The Early Decades of Commercial Air Conditioning in the US

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ABSTRACT

During the first four decades of the air conditioning industry's existence, the overwhelming majority of installations were "commercial comfort" air conditioning, purchased by retailers to increase demand for their products. Air conditioning spread unevenly through the commercial sector and across the country. This paper argues that this pattern resulted from businessmen in monopolistically competitive markets adopting air conditioning when benefits of adoption outweighed the costs. The argument is supported by narrative evidence and cross section and time series data. Air conditioning adoption by retailers was sensitive to the type of good or service sold, climate, electricity rates, and urbanization.

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Modern air conditioning grew out of efforts by engineers in the late 19th and early 20th centuries to develop ventilation systems that would control the quality, temperature and humidity of indoor air. The first commercially viable applications of air conditioning occurred in manufacturing industries dealing with humidity-sensitive materials, but by the 1920s the vast majority of air conditioning horsepower in the United States was "commercial comfort" air conditioning, such as systems installed by owners of movie theaters and department stores in hopes attracting more customers. Retailers of goods and services and commercial landlords remained the major users of air conditioning into the 1960s, with capacity dwarfing that in residential and industrial settings, and the marketing and technical challenges posed by these commercial applications shaped the development of the technology and the industry during its first five decades.

The spread of commercial air conditioning from the 1920s to the 1950s was uneven. The technology was introduced early and spread quickly in some lines of business while remaining uncommon until the end of the period in others. Within given lines of business there were also differences across regions and markets in the prevalence and rate of diffusion of the new technology. I document these patterns using data from a variety of sources, and offer an explanation of them based in economic theory. In keeping with narrative evidence, I model the potential adopters of commercial air conditioning as monopolistic competitors in local retail markets. Pioneering firms adopt in the belief that the resulting increase in short and medium term profits due to increased demand will outweigh the cost of adoption, and their success forces competitors to adopt as well. The model points towards three types of factors to be considered in an economic explanation of the diffusion of commercial air conditioning: (i) factors that were likely to have affected the expected or actual impact of air conditioning on consumers' preferences for the firm's product, including climate and certain characteristics of the good or service being sold; (ii) market and industry characteristics, such as thickness of the market and the level of fixed costs, that affected the profit impact of any given increase in demand; and (iii) the installation and operating cost of air conditioning.

I argue that consideration of the nature of the good or service being sold goes a long way towards explaining which lines of business were early and enthusiastic adopters of air conditioning. For example, in the restaurant and movie theater businesses, where air conditioning took hold early, consumption of the product required the customer to spend a long time inside the retail establishment, an experience that could be made much more pleasant in the summer with air conditioning. I also offer empirical evidence that in several of the early adopting sectors, traditional summer declines in demand became smaller during the period of air conditioning's diffusion.

In 1940, the Edison Electric Institute (EEI) surveyed over 180 electric utilities about the air conditioning installations in their service areas. Using a data set created by matching information from this survey to economic, demographic, and climate data, I estimate regressions designed to explain differences across markets and regions in the amount of air conditioning installed in various retail sectors. The regressions show that as of 1940, climate was an important correlate of air conditioning prevalence, but so too was the extent of urbanization, confirming a prediction of the model. Finally, the regressions show that the adoption of air conditioning was very sensitive to electricity rates, which represented 50% or more of the operating cost of air conditioning, with an . elasticity of installed horsepower with respect to the electricity rate well above 1 in absolute value. This, combined with the fact that electricity rates were falling dramatically over the 1935-1955 period, could explain a substantial part of the growth in the prevalence of commercial air conditioning over the same period.

Little has been written on the economic history of air conditioning aside from the studies of the diffusion of residential air conditioning by Ormrod (1990) and Biddle (2008), although two recent books by historians include insightful accounts of economic trends that shaped or were influenced by the spread of this technology (Cooper 1998, Ackermann 2002). Beyond adding to this literature, this paper is intended as contribution to the larger economic history literature concerned with the diffusion and economic impact of key inventions (e.g., Gordon 1990).

The next section provides a historical account of the spread of commercial air conditioning, highlighting the importance of this sector to the growth of the air conditioning industry. Section III offers narrative evidence on the process by which air conditioning spread, and outlines a model of this process. Section IV documents differences across lines of retail businesses in the timing of initial adoption and diffusion of air conditioning, and Section V provides an account, based in the model, of these differences. Section VI contains the regression analysis of cross section differences in the prevalence of commercial air conditioning as of 1940, including a description of the data set, the specifications estimated, and the results. Section VII concludes.

I. Historical Overview

Stuart Cramer coined the phrase “air conditioning” in 1906 to describe his system for controlling humidity levels in textile factories. Textile manufacturers were interested in Cramer's system because the properties of wool and cotton fibers depended on the amount of moisture they absorbed, and higher humidity levels in the factory made the fibers more amenable to machine processing (Cooper 1998, pp. 17-23). Around the same time, Willis Carrier was also patenting devices to control indoor temperature and humidity, and was soon selling air conditioning systems to firms in industries that worked with humidity-sensitive or hygroscopic materials, including tobacco, chocolate, and gunpowder (Cooper 1998, p. 24, chapt. 2). These sorts of applications, designed to improve the efficiency of production processes involving hygroscopic materials, were dubbed "process" air conditioning by the early air conditioning engineers, to distinguish them from another type of application for which the engineers hoped to find profitable markets: "comfort" air conditioning, or ventilation systems designed to control the temperature and humidity of indoor spaces for the sake of human comfort.

Dreams of a robust residential market for comfort air conditioning systems would not begin to be realized until the late 1950s (Biddle 2008). However, the market for commercial comfort air conditioning systems – such as those purchased by owners of stores or restaurants to attract more customers – soon eclipsed the process air conditioning market and drove the development of the new technology (Cooper 1998, p. 81).[1] By 1940, almost 90% of the nation's air conditioning capacity was devoted to commercial comfort air conditioning.[2]

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[1] This paper follows the 20th century air conditioning industry practice of dividing potential applications of air conditioning into air conditioning for materials (process or industrial air conditioning) and air conditioning for people (comfort air conditioning, with its commercial and residential subdivisions). This scheme groups systems installed in office buildings for the benefit of workers with those installed in movie theaters for the sake of patrons. Arguably, it would make more economic sense to classify applications of air conditioning according to whether they were intended to make a production process more efficient or to make the product being sold more attractive to consumers, thus grouping the air conditioning of office buildings with the air conditioning of textile factories. However, from the point of view of the air conditioning industry, office building air conditioning was intended to make a product more attractive: the

Movie theaters provided the first large market for comfort air conditioning. In the second decade of the 20th century, new movie theaters were being built at an amazing pace. Ventilation was an important issue for the owners of these new theaters, both because of public health regulations and because crowded theaters became intolerably uncomfortable as outside temperatures rose. Powerful fan ventilation systems satisfied health regulations but did not really solve the comfort problem, so theater owners were eager to try products that promised to fill more seats during the slow summer season (Cooper 1998, pp. 82-85). During the teens, many theaters installed systems based on the evaporative cooling effect created by blowing water-saturated air into the theater, but this was only fully effective in the dry southwest. In 1917, an Alabama theater installed the first system in which coils filled with refrigerant were used to boost cooling power, and this soon became the dominant approach to theater cooling. Subsequent cost-saving innovations in the 1920s included delivery of cool air from the ceiling rather than the floor, and the recirculation of interior air (Cooper 1998, pp. 87-88, 99-100). By 1935, one air conditioning engineer could comment that "builders of new theaters would no more leave out air conditioning than they would neglect heating, for the public demands it and experience has shown that it pays" (Bloom, quoted in Cooper 1998, p. 99). Consolidated Edison estimated in 1936 that 149 of Chicago's 256 movie theaters had air conditioning systems, cooling about 75% of Chicago's theater seats and representing 33.4% of Chicago's air conditioning capacity (Porter and Rock 1937). But the movie houses were more than an important market for the air conditioning industry: they were a marketing tool. As the above-quoted engineer also remarked in 1935, "It is trite to say that the

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customers for such systems were the owners of the buildings, and the sales pitch was "your rental space will be more attractive to the firms that rent space in buildings like yours if it is air conditioned."

[2] This is based on the 1940 Edison Electric Institute survey of utilities, discussed in more detail below.

public became air-conditioning conscious through the avenue of movie theaters." (Cooper 1998, p. 82)

Department stores provided another major market for comfort air conditioning in the 1920s. As Ackermann (2002, p. 52) notes, a visit to a department store in the 1920s was "not a chore, but an entertainment event," a chance to see, to be seen, and to admire the goods on display. Shopping was much less entertaining if the store was sweltering, however, and department store sales plummeted in July and August (Ackermann 2002, p. 56). J.L Hudson's in Detroit was the first store to install air conditioning, and department stores in Boston and Manhattan soon followed suit. The effect on business, according to a testimonial provided by Hudson's to the Carrier Corporation, was "good beyond question" (Ackermann 2002, p. 57).

During the 1930s other branches of retailing followed the lead of the department stores, experimenting with air conditioning as a way to bring more customers through the doors during the slow summer months. In 1939 the trade journal *Chain Store Age* surveyed over 300 retail chains operating tens of thousands of outlets. Department and Variety (e.g., 5 and 10 cent store) chains had invested the most money in air conditioning, and 8.2% of all outlets were air conditioned. The highest percentage of air conditioned outlets, however, was reported by the drug store/soda fountain chains, at 29.7%. This was followed by restaurants at 21.3%, and shoe and apparel chains in the mid teens. Overall, 9% of the chain outlets were air conditioned, a figure that would rise to 10.5% on the eve of WWII (*Chain Store Age*, Nov. 1939, p. 101; Nov. 1941, p. 96).[3]

[3] Frequent references are made in this paper to information taken from the periodicals *Chain Store Age* and *Heating, Piping, and Air Conditioning* (HPAC). Information from unsigned articles is cited in text with page number and date of issue, while information from signed articles is cited by author's name and year, with the signed article listed in the references.

The war brought an abrupt halt to the expansion of commercial air conditioning, as the industry directed its efforts towards cooling war-related factories and offices, and struggled with shortages of crucial raw materials. Industry leaders, however, anticipated a post-war boom, and they turned out to be correct (Cooper 1998, pp 141-143). The retail chains surveyed by *Chain Store Age* in 1949 reported that 18.5% of their stores were air conditioned, and by 1954 the figure was up to 35% (HPAC, March 1950, p. 70; August 1955, p. 82). The Air Conditioning Research Institute's estimate of the installed value of central air conditioning systems doubled in real terms between 1950 and 1958.[4]

During this period owners of office buildings and hotels became important customers for the air conditioning industry. The industry had recognized commercial office space as an important potential market from the beginning, and in the twenties and early thirties, air conditioning systems were included in a few high-profile skyscrapers built in major metropolitan areas. Serious growth began in the late 1930s. In Chicago, for example, about 20,000 square feet of office space was air conditioned at the beginning of 1935; this number had increased to over 46,000 by the end of the decade.[5] This was nothing, however, compared to the explosion in office air conditioning that occurred in the 1950s. Periodic surveys of major office buildings in the US and Canada by the National Association of Building Owners and Managers reported air conditioning in 10% of sample buildings in 1941, 16% in 1951, and 30% by 1955 (HPAC June 1957, p. 132). In 1956 Charles Fenn, vice president of Carrier, claimed that "Virtually every major

[4] HPAC Sept. 1959, p. 53. The nominal value of the ARI series increased by 127%, and prices rose by about 20% over the same period.

[5] In 1935, Commonwealth Edison reported 7960 horsepower of air conditioning capacity installed in Chicago office space (HPAC, January 1935, p. 2), while the corresponding figure reported at the end of 1939 was 18,618. Square footage estimates are based on the conversion factor of .3 tons per sq. ft suggested in HPAC (Sept. 1935, p. 433). That the Chicago experience was typical is indicated by the fact that 137 electric utilities responding to EEI surveys in both 1938 and 1940 had an average growth of about 50% in horsepower installed in offices from the beginning of 1938 to the end of 1939.

office building constructed since World War II has included complete air conditioning," including 60 new office buildings in New York City alone, where he estimated that 22% of the "class A' office space was air conditioned. Penetration of the commercial office market in cities such as Philadelphia and Chicago ran only a bit behind this, and in Dallas and Houston "saturation (was) literally 100%" (HPAC, March 1956, p. 120).[6] In the late 1950s and early 1960s, sales of systems for office buildings accounted for about a third of non-residential air conditioning sales annually.

The air conditioning of hotels followed a similar pattern. Some luxury hotels in major cities had installed air conditioning in the 1920s and 1930s, but as of 1937 air conditioning was in only .5 % of the rooms of larger hotels nationwide, and in only 10% of their public spaces, such as banquet rooms and coffee shops (HPAC March 1937, p. 151). In the 1950s, however, a boom in the construction of new hotels fueled the spread of hotel air conditioning, and by the early 1960s over 60% of all hotels and motels had at least some air conditioning (HPAC March 1956, p. 121, HPAC January 1964, p. 121).

While the commercial comfort market grew dramatically in the 1950s, the industrial market remained small and specialized. As of 1956, less than 1% of all "modern factories" were air conditioned. Even in the textile industry, "the most air conditioned of all", only 8-10% of capacity was air conditioned in 1955.[7] But the leaders of the air conditioning industry saw this as more an opportunity than a problem. As Fenn pointed out, with an estimated 25-50 square feet of factory space for every square foot of

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[6] Fenn's market penetration numbers applied to "class A" office space, defined by the Urban Land Institute as "buildings that have excellent location and access, attract high quality tenants, and are managed professionally." In the Houston and Dallas markets, class A status might almost have definitionally required air conditioning by this time.

[7] This estimate from the Carrier Corp. may have been low. An article one year later attributed an estimate of 20% to "consultants in the textile field." (HPAC, Oct. 1956, p. 89)

office space, and with over twice as much cooling capacity needed for each square foot, the potential market was “absolutely enormous” (HPAC March 1956, p. 122; October 1956, p. 70). As the industry moved into the sixties, however, this market remained more potential than real.[8]

II. An Economic Model of the Spread of Air Conditioning

As the overview of the proceeding section makes clear, the story of the diffusion of air conditioning technology in the first half of the 20th century is for the most part the story of the spread of commercial comfort air conditioning, with businessmen in one retail industry after another deciding to offer their goods or services in an air conditioned environment, in hopes of attracting more customers. It should be added that within each line of business, the diffusion of air conditioning proceeded at different rates in different localities or markets. In this section, I use narrative evidence on businessmen’s decisions to adopt air conditioning to motivate an explanation of why the spread of commercial air conditioning in the United States happened as it did. I begin with the assumption that the decision to adopt air conditioning was driven by the profit motive, and identify factors that economic theory suggests should have influenced the expected impact of air conditioning on a firm’s profits. The explanation implies a set of hypotheses about the types of business that were likely to be early adopters of the new technology, and about the variation across markets in the prevalence of air conditioning within industries at a point in time.

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[8] For example, in 1963, sales to the entire industrial market were about the same as sales to hotels and motels, and even in factories built since the war, only 10% of the space was air conditioned (HPAC January 1964, p. 120).

In 1937, Verda Johnson, specialist on the retail drug field, wrote of the coming of air conditioning to drug stores:

> "The druggist is reasonably quick and willing to respond to any devices which will increase his business. He is accustomed to lively competition, for not only does he vie with other drug stores – and there are always plenty of them – but he competes with restaurants through his soda fountain and general stores with much of his other merchandise. His interest then, in air conditioning as a weapon to fight competition, build his business, add customers, and boost sales volume is genuine . . .
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> "The trend in air conditioning in the drug field shows . . . that the first installations are made by large chain store units, followed later by large local chains, then large independent stores, working down gradually towards the small neighborhood retailer . . ." (Johnson 1937)

The same themes are repeated in descriptions of the adoption of air conditioning in other lines of business: pioneers adopt air conditioning in an attempt to boost demand and profits, thus creating pressure for others serving the same market to adopt:

> "With so much capital invested in their theaters, exhibitors could not afford a drop in attendance during the summer. Air conditioning would draw in crowds and so defeat the traditional summer downturn . . . The appearance of air conditioning in a theater belonging to a national chain could spark its rapid adoption at a local level, fueled by the intense rivalry of exhibitors." (Cooper 1998, pp. 90-91)

> "The corner of 63rd and Halsted streets is probably the busiest and largest of Chicago's outlying or neighborhood shopping centers . . . (S)ince the 1937 increase in installations in this shopping center is of the nature of 200 per cent compared with about 35 per cent of the city as a whole, we recognize that certain unusual local sales stimulus accounts for this large increase. It is our belief that the competitive advantages of air conditioning in Englewood had arrived at such a point in 1937 that *many commercial operators suddenly recognized that they couldn't afford not to have air conditioning* . . .It is our belief that 1938 air conditioning sales in this section will overshadow those of 1937. Why? Simply because the competitive necessity of those merchants who are not yet prepared to offer summer comfort is more acute than ever." (Porter and Rock 1938, p. 173, emphasis in original)

> "There have been many instances in which the installation of air conditioning in one hotel in a community has forced other hotels in the same city to do likewise; in fact, every time we made another air conditioning installation in one particular hotel we were operating our principal competitor duplicated it in his hotel." (Lewis 1940, p. 345)

> "In 1937 there were no air conditioned restaurants in the area surveyed. Today there are four. Why? Well, one proprietor laughed when he was asked. "To stay in business, of course!" was his reply. Another restaurant manager remarked that it was a "must" in the restaurant business. Another restaurant proprietor, when asked if air conditioning increased his business, replied, "It does, and I have the figures to prove it." (Diamond 1949, p. 91)

In light of these accounts and others like them found in trade publications, I have adopted the following assumptions about the process by which commercial retail industries moved from a pre-air conditioning equilibrium to one in which air conditioning was standard: Firms are operating in a zero profit, monopolistically competitive equilibrium when they become aware of the possibilities of the new technology. At some point a few firms adopt the new technology; they draw business away from others in their market, forcing those others to adopt as well. The initial adopters are assumed to know that in time their move will be followed by competitors, and that if air conditioning increases industry-wide demand, entry will be attracted and profits will return to zero. However, the desire for profits still serves as a motivator for initial adopters, because adoption by competitors will take time, and new entry even more so.[9] In short, initial adopters are those who conclude that the increase in revenues

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[9] With respect to the assumption that firms are motivated by profits that can be made before entry restores long-run equilibrium, consider two passages from the pages of *Heating, Piping and Air Conditioning.* The first is in an article reporting on the installation of air conditioning in four St. Louis hotels: "Will competition cancel the benefits of these installations, so that each hotel will wind up with approximately the same amount of summer business as before? No, answers manager Charles Heiss of the Mayflower and Lennox Hotels. '(A) new class of clients will be created where none existed before . . . At present we are making a survey to determine the extent of this tendency.'" The second is an unidentified reader's answer to a question posed in an earlier issue: "In the April issue, J.O. asked what percentage increases in business can be expected in a store, a restaurant, and a hotel dining room due to the installation of a good summer air conditioning system . . . If at the time of installation all other (or the majority of) similar businesses in the town already had air conditioning systems, the owner of the specific company will find that he recovers the loss suffered before due to the inferiority of his facilities. The installation then represents a necessary measure to keep pace with the acknowledged progress of the trade, and the economy is given by the return to normal success. . . Things seem to be different, if no air conditioning systems are in operation in similar businesses of the town. The installation will, then, secure superiority and increase in profit. Still, such success will be only temporary, and the competition will, willingly or unwillingly, soon follow the example and regain balance. . . But the economical success does not end with the number of attracted customers. If

from adopting air conditioning will outweigh the installation and operating costs, and their move alters the calculations of competitors in a way favorable to the further spread of air conditioning. We should thus expect to see air conditioning being adopted sooner, and spreading more quickly, in industries and in markets in which the expected increase in demand due to the adoption of air conditioning is likely to be higher, and the cost of the technology lower.

To formalize these ideas and to provide a framework for discussing the types of markets and industries in which adoption of air conditioning was likely to provide a greater boost to profits, I employ a version of Salop's (1979) model of monopolistic competition, modified to allow situations in which a cut in price by all firms in a competitive equilibrium can increase the size of the total market.[10] I adopt a model of monopolistic competition rather than perfect competition for two reasons. First, the narrative evidence suggests that the commercial firms whose decisions about air conditioning are the subject of this paper were not price takers, but active competitors who perceived a downward sloping demand for their product and were concerned with competitors' activities. Second, and more important, the data reveal a strong correlation

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this were the case, the totality of similar businesses would only preserve their standing as before, and the owners could be inclined to come to an arrangement not to invest capital for a nonpaying improvement. Actually, the whole trade profits by air conditioning . . ." (HPAC June 1948, p. 103). Both commentators recognize that adoption of air conditioning by competitors cuts into the profits of the initial innovator, but both see economic profits persisting beyond the point that all competitors adopt the new technology, because air conditioning increases industry demand. Also, both show a high level of sophistication, with the hotelier conducting surveys to gauge the nature of the impact of air conditioning on demand, and the other commentator describing incentives to collusion. Arguably, men this sophisticated would also recognize that any growth in industry demand and profitability attracts entry, so they must consider such entry a distant enough prospect to ignore in their discussions.

[10] Salop's model can have a "monopoly" equilibrium, in which a price cut by one firm draws new consumers into the market, but does not attract consumers from other firms, and a "competitive" equilibrium, in which a price cut by one firm only increases demand at the expense of other firms. There are analogous equilibrium types in this model, but in the competitive equilibrium (which I assume, consistent with narrative evidence, to be the type of equilibrium that holds) price cuts or product improvements can both attract customers from competitors and draw new consumers into the market.

between the level of urbanization in a market and the prevalence of commercial air conditioning. This relationship arises directly in the monopolistic competition model, but not in an otherwise analogous model that assumes perfect competition.[11]

The model assumes n firms in an industry, each producing a differentiated version (brand) of the industry's product, with firm i's brand represented by its position b_i on a unit circle. There are L potential consumers in the market, each characterized by a most preferred brand b* and a reservation value for that brand v*. Values of b* are assumed to be uniformly distributed around the circular product space, and v* is uniformly distributed on the unit interval. The value to a consumer of any brand b_i is given by $v = v^* - c|b_i - b^*|$, where $|b_i - b^*|$ is the shorter arc length between b_i and b*, and c is a parameter reflecting the cost of being away from one's optimum. The consumer buys one unit of the industry's product if

$$v^* - c|b_i - b^*| - p_i > 0 \qquad (1)$$

for some i, where p_i is the price charged by firm i. If (1) is positive for more than one firm, the consumer buys from the firm for which the left hand side of (1) is greatest.

Figure 1a pictures the situation of firm i located at position 0 in brand space, with a competing firm located at position b_j . The rectangle represents the preference space for consumers with b* values between 0 and b_j, so that v* is graphed on the vertical axis and the height of the rectangle is 1. The solid diagonal line running from the southwest to the northeast has the equation $v^* - cb - p_i = 0$, while the other solid diagonal line has the equation $v^* - c|b - b_j| - p_j = 0$. The quadrilateral $ABDp_i$ then represents the share of

[11] The key issue is that the revenue gain from adopting air conditioning depends on the size of firms in equilibrium prior to the introduction of air conditioning. In a perfectly competitive model, this equilibrium firm size will depend only on cost-side parameters, while in the monopolistic competition model it will also depend on demand side factors.

potential consumers in this slice of preference space who buy from firm i, while $CBDp_j$ is the share buying from firm j. (Firm i also has consumers to the left of b*=0, not shown). If firm i lowers its price to p_i', and firm j does not respond, firm i's share grows to $AB'Ep_i$, with some consumers being lured from firm j, and some consumers being new to the market. This growth in firm i's sales (plus the additional consumers coming from the left of b*=0) corresponds to the slope of the Chamberlinian dd curve, which I will denote as $-s_{dd}$.

Figure 1a

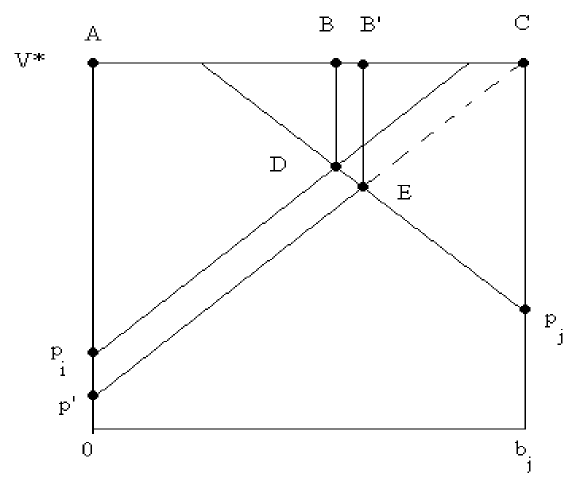


Figure 1b

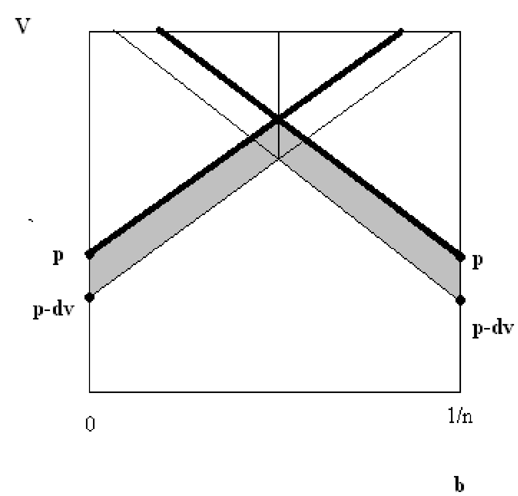


Figure 1b represent the same slice of preference space when the industry is in a competitive equilibrium (that is, in which price reduction by one firm will attract consumers from neighboring firms), with n firms evenly spaced around the circle, all charging the same price p. Firm i is again at b=0, and firm j at b=1/n. The L/n consumers in this slice of preference space who buy the industry's product are divided evenly between the two firms, and are represented by the area above the solid diagonals. Consider now a technical innovation that raises the value to the consumer of all brands of the product by dv. If only firm i adopts the innovation, the effect will be like that of a price reduction of size dv, and the firm will gain consumers as shown in Figure 1a. If other firms follow and adopt the innovation, and there is no entry into the industry, each firm will find that it has retained all of its pre-innovation consumers, and added some consumers that did not buy the industry's product before (the shaded area in Figure 1b).

Letting q equal the number of units sold by each firm, p the common equilibrium price, and characterizing common industry costs with a fixed cost F and a constant marginal cost m, the pre-innovation zero-profit competitive equilibrium can be characterized by

$$p = m + F/q \quad (2)$$

$$p = m + (-s_{dd})q \quad (3)$$

$$q = L((4n(1-p) - c)/4n^2) \quad (4)$$

$$(-s_{dd}) = (1/L)((2nc/(2n(1-p) + c) \quad (5)$$

Eq. (2) is the zero profit condition, eq. (3) is the profit maximizing condition of the monopolistic competitor, and eq. (4) and (5) follow from Figure 1a, as is described in detail in the appendix.

Assume now that when commercial air conditioning systems were first being developed, local commercial markets (restaurants, movie theaters, shoe stores, etc.) were in an equilibrium of the sort described by eqs. 2-5. Assume also that air conditioning was believed to increase demand by raising the value of the product to all consumers by dv, although expectations about the size of dv differed across markets and across firms within a market. As noted above, I assume that firms believed that additional profits (or quasi-rents) earned after air conditioning was introduced but before new entry drove profits back to zero would accrue for a long enough period of time to be an important factor in decision making, and I call the hypothetical situation in which the air conditioning has been adopted by all incumbent firms but new entry has not occurred the medium-run equilibrium. The increase in revenues experienced by firms in the medium-run equilibrium is given by

$$dR = [(p_0 - m)(dq/dv) + q_0(dp/dv)]dv \qquad (6)$$

where the 0 subscript denotes values in the pre-innovation equilibrium. (Initial adopters would experience an even greater increase in revenues in the period before competitors adopted air conditioning). The price change dp/dv is positive but less than one, and occurs as firms adjust prices upward to remain tangent to their dd curves. This leads dq/dv to fall short of the value of L/n, which it would take if prices did not adjust. Finally, based on the narrative evidence, I assume that there were economies of scale in the initial cost of installing air conditioning (HPAC Dec. 1938, p. 763), while operating cost was linear in square feet, so that the cost of adoption can be represented by the function $G(q_0)$, with G increasing at a decreasing rate in equilibrium establishment size.

The prospective increase in revenues characterized by eq. (6) would have been more positive in markets in which dv was larger, which depended on both the nature of the product or service sold and the length and intensity of the hot season in the market's location. It also would have depended on the values, in the market's pre-air conditioning equilibrium, of p_0, dq/dv, q_0, and dp/dv, which in turn depended on market characteristics represented by the parameters m, F, c, and L. Thus, the model can shed light on the relationship between urbanization and the adoption of air conditioning. The denser populations of urbanized markets correspond to a higher value of L in the model. It is also not unreasonable to assume that the higher urban rents led to higher values of fixed costs F for urban retailers. In the model, higher values of L and F are both associated with higher levels of q_0, which is consistent with the fact that retail establishment sizes in 1940, measured as employees per establishment, were much larger in more urbanized areas.[12] I show in the appendix that the impact of rising L on eq. (6) is ambiguous: in denser markets, any increase in v brings in more new customers, but denser markets have more firms competing and thus a lower margin of price over marginal cost. I also show that eq. (6) is larger in markets with higher values of F, which are associated with a higher equilibrium markup of price over marginal cost and a higher equilibrium quantity sold, both of which increase the revenue gain from the boost in demand that follows an increase in product quality. It is true that the higher q_0 in urban markets means a higher cost of adoption as well, but with economies of scale in the cost of adoption, the

[12] For example, in Illinois overall, the average general merchandise store had 31.7 employees, the average women's ready-to-wear clothing store had 4.9, the average restaurant had 6.6, and the average drug store/soda fountain had 4.7. The corresponding figures for the city of Chicago were 55.1, 5.6, 9.0, and 5.1. Likewise, employee per establishment averages in the city of Detroit for these types of stores ran 20% to over 100% higher than Michigan statewide averages.

increased revenue from adoption is more likely to exceed the increased cost in markets with larger establishment sizes.[13]

I use the reasoning of the previous two paragraphs first as a tool for explaining the order in which various lines of business adopted air conditioning, as indicated by narrative histories and evidence from various surveys conducted from the late 1930s to the late 1950s. In doing so, I focus mainly on differences in the impact of air conditioning on demand for the product or service being sold. I then turn to cross section data on within-industry differences in the prevalence of air conditioning across markets and geographical areas just before WWII. Here I concentrate on factors identified in the model that varied geographically, including the obvious factor of climate, but also the level of urbanization in the market being served and the cost of electricity, which would have affected the operating cost of the new technology.

III. Identifying the Early Adopters of Commercial Air Conditioning

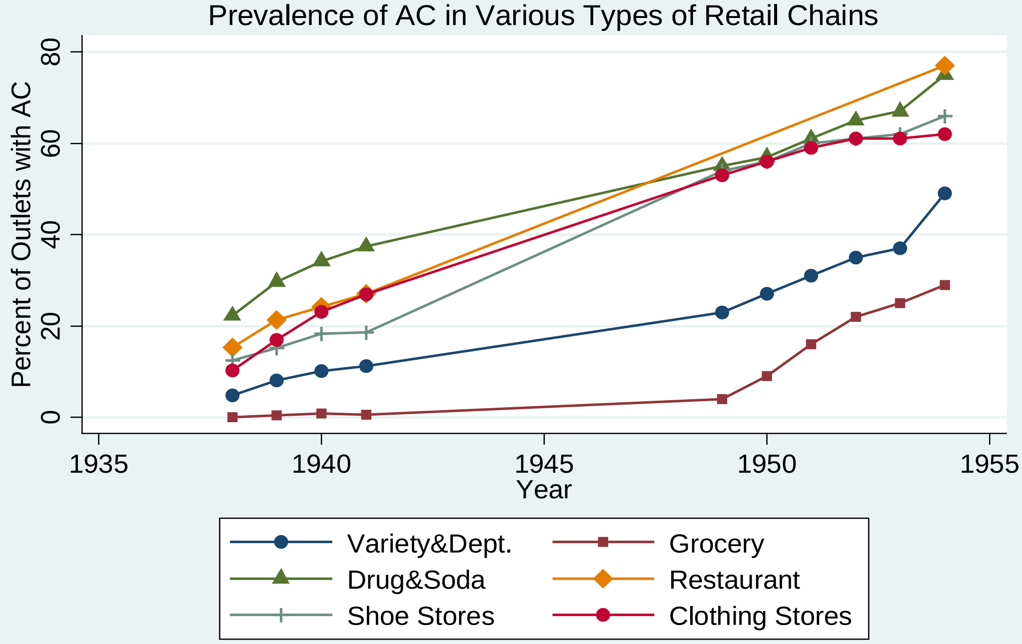
By all accounts, the motion picture exhibition industry was the first to embrace comfort air conditioning as a means to higher profits, and the first in which adoption of air conditioning approached saturation levels. My evidence on the timing of adoption in other retail and service industries is taken from several sources. Figure 2, which shows the growth in the percentage of chain store outlets with air conditioning in a number of retail lines, is based on surveys conducted by *Chain Store Age* intermittently between

[13] More specifically, consider a graph of the cost and benefit of adopting air conditioning against existing establishment size (q_0). The benefit line is the reduced form relationship between establishment size and eq. 6 as F and L increase, assumed to be positive, but which obviously falls nearly to zero as establishment size falls. The cost function has a positive intercept and increases at a decreasing rate. So, if the benefits line representing increased revenues is to exceed the cost line, it must cut it from below: expected revenue increase from adoption is more likely to exceed costs in markets with larger establishments.

1938 and 1954. The lines on the figure are derived from these reports as described in the appendix. In the late 1930s, drug store/soda fountain chains were the most eager adopters of air conditioning, while there was almost no air conditioning in grocery stores. Clothing stores, shoe stores, and restaurants were more likely to have air conditioning than department and variety stores, a group which includes everything from small 5&10 cent outlets to major urban department stores. While the prevalence of air conditioning increased considerably over the period for all these types of chains, there were no significant changes in the ordering from most air conditioned type to least. In the pre-war years, *Chain Store Age* also reported figures for an "other" category, which included automotive accessory and hardware stores, confectionary stores, and retail bakeries, and the percentage of these outlets air conditioned was close to that of grocery outlets. In 1954 the magazine reported that 14% of the outlets of automobile accessory or hardware chains were air conditioned, which was about half the level reported for grocery stores.

Figure 2

Prevalence of AC in Various Types of Retail Chains



To get a picture of air conditioning prevalence not limited to chain stores, I use two additional data sources. The first is a survey of electric utilities conducted by the Edison Electric Institute in 1940. In the 1930s, the installation of an air conditioning system required the cooperation of the local utility because of the special wiring requirements and high power demands associated with air conditioning (portable units that could be plugged into standard outlets were yet to be developed). As a result, utilities were aware of the extent of air conditioning in their service areas, and often took an active interest in promoting the use of the technology, as it represented a profitable source of extra demand and load smoothing (Cooper 1998, 127-28). In 1939 and 1940, EEI surveyed utilities concerning the number and size of air conditioning installations in their service areas. Respondents were asked to classify installations using the broad categories of commercial, industrial and residential, and within the latter two categories, by the type of business making the installation. Over 180 utilities, serving over half the nation's population, answered the 1940 survey, providing information on number of installations and horsepower installed. A sample page from EEI's summary of the 1940 survey, showing data reported by Commonwealth Edison Co. (serving Chicago) is reproduced as Figure 3. The categories provided to respondents by EEI in its survey reveal much about where commercial air conditioning was likely to be found in the late 1930s. Restaurants, department stores and drug stores are given separate lines, while all other retail stores are to be put in a miscellaneous category. Among retail service providers, barber and beauty shops, dentist and doctor offices, funeral homes, and hotels are also given separate lines.

Several of the 1940 EEI respondents were utilities that served only a major city.[14] This makes it possible to estimate the prevalence of air conditioning in these cities in specific lines of businesses, by comparing the number of installations reported for a particular type of retailer as of the end of 1939 to the number of retail establishments of that type in 1939, as reported in the 1940 Census of Business. These estimates are presented in the top (1939) panel of Table 1. Ranges are reported in the department store, drug store, and restaurant categories because it is unclear how to match the categories used by the respondents to the EEI survey to categories used by the Census Bureau. In the department store category, the lower end of the range is obtained by using the number of "General Merchandising" establishments reported for the city as the denominator, while the upper bound denominator includes department and dry goods stores, but not variety stores (which, according to Census documentation, do not necessarily carry clothing). The denominator for the lower bound in the drug store category is all drug stores, while the upper bound uses only the number of drug stores with fountains, as contemporary narrative evidence suggests that the drug stores adopted air conditioning mainly to boost their soda fountain business (e.g., Johnson (1937)). The lower bound in the restaurant category uses total eating and drinking places as the denominator, while the upper bound denominator excludes lunch counters, soft drink, juice and ice cream stands, and drinking places without food.

The Table 1 figures for 1939 in the drug store, restaurant, and department store categories are far less precise but in most respects consistent with the information from the *Chain Store Age* surveys. Drug Stores were clearly more likely to be air conditioned

[14] For each of the cities in listed in the table, the population of the city represented over 95% of the total population served by the utility, as reported in Federal Power Commission (1940).

Figure 3 – Sample Page From Summary Report of 1940 EEI Air Conditioning Survey

REPORT OF AIR CONDITIONING INSTALLATIONS MADE IN TERRITORY SERVED BY:

COMMONWEALTH EDISON COMPANY

APPLICATION	PRIOR To 1938		DURING 1938		DURING 1939		TOTAL AS OF 12/31/39	
	No.	HP*	No.	*HP	No.	*HP	No.	*HP
Residential:								
Apartments								
Private Homes	175	275.00	110	111.00	271	159.00	556	545.00
Commercial:								
Apartments								
Banks	12	1585.00	3	165.00	2	23.00	17	1773.00
Barber & Beauty Shops	22	180.00	8	33.00	5	19.00	35	232.00
Broadcasting Studios	8	430.00	4	51.00	2	20.00	14	501.00
Clubs	9	481.00					9	481.00
Funeral Homes	46	578.00	20	173.00	11	140.00	77	891.00
Hospitals	6	81.00	2	8.00	1	5.00	9	94.00
Hotels	31	4651.00	3	45.00	3	37.00	37	4733.00
Office Buildings	199	13018.00	55	859.00	61	740.00	315	14617.00
Offices, Doctors & Dentists	49	36.00	46	44.00	152	85.00	247	165.00
Offices, Miscellaneous	432	1532.00	226	191.00	446	340.00	1104	2063.00
Public Buildings	7	883.00	4	158.00			11	1041.00
Recreational	5	498.00	3	107.00	5	196.00	13	801.00
Restaurants	305	7001.00	88	1379.00	93	1128.00	486	9508.00
Stores, Department	57	3438.00	23	443.00	21	415.00	101	4296.00
Stores, Drug	53	645.00	23	228.00	39	375.00	115	1248.00
Stores, Retail Misc.	174	3640.00	39	297.00	44	432.00	257	4369.00
Theatres	176	22345.00	11	671.00	10	733.00	197	23749.00
Other Commercial								
Industrial:								
Candy Manufacturing	47	4417.00	2	23.00	8	265.00	57	4705.00
Drug & Chemical Mfg.								
Printing & Lithographing	31	2727.00	2	46.00	1	98.00	34	2871.00
Textile Manufacturing								
Tobacco Manufacturing								
Metal Working								
Food Processing	21	360.00	1	15.00	2	28.00	24	403.00
Fur Storage								
Other Industrial	42	2127.00	4	111.00	10	79.00	56	2317.00
TOTAL INSTALLATIONS	1907	70928.00	677	5158.00	1187	5317.00	3771	81403.00
Installations included above that use power other than central station electric.	62	2460.00	8	71.00	8	120.00	78	2651.00
Self Contained conditioners included above:								
1½ HP or less (Room Coolers)	503	543.00	363	269.00	854	551.00	1720	1363.00
2 HP or larger (Store Units)								

Total Population served	3,376,438
Total Meters served	976,855
Headquarters City	Chicago, Illinois

*HP includes all auxiliaries.

than restaurants in three of the five cities reporting information for both, and the ranges overlap for the fourth. In most cases, however, ranges for department store/variety store air conditioning rates overlap or exceed those for restaurants, contrary to what was reported for the chain stores. Barber and beauty shops generally have the lowest rates of air conditioning among the five types of business. The place of hotels in the hierarchy differs widely across cities.

The lower (Post-War) panel of Table 1 is based on articles published in *Heating, Piping and Air Conditioning* between 1948 and 1951 that provided information on installations for a variety of business types in Baltimore, St. Louis, and Chicago. Information from the 1948 Census of Business was used to convert number of installations into percentage of establishments air conditioned. Air conditioning prevalence increased considerably in all three cities in all types of businesses reported in the table. The figures reported for hotels must be considered upper bounds on the true percentage of establishments air conditioned, because by this time, room air conditioning units were coming into wide use, so that one hotel might account for many reported hotel installations. However, it is possible to calculate the growth rate in air conditioning horsepower per hotel employee between the two survey periods, which was about 6% in Chicago and St. Louis, and about 150% in Baltimore.

IV. Accounting for the Identity of the Early Adopters

I assume that after the motion picture theaters, the order in which different retail sectors adopted air conditioning corresponds more or less to the ranking of sectors in air conditioning prevalence as of 1940 (or after the war, for that matter), that is, drug stores air conditioned first, followed by restaurants and department stores/variety stores, followed by grocery stores and barber and beauty shops, and all of these ahead of hardware stores, auto parts stores, and most other types of retail stores and service providers not separately counted in the EEI or *Chain Store Age* surveys. I believe that the potential for air conditioning to increase consumer demand for the “good” being provided by retailers in these sectors (the size of the “dv” term in eq. 6) which is in turn related to the nature of the good being sold, is a key factor in explaining their status as early adopters of air conditioning.

First, the consumption of many types of goods requires the consumer to spend time in the retail establishment, time which could be unpleasant during summer months. The more time typically spent on site consuming what the retailer offers, the more air conditioning improves the value of that offering. Second, if the good is a necessity the unpleasant time spent in the hot retail establishment cannot be avoided by the consumer, but if it is not, purchase can be postponed, or a substitute can be purchased. This is a bigger problem for the retailer if from his point of view the product he is selling is perishable, like a seat at a showing of a movie. Good objective evidence that summer heat lowered consumer demand for a product (and thus for the potential to increase demand with air conditioning) would be a seasonal decline in sales during the summer months. Finally, the model indicates that any given increase in demand brought about by air conditioning will have a larger impact on medium term profits in businesses with higher fixed costs.

These considerations do a good job of explaining the role of movie theaters as the first major adopters of air conditioning.[15] Watching a movie required spending a long period of time in a crowded room, and the quality of this consumption experience clearly deteriorated rapidly as the outdoor temperature rose. Visiting a movie theater was also an experience that, from a consumer's point of view, could be easily shifted in time, and for which there were ready substitutes in the summer, including a visit to an amusement park or an "air dome", a temporary tent-theater in which some entrepreneurs would show movies. This led to large seasonal swings in demand for theater tickets during the teens and twenties. In some parts of the country movie theaters simply closed during the summer, and in others demand fell dramatically (Cooper 1998, 85-87). Also, as indicated by a passage quoted earlier, the seasonal nature of demand for this highly perishable product was particularly problematic for urban exhibitors, for whom other considerations favored the building of large theaters, making fixed costs high. According to Ackerman (2002, p. 58), air conditioning completely eliminated the summer drop in sales, and may have turned summer into the peak season for movie theaters.

For similar reasons, the potential benefit to restaurants of air conditioning was also large. Eating a meal in a restaurant requires time as well as money, a restaurant meal can be easily postponed by the consumer who can eat at home (or have an outdoor picnic in the summer), and restaurant seats, like theater seats, are highly perishable goods from

[15] It is historically inaccurate to assume that movie theaters were monopolistic competitors. By the mid 1920s, movie exhibition was part of a cartelized and vertically integrated movie industry (Conant 1960, pp. 48-57, 69-70). Theater operators were assigned to tiers with respect to the quality of movie they could show, and the admission price was dictated by the cartel. However, in this environment, it is still in the interest of the firm owner to adopt innovations that increase demand. Further, in a model in which a monopolist cannot vary price in the face of seasonally fluctuating demand, an innovation that raises demand in the slow season (e.g., air conditioning) will increase revenue more when the market is thicker, so that the prediction that firms are more likely to adopt in urban areas applies here as well as in markets described by the model of section II. Model details are available upon request.

the seller's point of view. Drug store/soda fountains may have benefited even more than restaurants from air conditioning, in part because of a difference between drug stores and restaurants in the nature of the food service. One enters a restaurant with the intention of purchasing a meal. When one enters a drug store there is no required fixed expenditure on food items, but if the interior is pleasant the customer may linger:

"In air conditioned drug stores, the fountain trade seems to benefit first and to the greatest extent. Checks mount steadily; where a soft drink was ordered before, a sandwich luncheon with a malted milk replaces it. The peak luncheon load, formerly from 11:30 to 1:30, extends, after the store is air conditioned, from 11 to 3." (Johnson 1937)

Johnson noted that the drug store/soda fountain actually combined the functions of a restaurant and a retail store, so derived a second sort of benefit from air conditioning:

"Customers drop in the store to purchase something, find the cool interior such a relief that they linger to shop around . . .(They) are in a better humor, more receptive and in no hurry to leave the store. They listen to many a sales solicitation they would have walked out on before." (Johnson 1937)

Johnson's observation here also provides some insight into the reasons that department and variety store owners were early adopters of air conditioning. Both types of store stocked many goods which were not necessities, and it was well understood by these retailers that the more time the shopper spent in the store, the more the shopper would buy. The *Chain Store Age* articles of the thirties commented on the fact that it was the larger stores in the department/variety category, that is, the big department stores, that air conditioned first, and the business model of the department stores of the early 20th century depended on keeping the consumer in the store for long periods of time. As noted earlier, department store shopping at this time was seen as a form of entertainment. The department stores created and catered to this perception by maintaining attractive displays emphasizing both the quantity and quality of the goods available (Ackermann

2002, pp. 51-52). This was costly, and air conditioning was a way to keep the consumer in the store longer, insuring a larger payoff on the investment in display. Smaller retailers of clothing and shoes also stood to benefit from air conditioning, as the customer had to spend time in the store trying on potential purchases.[16]

The demand situation facing department, variety, and clothing store owners contrasts with that faced by owners of grocery, hardware, and auto parts stores, who were late adopters of air conditioning. The grocery store sold necessities, and a visit to the grocery store could not be long postponed. The stereotypical grocery shopper arrived with a list and worked to complete it quickly. Visits to hardware and auto parts stores were also usually motivated by a particular need, and browsing and impulse buying were probably not important phenomena. Thus, opportunities for increasing sales through air conditioning were relatively small for these retailers.

It is not surprising that the hotel sector was a leading adopter of air conditioning in most of the cities listed in Table 1. Time in the hotel is an absolutely necessary part of the consumption of the hotel's services, the consumer can often postpone the purchase of the services to another season, and the service is perishable from the point of view of the seller. The relatively low rates of air conditioning in the Chicago and Cambridge hotels can be explained by the fact that the time the customer spent consuming hotel services was largely night time, and on most summer nights in the northern US, a hot hotel room could be cooled by opening the window. There are no dates on which the average minimum temperature in either Cambridge or Chicago is 70 degrees or above, while there are 91 such dates in Dallas, 42 in St. Louis, 35 in Washington DC, 32 in Brooklyn,

[16] There was also a cost side benefit of air conditioning for department stores and apparel stores: when a sweaty customer tried on an article of clothing but did not purchase it, it was sometimes necessary to mark it down (e.g. Ackermann (2002), p. 54).

and 63 in Baltimore. Baltimore's rate of air conditioning in 1939 was low given its average number of hot nights, which may be the reason for its very high growth in horsepower per hotel employee over the next decade.[17]

Barber shops and beauty parlors did not adopt air conditioning in great numbers, even by the 1950s, although demand side circumstances would have seemed to have favored it: consumption of the service required time, heat could make the experience less pleasant, and purchase could be postponed by the buyer but not stored by the seller. The barrier to adoption may have been the small size of the typical establishment, which, as noted earlier, makes it less likely that the revenue increase from air conditioning can cover the fixed cost of installation. According to the 1940 Census of Business, the average barber shop or beauty parlor in 1939 had about two employees, compared to 5 for the drug store/soda fountains, 6 for restaurants, 13 for variety stores and over 200 for department stores.

As noted above, an objective measure of the extent to which air conditioning might have stimulated a profitable boost to demand in a particular retail sector is provided by the seasonal patterns of sales in that sector before and during the period that air conditioning was being adopted. If the demand side factors highlighted in the previous paragraphs were indeed important in determining which types of retail establishments adopted air conditioning, then in the retail sectors that were early adopters of air conditioning one would expect to see large sales declines in the summer months during the years prior to the introduction of air conditioning. Evidence that these seasonal

[17] Urban hotels had two reasons for considering air conditioning. In addition to providing overnight lodging, they provided food service and rented large public spaces for banquets, convention meetings, etc. Some articles reporting on hotel air conditioning installations reported separately for installations in guest rooms and in "public spaces." (e.g., HPAC March 1937, p. 151), and installations for cooling guest rooms often reached only some of the hotel's rooms.

declines diminished after air conditioning became widely diffused in the sector would provide further support.

Table 2 presents measures of summer seasonality in a number of the retail lines for which evidence on air conditioning prevalence has been presented. The measure of seasonality due to hot weather is average monthly sales in July and August as a proportion of average monthly sales over the whole year. The top two lines of Table 2 are meant to provide a baseline; they show that neither retail sales broadly defined nor total consumption spending were subject to July and August declines during the period of interest.[18] The evidence on seasonality in department stores best fits the pattern described in the previous paragraph. In the 1919-1928 period, department store sales were typically about 24% below average during July and August. During the years that air conditioning diffused, however, this summer sales decline become less marked, so that it was only about 14% by the 1952-59. Shoe stores also fit the pattern, with an average summer decline of 13% in the pre-air conditioning years, but only 9% in the 1950s when over half of chain shoe stores were air conditioned. I was able to construct only one relatively short monthly sales series for women's apparel, and it shows a sharp July/August sales drop during the 1947-58 period. Further, the annual values for the summer sales drop have a statistically significant trend over this period, with the summer sales drop diminishing by a little over 1% per year. Also, Kuznets (1933) reports monthly seasonal index numbers for sales by New England department and clothing stores over the 1923-1930 period in several narrowly defined categories of women's apparel. In six of 9 categories presented,

[18] Since the total consumption series is quarterly, the seasonal measure used is average third quarter sales as a proportion of average sales. There is a monthly retail sales series covering earlier years compiled by Copeland (NBER macro history series m06001a&b), but it covered less than half of retail sales, and was dominated by department stores, so reflects their seasonal patterns (see Kuznets 1933, p. 438).

the July/August sales decline was greater than the 24% average decline for women's apparel in the 1947-50 period – and this in New England, where summers are mild relative to those in other parts of the country.[19] Again, the evidence suggests that air conditioning ameliorated a serious seasonal problem facing retailers in this line.

Table 2 shows that variety store owners faced a hot weather sales drop, but the decline in the later period is just as large as that during the earlier period. Grocery stores did not experience sales drops in the summer months during the 1919-1951 period, consistent with the characteristics of grocery store demand discussed above, and with the relatively late and incomplete adoption of air conditioning by grocers. However, the data for restaurants, which were enthusiastic adopters of air conditioning, show only small summer sales declines.

The data for drug stores are the most puzzling, as they are inconsistent with both the high rates of early air conditioning and the narrative evidence cited earlier. There is no indication of low summer sales prior to the introduction of air conditioning, and summer sales relative to average sales do not improve in the post-air conditioning period. Perhaps the model's assumption that demand for the industry's product will be larger in the post-air conditioning equilibrium is not correct in this case. As noted above, drug stores were in competition with restaurants and general stores, both of which were also adopting air conditioning during this period. The higher sales due to air conditioning reported by enthusiastic druggists in the 1930s might have been either a recapture of

[19] The categories were cotton dress goods, woolen dress goods, silk and velvet dress goods, linens, womens' dresses, misses' dresses, junior girls' ready to wear, aprons and house dresses, and waists, blouses, and sweaters. It is also worth noting that during this period in New England the July/August drop in shoe sales was well over 20%.

customers lost earlier to these competitors, or short-term gains that dissipated as restaurants, general stores, and other drug stores copied the initial innovators.

Although I was unable to find monthly time series on hotel revenues, information on monthly employment in year-round hotels collected for the 1940 Census of Business shows that the severity of the summer sales drop experienced by hotels, like the prevalence of hotel air conditioning, varied by region. July/August employment was 2% above the annual average in New England in 1939, while summer hotel employment in Illinois was 6% below its annual average, and in the South Atlantic region the drop was 7%. The July/August hotel employment drop for Washington DC, which has the highest rate of hotel air conditioning reported in table 1, was even larger, at 10%.[20]

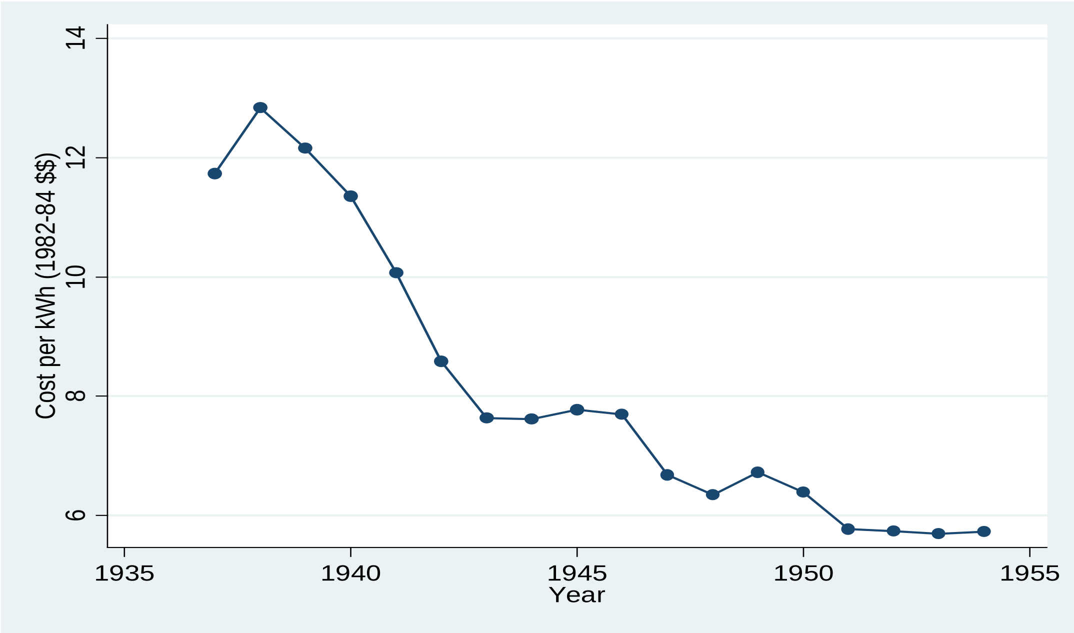
Section II provides a theory-based account of why air conditioning prevalence grew over time within particular markets and lines of business following its introduction: once a few merchants serving a market became the pioneer adopters, due perhaps to idiosyncratic cost situations or higher than average expectations about the impact of air conditioning on revenues, they drew business from competitors and forced them to adopt as well. However, the model suggests no endogenous process to explain the spread of air conditioning to new markets and to new lines of business as time passed. One important exogenous factor to consider is the cost of owning and operating an air conditioning system. If those costs were falling over time, then the probability that pioneering adopters would emerge in any given industry or market would increase.

I have conducted an analysis of trends in the cost of installing commercial air conditioning over the period 1931-68, based on information from articles in *Heating*,

[20] 1940 Census of Business, Vol. III, Table 3B of the Hotels section. Monthly employment is calculated as full time employees plus .5 times part time employees.

Piping, and Air Conditioning. The details of this analysis are described in the appendix, but the conclusions can be stated briefly. There is no evidence that the cost of installing air conditioning was declining over the 1930s. In the immediate postwar years the cost of installation was higher than in 1940, and from that point until the early 1960s there is little evidence of a trend in either direction. Thus, falling installation costs can be ruled out as a cause of the spread of commercial air conditioning.

Figure 4: Cost in Cents per kWh, Commercial and Industrial Service, US



There is good evidence that operating costs were falling, however. Figure 4 plots the average annual price per kWh for commercial and industrial electricity as reported by the Federal Power Commission, and shows electricity prices dropping dramatically from 1938 to 1950.[21] HPAC articles from the period indicate that electricity cost represented at least 40% of the total operating cost of air conditioning, often more, so that one can

[21] Average electricity rate cost is calculated as commercial and industrial revenue divided by kWh of service for privately owned utilities, from tables 9&10, Federal Power Commission (1954)

conservatively estimate that the electricity rate decline over this period led to a 25% fall in operating costs.

IV. Cross Section Differences in Air Conditioning Prevalence

Data and Empirical Specifications

The 1939 and 1940 EEI surveys of utilities provide information on variation across markets and regions in the prevalence of air conditioning at a relatively early point in the history of the technology's diffusion. In the EEI data the unit of analysis is the utility, and, as noted above, the data include the amount of air conditioning horsepower installed in the utility's service area, both overall and in certain types of businesses, as of the end of 1937 and as of the end of 1939 (see Figure 3). Using a process described in more detail in the appendix, I was able to determine the approximate service area in 1939 for most of the utilities in the EEI survey, and used these service area estimates to match data from the 1940 Census to each utility. This allows the estimation of regressions of installed air conditioning horsepower for certain types of businesses in an area on demographic and economic characteristics of that area, regressions which can be used to test hypotheses suggested by the model of section II.

Regressions were estimated separately for movie theaters, hotels, restaurants, retail stores (drug, department, and miscellaneous), and for an aggregate commercial retail category. As argued in section II, within a particular retail line we would expect to see more air conditioning where the cost of air conditioning was lower, where establishment sizes were larger (indicating higher fixed costs) and in more urbanized areas. Also, as air conditioning likely raised demand for the retailer's product or service more in areas with hotter climates, we would expect climate to be an important factor explaining regional variation in the early adoption of air conditioning.[22] Accordingly, the regressions took the form

$$\textbf{ln(Horsepower + 1)}_i = \beta_0 + \beta_1\textbf{ln(Population)}_i + \beta_2\textbf{ln(Income)}_i + \beta_3\textbf{(Establishment Size)}_i + \beta_4\textbf{(Urban Share)}_i + \beta_5\textbf{ln(Electricity Rate)}_i + \beta_6\textbf{(Heating Degree Days)}_i + \beta_7\textbf{(Cooling Degree Days)}_i + \beta_8\textbf{(Heating Degree Days X Cooling Degree Days)}_i + \beta_8\textbf{(Avg. Wind Speed)}_i + \beta_9\textbf{(Relative Humidity)}_i + \beta_{10}\textbf{(Sunshine)}_i + \varepsilon_i \quad (7)$$

Within each of the five categories, regressions were estimated for horsepower levels at the end of 1937 and the end of 1939, both using the same independent variable values. The log of the population of the service area controls for the wide differences in size across utility areas. The income variable is included in case the derived demand for commercial air conditioning reflects an income effect on consumer's consumer demand for a comfortable shopping environment, and is measured by the average value of family wage and salary income for families in which the head reported such income, calculated from the 1940 Census public use microdata (Ruggles et. al., 2004).[23]

In the commercial retail and retail store regressions, establishment size is measured as total retail employment divided by number of retail establishments. Employees per establishment was also the establishment size variable in the restaurant

[22] The hypothesized relationship between climate and adoption of commercial air conditioning corresponds with intuition, but one historian has argued that "neither region nor climate can explain the distribution pattern of early comfort installations." (Ackermann 2002, p. 45)

[23] Wage and salary income was the only income measure collected in the 1940 census. It was not reported at the county level, but was reported for multi county State Economic Areas (SEA) within states. In matching average income to utility areas, each county or city was assigned the average wage and salary income for its SEA. In the 1950 census, a version of the wage and salary income variable used here has a .91 correlation with average total family income at the SEA level.

regressions, while seats per establishment was used in the theater regression, and rooms per establishment in the hotel regression. However, for these three business types it was necessary to impute the establishment size variable, for although the 1940 Census of Business reported number of restaurants at the county and small city level, restaurant employment and information on theaters, theater seats, hotels and hotel rooms were reported only for states and large cities. The imputation procedure used samples of states and large cities to regress restaurant employment, theaters, theater seats, hotels, and hotel rooms on economic and demographic variables. The estimated coefficients from those regressions and the service area values of the independent variables were used to create predicted values for these variables at the utility service area level, which were then used to calculate imputed establishment size.[24]

Urban Share is the market density variable, and is the proportion of the service area's population living in urban areas. Electricity Rate is an average of the 1935 and 1937 commercial electricity rates for the utility, based on data collected by the Federal Power Commission. Heating degree days and cooling degree days are measures of an area's climate. The National Oceanic and Atmospheric Administration defines a degree day as follows: "Degree day is a quantitative index demonstrated to reflect demand for energy to heat or cool houses and businesses. . . .Heating degree days are summations of negative differences between the mean daily temperature and the 65°F base; cooling degree days are summations of positive differences from the same base. For example, cooling degree days for a station with daily mean temperatures during a seven-day period of 67,65,70,74,78,65 and 68, are 2,0,5,9,13,0,and 3, for a total for the week of 32 cooling

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[24] Details on the imputation procedure are in the appendix.

degree days." An interaction between heating degree days and cooling degree days is included, as previous research on the demand for residential air conditioning has shown that the impact on air conditioning demand of summer heat as measured by cooling degree days is greater in climates that also have colder winters (Biddle 2008). Relative humidity is average July afternoon relative humidity. The wind speed is average July wind speed, and the sunshine measure is the percentage of daylight hours during which the sun is visible during July. [25]

Results

Table 3 presents summary statistics for the variables used in the analysis. The number of observations is 123 when 1937 horsepower is the dependent variable and 132 when 1939 horsepower is the dependent variable.[26] The regression results for 1937 horsepower are presented in Table 4, and for 1939 horsepower in Table 5. As one would expect, population is highly significant in every regression. Also, both 1937 and 1939 regressions indicate that climate had a great deal to do with where commercial comfort air conditioning was adopted in the two decades after its introduction. In most of the regressions, the marginal effect of a one standard deviation increase in cooling degree days is in the neighborhood of 2, indicating that a standard deviation increase in summer heat resulted in a squaring of installed horsepower. As hotter summers are associated with milder winters, however, another way to represent the impact of climate on

[25] Details on the sources of the climate measures and electricity rate measures, as well as methods for assigning them to utility service areas, are described in the appendix.
[26] The difference in sample size between the 1937 and 1939 regressions reflects the fact that more utilities responded to the 1940 survey. The reduction from the 183 utilities responding to the 1940 survey to the 132 observations in the 1939 horsepower regressions arises from a number of factors, including: incomplete or improperly filled out responses, my inability to accurately estimate a service area or find an electricity rate, and cases in which I combined adjacent utilities into one observation, as described in the appendix.

commercial air conditioning demand is to note that the 1939 estimates imply that if Chicago had the climate of St. Louis (about 700 fewer heating degree days and 700 more cooling degree days) it would have had over three times the commercial air conditioning horsepower in 1939 than it actually did. However, wind speed, humidity and sunshine did not significantly affect air conditioning adoption.

The estimated income elasticity is positive in all but the restaurant regression, but never statistically significant. In the regressions for general retail, stores, and restaurants, the coefficients on both establishment size and the share of the service area's population in urban areas are positive and generally significant. As the monopolistic competition model predicts, the denser markets of urbanized areas were associated with more widespread adoption of air conditioning, even after controlling for the positive effect of larger establishment sizes (higher fixed costs) on the profitability of adoption. However, establishment size and the urban share variable are not significant in the hotel regressions, and establishment size has a negative coefficient in the movie theater regressions.

The elasticity of firms' demand for air conditioning with respect to the electricity rate is always negative, usually well above unity in absolute value, and significant except for stores in 1937 and restaurants in both years. The estimates imply that firm owners' decisions to adopt air conditioning were very sensitive to cost considerations, especially in light of the fact that electricity rates made up only about half of total air conditioning operating costs. The average of the two point estimates of the elasticity for commercial air conditioning in general is about -1.5, so that a 20% decrease in electricity rates (the standard deviation of electricity rates is about 20% of the mean) would lead to about a 30% increase in installed air conditioning horsepower.

In light of the large electricity rate elasticities in Tables 4 and 5, the substantial decline in electricity rates between 1939 and 1954 shown in Figure 3 was likely an important factor driving the growth of commercial air conditioning over the same period. As noted earlier, the percentage of all chain store outlets air conditioned rose from 8.2% to 35%. If we assume an electricity rate elasticity of -1.5, the fall in electricity rates over that period may explain as much as 10 percentage points of that increase.[27]

Alternative Regression Specifications

Although the dependent variable in eq. (7) is in log form, observations with zero horsepower reported for the relevant business type are kept in the regression with the dependent variable set to zero. Two alternative approaches to dealing with zero horsepower observations were also tried. One was to use tobit models. The other was to estimate a two equation model for each business type-year combination, in which the first equation was a linear probability model for presence or absence of air conditioning in a service area, and the second was estimated using only observations with positive values for the horsepower variable. For five of the models, fewer than 10% of the observations had no installations reported, and the alternative specifications yield nothing new. There are 20 zero observations in the 1937 stores model, but the tobit looks very

[27] Rates fell from about 12 to 8 cents between 1939 and 1946, or a 40% decline using the midpoint as a base. Multiplying that by 1.5 and by 8.2 predicts a prevalence of 13.1% by 1946. From 1946 to 1954 rates fell from 8 to 6, or 28%. Multiplying that by 1.5 then by 12.8 predicts a prevalence of 18.6%. Alternative approaches to this calculation are possible, e.g., using different bases for calculating the percentage changes. The most conservative has the electricity rate decline explaining 20% of the increase in air conditioning prevalence.

much like the corresponding regression reported in Table 4. Fifty-three observations had no installations in the 1937 hotel regression and 45 in the 1939 hotels sample; again, the tobit results look like the results from estimating eq. (7) on the full sample. In the linear probability model, population, climate, and electricity rate explain the presence or absence of air conditioning for a service area, and the electricity rate elasticity is smaller in absolute value when only observations with positive horsepower are included. The same pattern occurs for the movie theater models, in which 21 observations were zeros in 1937 and 15 for 1939. This suggests that climate and electricity rates affected both the timing of initial adoption of commercial air conditioning and the rate at which it spread following initial adoption.

I also experimented with alternatives to controlling for the large differences in size across utility areas. Using log of retail sales or log of the number of utility customers in place of log of population produces results very much like those reported in Tables 4 and 5. Expressing the dependent variables as a ratio of horsepower to dollars of sales in the stores, restaurants, and general retail equations changes little. The income variable sometimes becomes marginally significant; while the urban share coefficient is less likely to be significant when horsepower per establishment is used as the dependent variable.

VII. Conclusions

For the first four decades after the establishment of an air conditioning industry in the United States, the story of the diffusion of air conditioning was largely the story of its gradual adoption by commercial firms in the retail and service sectors. It was an uneven diffusion, both geographically and with respect to business type, but this paper has argued that some of the more prominent features of this diffusion process can be understood as a result of the proposition that businessmen adopted air conditioning when the monetary benefits of adoption outweighed the costs. In a hot climate air conditioning could provide a greater boost to demand, and data from 1939 show a strong correlation between the amount of air conditioning installed by firms in an area and the severity of that area's summer heat. Another index of the extent to which air conditioning could boost demand for a retailer is the size of the summer drop in demand for his product in the years before air conditioning became widespread. Department stores, shoe stores, women's clothing stores, and movie theaters all suffered from summer demand drops in the early decades of the 20th century, drops that can be easily understood in light of the nature of their products; and all were early adopters of air conditioning. Moreover, evidence has been presented that these declines in demand diminished as air conditioning became more prevalent. Grocery stores, as economic reasoning would predict, did not experience seasonal drops in demand, nor were they early adopters of air conditioning.

On the cost side, air conditioning adoption was quite sensitive to the electricity rate, which was an important determinant of operating cost. Cross section differences in electricity rates are related to cross section differences in air conditioning prevalence, and a large decline in electricity rates from the mid thirties on helps to explain the growth in air conditioning within and across lines of business. Finally, the tendency for air conditioning to be more prevalent in large urban areas can be explained in the context of the paper's model of monopolistic competition.

Some of the features of commercial air conditioning's history either do not fit or are left unexplained by this basic story. For example, drug stores/soda fountains were among the earliest and most eager adopters of air conditioning, but there is no evidence that they were plagued by a summer sales drop, nor that relative summer sales grew for this sector as it became more air conditioned. Perhaps it is more accurate to think of these firms as having been caught in a prisoner's dilemma: adoption would not boost profits, but failure to adopt would sacrifice demand to stores, restaurants, and competitors that had adopted. Also, although falling electricity rates and a high elasticity of demand with respect to operating cost can explain some of the increase in the prevalence of commercial air conditioning during the middle decades of the 20th century, much remains unexplained. In particular, there is no reason to think that installation costs were falling. Real incomes were rising, but this paper offers only weak evidence for a derived income effect on retail firms' demand for air conditioning. The percentage of people living in urban areas did increase by almost 15 points between 1940 and 1960, and given the large estimated impact of urbanicity in the cross section regressions, this may have been another factor contributing to the growing prevalence of commercial air conditioning

Understanding the when and where of commercial air conditioning is a first step towards understanding the ultimate economic consequences of air conditioning technology for American economic development. Given that most air conditioning in the US up to 1960 was commercial comfort air conditioning, it would seem that the first order impact of the technology during this period was to make certain consumption activities more pleasant than they had been before, increasing consumer surplus rather than raising physical output per worker in any obviously measureable way.

Appendix

Deriving the equilibrium conditions of the model

To derive eq. (4), note from figure 1b that in long run equilibrium, firm i captures a share of the preference space represented by a rectangle and a right triangle. The rectangle's sides have lengths (1/2n) and 1 – (c/2n) – p. The triangle has legs of length (c/2n) and (1/2n). Adding the areas of the rectangle and triangle, multiplying by 2 (to capture consumers to the left of b=0) and multiplying by L gives equation (4). Eq. 5 is the slope of the Chamberlinian dd curve, or dp_i/dq_i when the prices of all other firms are unchanged. Referring again to fig. 1b, note that if firm i located at b=0 lowers its price (a downward shift in the positively sloped diagonal), it draws into the market consumers in an area of size dp/2n. The consumers attracted from the neighboring firm are in an area of height (1 – (c/2n) – p) and width dp/2c. Adding these two areas together, multiplying by 2L, and dividing by dp gives dq/dp (technically, an approximation that ignores second order terms), and the negative reciprocal of this is eq. (5).

Comparative Static Results

As the text notes, the impact on medium run revenue of an increase in v such as would be brought about by air conditioning depends on L and F. When all firms adopt the innovation that raises the value of the product by dv, there is a shift downward of the diagonals of size dv, offset by a shift upward as firms have adjusted price to their new demand situation. Thus, the net effect is given by dq = (L/n)(1 – dp/dv)dv. This allows eq. (6), which characterizes the medium run revenue increase due an increase in v, to be written as

$$dR/dv = (p_0 - m)(L/n_0)[1 - (dq/dv)] + q_0(dp/dv) \qquad \text{(A1)}$$

To determine the effect of number of consumers in the market L on the marginal benefit of raising v through air conditioning, first derive dp/dv, by totally differentiating eq. (3):

$$dp = (\partial q/\partial v)(-s_{dd})dv + (\partial q/\partial p)(-s_{dd})dp + q(\partial(-s_{dd})/\partial p)dp$$

Using the fact that $(\partial q/\partial v) = (\partial q/\partial p) = (L/n)$ along with eqs. (4) and (5) one can then solve for

$$dp/dv = [2c(2n(1 - p) + c)]/[(2n(1 - p) + c)^2 + 3c^2] \qquad \text{(A2)}$$

Since a competitive equilibrium requires that $c<2n(1 - p)$, $dp/dv<1$, so that $dq/dv > 0$.

Let θ represent dp/dv. Then differentiate (A1) to get

$$dR/dvdL = (L/n_0)(1 - \theta)(dp_0/dL) + (p_0 - m)(1/n_0)(1 - \theta) -$$

$$(p_0 - m)(L/n^2_0)(1 - \theta)(dn_0/dL) - (p_0 - m)(L/n_0)(d\theta/dL) + q_0(d\theta/dL)$$

$-\theta(q_0/(p_0 - m))\,(dp_0/dL)$ (A3)

in which the last term comes from the fact that $(dq_0/dL) = -(q_0/(p_0 - m))\,(dp_0/dL)$, which can be derived from eq. (2). Rewrite (A3) as

$dR/dvdL = [(p_0 - m)(1/n_0)(1 - \theta)](1 - \varepsilon_{nL})$

$+ [(L/n_0)(1 - \theta) - \theta(q_0/(p_0 - m)](dp_0/dL)$

$+ [q_0 - (p_0 - m)(L/n_0)](d\theta/dL)$ (A4)

in which $\varepsilon_{nL} = (L/n_0)(dn_0/dL)$, the elasticity of number of firms with respect to the number of potential customers.

To derive (dp_0/dL) and other expressions comparing values of n and p across different equilibriums, plug eq. (4) and eq. (5) into eq. (3). This leads to a quadratic in p, the relevant root of which is:

$p = (4n^2(m+1) + 6c - 4n(n^2(m-1)^2 + nc(m-1) + 3.25c^2)^{.5})/8n^2$ (A5)

A second quadratic in p is obtained when eq. (4) is substituted into eq. (2), the relevant root of which is

$p = (4n(m+1) - c - (c^2 + 8nc(m-1) + 16\,n^2(m-1)^2 - 64n^3\,(F/L))^{.5})/8n$ (A6)

In simulations for a wide range of admissible values of m, c, and F/L, (A5) is decreasing in n and (A6) is increasing in n, with their intersection indicating the equilibrium values of n and p. An increase in L shifts eq. (A6) down in p-n space, but leaves (A5) unaffected, so that $dn/dL > 0$, and $dp/dL < 0$. Since $dp/dL < 0$, it follows that $dq/dL > 0$, so that $\varepsilon_{nL} < 1$. This and the result that $0 < \theta < 1$ make the first term of (A4) positive.

Using (A2) and the substitution $\sigma = (2n(1 - p) + c)$, one can derive

$d\theta/dL = [2c(d\sigma/dL)(3c^2 - \sigma^2)]/[(2n(1 - p) + c)^2 + 3c^2]^2$

The denominator is obviously positive, is as $2c(d\sigma/dL)$ since $dn/dL > 0$ and $dp/dL < 0$. $(3c^2 - \sigma^2) = (2c^2 - 4n^2(1-p)^2 - 4n(1-p)c)$. Since $c<2n(1 - p)$, $c^2 < 4n^2(1-p)^2$ and $c^2 < 4n(1-p)$. Thus, $d\theta/dL <0$.

In the first line of (A4), the coefficient of the negative term dp/dL is $[(L/n_0)(1 - \theta) - \theta(q_0/(p_0 - m)] = (L/n_0)(1 - (1 + \sigma/2c)\theta)$, where $(q_0/(p_0 - m))$ has been substituted out using eqs. (3) and (5). Again using the fact that $c<2n(1 - p)$ in a competitive equilibrium, one can show that $(1 + \sigma/2c)\theta > 1$, so that the first term in (A4) is positive.

The coefficient of $(d\theta/dL)$ in (A4) is $[q_0 – (p_0 – m)(L/n_0)] = q[1 – (2c/(2n(1-p) + c)] = q[(2n(1-p) - c)/(2n(1-p) + c))$ where the second term in the equality requires using eqs. (3) and (5), and the third is positive because $2n(1-p) > c$. So, the third term in (A4) is negative, making the expression ambiguous.

So, as the number of consumers in the market rises, the marginal gain to medium term revenues from raising v with air conditioning may be growing or shrinking.

The impact of fixed costs F on medium run profits, obtained by differentiating (A1), is

$$dR/dvdF = (L/n_0)(1 – \theta)(dp_0/dF) – (p_0 – m)(L/n_0)(d\theta/dF) –$$

$$(p_0 – m)(L/n^2{}_0)(1 – \theta)(dn_0/dF) + q_0(d\theta/dF) + (\theta/(p_0 – m))$$

$$– \theta(q_0/(p_0 – m))\ (dp_0/dF) \qquad \text{(A7)}$$

where the last two terms reflect the fact that $dq_0/dF = (1/(p_0 – m))(1 – q_0(dp_0/dF))$, from eq. 2. (A7) can be rearranged as

$$d\pi/dvdF = [\theta/(p_0 – m)] – [(p_0 – m)(L/n^2{}_0)(1 – \theta)](dn_0/dF)$$

$$+ [q_0 – (p_0 – m)(L/n_0)](d\theta/dF)$$

$$+ [(L/n_0)(1 – \theta) – \theta(q_0/(p_0 – m)](dp_0/dF) \qquad \text{(A8)}$$

Returning to (A5) and (A6), which identify the equilibrium values of p and n, note that an increase in F leaves (A5) unaffected while shifting (A6) up, so that $dn_0/dF < 0$ and $dp_0/dF> 0$. This allow one to conclude that $(d\sigma /dF) < 0$, so that $d\theta/dF > 0$. It has already been shon that the coefficient of $d\theta/dF$ in (A8) is positive. Thus, the first three terms in (A8) exert a positive influence on $d\pi/dvdF$. The coefficient of (dp_0/dF) has been shown to be negative. However, the zero profit condition insures that $q_0(dp_0/dF)$ will be very close to 1 in value, so that $–\theta(q_0/(p_0 – m)](dp_0/dF)$ is essentially cancelled by the first term in (A8), leaving the entire expression positive.

Air Conditioning Prevalence in Chain Stores

Chain Store Age first reports figures on percentage of all outlets currently air conditioned for all 300 chains responding to their 1939 store modernization survey, and for a panel subsample of 95 chains (operating over 16000 stores) that responded both in 1938 and 1939 (Nov. 1939, p. 101). Likewise, the Nov. 1940 issue (pp. 98-99) reports for all chains responding in 1940 (495 chains, over 30000 stores) and a panel of 149 chains responding in both 1939 and 1940; and the Nov. 1941 issue follows the same pattern (pp. 96-97). In all categories except shoes and apparel, figures from the full sample are very close to those from the panel subsamples in 1939, 1940 and 1941, so figures from the 1938-39 panel are used for 1938, and for 1939-41 figures from the annual full samples are used. In the shoe category, the percentage air conditioned for the 1938-39 panel is very high relative to the 1939 and 1940 full samples, making the 1938 figure from the 1938-39 panel suspect. So, the 1938 figure is imputed by applying the growth rate from the 1938-39 panel to the 1939 full sample estimate. Figures for the remaining years are from the full samples. In the apparel category, the 1941 full sample percentage shows an increase over the previous years' full sample percentages that is far above what the growth rate from the 1940-1941 panel would indicate. So, the 1941 figure for apparel is imputed by applying the 1940-41 panel growth rate to the 1940 full sample percentage. Full sample percentages are used for the earlier years. All figures from 1949 to 1954 are based on results of annual cross section surveys reported in the February issues of 1954 and 1955.

Analysis of Data on the Installation Cost of Commercial Air Conditioning, 1931-1955

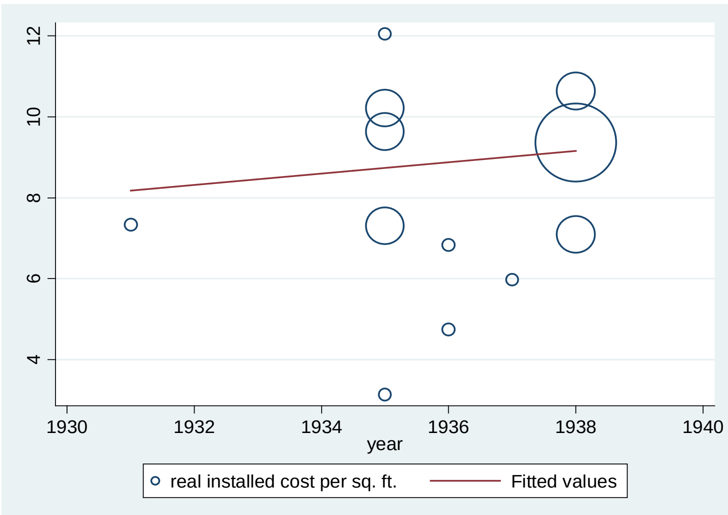
Data on installation cost of commercial air conditioning are taken from articles published in *Heating, Piping, and Air Conditioning*. Cost numbers come from articles describing a particular installation or from articles concerned specifically with the cost of air conditioning which report either the author's (typically an HVAC engineer) assessment of typical costs for a certain class of installations, or the results of a survey of either engineers or owners of large commercial systems.

I used articles in which installation cost was reported as either cost per ton of cooling power or cost per square foot of space cooled, and which included in the installation cost not only the cost of the air conditioning equipment, but also the cost of any ductwork, controls, remodeling, etc. needed specifically for the air conditioning system, and the labor of installation. If an article reported a range for a type of cost, I used the midpoint of the reported range. If results of a survey were reported, I used means of the relevant cost variables. For analysis involving weights, I assigned a weight of one to cost figures from an article describing a particular installation, a weight of ten to figures from an article giving an expert assessment of typical costs, and a weight equal to the sample size when the cost figure was the mean value from a survey. Articles also described the type of building into which the system was installed (e.g., church, office building, or hotel) and for some analyses I made use of this information as well.

It makes sense to divide the data into three periods: Pre WWII, War Years, and Post-WWII. The 30s were growth years for air conditioning, with manufacturers and HVAC engineering firms looking for new markets in an economy slowly recovering from the depression. During the war, materials used in the manufacture of air conditioning systems (especially coolants like freon) were vital war materials, so that commercial production of air conditioning practically stopped, and articles dealing with costs or profitability of installing commercial air conditioning disappeared from the trade journals. The war raised nominal prices and wages considerably, and in the post-war period demand for commercial air conditioning boomed.

Overall, I do not find evidence for an important trend in the initial cost of AC, whether in the pre-War or post war periods. However, at any point in time there is a great deal of variability in costs across individual installations due to differences in building architecture and utilization, local labor costs, and so on, and the lack of evidence for a trends may simply reflect this high variability.

The scatter plot below shows the pre-war cost estimates for installed cost of air conditioning per square foot of cooled space. The size of the circles represents the weight assigned to each estimate, and the line is the weighted least squares fit. The slight trend is not statistically significant, and changes little when no weights are used or when the sample is limited to office buildings.



In 1947 John Hertzler, President of York Corporation, gave an address on the cost and price situation in the industry. Using 1941 as a base year, he noted that rising labor and materials costs had raised the total cost of air conditioning equipment by 35%, while the total installing air conditioning into buildings had risen by 60-65%, largely due to the higher wages and lower productivity of the labor hired by mechanical contractors. Both the GDP deflator and the CPI indicate a general rise in the price level of about 50% over the same period, suggesting an increase in the real cost of installing AC. I have four reliable estimates of the per ton cost of AC in 1938 (two expert assessments, two averages from surveys) which lead to a fairly precise mean estimate of $400 per ton. Three of these also had per square foot estimates, which average to $1.27. I have no cost estimates for the immediate post war years, but averaging one per ton estimate for 1947 with two from 1951 gives an average of $398 per ton, or a 50% increase in nominal cost over the 1938 value, although it should be noted that the two 1951 observations come from Texas, where costs tended to be lower. I have two comparable observations on cost per square foot from 1952 which average $2.99. This would suggest an increase of 135% from 1938 to 1952, a period during which the CPI rose 88%. My data then, along with Hertzler's assessment, suggest a real increase in the cost of installing AC, perhaps a large one, between the late 1930s and 1950. There is certainly no evidence that it declined.

In the post-war period there is again little evidence of major movements in the real price of installing air conditioning. My cost per ton data from these years include a subset of observations from installations in Texas churches, which I dealt with with separately because of their distinctiveness and homogeneity. Both the church data and the general data show slight downward trends, with the trend line for the general data indicating about a 20% decline in real cost over the 20 year period covered, but this is not statistically significant, while the data for cost per square foot have an (insignificant) upward trend of about the same magnitude.

The article on Hertzler's address, mentioned above, represents a rare mention in the articles that I examined of the problem of rising costs. More notable is the scarcity of references to falling costs. *Heating, Piping, and Air Conditioning* was both a technical trade journal and a journal of advocacy for the professional group it served, and during the period I examined included a number of articles concerned with ways to convince potential customers that air conditioning "paid", increasing revenues more than costs. If cost of installation fell significantly over some period, it seems likely that HPAC would have informed its readers of that fact, so that they could in turn inform their clients. Yet I did not see such claims made in these articles, which I take as evidence that there were no dramatic price trends in the cost of installing air conditioning.

Constructing estimated service areas for utilities in the EEI Survey

The basic source used for estimating service areas for utilities is Federal Power Commission (1940), which was intended as a "complete and authoritative list of electric utilities operating in the United States" (p. iii). For each listed utility, the directory reports the number of electrical customers and a list of "communities served", which includes any named community in the service area with a population over 250. When a utility served a single community (e.g., Superior (WI) Water Light and Power Co.), that community would be designated as the service area, and census information reported for that community would be assigned to it. When a utility served several communities, as many of those communities as possible would be located on a map. All counties for which the population of communities served by the utility was greater than the population of communities not served by the utility would be designated as part of the utility's service area, and census data would be assigned to the utility based on the result. In some cases, this approximated service area based on county units could be improved by adding a substantially sized city served by the utility but in a county not dominated by the utility, or subtracting a city not served by the utility in a county it otherwise dominated. A small number of utilities in the EEI data set were not assigned service areas because the county-based method described above did not, in my judgment, produce a sufficiently good approximation to the true service area of the utility. In ten cases, a "utility" in the data set represents a combination of two, three, or four utilities because the approximated area served by the utilities in combination could be estimated much more accurately than the service area for any of the individual utilities. In these cases, the rate variables used were averages of the rates reported for the constituent utilities, weighted by number of customers served by each utility. In 17 cases, the figures reported to the EEI referred only to a particular city or district within the utility's service area, and in such cases the census data matched to the utility pertained to this subset of the overall service area. In most cases this was clearly noted on the form in the EEI report; in two it could be inferred from the population and customer number reported to the EEI by the utility.

Imputing Restaurant, Theater and Hotel Establishment Sizes for Utility Service Areas

The imputation sample for restaurant employment included 47 states and 17 cities. The log of restaurant employment was regressed on the log of ((restaurant sales/total retail sales) X (retail employment)) and the percent of the population in urban areas. The r-square of the regression was .99. The imputation sample for theater seats and number of theaters included 49 states. Log of the number of theaters and the log of the number of theater seats were regressed on log of population, the percent of the population in urban areas, and the logs of per capita retail sales and the ratio of payroll to employees in the service sector. R-squares for these regressions were .94 and .98. The imputation sample for hotels and hotel rooms included 49 states and 31 cities. Log of hotels and log of rooms were regressed on log of population, the percent of the population in urban areas, percent of population white, and the logs of per capita retail sales, per capita service sector sales, and the ratio of payroll to employees in the service sector. The r-squares of these regressions were about .9. When a utility service area corresponded to a major city, imputed values for the hotel variables were replaced with actual values.

Electricity rates

Electricity rates for 1935 are taken from Federal Power Commission (1936). This publication lists utilities by name, and for each utility reports electricity rates for several billing demand/monthly consumption levels (where billing demand corresponds to the total connected load) and several "Schedule Designations", so that a utility may have offered several different rates for the same billing demand/consumption level combination. Commercial rates are those indicated for a billing demand of 3 kilowatts and a monthly consumption level of 375 kWh in Table 1, which reports "Net monthly bills for commercial light and incidental power service". If more than one rate was reported for a utility at this level of service, the median rate was recorded.

Electricity rates for 1937 come from Federal Power Commission (1937), which lists rates by community. The commercial rate, taken from the "Commercial Light Service" section of table 3, is the rate listed in the 3 kW, 375 kWh column for the largest community in the utility's service area. If two rates are listed, the simple average of the two is used

Climate Variables

If the utility chiefly served the residents of single city, annual average heating and cooling degree day values for the weather station closest to that city were assigned to the utility using values reported in *Annual Degree Days to Selected Bases - CLIM81 Supplement Number 2* (accessed at http://hurricane.ncdc.noaa.gov/climatenormals/clim81_supp/CLIM81_Sup_02.dat). If the vast majority of the utility's customers lived in a small number of cities, population weighted averages for the appropriate annual average heating and cooling degree day values were assigned. For utilities serving large areas within a state or several states, heating and cooling degree days were assigned by calculating weighted averages of values for substate areas known as "climate divisions" as reported in *Divisional Normals and Standard Deviations of Temperature, Precipitation, and Heating and Cooling Degree Days 1971-2000* accessed at http://cdo.ncdc.noaa.gov/climatenormals/clim85/CLIM85_HDD03.pdf

The relative humidity, wind speed, and sunshine measures are reported for fewer weather stations than degree days, so that more approximation was required in assigning them to the utilities. Basically, a utility would be assigned a value for a city that was in or near its service area and had data on these variables reported in *Comparative Climatic Data for the United States through 2006* (accessed at http://www1.ncdc.noaa.gov/pub/data/ccd-data/CCD-2006_fixed.pdf)

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Table 1: Percentage of Various Types of Establishments with Air Conditioning, Selected Cities, 1939 and circa 1950

	Barber & Beauty Shops[a]	Hotels[b]	Department Stores[c]	Drug Stores[d]	Restaurants[e]
1939					
Baltimore (Consolidated Gas, Electric, Light, & Power)	1.2	4.0	11.2 – 18.4	10.2 – 13.7	3.6 – 6.4
Brooklyn (Brooklyn Edison)	.1	12.8	0.4 – 0.6	--	1.5 – 2.2
Cambridge MA (Cambridge Electric Light)	.5	0.0	9.1 – 15.8	0.0	6.5 – 8.9
Chicago (Commonwealth Edison)	.5	6.7	9.4 – 15.8	6.0 – 7.4	4.4 – 13.1
Dallas (Dallas Power & Light)	1.8	19.4	4.7 – 9.2	12.7 – 15.5	5.7 – 8.9
St. Louis (Union Electric Co. of Missouri)	3.0	38.1	--	--	4.2 – 8.8
Washington DC	1.2	59.3	17.7 – 31.2	19.5 – 22.8	14.3 – 16.5
Post-War					
Baltimore (1948) (Consolidated Gas, Electric, Light, & Power)	3.1	15.3	32.9 – 69.7	23.6 – 27.6	15.4 – 24.9
Chicago (1951) (Commonwealth Edison)	1.2	17.5	--	18.1 – 23.8	13.1 – 37.4
St. Louis (1949) (Union Electric Co. of Missouri)	6.3	88.0	--	--	28.2 – 57.1

General Note: Cell entries are percentages, based on number of installations divided by number of establishments. In the upper panel, information on the number of installations is taken from Edison Electric Institute (1940), and information on number of establishments in 1939 from the 1940 Census of Business. In the lower panel, information on number of installations in Baltimore is from Priester (1949); in St. Louis from HPAC, Jan. 1952, p. 146; and in Chicago from HPAC, March 1950, p. 99. Information on number of establishments in 1948 is from the 1948 Census of Business.

[a] The denominator is the sum of barber shops, beauty parlors, and barber and beauty shops for the city, reported for 1939 in vol. III, table 3 of the Services section, and for the post war years in vol. VII, table 105.

[b] The denominator is number of hotels, reported for 1939 in vol. III, tables 2 and 5B of the Hotels section, and for the post war years in vol. VII, table 103c.

[c] The denominator for the lower bound is the number of establishments in the General Merchandising Group and the denominator for the upper bound is that number minus the number of variety stores. The information for 1939 is taken from vol. 1, pt. 3, table 2, and for 1948 from vol. III, table 104.

[d] The denominator for the lower bound is the number of drug stores in 1939, and the number of drug and proprietary stores for the post war years. The denominator for the upper bound includes only drug stores (or drug and proprietary stores) with fountains. See note C for source tables.

[e] The denominator for the lower bound is the number of eating and drinking places. The denominator for the upper bound excludes drinking places without meals, lunch counters, and soft drink, juice and ice cream stands. The 1948 Census did not separately report number of drinking places not serving meals, so the number of such establishments is inferred from the proportion of drinking places in the city that did not serve meals in 1939. See note C for source tables.

Table 2: Measures of Seasonality in Retail

Retail Sector	Period Covered	July/August Sales as a Proportion of Average Monthly Sales
Total Personal Consumption Expenditures [a]	1939 – 1951	.99
Retail Stores [b]	1935 – 1951	.99
Department Stores [c]	1919 – 1928	.76
	1935 – 1951	.80
	1952 – 1959	.86
Variety Stores [d]	1919 – 1928	.91
	1935 – 1951	.91
Drug Stores [e]	1919 – 1923	1.05
	1947 – 1960	.98
Grocery Store Chains [f]	1919 – 1923	.98
	1935 – 1955	.99
Restaurants [g]	1923 – 1938	.97
Shoe Stores [h]	1919 – 1923	.87
	1950 – 1958	.91
Women's Apparel [i]	1947 – 1958	.83

[a] NBER macro history series q060085. Seasonal measure is 3rd quarter sales as a proportion of average quarterly sales. [b]NBER macro history series m06089a&b. [c] NBER macro history series m06002b. [d] NBER macro history series m06005&m06004c. [e] Earlier value from Federal Reserve Bulletin, Jan. 1924, p. 17. Later value from monthly sales figures reported in biennial statistical supplements to the *Survey of Current Business*. [f] NBER macro history series m06008a&b. [g] NBER macro history series m06007, which covers 3 restaurant chains. [h] Earlier value from Federal Reserve Bulletin, Jan. 1924, p. 17. Later value from monthly sales figures reported in biennial statistical supplements to the *Survey of Current Business*. [i] Calculated from monthly sales figures reported in biennial statistical supplements to the *Survey of Current Business*.

Table 3: Summary Statistics for Variables used in the Regression Analysis

Horsepower Variables from EEI Survey of Utilities (n=123 in 1937 sample, 132 in 1939 sample)				
Sector	**1937 Mean**	**1937 Stand. Dev.**	**1939 Mean**	**1939 Stand. Dev.**
Commercial Retail[a]	2899	6754	3730	8895
Department, Drug, and Misc. Retail Stores	999.1	2213	1247	2412
Restaurants	326.9	837.2	535.2	1812
Hotels	257.7	803.9	336.5	1032
Movie Theaters	1082	3028	1210	3315

Independent Variables (statistics for 1939 sample of 132 utility service areas)			
Variable	**Source[b]**	**Mean**	**Stand. Dev.**
Population (000s)	1940 Population Census	506.4	686.4
Family Wage and Salary Income (millions)	1940 Population Census	1274.2	290.0
Hotel Rooms (imputed)	1940 Census of Business	5777.9	9607.0
Theater Seats (imputed)	1940 Census of Business	37203.0	53880.6
Employees per establishment (All Retail)	1940 Census of Business	2.91	.99
Employees per establishment (Restaurants, imputed)	1940 Census of Business	3.51	1.56
Rooms per Hotel (imputed)	1940 Census of Business	49.6	24.5
Seats Per Theater(imputed)	1940 Census of Business	837.4	330.7
Proportion of population in Urbanized Area	1940 Population Census	.665	.261
Commercial electricity rate (monthly)	Federal Power Commission 1935, 1937	20.8	3.9
Heating Degree Days (000s)	NOAA[c]	4.95	1.94
Cooling Degree Days (000s)	NOAA	1.27	.82
Avg. Wind Speed (July)	NOAA	8.00	1.47
PM Relative Humidity (July)	NOAA	55.9	10.6
Sunshine (July)	NOAA	67.7	7.6

[a] Includes horsepower reported for the categories barber and beauty shops, studios, funeral homes, hotels, recreation, clubs, restaurants, department stores, drug stores, miscellaneous stores, movie theaters, and other commercial.
[b] 1940 Census of Business variables pertain to 1939; monetary variables are in current dollars as reported in the sources.
[c]Data from the National Climatic Data Center, National Oceanic and Atmospheric Administration. See data appendix for complete citation of sources.

Table 4: Regressions for Installed Horsepower, End of 1937

	Commercial Retail	Department Drug and Misc. Stores	Restaurants	Hotels	Movie Theaters
Log Population	1.248** (0.090)	1.446** (0.124)	1.310** (0.100)	0.792** (0.195)	1.323** (0.153)
Log Family Income	0.962 (0.761)	1.129 (1.056)	-1.004 (0.803)	1.776 (1.122)	0.808 (1.563)
Establishment Size	0.202 (0.148)	0.322+ (0.170)	0.304* (0.130)	-0.002 (0.012)	-0.003 (0.002)
Share of Service Area Population in Urban Areas	2.144** (0.639)	2.170* (0.913)	2.789** (0.781)	0.776 (1.213)	6.964* (3.242)
Log of Electricity Rate	-1.712** (0.621)	-1.071 (1.217)	-0.586 (0.785)	-3.132* (1.383)	-2.026* (0.808)
Heating Degree Days	0.133 (0.093)	0.017 (0.123)	0.397* (0.184)	0.492* (0.198)	0.163 (0.151)
Cooling Degree Days	0.984** (0.251)	0.936** (0.322)	1.122** (0.418)	2.187** (0.482)	1.036** (0.342)
(Heating Days) X (Cooling Days)	0.248** (0.072)	0.326** (0.105)	0.168 (0.114)	-0.024 (0.165)	0.213+ (0.120)
Wind Speed	-0.019 (0.095)	-0.045 (0.107)	-0.155 (0.101)	0.000 (0.161)	-0.035 (0.117)
Relative Humidity	0.008 (0.012)	0.007 (0.018)	0.019 (0.019)	0.014 (0.022)	0.028 (0.023)
Sunshine	0.027 (0.017)	0.018 (0.026)	0.046+ (0.025)	0.057 (0.041)	0.041 (0.032)
Observations	123	123	123	123	123
R-square	0.79	0.71	0.69	0.39	0.65

Robust standard errors in parentheses
+ significant at 10%; * significant at 5%; ** significant at 1%
[a] Includes horsepower reported for the categories barber and beauty shops, studios, funeral homes, hotels, recreation, clubs, restaurants, department stores, drug stores, miscellaneous stores, movie theaters, and other commercial.

Table 5: Regressions for Installed Horsepower, End of 1939

	Commercial Retail[a]	Department Drug and Misc. Stores	Restaurants	Hotels	Movie Theaters
Log Sales	1.158** (0.062)	1.251** (0.096)	1.179** (0.074)	0.981** (0.168)	1.280** (0.120)
Log Family Income	0.572 (0.466)	0.481 (0.850)	-0.362 (0.571)	1.289 (1.010)	0.683 (1.122)
Establishment Size	0.238* (0.098)	0.326* (0.156)	0.318** (0.101)	-0.002 (0.011)	-0.004+ (0.002)
Share of Service Area Population in Urban Areas	1.954** (0.410)	2.292** (0.775)	2.003** (0.571)	1.150 (1.112)	6.580** (2.472)
Log of Electricity Rate	-1.262** (0.376)	-1.950** (0.596)	-0.442 (0.738)	-4.137** (0.986)	-2.296** (0.677)
Heating Degree Days	0.212** (0.065)	0.094 (0.116)	0.410* (0.186)	0.544** (0.174)	0.296* (0.121)
Cooling Degree Days	1.012** (0.160)	1.008** (0.283)	1.167** (0.417)	2.400** (0.436)	1.263** (0.287)
(Heating Days) X (Cooling Days)	0.165** (0.051)	0.224* (0.099)	0.121 (0.115)	-0.013 (0.146)	0.128 (0.094)
Wind Speed	-0.037 (0.052)	-0.045 (0.068)	-0.150 (0.099)	0.065 (0.147)	-0.035 (0.107)
Relative Humidity	0.002 (0.007)	-0.020 (0.012)	0.016 (0.016)	0.010 (0.021)	0.009 (0.015)
Sunshine	0.015 (0.011)	0.007 (0.017)	0.028 (0.019)	0.060+ (0.034)	0.001 (0.022)
Observations R-square	132 0.87	132 0.74	132 0.68	132 0.53	132 0.66

Robust standard errors in parentheses
+ significant at 10%; * significant at 5%; ** significant at 1%
[a] Includes horsepower reported for the categories barber and beauty shops, studios, funeral homes, hotels, recreation, clubs, restaurants, department stores, drug stores, miscellaneous stores, movie theaters, and other commercial.