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Capacity Investment under Demand Uncertainty: The Role of Imports in the U.S. Cement Industry.*

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Abstract

Demand uncertainty is thought to influence irreversible capacity decisions. This paper examines the nature of this relationship in the U.S. cement industry. Firms in this sector deliver cement for local markets either from domestic plants or from imports. Since cement is costly to transport over land, the difference in marginal cost between local production and imports varies across markets. In the presence of uncertain demand, capacity choices are shown theoretically to depend on whether firms are located on the coast or inland. Industry data from 1994 to 2006 are consistent with the predictions of the model. There is a positive relationship between capacity investment and demand uncertainty only for landlocked areas. The results provide a new rationale to explain the coexistence of home production and imports in the U.S. cement market for large multinational firms, even in the long run.

1 Introduction

The relationship between uncertainty and investment decisions has been the subject of a long-standing academic debate since the early work of Jorgenson (1971). Contrasting results about the nature of this relationship have been obtained in numerous theoretical and empirical contributions to both strands of the literature. As summarized by Abel et al. (1996), theoretical arguments can be made to ensure either a positive or a negative relationship between demand uncertainty and investment. A mean-preserving increase in the variance of demand may induce a positive effect on the value of a marginal unit of capital, and, hence, on investment, due to the increased probability of high demand states. There may also be a counteracting negative effect when there is an option to delay investment until uncertainty is partly resolved (Dixit and Pindyck, 1992). The empirical literature reflects the ambiguity of these theoretical results (Carruth et al., 2000).

We investigate this question by building on the framework developed by Rothschild and Stiglitz (1971) and then by exploring theoretical predictions using data on the U.S. cement sector. Local demand for cement can be met by the output from two technologies: capital-intensive local production or imports from abroad. We show that there is a positive relationship between demand uncertainty and investment in cement capacity only in landlocked districts, where high import costs effectively restrict the production set to the local production technology. The option to satisfy high demand states with imports in coastal regions once uncertainty is partly resolved introduces a new counteracting negative effect of uncertainty on investment. The main contribution of the paper is to explicate the role of the production set in the relationship between uncertainty and investment. Imports act as an alternative—more flexible and less capital-intensive—source of production than local capacity.

There are four main reasons why the US cement industry is an attractive industry in which to study the role of uncertainty in investment decisions. First, the industry is regionally segmented. The 113 active cement plants in 2006 in the U.S. operated across different economic environments. Second, demand for cement in each regional market is largely uncertain, and regions vary in the extent of local demand uncertainty. Demand is affected by both the general business cycle and the local cycles typical of the construction industry. Third, capacity decisions are the major firm-level decisions in the industry since cement production is very capital-intensive.

Last, in recent decades, long-haul maritime imports have begun to play an increasing role in absorbing fluctuations in U.S. domestic demand. Regional demand is often now met by a mix of local production capacity and imports from overseas. Further, a large fraction of the installed base of U.S. cement capacity is controlled by the large multinational firms that dominate this industry worldwide.[1] These firms use their global production networks to adapt to the demand fluctuations in a given market, suggesting that the choice of the production mix used to satisfy local demand is often a decision made within a given firm, as well as a market-level outcome.[2]

[1]Ghemawat and Thomas (2008) describe the worldwide cement industry as a network of regional oligopolies. Major cement firms such as Cemex, Holcim and Lafarge typically operate a large number of plants. According to their 2009 websites, Cemex operates in 79 plants (in 50 countries), Holcim 151 plants (in 70 countries), and Lafarge 166 plants (in 79 countries). The USGS reports that, of the ten largest U.S. cement producers that made up 80 percent of U.S. production in 2006, eight were foreign-owned.

[2]In the early 2000s, according to industry sources, global cement firms such as Cemex, Holcim, Lafarge, and Lehigh (Heidelberger) operated import terminals located on the East Coast, and Lafarge, Lehigh (Heidelberger) and Taiheiyo on the West Coast. The USGS notes that, in the U.S. "...since the early 1990s, the majority of cement imports have been controlled by domestic cement producers, and they import only as needed to make up for production shortfalls." (USGS, 2006, p.166).

Our theoretical model of the U.S. cement industry captures these four characteristics, allowing the relative cost of imports to vary across U.S. regions. In a setting of oligopolistic competition in a local market, each firm has to make two decisions in sequence. First, it decides its domestic capacity given that demand is uncertain at this stage. Second, the level of demand in the following period is revealed, and the firm decides its production mix from its domestic capacity and imports. In the context of the model, domestic capacity and imports can be considered substitutable inputs, and they play similar roles to capital and labor in Rothschild and Stiglitz's model (Rothschild and Stiglitz, 1971). We extend their results and show that the domestic capacity choice is either increasing or decreasing on the level of uncertainty, depending on the relative marginal cost of the domestic versus the import technology. Specifically, capacity is increasing with uncertainty if the cost of imports is relatively large, and decreasing if the cost of imports is relatively small. This contingent property is at the crux of our empirical analysis.

The assumptions we make in our model of the U.S. cement industry are similar to the industry features captured in two recent empirical papers (Ryan, 2011; Perez-Saiz, 2011). These two papers focus on the role of environmental or antitrust regulation in investment decisions. Ryan uses a dynamic Markov game in the tradition of Ericson and Pakes (1995), while Perez-Saiz (2011) uses a finite four-stage game allowing for mergers and acquisitions. Both models feature an investment phase followed by a Cournot competition production phase under capacity constraints, a feature also present in our model. Neither of these two models allows for demand uncertainty or the control of imports by domestic firms, which are the two salient features of the U.S. industry that we study here.

Our empirical analysis of investment decisions in the U.S. cement industry between 1998 and 2006 provides evidence that is consistent with the predictions of our model. The nature of the relationship between demand uncertainty and investment is related to local access to the flexible production technology—imports from abroad. An increase in local demand uncertainty is associated with a significant increase in production capacity and average plant size only in landlocked districts. These results suggest that firms respond to an increase in uncertainty about future returns from an investment by choosing to make larger irreversible investments only when imports are prohibitively costly. The significance of our empirical contribution comes from the fact that the monotonic relationship between uncertainty and investment is not robust in the data overall. We make it explicit that the relationship is present when the production set does not include a more flexible alternative technology.

Previous empirical studies have reached mixed conclusions about the influence of different types of uncertainty on investment. Goldberg (1993) finds a negative relationship between investment and exchange rate variability in some sectors, and Campa and Goldberg (1995) find that exchange rate variability has no significant effect on investment levels in U.S. manufacturing. Bell and Campa (1997) find no relationship between product demand uncertainty at the country level and capacity investment in the chemical processing industry. Ghosal and Loungani (1996, 2000) find a negative relationship between investment and uncertainty, focusing on the role of concentration ratios or whether industries are dominated by small firms. The Carruth et al. (2000) survey suggests that production set flexibility is a possible explanation for the ambiguous results obtained in previous studies. Our findings from the U.S. cement industry support this suggestion.

The rest of the paper is organized as follows: Section 2 develops the analytical model. This section also reviews some of the closely related literature on investment decisions under uncertainty. Section 3 describes the data used in the paper. Section 4 develops the methodology employed and gives the empirical results. Section 5 discusses some of the implications of these results and concludes.

2 An Analytical Model

2.1 Key assumptions

Our model features a local oligopoly that faces fluctuating demand. Each firm can source production from plants located in two areas, some located in the market in question—i.e., "home" plants—and some located abroad—i.e., "foreign" plants from which it may import. Home plants have a lower variable cost and are capacity constrained. Production from foreign plants has a higher variable cost that includes the cost of transport to the home market. Foreign plants are not capacity constrained because there are many of them that can potentially export to this market.[3]

We focus on the dependence of the home capacity decisions on import costs as demand uncertainty increases. Imports will be required at peak demand levels, given the home capacity constraint. As a consequence, the optimal capacity depends on the relative costs of imports versus domestic production and on the level of demand uncertainty. Intuitively, the lower the import costs, the lower is the optimal level of home capacity. The model remains simple enough to be analytically tractable so that we can compare its comparative static

[3]Salvo (2010) studies the cement industry in Brazil, where there are very few multinational firms. He models importers as a competitive fringe, and does not allow local firms to face a choice of production technologies. The observed production mix in the data could result from the local capacity choices made by U.S. firms and imports from different firms. However, industry sources confirm that most importers into the U.S. market also have U.S. production facilities.

properties with those of other models in the industrial organization literature that study the link between capacity and uncertainty.

The inverse demand function is assumed to be linear: $p = a + \lambda\theta - bq$, in which p is the price, q the quantity sold in the market, and a and b two positive parameters. Uncertainty is introduced through the random variable θ, assumed to be uniformly distributed on the interval $[-1; +1]$ with density 1/2. The parameter λ measures the range of demand variation, and the case of no uncertainty corresponds to $\lambda = 0$.

N firms are assumed to operate in the home market. The cost function for the home technology consists of two terms: a linear investment cost c_k relative to a capacity choice denoted K, and a linear production cost c_h.[4] There is no investment cost for the foreign technology, which has a linear production cost c_f. In the case of no uncertainty, the home technology is preferred to the foreign one, $c_h + c_k < c_f$, and demand is high enough to make production worthwhile, $a > c_h + c_k$. Furthermore, λ is limited, so that in all realized demand states, it is worth producing with the home technology: $0 < \lambda < a - c_h$.

The decision process takes place in three stages. First, each firm decides its local capacity K relative to the home technology. Second, uncertainty is resolved for the time period in question, and the realized value of θ is revealed to the firm. Third, the firm makes production decisions (q_h, q_f) using the home and foreign technologies respectively. It is explicitly assumed that the production decisions of any given firm do not depend on the capacity of its competitors. This assumption means that firms do not select their capacity to preempt competitors, but only to face demand fluctuations optimally.[5] The firms maximize

[4]The introduction of a fixed component in the investment cost is immaterial for the analysis.

[5]We, hence, rule out the possibility that firms operate with excess capacity to deter entry. There have been many theoretical contributions that motivate such strategic behavior, such as Spence (1977) and Dixit (1980). A number of empirical studies have tested this hypothesis in specific industry studies; see, for

their expected profit, with no risk aversion.

2.2 Comparative Static Properties of the Model

Under these assumptions, there is a unique equilibrium of the model. The equilibrium capacity, denoted $K^*(c_f, \lambda, N)$, is the total capacity chosen by the industry, and K^*/N is the individual capacity of each firm. We now discuss the properties of equilibrium capacity and, in particular, how it varies with import costs, c_f, and demand uncertainty, λ.

Since $c_h + c_k < c_f$, the equilibrium capacity in the case of no uncertainty $K^*(c_f, 0, N)$ is simply the equilibrium quantity in the standard symmetric Cournot-Nash model with marginal cost $c_h + c_k$. Production is equal to capacity, both are independent of c_f, and there are no imports. With sufficiently large uncertainty, however, there is a decoupling between production and capacity. Capacity is equal to demand only at an intermediate realized level of demand. In low realized demand states, the industry has excess capacity, and production is determined by the home plants' variable cost. For high realized demand states, the industry imports to satisfy demand, and the quantity sold is determined by the import cost. Therefore, if uncertainty is sufficiently large, imports are expected to be positive, and the capacity choice is influenced by both the cost of imports and the level of uncertainty.

Proposition 1 *The following comparative static properties hold:*

1. *The equilibrium capacity is increasing with respect to* c_f, $\frac{\delta K^*}{\delta c_f} \geqslant 0$.

2. *The effect of the import cost on capacity is increasing with respect to* λ, $\frac{\delta^2 K^*}{\delta c_f \delta \lambda} \geqslant 0$.

example, Ghemawat (1984) and Mathis and Koscianski (1997). As noted by Lieberman (1987), the empirical results provide limited supporting evidence of this type of behavior.

3. The equilibrium capacity is either increasing or decreasing with respect to λ,

(i) if $c_f \geq 2c_k + c_h$ then $\frac{\delta K^*}{\delta \lambda} \geqslant 0$

(ii) if $c_f \leqslant 2c_k + c_h$ then $\frac{\delta K^*}{\delta \lambda} \leqslant 0$.

The analytical expression of the equilibrium capacity and the proof are in appendix 1. Proposition (1.1) states how the cost of imports influences the level of investment. The more expensive are imports, the larger is the optimal level of local capacity. The magnitude of this effect is related to the level of uncertainty. For sufficiently large uncertainty, it is strictly positive, and is increasing in the extent of uncertainty, as stated in Proposition (1.2). The cross-effect between uncertainty and the import cost is positive; therefore, the effect of uncertainty on capacity is increasing with respect to the import cost. The effect of uncertainty is predicted to be larger in landlocked markets, where import costs are high, than in coastal markets.

Turning to the sign of the effect of uncertainty on investment: There is a threshold import cost such that a rise in uncertainty has a positive (negative) effect on capacity if the cost of import is higher (lower) than the threshold level (Proposition (1.3)). Hence, this framework provides a clear-cut answer about the sign of the relationship between uncertainty and investment. In our model, consistent with intuition, uncertainty leads to higher capacity when imports are expensive and leads to lower capacity when they are relatively lower cost. Proposition 1, thus, provides simple and direct predictions that can be evaluated in the data.

Results (2) and (3) of Proposition 1 can be interpreted in terms of options (Dixit and Pindyck, 1992). There are two valuable options in this model when demand is uncertain.

Investing in an additional unit of capacity creates the option to produce locally in the future or to produce less than installed capacity once the level of demand is revealed. The second is the option to import once the level of demand is revealed, which plays a similar role to that of the option to expand capacity in the future in the option-value literature. An increase in uncertainty increases the value of these two options, and the overall effect on investment depends on the comparison of these changes. The distinction between cases 3(i) and 3(ii) in Proposition 1.3 could be restated as the comparison of $c_f - (c_h + c_k)$, the opportunity cost of importing, and c_k, the cost of investing more than necessary.

Figure 1 illustrates how the equilibrium capacity K^* depends on both demand uncertainty and the relative cost of imports. Suppose that for a landlocked district, we have $c_f \geq 2c_k + c_h$, while the reverse is true for a coastal district. The line AC traces out the predicted relationship between capacity and demand uncertainty in landlocked districts, and the line BD does the same for coastal districts. Proposition (1.3) states that the slope of AC is positive and the slope of BD is negative.

The market structure does not affect the results obtained in Proposition (1), where the number of firms N was considered fixed. The relationship between the number of firms and the total and individual investment that holds in a linear Cournot game continues to hold in this setting. The following Lemma was established for the proof of Proposition 1:

Lemma 1 *Whatever the level of uncertainty λ, we have*

$$K^*(c_f, \lambda, N) = \frac{2N}{(N+1)} K^*(c_f, \lambda, 1)$$

The number of firms does not affect the sign of the relationship between uncertainty and capacity, even though it does influence its magnitude. The proof of this Lemma is in Appendix 1. In particular, the threshold import price in Proposition (1.3) does not depend upon the market structure.

With an endogenous market structure, uncertainty could influence the equilibrium number of firms, which would, in turn, affect the equilibrium capacity. The results of Proposition 1 would be modified by this indirect effect. However, it is unclear why demand uncertainty would be a primary determinant of the number of cement firms in a market. Among the primary determinants are the traditional ratio of the market size relative to scale economies and the U.S. antitrust policy (Collomb and Ponssard, 1984; Dumez and Jeunemaître, 2000). While we do not have data on the number of firms, our data do contain the number of plants in each district in each year. We include the number of plants in each market as a control variable in our main analysis, controlling for changes in market structure resulting from the entry of new plants and changes in market structure due to ownership consolidation. We also see that the number of plants within a district is uncorrelated with demand variability in the data overall.

2.3 Capacity decisions and uncertainty in industrial organization and international economics

There are a number of theory papers that relate directly or indirectly to our work. Demers (1991) analyzes capacity choice in a dynamic oligopolistic Markov model and shows that the equilibrium capacity is decreasing with uncertainty. In his model, the firm is constrained to always produce as much as its earlier capacity commitment—possibly more with a penalty cost, but never less. Gabszewicz and Poddar (1997) consider a two-stage game and show that firms invest more with uncertainty. In their framework, firms can produce less and not more than their capacity. In our model, firms have access to two technologies at varying costs: domestic production and imports. Demers' model can be viewed as similar to our analysis for coastal markets, while Gabszewicz and Poddar's model could be compared to our analysis for landlocked markets. Our two-technology setting generates the contrasting predictions of our model for these two different geographic markets.

Since the firms in this empirical setting are often multinational firms engaged in both imports and FDI, our paper also relates to the theory model set out in Rob and Vettas (2003). In their model, as in ours, firms have the choice between home and foreign plants to satisfy an uncertain demand. Their paper focuses on the optimal strategy mix between FDI and exports as demand grows over time, while we focus on the optimal strategy mix (between domestic production and imports) when demand uncertainty varies across settings with differing variable costs of imports. In both models, FDI and exports (domestic production and imports, respectively, in our model) will co-exist under some circumstances.[6] We show that capacity investment decisions in the cement industry are consistent with our model's predictions. As Blonigen (2001) and Head and Ries (2001) note, much of the prior existing theory on FDI offers only limited explanation of the empirical regularity that firms often serve a given market through both exports and local production.

[6]Kogut and Kulatilaka (1994) show how the value of joint ownership of production facilities in more than one country can be related to the operating flexibility this offers under exchange rate uncertainty. When firms have local capacity constraints, their model can also generate the predictions that firms simultaneously export to and produce in a given market.

3 Data

The data used in this paper are published by the U.S. Geological Survey (USGS) and summarized in the annual *Minerals Yearbook* (USGS, 2006).[7] Figure 2 presents the evolution of cement consumption and imports in the U.S. between 1980 and 2006. Imports are positively correlated with domestic consumption and tend to be more volatile over time.[8] The data divide the U.S. into 23 regional districts, the boundaries of which differ slightly across years. We construct time series data by district for cement capacity, production, and demand, by grouping together districts where necessary.[9] As noted in Ryan (2011), the USGS's intention is that a district defines a local market, including the set of firms that compete in a given geography within one district. These data are available for each year between 1994 and 2006.

3.1 Capacity and Capacity Investment

District-level capacity is measured in the data as the finish-grinding capacity in thousands of metric tons, based on the grinding capacity required to produce a plant's normal output mix, including both portland and masonry cement, allowing for downtime for routine maintenance. Production, in thousands of metric tons, includes cement produced using imported clinker. The USGS *Minerals Yearbook* also reports data on the number of active plants by district, which permits a measure of the average plant size for each district in each year.

Table 1, Panel A summarizes the levels of capacity and production in each district in

[7]We are grateful to Hendrik G. van Oss for advice on interpreting these data.

[8]The "beta" of a regression of the percentage deviation from the mean level of imports on the equivalent for domestic demand is 2.55.

[9]The district containing Alaska, Hawaii, Oregon, and Washington, the district containing Georgia, Virginia, West Virginia, South Carolina, Maryland, and the district containing Michigan and Wisconsin sometimes appear in the *Minerals Yearbook* broken up into different groupings.

2006. In the 11 years leading up to 2006, investment in net new capacity had led to an increase of 26 percent in the total metric tonnage of cement capacity country-wide. The total number of plants declined by five, from 118 in 1994 to 113 in 2006, meaning that the average plant size increased by 31 percent.[10]

These aggregate changes mask substantial variation in investment levels across districts. The standard deviation of the percentage change in capacity is 29 percent. Three districts—Ohio, and Eastern and Western Pennsylvania—saw declines in capacity. Northern Texas and the district containing Georgia, Virginia, West Virginia, South Carolina, and Maryland saw the largest absolute increases in capacity. The percentage increases were largest in Kansas, the district containing Kentucky, Mississippi, and Tennessee, as well as in Northern Texas, and Florida, at 85, 74, 68, and 67 percent, respectively. The largest increases in average plant size took place in the Colorado and Wyoming district, which also saw a plant closure. Other large increases were seen in Kansas and Northern Texas. There were no decreases in average plant size in any district.

3.2 Relative Marginal Costs of Flexible Production

The import of cement to areas such as Florida, California, New York, and Texas has increased steadily since the improvements in shipping technology in the late 1970s, with imports coming from South America, Europe, and Asia. Cembureau estimates that it is now less costly to ship cement across the Atlantic Ocean than to truck it 300km overland (Cembureau, 2008).[11]

In the early 2000s, according to industry sources, global cement firms such as Cemex,

[10]While regulation may play a role in capacity decisions, it is more likely to act as a very local constraint (at the city or town level) and is unlikely to matter differently in landlocked and coastal districts.

[11]See: http://www.cembureau.be/about-cement/cement-industry-main-characteristics

Holcim, Lafarge, and Lehigh (Heidelberger) operated import terminals located on the East Coast, and Lafarge, Lehigh (Heidelberger) and Taiheiyo on the West Coast. The USGS breaks down total imports of cement and clinker into the U.S. by customs district. Major import terminals include Tampa, FL, New Orleans, LA, Los Angeles, CA, Miami, FL, and Houston-Galveston, TX. Smaller import terminals are spread out over the East Coast of the U.S. and include Baltimore, MD, New York City, NY, Norfolk, VA, and Philadelphia, PA.[12] In each year, there are also imports to Detroit, MI and other northern midwestern districts from Canada.

The first column of Table 1, Panel B indicates our classification of districts into landlocked or coastal. This classification is based on overland distance from the coast and, specifically, from a port where cement is imported. All of our results are robust to classifying both the Michigan and Wisconsin district and the Ohio district as coastal rather than landlocked, reflecting their accessibility via lake transport from Canada.[13]

3.3 Demand Uncertainty

The demand data are aggregated from the USGS state-level cement shipments to final customers. It includes cement produced from imported clinker and imported cement shipped by domestic producers and importers. One of the key variables in the theoretical model set out in Section 2 is market-level demand uncertainty at the time when capacity investment decisions are made. In the model, this variable is the parameter that measures the variance

[12] This list is not comprehensive. Annual statistics can be found in Table 18 of the Cement Yearbook.

[13] Alabama has limited imports from the terminal at Mobile, although the largest cities in this district are located relatively far inland. Arizona imports cement from Mexico at Nogales, an inland border crossing. Nonetheless, all our results are also robust to classifying both or each of these districts as coastal rather than landlocked. These results and the results from other alternative district classifications are available from the authors on request.

in demand over the productive lifetime of the investment. As a proxy for expected future demand uncertainty in a district, we calculate the variance in demand over the past four years and the current year—a measure of recent local demand volatility.

We make two further adjustments to this uncertainty measure: We use de-trended data to account for changes in demand levels that are consistent with patterns that are arguably predictable and would, otherwise, lead us to overstate uncertainty in fast-growing districts. Specifically, we regress demand by district over the past five years on a constant. The larger the residuals from this regression on a trend, the less informative are recent demand levels in predicting current demand. To measure the average difficulty of predicting current demand using the data from recent years, we take the standard deviation of the residual values over the current year and the prior four years.

Second, since this measure of demand variation is increasing in the level of demand in a district, we also normalize the standard deviation by the mean demand level over the five years in question. This normalized standard deviation measure summarizes the extent of recent demand volatility across districts, adjusting for differences in district size. Our intent is to capture the plant manager's view about the difficulty of predicting the local demand level in any one upcoming year using information about past demand levels and growth rates.[14]

We note that our measure of uncertainty, or demand volatility, is backwards-looking since it is constructed using district-level data from the current and last four years.[15] Any increase

[14]Table 1, Panel B lists the district-level mean demand uncertainty over the data period. All of our results are robust to assuming that the plant manager looks back at the residuals (measuring the difficulty of predicting a given year's demand) for the past three years or the past five years, in assessing the extent of overall demand uncertainty.

[15]Carruth et al. (2000) contains a discussion about the relative merits of different measures of uncertainty. Guiso and Parigi (1999) is one of very few studies that uses survey data on managers' certainty about future

in volatility in a given year within a district is due to the level of demand in the current year being less similar than was the level of demand four years ago to the level of demand for the three years in between. In some specifications, we classify districts into high and low demand volatility districts, capturing whether the level of volatility is higher or lower than the median level across districts over the entire time period.

While this measure of recent demand uncertainty has been adjusted to account for differences in the average growth rates by district by de-trending, predictable demand growth is also likely to have an independent effect on investment decisions and, hence, on capacity levels within a district. We construct a measure of recent demand growth within a district at any point in time as the average percentage change in the level of demand over the prior four years. This measure is included as a control variable in our main regressions. Table 2 shows correlation coefficients in 2006 for the key variables used in the study.

4 Empirical Analysis

The analytical model developed in Section 2 illustrates how the relationship between local investment decisions and demand volatility depends on the relative marginal costs of the capital intensive and flexible (less capital intensive) production technologies. In this setting, the investment in local cement production capacity incurs high fixed costs and relatively low variable production costs, compared to the alternative production technology of importing cement. We now investigate whether observed investment decisions in the U.S. are consistent with the model's predictions.

demand as a measure of firm-level uncertainty.

4.1 Preliminary Analysis

4.1.1 Import costs and capacity levels

Lafarge, one of the largest global cement producers, provided some estimates about the import costs to different U.S. states, which confirm that there are substantial differences between coastal and landlocked districts. For instance, the cost, insurance, and freight value (CIF value) at the first point of arrival in the U.S. was estimated at around $60 per ton for cement arriving at ports on the West Coast in 2010.[16] However, the additional costs incurred for transporting the cement to the final market led to very different total import costs by region. For example, the cost of importing cement to Colorado and Wyoming was estimated at around $110 per ton. This means that nearly 50 percent of the variable cost of the cement imported to this region consists of handling costs and the cost of freight to market, by rail in this case. In contrast, the cost of importing cement to Oregon is just over $60 dollars, incurring only $3 of additional costs of handling at the port of entry (Portland).

Interviews with managers at Lafarge suggested that local investment decisions depended critically on whether there was nearby access to a deep-water harbor. By way of illustration, in the Colorado and Wyoming region, the ratio of local production capacity to demand in each year, averaged over the years 1994 to 2006, was 1.04. That is, in an average year, over 100 percent of local demand could be met by local capacity. In the Alaska, Hawaii, Oregon and Washington district, where final import costs are $61 per ton, the ratio of capacity to annual local production is 0.74, on average, over the same time period. This means that an average of 26 percent of local demand could not be met by local capacity and was,

[16] For confidentiality reasons, the import costs provided by Lafarge have been rounded to the nearest $10 per ton, and we do not use this proprietary data in the main analysis of the paper.

presumably, fulfilled by imports.

This pattern is borne out in the USGS data across all firms. As described in Section 3 and in Panel B of Table 1, we have classified the USGS districts into those that are landlocked and those that are coastal, based on proximity to a cement-importing port. The mean estimate of Lafarge's estimated import costs are $94 per ton for the former group, and $73 per ton for the latter. Across the regions classified as landlocked, the average ratio of local capacity to local demand over the time period of the data is 1.26. The same ratio for coastal districts is 1.04. This difference, while not statistically significant, provides some evidence that investment decisions in the past—determining the extent to which local capacity can satisfy local demand—appear to have been related to the cost of cement imports.

4.1.2 Demand uncertainty and capacity levels

An initial examination of the average relationship between the level of demand uncertainty and capacity is inconclusive. As an illustration: The district comprising of the three states of Iowa, Nebraska and South Dakota is classified in Table 1 as having low demand volatility. That is, its demand volatility over the entire period, as defined in the previous section, is below the median level for all districts. The neighboring district of Kansas, in contrast, has a high level of demand volatility. Both of these districts, though, have the same average ratio of local capacity to local demand, of 1.59. Previous investment decisions in each of these districts has led to a situation in which local demand can be met, on average, by two thirds of local production capacity over the time period studied.

More generally, looking once more across all districts, there is some evidence of a positive association between demand uncertainty and capacity levels overall. The districts classified as having low demand volatility, as shown in Table 1, have an average ratio of local capacity to local demand of 1.11. The districts classified as having high demand volatility have a mean ratio of local capacity to local demand of 1.25. However, the difference across these two groups is insignificant at standard levels.

4.1.3 Changes over time

The previous two subsections show that there is no clear statistical relationship between capacity relative to demand and either local import costs or local demand uncertainty over the entire time period considered in the study. The theoretical model developed in Section 2 generates the prediction that these relationships depend critically on the interaction between import costs and demand uncertainty. In this empirical setting, capacity is long-lived. It is likely that capacity levels at the start of the time period reflected, to a large extent, investment decisions that were made prior to the late 1790s' shocks to shipping technology that lowered the costs of cement imports to coastal regions. Over time, however, ongoing investment decisions led to a situation in which a larger share of local capacity is the result of decisions that were made after the shock to import costs in coastal regions.

Table 3 presents some evidence about how capacity levels evolved in different district groups over the time period studied. Using data from 1994 and 2006, it shows that capacity levels have developed differently in landlocked and coastal districts, particularly for high-demand-uncertainty districts. Looking first at the panel showing unused capacity (measured as capacity less production, divided by capacity): In 1994, the extent of unused capacity looked very similar across landlocked and coastal districts. In low-volatility districts, both landlocked and coastal districts had unused capacity of around 20 percent. In high-volatility districts, both landlocked and coastal districts had unused capacity of around 14 percent.

Over the next 12 years, low-volatility landlocked districts saw a small decline in unused capacity, whereas high-uncertainty districts saw an increase. These trends were reversed in coastal districts—there was growth in unused capacity in low-uncertainty districts but a large decline in unused capacity in high-uncertainty coastal districts. Among high demand uncertainty districts, then, investment patterns over the time period appear to have varied with whether or not the district had access to low cost imports. Consistent with the predictions of the theoretical model, there was much less new investment in capacity in coastal districts than in landlocked districts.

The second panel shows that changes in the average plant size across district groups also evolved differently for landlocked and coastal districts, and particularly among high-demand-uncertainty districts. High-demand-uncertainty landlocked districts saw increases in average plant size that exceeded those in low-uncertainty landlocked districts, but also that exceeded the increases in high-demand-uncertainty coastal districts.

Table 3, then, offers the suggestion that the relationship between uncertainty and investment depends on having access, over time and across districts, to a flexible production technology—in this case, low-cost imports. We now turn to a more formal econometric analysis of the data.

4.2 Main Analysis

4.2.1 Estimation Strategy

In the main analysis of the paper, we study the relationships between firms' investment decisions and changes in demand uncertainty between 1994 and 2006, exploiting the panel nature of the data. The estimated equation is:

$$y_{i,t} = \alpha + (\beta + \gamma L_i)(V_{i,t} + \mathbf{X}_{i,t}) + \mu D_i + i.Year_t + \varepsilon_{i,t} \tag{1}$$

The key variable of interest on the right-hand side of equation (1) is the measure of demand uncertainty, $V_{i,t}$, which is the level of recent demand volatility in district i in year t, as defined in Section 3. L_i indicates whether district i is landlocked, and the association between demand uncertainty and the dependent variable $y_{i,t}$ is allowed to vary with whether or not the district is landlocked. $\mathbf{X}_{i,t}$ is a vector of time-varying district-level control variables—demand growth and the number of plants. The association of these variables with the dependent variable is also allowed to depend on whether the district is landlocked. District fixed effects, D_i, are included so that the equation relates capacity levels relative to the district-level mean to demand uncertainty relative to district-level mean. α is a constant term, and $Year_t$ are year fixed effects.

The dependent variable in equation (1) is one of two measures of capacity: The first dependent variable is the installed capacity in the district. Because the districts are of different sizes, and the right-hand-side variables are all scaled to facilitate comparison across districts, we apply a scaling factor to the dependent variable. Using annual unused capacity as a scaling factor would introduce variation in the measure reflecting annual production decisions rather than annual investment decisions. Thus, we need to scale capacity by a measure that does not vary over time in a district. To do this we use the mean district-level production over the time period. The variable used is annual capacity divided by mean production. Variation over time in this measure within a district is due entirely to changes in capacity—that is, due to the investment decisions that we want to study.

The second dependent variable used is the average plant size in a district. Since individual plants are comparable across different districts, it is not necessary to scale this variable to adjust for differences in district size. Variation over time in this variable reflects capacity expansions or contractions at existing plants since plant openings and closings in a district are included as a control variable.

The estimated equation given in equation (1) controls for any non-time-varying observable and unobservable characteristics correlated with capacity in a district and demand uncertainty by including district fixed effects. In an alternative specification, we estimate equation (1) in first differences, where the estimated coefficients measure the association between yearly changes in capacity and yearly changes in demand uncertainty.

As is common in the analysis of panel data, the observations are likely to be correlated within groups—in our case, within districts. In addition to the clustering problem arising from the fact that observations within a district are likely to share some unobserved component, our measure of demand uncertainty in any year is based on the variance in local demand levels over that year and the past four years. This introduces serial correlation in the observations from a given district. We estimate the fixed effects and first differences specifications using OLS regressions and report Newey-West standard errors with a maximum lag order of correlation within a district of four years (Newey and West, 1987). This correction addresses serial correlation in the errors within a district resulting from how we measure local demand uncertainty.

Having estimated the coefficients in each specification, we then test whether differences in the estimated coefficients are significantly different from zero, and significantly different from each other, in ways that are consistent with the model's predictions. To test whether a change in demand uncertainty is associated with a change in capacity in coastal districts, we examine the significance of the coefficient estimate for demand uncertainty. To test whether a change in demand uncertainty is associated with a change in capacity in landlocked districts, we test whether the linear combination of the coefficients on demand uncertainty and the interaction of demand uncertainty and the landlocked indicator is significantly different from zero. We then test whether changes in demand uncertainty have significantly different effects on capacity in coastal versus landlocked districts.

4.2.2 Results

The results of estimating equation (1) are given in Table 4. The specifications in Columns 1 and 2 show that, on average, there is a small positive association between changes in demand uncertainty and investment in capacity.

Column 3 allows the relationship between demand uncertainty and investment to depend on whether the district is landlocked or coastal. There is a negative association between demand uncertainty and investment in coastal districts, although the estimated coefficient is not significantly different from zero. Column 4 includes the control variables of demand growth and the number of plants, both also interacted with the landlocked indicator variable.

The coefficient on the interaction of landlocked and demand uncertainty is positive and significant at the five percent level in both Columns 3 and 4.

The first two columns of Table 4, Panel B report the estimated change in the ratio of local capacity to mean local production associated with a one-standard-deviation increase in local demand uncertainty. In coastal districts, this increase in demand volatility is associated with a small and insignificant decrease in the ratio of capacity to mean production. In landlocked districts, the same increase in demand uncertainty is associated with a significant increase in the ratio of capacity to mean production, of 0.051. Since the mean level of this ratio is 1.23, this corresponds to a predicted increase of 4.07 percent. Column 3 of Panel B reports that the difference in the response to changes in uncertainty between landlocked and coastal districts is significant at the five-percent level—the relationship is significantly more positive in landlocked districts.

Columns 5 to 8 of Table 4, Panel A report the analogous results for investment measured by changes in average plant size within a district over time. It is noteworthy that there is no significant association between increases in demand uncertainty and average plant size across all districts in the data. The estimated coefficients on demand uncertainty in Columns 5 and 6 are positive but not significantly different from zero.

The results in Columns 7 and 8 look very similar to the results in Columns 3 and 4. An increase in demand uncertainty is associated with a significant increase in the average plant size in landlocked districts. This increase is also significantly different from the response in coastal districts. Panel B shows that a one-standard-deviation increase in demand uncertainty is associated with an insignificant decrease in average plant size of 9.44 thousand tons. The same increase in demand uncertainty is associated with a 37.11 thousand-ton increase in average plant size in landlocked districts. The mean plant size in the data is 873 thousand tons, so the predicted increase in landlocked districts is an increase in plant size of 4.25 percent.

Table 5 presents the results of equation (1) estimated in first differences. The findings are very similar to the results shown in Table 4. In these specifications, there is a positive and significant relationship between increases in demand uncertainty and investment in capacity, although this relationship is not significant in Column 6, where investment is measured by increases in average plant size. The estimated coefficients in Columns 4 and 8, however, confirm that the positive relationship is larger in landlocked districts.

Panel B of Table 5 reveals that the difference between the relevant coefficients for landlocked and coastal districts is significant at the 11-percent level for change in capacity and significant at the ten-percent level for changes in average plant size. The predicted increase in capacity associated with a one-standard-deviation increase in demand uncertainty is 0.025, corresponding to an increase of 2.03 percent of the mean level. Average plant size is predicted to increase by 17 thousand tons, or by 1.95 percent of the mean level. In both cases, the predicted increase is about half as large as in the fixed effects specification shown in Table 4.

These results, which control for district-level factors related to both demand uncertainty and investment, show that investment is positively associated with an increase in demand uncertainty only in landlocked districts. With reference to Figure 1, the results establish that the line AC has a significant positive slope. This line is the elasticity of capacity choice with respect to demand uncertainty. In contrast, the elasticity of capacity choice with respect to demand uncertainty in coastal districts, given by line DB, does not have a positive slope. If anything, this relationship is negative, although not significant. Moreover, the slope of the line AC is significantly more positive than the slope of the line BD. This suggests that the flexibility offered by a choice between two different production technologies (in this case, local production and imports), where the technologies differ in the amount of investment required, has a significant role in determining the overall relationship between demand volatility and investment.

5 Concluding Comments

This paper contributes to the literature about the theory of irreversible decisions under uncertainty at the microeconomic level. It demonstrates theoretically that the relationship between demand uncertainty and investment depends on the nature of the production set available.

The capacity decisions of U.S. cement firms are shown to be consistent with the theory: The amount of domestic excess capacity over an uncertain business cycle depends on the relative cost of imports, which varies from coastal to landlocked markets. The positive relationship between demand uncertainty and investment predicted by theory models with only one technology is, indeed, present in landlocked districts, where imports are prohibitively costly. This finding is obscured when we do not consider landlocked and coastal districts separately. At the country level, the positive relationship between uncertainty and investment is not robust across different measures of investment.

The paper also provides a new rationale to explain the coexistence of home production and imports in the U.S. cement market by large multinational firms. Adding demand uncertainty to the proximity-concentration trade-off described in Brainard (1997) can explain why we see imports and domestic production—even in the long run—in districts where the variable cost of imported cement is not too much greater than that of domestic production. The greater the demand uncertainty in these districts, the larger the average ratio of imports to FDI.

There are several possible applications of the model developed in this study. Ryan (2011) and Perez-Saiz (2011) construct models of the U.S. cement industry that they use to discuss the impact of various environmental or antitrust policies on social welfare via their impact on the market structure. This paper may also contribute to this line of inquiry, more specifically on the efficiency of unilateral climate policies.[17] One prominent issue that affects the efficiency of such policies is the extent of carbon leakage–an increase in foreign emissions substituting for any decrease in domestic emissions arising from relocation of production capacity to another country. Our model suggests that there may be long-term effects on investment levels associated with a change in the relative costs of imports, where demand uncertainty plays a crucial role in quantifying this impact.[18]

[17]Examples of unilateral climate policies include the Cap and Trade policies under debate in a number of countries, such as the Australia, Canada, EU, and the U.S..

[18]See Meunier et al. (2012), for a critical assessment of the EU policy for 2013-2020 along these lines.

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Appendix 1: Proofs

The monopoly capacity

We first establish the monopoly capacity $K^*(c_f, \lambda, 1)$, and then consider the oligopoly case.

Lemma 2 *The monopoly capacity* $K^*(c_f, \lambda, 1)$ *is:*

Case 1: if $0 \leq \lambda \leq \min\{c_k, c_f - (c_h + c_k)\}$*, then*

$$K^* = [a - (c_h + c_k)] / 2b. \tag{2}$$

Case 2: if $c_f \geq 2c_k + c_h$ *and* $c_k \leq \lambda \leq (c_f - c_h)^2/4c_k$*, then*

$$K^* = \left[a - c_h + \lambda - 2(\lambda c_k)^{1/2}\right] / 2b. \tag{3}$$

Case 3: if $c_f \leq 2c_k + c_h$ *and* $c_f - (c_h + c_k) \leq \lambda \leq (c_f - c_h)^2 / 4(c_f - c_h - c_k)$*, then*

$$K^* = (a - c_f - \lambda) / 2b + [\lambda(c_f - c_k - c_h)]^{1/2} / b. \tag{4}$$

Case 4: If $\lambda \geq \max\{(c_f - c_h)^2/(4c_k), (c_f - c_h)^2 / 4(c_f - c_h - c_k)\}$*, then*

$$K^* = [a - (c_h + c_f)/2 + \lambda(1 - 2c_k/(c_f - c_h))] / 2b. \tag{5}$$

Proof. We denote q_h (resp. q_f) the local production (resp. the quantity imported). The firm's profit is

$$\pi = \frac{1}{2} \int_{-1}^{+1} \max_{(q_h \leq K, q_f)} [pq - c_h q_h - c_f q_f] \, d\theta - c_k K \tag{6}$$

In each demand state θ, the firm maximizes its short-term revenue: $pq - c_h q_h - c_f q_f$ subject to the constraint $q_h \leq K$. Three situations can arise; let us denote two thresholds states: $\theta^- = \max\{-1, (2bK + c_h - a)/\lambda\}$ and $\theta^+ = \min\{1, (2bK + c_f - a)/\lambda\}$; then,

- if $\theta \leq \theta^-$, $q_h = (a - c_h + \lambda\theta)/2b$ and $q_f = 0$;
- if $\theta^- < \theta \leq \theta^+$, $q_h = K$, and $q_f = 0$;
- if $\theta^+ \leq \theta$, $q_h = K$ and $q_f = (a - c_f + \lambda\theta)/2b - K$.

In the long term, the monopoly chooses its capacity to maximize its profit (6). The profit of the firm is concave; the optimal capacity is the solution of the first-order condition

$$\int_{\theta^-}^{\theta^+} [a + \lambda\theta - 2bK - c_h]d\theta + \int_{\theta^+}^{1} (c_f - c_k)d\theta. \tag{7}$$

Several cases should be distinguished depending on whether, at equilibrium, θ^- (resp. θ^+) is equal to or larger (resp. lower) than -1 (resp. 1)—that is, whether in some demand states, the firm has excess capacity ($\theta^- > -1$) or imports ($\theta^+ < 1$). For sufficiently large λ, both situations happen and

$$\theta^- = (2bK^* + c_h - a)/\lambda \tag{8}$$

$$\theta^+ = (2bK^* + c_f - a)/\lambda. \tag{9}$$

We will consider this case (4 in lemma 1) only for the sake of exposition, but similar calculations could be done to obtain the expression of K^* and boundary conditions in other cases. By substituting (8) into (7):

$$\begin{aligned} 2c_k &= \int_{\theta^-}^{\theta^+} \lambda(\theta - \theta^-)d\theta + [1 - \theta^+](c_f - c_h) \\ &= \lambda(\theta^+ - \theta^-)^2/2 + \left(1 - \theta^+\right)(c_f - c_h) \end{aligned} \tag{10}$$

and, from (9) and (8), $\theta^+ - \theta^- = (c_f - c_h)/\lambda$, substituting into (10) gives

$$\theta^+ = 1 + (c_f - c_h)/2\lambda - 2c_k/(c_f - c_h)$$

and replacing θ^+ by (9) gives:

$$K^* = [a - (c_f + c_h)/2 + \lambda(1 - 2c_k/c_f - c_h)]/2b. \tag{11}$$

Finally, we have to check that the expressions (8) and (9), used for θ^- and θ^+, are consistent with the capacity (11); that is, that the right hand side of (8) (resp. 9) is larger than -1 (resp. lower than 1). The monopoly capacity is given by (11) if and only if

$$\lambda \geq \max\left\{(c_f - c_h)^2/4(c_f - c_h - c_k), (c_f - c_h)^2/4c_k\right\}. \tag{12}$$

To find the expression of the equilibrium capacity in case 2, we have to use expression (8) together with $\theta^+ = 1$, and, in case 3, the expression (9) together with $\theta^- = -1$; finally, for small λ (case 1), $\theta^- = -1$ and $\theta^+ = 1$. ■

Proof of Lemma 1

In order to limit the introduction of notation, only a brief sketch of the proof is provided here. A more detailed version can be obtained from the authors on request. We assume that there are N firms with $N \in \mathbb{N}^*$. Each firm simultaneously chooses its capacity and a production plan $(q_h(\theta), q_f(\theta))$. There is a unique symmetric equilibrium of this game, the individual equilibrium capacity is $K^*(c_f, \lambda, N) = 2K(c_f, \lambda, 1)/(N+1)$. This relationship between the quantities in oligopoly and in monopoly holds in a standard Cournot game with linear demand and costs. This property is preserved here because of the linearity of the framework (demand, cost, and uncertainty) and because we do not consider the strategic effect of a firm's capacity on its rivals' production.

Proof. At an equilibrium: in each demand state, firms play a constrained Cournot game with two technologies available, and each firm's capacity is a solution of a first-order equation that equalizes the capacity cost c_k with expected short-term marginal profit. Any equilibrium is symmetric because the expected marginal short-term profit of two firms is equal if and only if their capacities are equal (this is related to the absence of a strategic effect of capacity on a competitor's production). Then, the only possible equilibrium is symmetric, and the individual equilibrium capacity $K^*(c_f, \lambda, N)$ is the unique solution of equation

$$\int_{\theta^-(N,K)}^{\theta^+(N,K)} (a - c_h + \lambda\theta - (N+1)bK)\, d\theta + \int_{\theta^+(N,K)}^{1} (c_f - c_h) d\theta - 2c_k = 0 \tag{13}$$

where $\theta^-(N,K)$ and $\theta^+(N,K)$ are :

$$\theta^- = \max\left\{\left((N+1)bK + c_h - a\right)/\lambda, -1\right\}, \tag{14}$$

$$\theta^+ = \min\left\{\left((N+1)bK + c_f - a\right)/\lambda, +1\right\}, \tag{15}$$

and equilibrium production levels are the constrained Cournot production levels:

$$\begin{aligned} 0 \le \theta \le \theta^- &: \quad q_h = (a + \lambda\theta - c_h)/(N+1)b \text{ and } q_f = 0; \\ \theta^- \le \theta \le \theta^+ &: \quad q_h = K^* \text{ and } q_f = 0; \\ \theta^+ \le \theta \le 1 &: \quad q_h = K^* \text{ and } q_f = (a + \lambda\theta - c_f)/(N+1)b - K^* \end{aligned} \tag{16}$$

With these expressions, it is possible to reproduce the calculations done for the monopoly case. Expressions (14) and (15) of threshold states are functions of $(N+1)K^*$; the first integrand of the equation (13) is also a function of $(N+1)K^*$; therefore, by substituting the expressions (14) and (15) into (13), it can be seen that $(N+1)K^*(c_f, \lambda, N)$ solves the same equation as $2K^*(c_f, \lambda, 1)$ and

$$K^*(c_f, \lambda, N) = 2K^*(c_f, \lambda, 1)/(N+1). \tag{17}$$

And, finally, the capacity (17) and production levels (16) are equilibrium strategies because the individual profit of each firm is concave and the first-order conditions are satisfied. ■

Proof of proposition 1

Proof. From Lemma 1, the equilibrium capacity is proportional to the monopoly capacity. So the proposition is true for a Monopoly if and only if it is true for an oligopoly. We use the explicit expressions obtained in 2 for the monopoly case.

We detail calculations only for case 4 of Lemma 2, but the results could be obtained in all cases.

(1) By differentiating the expression (11),

$$\frac{\partial K^*}{\partial c_f} = (2\lambda c_k/c_f - 1/2) \, / \, (a - c_h - c_k)$$

which is non-negative from (12).

(2) From the derivative obtained above,

$$\frac{\partial^2 K^*}{\partial c_f \partial \lambda} = \frac{1}{a - c_h - c_k} \frac{2c_k}{(c_f - c_h)^2} \geq 0.$$

(3) From (11)

$$\frac{\partial K^*}{\partial \lambda} = [1 - 2c_k/(c_f - c_h)] \, / \, (a - c_h - c_k) \, ,$$

which is non-negative (resp. non-positive) if $c_f \geq 2c_k + c_h$ (resp. $c_f \leq 2c_k + c_h$), which proves (3a) (Resp. 3b).

■

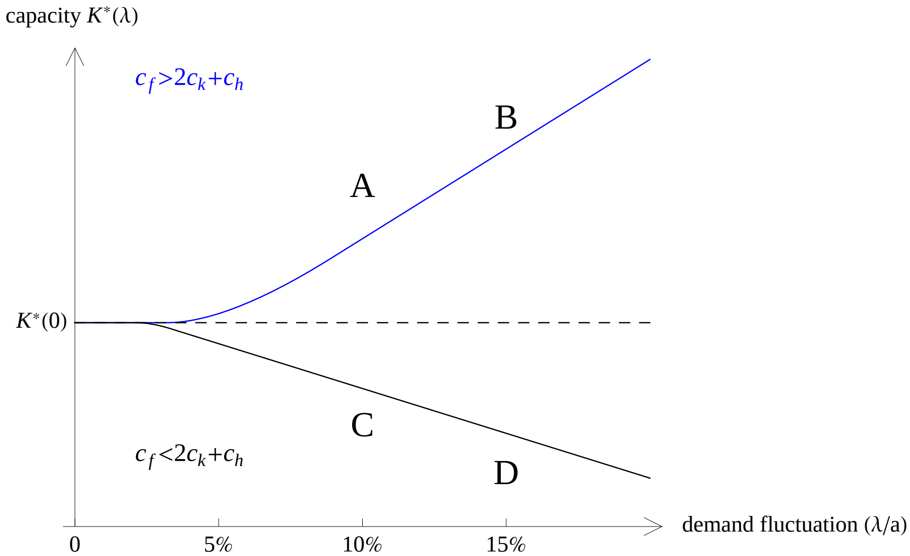

Figure 1: Capacity in landlocked and coastal districts as a function of demand uncertainty

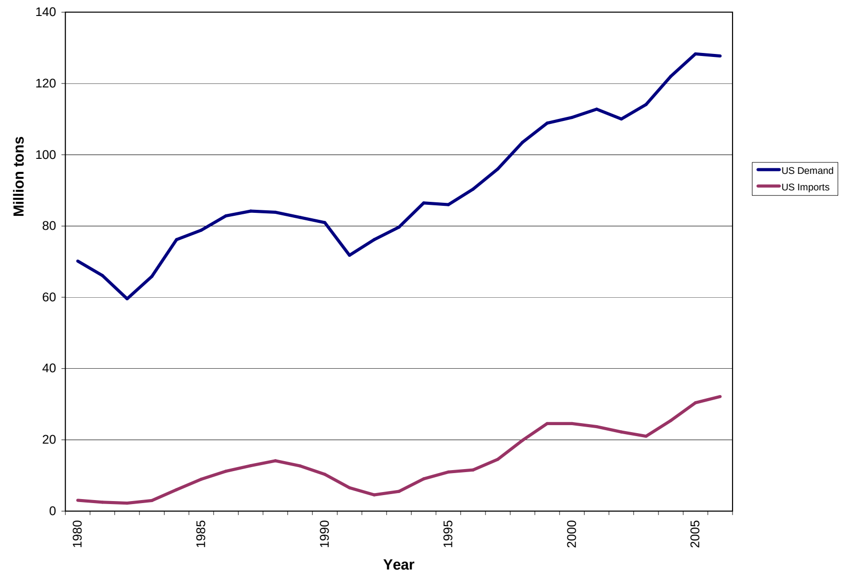

Figure 2: Demand and imports in the US cement market, 1980-2006.

Table 1: Summary Statistics, the U.S. Cement Industry at the District Level.

Panel A: The Industry in 2006

District Number	District Name	Active Plants #	Capacity 000 metric tons	Average Plant Size 000 metric tons	Production 000 metric tons
1	Alabama	5	6036	1207	5201
2	Alaska, Hawaii, Oregon, Washington	4	2540	635	1906
3	Arizona, New Mexico	3	3310	1103	2549
4	Arkansas, Oklahoma	4	3260	815	2703
5	California, Northern	3	2853	951	2454
6	California, Southern	8	10238	1280	8495
7	Colorado, Wyoming	3	3450	1150	2579
8	Florida	7	7301	1043	5876
9	Georgia, Virginia, West Virginia, South Carolina, Maryland	10	11636	1164	8412
10	Idaho, Montana, Nevada, Utah	6	3750	625	3043
11	Illinois	4	3420	855	3108
12	Indiana	4	3720	930	3025
13	Iowa, Nebraska, South Dakota	5	6048	1210	4558
14	Kansas	4	3329	832	3003
15	Kentucky, Mississippi, Tennessee	4	3700	925	3492
16	Michigan, Wisconsin	5	7328	1466	5437
17	Missouri	5	6958	1392	5240
18	New York, Maine	5	4203	841	3356
19	Ohio	2	1304	652	966
20	Pennsylvania, Eastern	7	4530	647	4411
21	Pennsylvania, Western	3	1770	590	1605
22	Texas, Northern	6	7594	1266	6467
23	Texas, Southern	6	5850	975	4882

Panel B: 1994-2006

District Number	District Name	Landlocked Indicator	Mean Demand Volatility	High Demand Volatility Indicator
1	Alabama	1	0.024	0
2	Alaska, Hawaii, Oregon, Washington	0	0.012	0
3	Arizona, New Mexico	1	0.024	0
4	Arkansas, Oklahoma	1	0.037	1
5	California, Northern	0	0.027	0
6	California, Southern	0	0.032	1
7	Colorado, Wyoming	1	0.041	1
8	Florida	0	0.023	0
9	Georgia, Virginia, West Virginia, South Carolina, Maryland	0	0.021	0
10	Idaho, Montana, Nevada, Utah	1	0.025	0
11	Illinois	1	0.028	0
12	Indiana	1	0.028	0
13	Iowa, Nebraska, South Dakota	1	0.016	0
14	Kansas	1	0.030	1
15	Kentucky, Mississippi, Tennessee	1	0.032	1
16	Michigan, Wisconsin	1	0.026	0
17	Missouri	1	0.030	1
18	New York, Maine	0	0.026	0
19	Ohio	1	0.025	0
20	Pennsylvania, Eastern	0	0.044	1
21	Pennsylvania, Western	1	0.042	1
22	Texas, Northern	1	0.046	1
23	Texas, Southern	0	0.028	0

Table 2: Pairwise Correlations in 2006

2006	Number of Plants	Capacity	Average Plant Size	Production	Landlocked	Demand Growth	Demand Volatility
Number of Plants	1						
Capacity	0.8732	1					
Average Plant Size	0.3153	0.713	1				
Production	0.8853	0.9857	0.6798	1			
Landlocked Indicator	-0.5377	-0.3383	0.1117	-0.3524	1		
Demand Growth	0.3102	0.3642	0.2971	0.3791	-0.3973	1	
Demand Volatility	-0.0505	-0.0856	-0.0578	0.0024	0.2016	0.0963	1

Table 3: Capacity-related Variables by District Group, 1994, 2006, and 1994-2006

(Standard deviations, across districts in each group, in parentheses)

((Capacity(t)-Production(t))/Capacity(t))

	1994		2006		Percentage Change 1994-2006	
	Low Uncertainty	High Uncertainty	Low Uncertainty	High Uncertainty	Low Uncertainty	High Uncertainty
Landlocked	0.20 (0.09)	0.13 (0.07)	0.20 (0.06)	0.15 (0.08)	-0.01 (0.08)	0.02 (0.09)
Coastal	0.19 (0.08)	0.15 (0.04)	0.20 (0.05)	0.10 (0.10)	0.02 (0.06)	-0.05 (0.15)

Average Plant Size ('000 metric tons)

	1994		2006		Percentage Change 1994-2006	
	Low Uncertainty	High Uncertainty	Low Uncertainty	High Uncertainty	Low Uncertainty	High Uncertainty
Landlocked	800 (276)	645 (191)	1006 (293)	996 (284)	28.62 (15.86)	56.65 (30.98)
Coastal	793 (132)	801 (270)	935 (181)	963 (447)	18.77 (21.37)	17.59 (16.21)

Table 4: Panel Regressions of Changes in Capacity, Including District Fixed Effects

Panel A: Regression Output

	1	2	3	4	5	6	7	8
VARIABLES	Capacity	Capacity	Capacity	Capacity	Average Plant Size	Average Plant Size	Average Plant Size	Average Plant Size
Demand Volatility	2.218*	2.436*	-0.129	-0.238	1,582	1,574	-846	-701
	[1.253]	[1.257]	[1.134]	[0.991]	[1,089]	[978]	[807]	[810]
Demand Growth		0.516		0.311		264		76
		[0.596]		[0.490]		[453]		[364]
Number of Plants		0.103		0.171***		-120**		-66
		[0.062]		[0.065]		[47]		[44]
Landlocked * Demand Volatility			3.584**	4.060**			3,708**	3,459**
			[1.661]	[1.772]			[1,552]	[1,387]
Landlocked * Demand Growth				0.438				387
				[0.834]				[640]
Landlocked * Number of Plants				-0.117				-92
				[0.117]				[86]
Constant	1.205***	0.679**	1.184***	0.888*	1,088***	1,677***	1,066***	1,840***
	[0.049]	[0.323]	[0.052]	[0.481]	[36]	[237]	[38]	[359]
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
District Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	207	207	207	207	207	207	207	207

**The dependent variable in Columns 1 to 4 is yearly capacity for the district divided by the district-mean production level. Any changes over time within a district hence reflect changes in capacity.*

Panel B: Tests of significance of the differences in investment across district groups*

	From Column 4, Capacity			From Column 8, Average Plant Size		
	Coastal	**Landlocked**	**Significant difference across columns?**	**Coastal**	**Landlocked**	**Significant difference across columns?**
Demand Volatility	-0.003	0.051***	Yes**	-9.44	37.11**	Yes**
	[0.013]	[0.021]		[10.90]	[15.71]	

**Predicted increase in the dependent variable associated with one standard deviation increase in demand uncertainty*

*** p<0.01, ** p<0.05, * p<0.1
Newey-West standard errors in parentheses.

Table 5: Panel Regressions of Changes in Capacity, First Differences Specification

Panel A: Regression Output

	1	2	3	4	5	6	7	8
VARIABLES	Change in Capacity	Change in Capacity	Change in Capacity	Change in Capacity	Change in Average Plant Size	Change in Average Plant Size	Change in Average Plant Size	Change in Average Plant Size
Change in Demand Volatility	1.018*	1.329*	0.025	0.014	1,068*	847	131	-231
	[0.592]	[0.697]	[0.559]	[0.639]	[644]	[517]	[514]	[438]
Change in Demand Growth		0.226		-0.268		151		-250
		[0.421]		[0.320]		[310]		[228]
Change in the Number of Plants		0.087		0.098***		-138***		-106***
		[0.054]		[0.032]		[41]		[26]
Landlocked * Change in Demand Volatility			1.484	1.870			1,399	1,478*
			[0.980]	[1.143]			[1,030]	[806]
Landlocked * Change in Demand Growth				0.677				522
				[0.704]				[514]
Landlocked * Change in the Number of Plants				-0.019				-66
				[0.119]				[84]
Constant	0.025***	0.026***	0.025***	0.026***	20***	19***	20***	19***
	[0.007]	[0.006]	[0.007]	[0.006]	[5]	[5]	[5]	[5]
Observations	184	184	184		184	184		184

**The dependent variable in Columns 1 to 4 is yearly capacity for the district divided by the district-mean production level.*

Panel B: Tests of significance of the differences in investment across district groups*

	From Column 4, Change in Capacity			From Column 8, Change in Average Plant Size		
	Coastal	**Landlocked**	**Significant difference across columns?**	**Coastal**	**Landlocked**	**Significant difference across columns?**
Demand Volatility	0.000	0.025**	No†	-3.11	16.78*	Yes*
	[0.009]	[0.013]		[5.89]	[8.91]	

**Predicted increase in the dependent variable associated with one standard deviation increase in demand uncertainty*

*** p<0.01, ** p<0.05, * p<0.1. († indicates this coefficient is significant at the 11% level).
Newey-West standard errors in parentheses