44] In particular, they likely built their credibility during earlier debates about the nature of steel which required extensive chemical testing.[45] The expertise and credibility developed during this period could then be used to certify the quality of the product of the cement industry as it expanded.

On the basis of the evidence assembled here, we cannot immediately single out or eliminate most of these potential causes. While the rise in consumption of natural and imported portland cement up until 1900 as well as domestic portland cement produced using vertical kilns suggests potential roles for increased demand and protection, the substantial fall in the real

[42] Brown, "Directory".

[43] Lesley et al. state private testing firms not only certified but actively assisted domestic manufacturers to overcome quality control problems and in relationships with customers.

[44] Wright, "Can a Nation".

[45] Misa, "Nation"; and Rosenberg, "Commercial".

price of portland cement, $8.43 per barrel in 1890 to $4.86 per barrel in 1902, is consistent with a supply shock being the main determinant of the rise of the American portland cement industry during this period.[46] Furthermore, as the development, by the American Society for Testing Materials, of standard specifications for cement and its testing was not until 1904, it seems more likely standardisation contributed to the increase in demand post-1904, rather than, as argued by Philip Anderson, to the rise of the American portland cement industry to domestic dominance.[47] The timing of the changes suggests the successful commercialisation of the rotary kiln is the most likely determinant. The continued increase in consumption of cement over the 1900s, without further large price declines, suggests an increase in demand, due to a combination of the diffusion of concrete and reinforced concrete construction and product standardisation becoming more important. Protection may have discouraged import competition once the rotary kiln had diffused internationally, though cheap fuel is also a potential cause of this too. Finally, it is also worth noting that while this account is consistent with the general literature, as it features technological change suitable for American factor endowments, the importance of minerals abundance, rather than capital abundance is consistent with Wright's argument. While this information is suggestive of a role for the institutions highlighted by David

[46]The real fall is even larger if quality improvements are taken into account. 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,"History").

[47]Anderson, " Collective Interpretation". The 1885 recommendations by the American Society of Civil Engineers for cement testing were widely criticised as being too broad, leading to hundreds of possible specifications; Lesley et al., "History". See Slaton,"Reinforced concrete", for further discussion of specifications in cement and concrete.

and Wright, to determine if there was a widespread substantial contribution of the geological surveys. To evaluate this more systematically, we perform an econometric analysis.

ECONOMETRIC MODEL

To test the hypotheses of Wright and David, we propose a structural entry model that includes variables that aim to capture the contribution of the institutions highlighted by David and Wright and other complementary institutions. We then analyze the sign and significance of each of these variables to determine if they contribute consistently with the earlier arguments. The specific institutions we focus on are the geological surveys and transportation network. These institutions are analysed as, unlike other aspects of the argument of David and Wright, there is significant variation across regions within the United States in their presence and likely effects. It would be difficult for example to examine the contribution of universities as graduates are highly mobile. Railroads and the information in geological maps are tied to specific locations. Furthermore, such variation can be taken as exogenous in their relationship to the cement industry.

The main set of data constructed for this paper covers plant numbers and identities, operating dates and raw materials used. A list of the 324 plants operating in the continental US between 1870 and 2003 is compiled from three sets of sources. The number of portland and natural cement plants operating in each state, or group of states, for each year between 1890 and 2003, is reported in the Cement chapters for these years. The identity of the plants operating is determined using: lists of plants accompanying these statistics for certain years up to the 1932-1933 edition, state reports that were published by the Bureau of Mines from 1952, and other sources including state geological surveys, company annual reports, industry directories and trade journals. For our analysis we exclude plants that did not use raw materials located at the site of the kilns and plants that produced the specialty product white cement. This provides a list of possible sites at which a cement plant could have been located. In general there have not been major scientific changes in what makes a site useable for cement production since this period so all subsequent sites were potential locations for cement plants if the materials were known and entry would have been profitable. These sites are located in a total of 168 counties.

The entry model, which we adapt from earlier work discussed below, begins with the idea that entry will occur only if a firm believes that entry is profitable. Profits, in this literature, is specified as having three components. First there is variable profits which is the product of market size and profitability per unit sold. Second there are entry costs which can be considered as including any scale-free costs or benefits of entry. This gives rise to the following equation:

$$E = \begin{cases} 1 & \text{if} \quad \text{Variable Profit per unit} * \text{Market Size} - \text{Entry Costs} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

However, as much of this data is typically unavailable to researchers, the standard practice is to replace each of these variables with a set of proxies, which we specify below. Before proceeding it is important to discuss how the specifics of our case leads our approach to differ significantly from earlier applications. Most applications, following that of Timothy Bresnahan and Peter Reiss begin with specifying a market and apply an ordered probit model to model the number of firms in the market, assuming the market is in equilibrium.[48] However, in our application it is unclear what the market is facing different firms. 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. Instead of the unit of observation being the market, our unit of observation is the county, and we construct estimates of market size, number of competitors and other characteristics for plants operating in this county. We do not begin with the plant because several counties have several plants entering and our data does not permit meaningful analysis of different choices by plants within a county. Even if we were willing to define markets, we would be reluctant as the Bresnahan and Reiss type models assume a degree of symmetry and equilibrium that is not appropriate for the early development of the cement industry (and probably at the birth of other industries). Finally, also note that most plants in our sample operate for at least a decade and often decades, though some do only operate for short periods. Unlike many new industries, except for two states, there are no shake-outs.

A second difference in our application is that most of these studies are cross-sectional, except for the paper by Otto Toivanen and Michael Waterson which estimates two models with annual data.[49] We divide the sample into effectively two periods: 1889 - 1899 and 1900 - 1913. As we argue both demand and technology changes dramatically between 1889 and 1913 it is unlikely that a single model estimated with multiple periods will hold. Likelihood ratio tests for a reduced form probit confirm this, rejecting a single specification to an alternative two period specification in all cases. We break the sample period at 1900 as this is when the coal-fired rotary kiln becomes

[48]Bresnahan and Reiss, "Entry and Competition".

[49]Toivanen and Waterson, "Market structure".

the technological standard. Unlike Toivanen and Waterson we do not use annual data as we cannot observe entry and operating dates with sufficient precision for some portland cement plants and many natural cement plants, and, again, our data set is probably not rich enough to meaningfully model annual decisions.

The third difference in our application is in the functional form used for the profit equation. Bresnahan and Reiss and Toivanen and Waterson use linear expressions for each component of the profit equation. In the paper by David Dranove, Anne Gron and Michael Mazzeo the natural log of population is used, which though easier to estimate does not quite match the set up in equation (1).[50] We find that the linear specification yielded for many markets predicted negative market sizes. This problem is probably avoided by the earlier work because of the relative homogeneity of markets considered. Our application means we cannot avoid including markets of substantially different sizes and construction is probably not linearly related to population so we wish to allow for some non-linearity in the relationship. Hence we use a hybrid specification as follows:

$$\Pi = (ln(Pop) + \lambda_1 urbshr + \lambda_2 rrdgr) * (\beta_0 + \beta_1 import + \beta_2 oil + \beta_3 pc400 + \beta_4 nc400) - (\gamma_0 + \gamma_1 fmh + \gamma_2 prpc + \gamma_3 prnc) \quad (2)$$

As we do not observe profits, we instead use as the dependant variable a dummy variable, *entry*, which takes the value of 1 if entry takes place. Note that if more than one firm enters, all variables are constructed for the first entrant. Hence we do not make any use on the number of entrants in a market. If entry does not take place, we construct all variables for the first

[50]Dranove et al., “Differentiation and competition”.

entrant in a subsequent period e.g. we count the number of competitors that 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 168 counties in the first period and 155 counties in the second period. A small number of counties are not included as all entry takes place before 1889.

The variables we use are defined in Table 4, though more detail on their construction is provided in an appendix. The first set of variables control for market size. Because construction is not available, we resort to the standard measure of population, *Pop*. In addition, we add measures of the share of the population living in urban areas, *urbshr*, and growth in railroad mileage, *rrdgr*. The urbanisation share is included to capture a greater intensity of demand for concrete and cement in urban areas. The growth in railroad mileage is included to capture the effects of an increased railroad mileage. As the effect of greater mileage is to increase the degree the firm can reach its market this variable is included in the determinants of market size.

Three sets of variables are used to control for factors affecting profitability. To control for the affect of the availability of oil, we include a dummy for counties near where fuel oil is produced *oil*. This is included only in the first period. As is more standard in these models, we control for competition from imports, *import* and the number of firms producing portland cement *pc400* and number of plants producing natural cement *nc400* within 400 miles of the plant. While most firms in the industry have one plant, in the natural cement industry during the 1890s there were active cartels. However, to treat these groups of plants as a single plant would be in some cases, because of the numbers involved, inaccurate.

Finally, we have three sets of variables to capture the determinants of entry costs. The first variable, *fmh*, is our 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 was identified as having limestone but only marl was used, this county is not recorded as having had its raw materials identified. We construct this variable as follows. For the first period, we use the information contained in the USGS publication "Useful Minerals of the United States" for 1887. Though this information is openly stated by the authors to be incomplete and 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 discussed earlier. Though it is published a few years after the start of our period, it clearly draws on earlier sources.

As firms may also learn about the location of resources by observing other plants producing there we include two other dummy variables. The first controls for previous production of portland cement in the county, *prpc* or, if there was no previous portland cement production, natural cement production, *prnc*.

ECONOMETRIC EVIDENCE

We report the results of estimating the entry model for both periods in Table 5. The main finding is that there is not strong evidence that information provided in the geological surveys systematically reduced entry costs. However, there is also not overwhelming evidence in favor of the growth of railroad mileage as being a critical contribution either.

We will discuss the results for the first period. For low levels of urbanisation, less than about 14.24%, there is a negative relationship between urbanisation and the likelihood of entry. All of the 51 counties in this range are in the western, plain and southern states, with the boundary county being Hays, TX, which is in between Austin and San Antonio. Hence, the relationship is positive for most counties. Surprisingly the growth of railroad mileage enters negatively. This is probably picking up a demand effect as it tends to be areas with low mileage with the most rapid growth. There is not an overwhelming effect of increasing density of railroads opening up markets for cement though. In the profitability variables, oil enters significantly negative which is also surprising. Imports have a significant positive effect, probably reflecting that markets which were potentially importable tended also have higher demand. The effect of natural cement is positive for low number of plants (less than 27). This implies that on the East Coast and some plants near the Louisville cluster of natural cement plants, the competitive effects outweighed any other benefits from being located near a natural cement plant. In the first period it was not possible to get a model including measures of competition from Portland cement firms to converge. This is perhaps not surprising as domestic Portland cement production was such a small portion of the domestic market being near a competitor had little effect on an entrant either way. Finally, examining the effect of the variables on entry costs, the measure of geological survey contribution has the wrong sign but is not even close to significant. However, having either portland cement production or natural cement production previously in the county effectively reduces the entry costs. Interestingly the effect is larger for natural cement production.

In the second period, the results change. For areas with an urbanisation share of less than 44.1% the effect of urbanisation is positive. An example of a boundary county is Berkeley, WV, which is near Washington DC. This includes 101 counties. Railroad growth has now a positive significant effect on market size. These results in combination suggest that after early entry took place in the most urbanised and largest markets, in the later period entry diffused to the smaller, less urbanised and more rapidly growing areas. In the variable affecting profitability, import now is positive but statistically insignificant. Natural cement has a positive effect if there are less than about 6 plants - this covers all areas except for a few on the east coast. With Portland cement, the effect is now as expected, negative unless there are more than 43 competitors. Only 12 counties are covered by this - either counties on the great lakes or in areas in between several large groups of firms like in Western Pennsylvania, West Virginia and Ohio. Being in an area identified as containing raw materials now reduces entry costs but with a p-value of 0.237. Being in an area with previous natural cement production also has an insignificant effect and smaller than being in a county with previous Portland cement production which now almost doubles the effect.

CONCLUDING REMARKS

The rise of the American portland cement industry is another example of how factor endowments, in particular minerals abundance, combined with innovation led to a particular form of industrialisation in the United States. There is qualitative evidence that suggests that the state geological surveys and university-industry links, institutions highlighted in recent work by David and Wright, contributed to the development of the cement industry. However, a subsequent econometric analysis of entry by county, did not find a systematic positive relationship between industry development. Instead, the successful adoption of the rotary kiln, which could only occur in an oil-abundant economy, combined with an increase in demand due to the diffusion of reinforced concrete and product standardisation, appear to have been the central determinants. In addition, American producers had to overcome an asymmetric information problem related to their quality. This was assisted by both the universities, institutions highlighted by David and Wright, and private testing laboratories, earlier highlighted by Rosenberg.

Analyzing a single industry, even if it is one particularly suited to the particular hypothesis, still runs the risk of yielding findings that do not generalize. There may have been more direct relationships, in other industries, between state geological research and industry development. Quality control may be of greater concern to the cement industry, than other industries, as its product goes into bridges, tunnels, skyscrapers and dams. However, we can suggest two directions for further work. First, more studies of competition between minerals intensive manufacturing industries are likely to be informative on the role of the institutions highlighted by David and Wright, compared with the mechanisms identified in earlier literature. Second, the cement industry appears to be an interesting industry worthy of more study for understanding industrialisation, related phenomena such as urbanisation, and the effects of public policy.

APPENDIX: CONSTRUCTION OF THE DATASET

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 estimates made by chapter authors prior to this. Consumption is calculated by adding imports to domestic production and subtracting 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 William Thorndale and William Dollarhide are used.[51] 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.[52] 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 David I. Rosenbaum and Supachat Sukharomana and studies cited therein.[53] From the 1960s most distribution terminals are within this distance.

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 collected by hand all such towns from each of Census of Population and calculated the urban

[51] Thorndale et al., "Map".

[52] U.S. Bureau of the Census, "Population".

[53] Rosenbaum et al., "Oligopolistic pricing".

population for each county. The ratio of urban population to total population is used to calculate the urbanization rate.

Railroad Growth: As there does not exist county level estimates of railroad mileage we estimated railroad mileage by county as follows. First, we obtained estimates of railroad mileage by state from the Statistical Abstract of the United States. We then allocated this mileage by county according to county population shares. Finally, we aggregated the estimated mileage for all counties within 200 miles of the plant. We then took the exponential growth rate over the previous decade to give the estimated growth rate in mileage.

Import Capturing import competition is complicated by the river and lake system. We state a county is faced by import competition if it features the following:

- Coastal
- On or near the inland river system as far as Kansas City, St. Louis or Cincinatti, Columbus, Indianapolis.
- On the Great Lakes
- 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.

REFERENCES

Anderson, Philip. "Collective Interpretation and Collective Action in Population-Level Learning: Technology Choice in the American Cement Industry." *Advances in Strategic Management* 16, (1999): 277-307.

Bayle, Francis L. *A History of the Glens Falls Portland Cement Co.* Glens Falls: Glens Falls Portland Cement Co, 1949.

Bresnahan, Timothy F. and Peter C. Reiss. "Entry and Competition in Concentrated Markets.", *Journal of Political Economy* 99, no. 5 (1991): 977-1009.

Brown, Charles Caroll. *Directory of American Cement Industries and Handbook for Cement Users.* New York: Municipal Engineering Co, 1901, 1904, 1906, 1909.

Condit, Carl W. *American Building Art: The Nineteenth Century.* New York: Oxford University Press, 1960.

Cummings, Uriah. *American Cements.* Boston MA: Rogers & Manson, 1898.

David, Paul and Gavin Wright. "Increasing Returns and the Genesis of American Resource Abundance." *Industrial and Corporate Change* 6, no. 2 (1997): 203-45.

Dranove, David, Anne Gron and Michael J. Mazzeo. "Differentation and Competition in HMO Markets." *Journal of Industrial Economics* 51, no. 4 (2003): 433-54.

Engerman, Stanley L. and Kenneth L. Sokoloff. "Technology and Industrialization, 1790-1914." In *The Cambridge Economic History of the United States, Volume II*, edited by Stanley L. Engerman and Robert E. Gallman, 367-401. Cambridge: Cambridge University Press, 2000.

Francis, A. J. *The Cement Industry 1796 - 1914: A History.* Devon: David & Charles Ltd, 1977.

Giron, Pierre. "The Burning of Portland Cement." *Proceedings of the Engineers' Club of Philadelphia* 10, no. 3 (1893): 197-213.

Hadley, Earl J. *The Magic Powder: History of the Universal Atlas Cement Company and the Cement Industry.* New York: Putnam, 1945.

Hahn, Thomas F. and Emory L. Kemp. *Cement Mills Along the Potomac River.* Institute for the History of Technology & Industrial Archaelogy Monograph Series, vol. 2, no. 1, Morgantown WV: West Virginia Institute for the History of Technology & Industrial Archaelogy, 1994.

Harley, C. Knick. "Ocean Freight Rates and Productivity, 1740-1913: The Primacy of Mechanical Invention Reaffirmed." This Journal 48, no. 4 (1988): 851-76.

Harley, C. Knick. "The shift from sailing ships to steamships, 1850-1890: a study in technological change and its diffusion." In *Essays on a Mature Economy: Britan after 1840*, edited by Donald N. McCloskey, 215-238. London: Methuen & Co.

Irwin, Douglas A. "Explaining America's Surge in Manufactured Exports, 1880 - 1913." *Review of Economics and Statistics* 85, no. 2 (2003): 364-76.

Lathbury & Spackman. *American Engineering Practice in the Construction of Rotary Portland Cement Plants.* Philadelphia PA: G.M.S. Armstrong, 1902.

Lesley, Robert W. "History of the Portland Cement Industry in the United States." *Journal of the Franklin Institute* 146, no. 5 (1898): 324-36.

Lesley, Robert W., John B. Lober and George S. Bartlett. *History of the Portland Cement Industry in the United States.* Chicago: International Trade Press, 1924.

Marchildon, Gregory P. "Portland Cement: Product and Process Upheaval during the Second Industrial Revolution." Revised version of a paper delivered at the Society for the History of Technology Conference, 17 October, 1993.

Meyer, David R. "Midwestern Industrialization and the American Manufacturing Belt in the Nineteenth Century", This Journal 49, no. 4 (1989): 921-937.

Miller, Benjamin L. "The Contribution of David O. Saylor to Early History of the Portland Cement Industry in America." Easton PA: Pennsylvania German Society, 1930.

Misa, Thomas J. *A Nation of Steel: the Making of Modern America, 1865-1925.* Baltimore MD: John Hopkins University Press, 1995.

Puffert, Douglas J. " The Standardization of Track Gauge on North American Railways, 1830-1890", This Journal 60, no. 4 (2000): 933-960.

Rosenbaum, David I. and Supachat Sukharomana. "Oligopolistic Pricing over the Deterministic Market Demand Cycle: Some Evidence from the US Portland Cement Industry." *International Journal of Industrial Organization* 19, no. 6 (2001): 863-84.

Rosenberg, Nathan. "The Commercial Exploitation of Science by American Industry." In *The Uneasy Alliance*, edited by K.B. Clark, R.H. Hays and C. Lorenz, 19-51. Boston MA: Harvard Business School Press, 1985.

Selkreg, John H. *Landmarks of Tompkins County.* Syracuse NY: D. Mason & Co, 1894. At http://www.rootsweb.com/nytompki/Landmarks/contents.htm, 06/03/2004.

Skempton, A.W. "Portland Cements, 1843-1887." *Transactions of the Newcomen Society* 35 (1962-1963), 117-51. Reprinted in Newby, Frank, ed. *Early Reinforced Concrete.* Studies in the History of Civil Engineering, vol. 11. Aldershot UK: Ashgate Publishing, 2001.

Slaton, Amy E. *Reinforced Concrete and the Modernization of American Building.* Baltimore MD: John Hopkins University Press, 2001.

Socolow, Arthur A., ed. *The State Geological Surveys A History.* Grand Forks ND: Association of American State Geologists, 1988.

Stanger, William H. and Bertram Blount. "The Rotatory Process of Cement Manufacture." *Minutes of the Proceedings of the Institution of Civil Engineers*, 145 (1901): 44-72.

Tariff Commission. *Report of the Tariff Commission.* Washington DC: GPO, 1883.

Toivanen, Otto and Michael Waterson. "Market structure and entry: where's the beef?" *RAND Journal of Economics* 36, no. 3 (2005): 680-99.

Thorndale, William and William Dollarhide. *Map Guide to the U.S. Federal Censuses, 1790-1920.* Baltimore MD: Genealogical Publishing Company, 1987.

United States Bureau of the Census. *Population of the States and Counties of the United States: 1790 to 1990*. Washington DC: GPO, 1996.

United States Department of the Interior. *Report on the Agencies of Transportation in the United States*. Washington DC: GPO, 1883.

United States Department of the Interior. *Report on Transportation Business in the United States at the 11th Census 1890*. Washington DC: 1895.

Wermiel, Sara. *The Fireproof Building: Technology and Public Safety in the Nineteenth-Century American City*. Baltimore MD: John Hopkins University Press, 2000.

Williamson, Harold. *The American Petroleum Industry*. Evanston IL: Northwestern University Press, 1963.

Wright, Gavin. "The Origins of American Industrial Success, 1879-1940." *American Economic Review* 80, no. 4 (1990): 651-68.

Wright, Gavin. "Can a Nation Learn? American Technology as a Network Phenomenon." In *Learning by Doing in Markets, Firms and Countries*, edited by Naomi R. Lamoreaux, Daniel M.G. Raff and Peter Temin, 295-332. Chicago IL: University of Chicago Press, 1999.

Table 1

INDUSTRY DEVELOPMENT

Year	U.S. cement consumption	Portland cement share	Natural cement share	Import cement share	Exports mill. bbls	Portland cement price	Natural cement price
1880	2.26	1.86	89.87	8.27	n.a.	11.00	3.12
1890	9.72	3.45	76.58	19.97	0	8.43	2.06
1902	27.38	61.70	29.38	7.17	0.34	4.86	2.04
1913	90.07	98.96	0.83	0.1	2.96	3.34	1.54

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

Source: Appendix

Table 2

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 3
NATURAL CEMENT INDUSTRY AND STATE GEOLOGICAL SURVEYS

Event	States in 1890		Production
	Producing	Non-producing	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 4
DEFINITIONS OF THE VARIABLES

Variable	Description
Entry	Dummy variable = 1 at least one entrant during the period
Pop	State market size in millions
urbshr	Ratio of urban population to total population
rrdgr	Growth in the mileage of railroad over previous decade.
import	Dummy variable equals 1 if county exposed to import competition
oil	Dummy variable equals 1 if county or a neighbouring county produces fuel oil
pc400	Number of firms producing portland cement operating within 400 miles
nc400	Number of plants producing natural cement operating within 400 miles
fmh	Dummy variable equals 1 if a USGS publication identified raw materials subsequently used
prpc	Dummy variable equals 1 if Portland cement production occurred in the county before the current entrant
prnc	Dummy variable equals 1 if Natural cement production, and no Portland cement production occurred in the county before the current entrant

* Squared versions of these variables are used as well

Source: Text and Appendix

Table 5
ENTRY MODEL

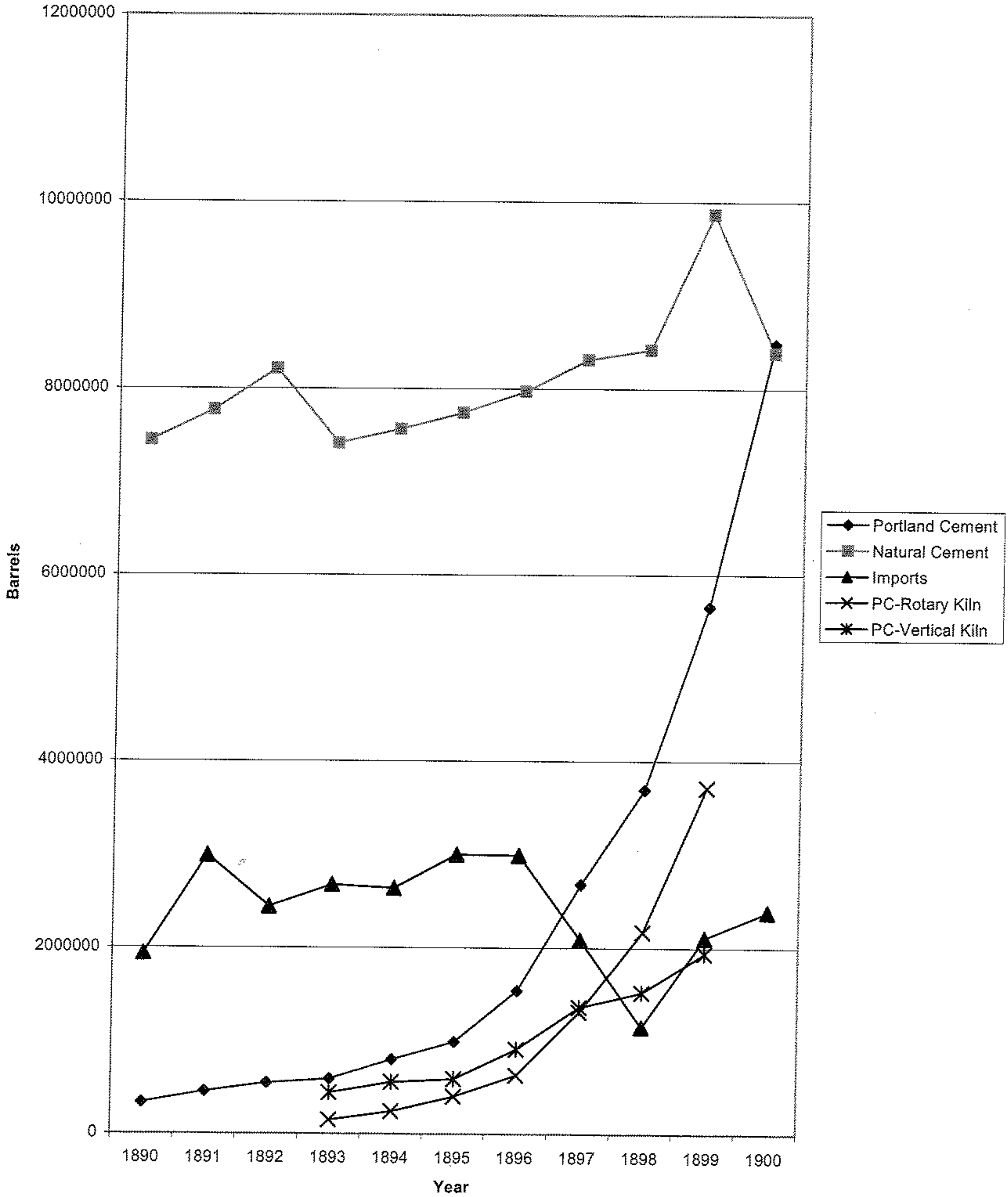
Variables	1889-1899			1900-1913	
Dependant	entry			entry	
Explanatory	Coefficients	Standard Errors	Explanatory	Coefficients	Standard Errors
Market Size					
urbshr	-10.601***	0.154	urbshr	48.27***	2.38
urbshrsq	37.22***	0.30	urbshrsq	-54.77***	.3.54
rrdgr	-321.05***	0.55	rrdgr	44.53***	5.34
Variable Profits					
oil	-0.286***	0.092			
import	0.174**	0.089	import	0.014	0.024
pc400			pc400	-0.012***	0.004
pc400sq			pc400sq	0.00014**	0.00007
nc400	0.014***	.005	nc400	0.062***	0.021
nc400sq	-0.0003***	.00008	nc400sq	-.005***	0.002
constant	0.0007	0.30	constant	0.238***	0.072
Entry Costs					
fmh	0.40	0.37	fmh	-0.293	0.248
prpc	-1.028*	0.545	prpc	-0.902**	0.382
prnc	-1.494***	0.424	prnc	-0.478	0.446
constant	1.42***	0.235	constant	2.29***	0.66
sample	168			155	
Log likelihood	-48.58			-89.14	

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

**= Significant at the 5 per cent level.

*= Significant at the 10 per cent level.

Graph One: Cement Consumption By Type



Graph Two: Share of Cement Types