Single Bidders and Tacit Collusion in Highway Procurement Auctions

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Abstract:

Collusion in auctions can take different forms, one of which is refraining from bidding. Such behavior may be overt or tacit. Certain elements of the institutions of highway procurement auctions facilitate collusive outcomes, namely, publicly available information, small number of potential bidders, and repeated interactions. In this paper we collect data on asphalt paving auctions conducted by the Kentucky Transportation Cabinet during the years 2005-2007, and estimate bidding functions for each of the 31 firms licensed to bid on state and federal jobs. We include variables that affect the firm's cost of carrying out the work as well as variables that capture competitive and strategic effects. Most importantly, we determine the potential service area of each asphalt plant and use that information to determine the potential bidders for each paving project during the sample period. Our empirical results identify (1) regions with several potential and actual competitors where bidding is highly competitive, (2) regions with only one viable supplier and commensurately elevated bids, and (3) regions with two or three potential competitors but where firms appear to tacitly refrain from bidding, resulting in single-bidder auctions with prices approaching monopoly levels.

People of the same trade seldom meet together, even for merriment and diversion, but the conversation ends in a conspiracy against the public, or in some contrivance to raise prices.[1]

BID LETTING FOR JANUARY 21, 2005 PARTS 1, 2, & 3: Have been advertised with 56 projects consisting of grade and drain with asphalt surface, guardrail, asphalt resurfacing, right-of-way mowing and litter removal, slide repair, fine turf mowing, bridge painting and cleaning, bridge deck restoration and waterproofing, culvert replacement, etc. ***Letting eve activities will be held at the Marriott's Griffin Gate Resort in Lexington. Please note the attached revised reservation form from the Marriott Griffin Gate for the 2005 Kentucky Association of Highway Contractors Bid Lettings****.*[2]

Introduction

Understanding firms' attempts to collude drives much of economists' study of oligopoly. Detection and deterrence of collusion are perhaps the primary challenges of antitrust policy.[3] In auction markets collusion has attracted less attention than a general focus on design mechanisms and other factors affecting the competitiveness of such markets.[4] Much of the attention paid to collusion in auction markets has been motivated by price fixing and bid rigging conspiracies in public procurement auctions.[5]

Bid rigging schemes can take on a variety of forms. Sometimes all participants in the auction are part of the conspiracy, and then the challenge becomes determining which conspirator will win the auction and how other conspirators will be compensated. Things change somewhat if non-conspirators participate in the auction. Accommodating behavior by co-conspirators often takes the form of submitting complementary bids above (in a procurement auction) the predetermined winner's bid. If the collusive behavior is overt then it violates federal antitrust laws in the U.S.[6]

Various methods have been proposed for detecting overt collusion in auction markets. As Harrington (2008), Porter and Zona (1993), and others have noted, however, refraining from bidding is another form that collusion may take. Such behavior may be overt, if it is the result of explicit communication among firms, or tacit, if it arises without overt behavior. While overt agreements not to bid have been the object of study, we are not aware of any empirical analysis of tacit refusals to bid in procurement auctions.

During the 1980's there were hundreds of bid rigging prosecutions and convictions in public procurement auctions across the country.[7] Since then, government officials have aggressively

[1] Smith (1776), Book I, Ch. X, Part II.
[2] Kentucky Association of Highway Contractors newsletter: *Highway Highlights*, January 18, 2005.
[3] Porter (2005), p. 147.
[4] See, for example, Klemperer (2004).
[5] Hendricks, McAfee, and Williams (2015) provide an overview of this literature.
[6] Werden (2004) extensively discusses the definition and proof of collusive agreements under the antitrust laws.
[7] USGAO (1990): http://archive.gao.gov/d22t8/142779.pdf

monitored bidding behavior, and there has been a relatively reduced emphasis on §1 Sherman Act prosecutions since the 1980's. That does not mean that concerns over the competitiveness of bidding, especially in highway procurement auctions, have gone away. Instead, the trend has been toward single-bidder auctions, with resulting higher prices for public transportation projects.[8]

The difference that a second bidder can make in highway procurement auctions is sizable. As can be seen in Table 1, in Kentucky during the 2005-07 period sixty-three percent of asphalt paving projects only had one bidder, and ninety percent had one or two bidders. Winning bids for single-bid asphalt projects averaged 2.22 percent above the state highway engineer's estimate of the cost of the job. Winning bids when there were two bidders averaged 13.53 percent below the engineer's estimate, and with three bidders the low bid averaged 16.73 percent below the engineer's estimate. It is clear that firms in single-bid auctions are able to raise bids above the competitive level. The nearly 16 percent difference made by a second bidder cost Kentucky taxpayers nearly $100 million of the $608 million spent on paving contracts during 2005-07.

At one level, the goal of this paper is to explore the nature of bidding in highway procurement auctions. At another level, we hope to add to economists' understanding of tacit collusion in oligopoly markets. The primary question is whether so many auctions attract only a single bidder because rival firms are coordinating their bids. We start by reviewing the history of bid rigging in the asphalt industry and methods used to detect collusion in auctions. We discuss how procedural mechanics of highway procurement auctions and economic aspects of asphalt paving create a bidding environment that facilitates coordination in the repeated bidding game that rival contractors engage in. We then determine feasible service areas for all asphalt contractors in Kentucky and estimate their bidding functions to see what factors influence the decision to bid. We find that, in many parts of the state, county boundaries create a natural focal point for bidding that helps firms solve their repeated coordination game by refraining from bidding in rival firms' territories.

Bid Rigging in the Asphalt Industry

During the period of analysis in this paper, there is no evidence of overt collusion in Kentucky, nor is there any suspicion of illegal activity, even though the Kentucky Transportation Cabinet annually gathered highway contractors for a bid-letting meeting and sponsored a social function the night before. Since several of the principals and companies contained in our empirical analysis were implicated in bid

[8] AASHTO/FHWA Survey on Construction Cost Increases and Competition, April 2006.

rigging and illegal collusion in Kentucky during the early 1980's, a brief overview of past overt collusion in highway procurement auctions is warranted.[9]

Antitrust enforcement changed its focus in the early 1980's, switching from large monopoly cases to price fixing and collusion. A pattern of highway bid rigging was uncovered in Tennessee and found in other states. In Tennessee contractors would gather in a Nashville hotel the night before bid lettings to determine who would be the winning (low) bidder. Other contractors would submit complementary (higher) bids, in return for payoffs from the winner or the promise of being the low bidder in a future auction (rotation of low bidders).[10] By 1984 the federal investigation of highway bidding had expanded into 29 states, with 181 corporations and 189 individuals pleading guilty, 21 corporations and 25 individuals being convicted at trial, and 16 corporations and 22 individuals being acquitted.[11] In all, there were over 600 highway bid-rigging cases during the 1980's.[12]

Since the 1980's the Department of Justice has moved away from bid rigging, in no small part because of a general belief that overt collusion occurs less frequently due to the heavy prosecution during the 1980's and better methods, such as wiretaps, for detecting bid rigging. This is not to say, however, that highway procurement auctions are highly competitive. In an August 2005 meeting of the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Construction, the committee identified single-bid contracts and decreasing competition as major concerns. According to a survey commissioned by AASHTO (2006) the average number of bidders per project declined from 4.24 in 2002 to 3.36 in 2005. For Kentucky the average number of bidders declined from 2.94 in 2002 to 2.18 in 2005.[13] As is evident in Table 1, single-bid contracts are more prevalent in asphalt resurfacing projects than other highway construction or maintenance projects.

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[9] The owner of Mountain Enterprises, an asphalt paving company in eastern Kentucky, provided the following description of how the collusion worked (Lawson, 1983, pp. 9-10). "It was agreed that Kentucky Virginia Stone would take both of the jobs available at that letting and the two jobs available at the next letting were then split up. So that Mountain Enterprises got one of the four, Kentucky Virginia Stone got three of the four, and that roughly split or equaled out the tonnages on those four jobs. These were the first four jobs which were made subject to the agreement between Kentucky Virginia Stone and Mountain Enterprises. . . . They would work out who was going to get which job and then information would be passed so that someone could either submit a complementary bid or not bid."

[10] Sniffen (1982).,

[11] Sniffen (1984),

[12] Ryan (2004).

[13] Two major reasons cited by departments of transportation for the decline of bids were industry consolidation and increased work with the same number of contractors. Data from Kentucky, however, indicate that industry consolidation was not a problem—during 2005-2007 the average number of projects per firm was 10.4 in Kentucky, while the average from 1994-2007 was 11.2 projects per firm.

These facts motivate our analysis. The question remains whether the high level of single-bid contracts represents an efficient equilibrium or is the result of tacit collusion.

Detecting Collusion in Auctions

Detecting collusion and cartels has long been a primary concern of industrial organization economists (e.g. Stigler, 1964). Both Porter (2005) and Harrington (2008) have suggested that economists are best positioned to play the role of detective—diagnosing either explicit or tacit cooperation among firms. Concomitant with increased focus on price fixing and bid rigging by federal antitrust investigators in the 1980s, economists began paying greater attention and worked to develop methods to identify collusive behavior in auctions, e.g. Graham and Marshall (1987) and McAfee and McMillan (1987). Isaac and Walker (1985) investigated bid rigging in sealed bid auctions and the effect of non-cooperating bidders in a laboratory experiment setting. Building on theoretical and empirical research on bid rigging in auctions, both Klemperer (2002) and Marshall and Marx (2009) discussed the importance of auction design in thwarting collusion.[14]

Highway procurement auctions have been a particular area of focus both because of readily available data and high susceptibility to collusion. Funderburk (1974) described an early use of economic analysis to identify the existence of a conspiracy among bidders for liquid asphalt contracts with the Oklahoma transportation department. Feinstein, Block, and Nold (1985) theoretically and empirically analyzed information asymmetries between highway construction cartels and the states that purchased their services. They found that cartels actively fed the North Carolina transportation department misinformation in order to change the purchasers' (the state) expectation on what constitutes a "good buy."[15]

Porter and Zona (1993) developed an econometric test to detect bid-rigging in highway procurement auctions. They focused specifically on auctions where there were more than two bids, and attempted to detect "phantom" bidding. A phantom bid is a one that looks competitive because multiple firms are bidding, however, the identities of the low and high bidders are determined by the participating firms before the bids are submitted. This overt collusion gives the appearance that numerous firms are competing for a project, but the reality is the winner of the bid is predetermined.

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[14] A thorough summary of this literature is contained in Hendricks, McAfee, and Williams (2015).
[15] Brannman and Klein (1992) also investigated highway construction bid rigging in North Carolina.

Bajari and Ye (2003) developed econometric tools to detect collusive behavior and empirically analyzed data on highway seal-coating contracts in Minnesota, North Dakota and South Dakota. They incorporated cost asymmetries among bidders in their model. Cost asymmetries arise due to locations of firms, capacity constraints, and knowledge of local rules and regulations. They tested for conditional independence to see if bids are independent and exchangeability to see if costs and not just the presence of competitors are actually driving bid levels. Lastly, they took into account industry experts' opinions about realistic distribution of markups to see if the market is competitive or collusive.

The literature on collusion in auctions has also extended into other sectors including electricity, timber, the electromagnetic spectrum, public works, and the dairy industry. Fabra (2003) modeled tacit collusion in uniform-price and discriminatory auctions in a repeated setting which allows the firms to sustain collusive behavior, focusing on the electricity industry in England and Wales. Baldwin, Marshall, and Richard (1997) controlled for demand conditions and found that a collusive model outperforms the 'standard' model of non-cooperative behavior in Pacific Northwest timber auctions. Price (2008) extended Bajari and Ye's (2003) model into timber auctions in British Columbia and incorporated the spatial distribution of bidders to detect collusion. Cramton and Schwartz (2000) investigated the FCC's simultaneous ascending auction design and found that it facilitates tacit collusion in spectrum auctions around the country. Lee and Hahn (2002) and Ishii (2009) have analyzed bidding on public works projects in Korea and Japan, finding evidence of collusive behavior. Research has also focused on collusion in school milk procurement auctions during the 1980s and 1990s. Pesendorfer (2000), Porter and Zona (1999), Lee (1999), Lanzillotti (1996), and Scott (2000) analyzed bid-rigging in Florida and Tennessee, Ohio, Texas, and Kentucky respectively.

Highway Procurement Auctions

Certain elements of the institutions of highway procurement auctions, as well as political and geographical factors, create a market environment that facilitates collusive outcomes. Since the approach taken by the Kentucky Transportation Cabinet (KYTC) to procure construction and maintenance work is generally representative, we will use it as an example. There are many different types of projects to be carried out, ranging from constructing new roads, resurfacing existing roads, trimming trees and mowing grass, maintaining and replacing bridges, building fences, and painting lines.

Of particular importance is that when certain funds are used KYTC is required to separate funds by county, and so it usually separates projects by county.[16]

For reasons that will be discussed below, our primary interest is asphalt paving projects. Major asphalt jobs originate from a comprehensive full planning process, are attached to a Six-Year Plan and State Transportation Improvement Plan, and are approved by the state legislature. Minor, routine asphalt resurfacing projects are typically initiated within the KYTC and do not need to be approved by the legislature. The vast majority of the projects that were analyzed for this paper are minor resurfacing projects.[17]

In Kentucky, projects are let on a monthly schedule, but this can vary from state to state. In most States each project is advertised for a certain period of time, bid proposals and plans are available for purchase, and then bids are submitted. Most states require that contractors working for them must be prequalified and also require that bid proposal and/or project plans must be purchased.[18] In Kentucky the project must be advertised between 7 to 21 days before the project is to be let. Firms must purchase a bid proposal to be eligible to bid on a project. The bid proposal costs $10 and the names of firms which purchase bid proposals are publicly available the Friday before the bids are opened.

All firms in Kentucky must be pre-qualified by the transportation cabinet and the list of pre-qualified firms is publicly available. Care is taken by KYTC that a contractor does not take on too much work, and officials hold meetings with all potential contractors on projects scheduled for the upcoming year to determine the letting schedule. Projects are moved around on the calendar in order to accommodate potential contractors.

Sealed bids are opened and read aloud once a month at the Kentucky Transportation Cabinet. KYTC then analyzes the bids for 10 days before awarding a contract. The bids are analyzed to see if the bid is unbalanced, front-loaded, or if there is any indication of collusion.[19] The transportation cabinet looks at the overall total of each bid and compares it to the state highway engineer's estimate. In some states the engineer's estimate is available before the day of bidding, while in other states like Kentucky

[16] A KYTC transportation official stated that for certain types of projects designated "rural secondary" the money must go to the specific counties.
[17] Kentucky Transportation Cabinet (2004).
[18] Anderson, S. D. and Byron C. Blaschke (2004).
[19] Kentucky and other states use the AASHTO Transport System, which is a program that is used to detect collusion. It can compare the bids to the engineer's estimate and the other contractors who bid, and also create reports on past bidding behavior, market prices, and price differences according to various parameters such as geography.

it is not available until after bids are opened. An informal rule in Kentucky is that if a bid is 7 percent over the engineer's estimate it should be rejected, however this rule is infrequently followed. If everything is judged by KYTC to be reasonable then the project is awarded, even if there is only one bidder.

Economic Aspects of Asphalt Paving

We focus on asphalt paving and do not consider other types of projects such as grade and drain, bridge work, mowing, etc. The important element of the asphalt paving process is the time constraint, which limits how far away from its plant a particular firm can bid—the firm's feasible service area. Projects farther away from a plant result in higher costs to the firm because asphalt is heavy and hence costly to transport. As a result, the geographic scope of the market for asphalt projects is much smaller than geographic market scope for road and bridge construction, mowing, and other highway maintenance projects. Other factors relevant to asphalt production and paving are high start-up costs (some of which take the form of environmental permits), economies of scale at the plant level, potential problems of obtaining aggregate (sand and gravel), and the fact that hot-mix asphalt must be compacted while it is very hot. These factors greatly influence the competitive landscape faced by asphalt contractors bidding in procurement auctions.

The process of paving a road begins with the extraction of rock (aggregate) from a quarry and the distillation of asphalt cement or bitumen from crude oil. The cost of producing asphalt varies as the prices of aggregate and asphalt cement vary. These two components are combined at high temperatures at an asphalt plant when asphalt cement is in liquid form. The resulting hot-mix asphalt is dispensed into trucks and driven to the project site. Care has to be taken to not let the mixture cool too much before compaction. It must be laid and compacted before the temperature of the mixture falls below 85°C (185°F). Below this temperature the asphalt starts to crack and will not set properly.

Transportation of the hot-mix asphalt from the plant to the project site is another significant cost. The trucks are often insulated and the bed is usually covered with a tarp. A general guideline is that hot-mix asphalt has 2 to 3 hours in an insulated truck before it becomes too cool.[20] However, an official of the Kentucky Transportation Cabinet stated that a more realistic time is between 45 to 60 minutes from when the hot-mix asphalt is dispensed to when it is compacted. This time frame is critical

[20] AASHTO, (2000).

in determining the extent of a firm's feasible service area. The calculation of feasible service areas is important in the analysis of tacit collusion, and is discussed further in the Data section.

Coordination of Bidding in a Repeated Game

There is considerable variation in the bidding environment faced by different asphalt paving firms in Kentucky. Northern Kentucky and the greater Louisville area are large urban markets, and can support multiple asphalt companies. In addition to dense public road networks, there is considerable commercial demand for asphalt paving and so the market environment is very competitive with multiple firms. In eastern Kentucky the market is much thinner, because of sparse population and negligible commercial paving demand. Since the 1980s, the region has been served by one multi-plant firm, which operates each of its plants on a rotating basis with transient plant and paving crews. The market environment resembles natural monopoly, in that there only seems to be enough business to support one efficient-sized firm.

In many other parts of the state the demand for asphalt paving is sufficient to support geographically dispersed oligopolists with overlapping feasible service territories. It is in this type of market environment that strategic interactions among firms become important. The prevalence of these oligopoly/duopoly markets can be seen in Figure 1, which illustrates every asphalt plant in Kentucky approved to bid on state contracts during the sample period.[21] As can be seen, 31.7 percent of the 120 counties in Kentucky did not have an asphalt plant located within the county, 60.0 percent of counties had one plant, and 8.4 percent had more than one plant within the county.

Bidding in a competitive environment has been thoroughly discussed by other authors. We will have little to add, except to use competitive areas as a benchmark for comparison. Bidding under natural monopoly is straightforward: how high can a firm bid above the state engineer's estimate and not get rejected by KYTC?[22] Oligopoly bidding gets interesting—how to determine who should win a particular auction, how to rotate winners, and how the designated losers should bid, if at all?

This bidding scenario thus has elements of a repeated coordination game where the Nash equilibrium coordination requires either side payments or rotation of winners. Side payments are by definition overt and illegal. Complementary bids and refraining from bidding are illegal if firms directly

[21] Figure 1 is taken from the Plantmix Asphalt Industry of Kentucky web site.
[22] There are numerous examples of single-bidder paving companies playing "chicken" with the KYTC, having an initial bid rejected and the project being put up for rebid. On several occasions there have been three and four rounds of rejected bids and rebidding. The usual outcome is that the KYTC ultimately blinks when there is no viable alternative supplier.

and overtly agree to pursue such strategies. Refraining from bidding generally is not illegal if a firm unilaterally decides that such a strategy is in its own best economic interest.[23] The global profit maximum for all players occurs when the low-cost firm for each project wins the auction. If each player wins often enough so as to consider the outcome equitable, then the only problem is devising a bid rotation scheme where the low-cost firm is always the designated winner. With multiple firms and multiple projects, overt communication may be required to reach this outcome.[24] When the number of potential bidders is small, however, firms may recognize their mutual self interest in suppressing competition without direct communication.[25] The existence of a natural focal point may obviate the need for overt collusion. If procurement auctions are configured so as to create an easy way for firms to allocate contracts and refrain from bidding against one another without openly communicating, then tacit collusion may accomplish the same outcome as would occur under an illegal cartel.[26]

The problem can be modeled as follows. Consider two firms, X and Y, who produce a product that is costly to deliver and who are located at some distance from each other. They can bid on a project that is located distances d_x from X and d_y from Y. Each incurs production and transportation costs of C_x and C_y, respectively, if they win the bid and carry out the project. There is a random element of ε associated with each firm's costs, so that neither knows its own or its rival's costs with certainty ex ante. The following diagram illustrates this scenario:

Firm X **Project #1** **Firm Y**

|__________d_x________|____________________d_y____________________|

There are three possibilities: (1) $d_x < d_y$ such that $|C_x - C_y| > \varepsilon$, i.e. firm X is considerably closer and so has a clear cost advantage; (2) $d_x > d_y$ such that $|C_x - C_y| > \varepsilon$, i.e. firm Y is considerably closer and so has

[23] See Werden's (2004) discussion of the legal status and treatment of tacit vs. overt collusion, especially pp. 734-759. Yao and DeSanti (1993) also discuss the legal quandaries of prosecuting tacit collusion.

[24] This is precisely the scenario studied by Porter and Zona (1993), whereby highway contractors on Long Island devised a bid rotation scheme with designated losers submitting complementary bids.

[25] As Fraas and Greer (1977, pp. 29-31) point out, the necessity of a formal collusive agreement increases as structural conditions become more adverse to tacit cooperation. With two firms selling a standardized product overt collusion may be immanently possible but not really needed. Their empirical analysis of 606 explicit price fixing cases from 1910 to 1972 confirms this conjecture.

[26] Green, Marshall, and Marx (2015) argue that most market environments are sufficiently complex that collusion will be unsuccessful in the absence of explicit communication. But in a market that is so simple and transparent that "there is a unique candidate for the optimal collusive agreement", i.e. a focal point, then tacit collusion may suffice.

a clear cost advantage; and $d_x \approx d_y$ such that $|C_x - C_y| < \varepsilon$, i.e. firms X and Y are roughly equidistant and so neither firm has a clear cost advantage.

Suppose firms X and Y bid on Project #1 in a one-shot game where firm X has a clear cost advantage, i.e. condition (1) above holds. Let us restrict bid options for each firm to bidding competitively (P_c) or bidding monopolistically (P_m). Since firm X has a clear cost advantage, it will always win if both firms bid competitively.[27] The payoff matrix for this game is:

		Firm Y	
		P_c	**P_m**
Firm X	**P_c**	**π_c , 0**	**π_c , 0**
	P_m	**0 , π_c**	**π_m , 0**

Without digressing into a deeper discussion of economic profits, let us assume that winning the auction when bidding is noncompetitive yields more profit (π_m) than winning when bidding is competitive (π_c) and that either is better than not winning the auction ($\pi = 0$).

The Nash equilibrium to this game is that both firms bid competitively, firm X has the lower bid due to its locational cost advantage, and it then earns competitive profits on the project. Likewise, because of symmetry, if firm Y has a significant locational advantage in a one-shot game it would win the bid and earn competitive profits.

The third possibility is that the project is roughly equidistant from each firm, so that neither has a clear cost advantage. The payoff matrix for this game is:

		Firm Y	
		P_c	**P_m**
Firm X	**P_c**	**½π_c , ½π_c**	**π_c , 0**
	P_m	**0 , π_c**	**½π_m , ½π_m**

where the payoffs on the diagonal represent expected profits if both pursue the same bidding strategy and random elements determine who actually wins the auction. If $½\pi_m > \pi_c$, then this payoff matrix

[27] Let us assert that firm X also wins if both firms bid noncompetitively, since its bid will be lower than firm Y's if both use the same relative markup.

has the form of a traditional coordination game and there are two Nash equilibria to the game, with the strategy pair (P_m , P_m) clearly dominating.

In actuality many asphalt paving firms in Kentucky play this game repeatedly against an identifiable rival, with the KYTC putting projects up for bid in various locations at regular intervals. If roughly half the projects let for bids were clearly closer to firm X and the other half were clearly closer to firm Y, then it would not be surprising at all if the two firms used distance as a focal point for cooperation and bid noncompetitively, with the more distant firm's noncompetitive bid being higher than the closer firm's noncompetitive bid. The payoff matrix to this repeated game would resemble that immediately above, and the dominant Nash equilibrium would be characterized by noncompetitive bidding by each firm.[28]

Projects roughly equidistant from both firms create a problem for such coordination, however, and so relying solely on distance as a focal point for cooperation may give rise to outbreaks of competitive bidding (price wars) or temptations to overtly collude. Fortunately for asphalt oligopolists (and unfortunately for Kentucky taxpayers), KYTC refines this focal point by assigning asphalt projects strictly according to county boundaries. In adjacent counties where there is only one company with an asphalt plant in each county, the natural focal point outcome is hard to miss.

The different possible bidding scenarios can be seen in Figure 2. It illustrates two firms (X and Y), four counties (A-D), and four projects (1-4). Project 1 is located in county A where firm X has the only asphalt plant. Project 2 is located in adjacent county B where rival firm Y has the only asphalt plant. Project 3 is located in county C where both firms X and Y have asphalt plants. Project 4 is located in county D where neither firm X nor Y has an asphalt plant.

Projects 1 and 2 are roughly equidistant from both firm X and firm Y. In a "flat" world, each firm would have similar costs of carrying out each of the two projects. With no focal point for cooperation, it is not clear how the two firms might reach a noncompetitive bidding equilibrium without overt communication. If projects are delineated by county lines, however, and each firm is the sole supplier of asphalt in its own county, then the natural focal point for cooperation is for firm X to carry out project #1 and firm Y to carry out project #2, both at noncompetitively high bids.

For projects 3 and 4, there are no natural focal points for cooperation. Project 3 is located in county C, where rival firms X and Y both have asphalt plants, and is roughly equidistant from both firms.

[28] This is precisely the collusive outcome achieved by Oklahoma asphalt companies during the 1960's as described in Funderburk (1974).

With no clear focal point to guide the firms' cooperative instincts, competitive bidding is likely to occur absent overt communication between the firms. Project 4 is located in county D, which is adjacent to both Counties A and B and has no asphalt plant located within its boundaries. Project 4 is also roughly equidistant from the asphalt plants of both X and Y. Again there is no clear focal point for cooperation, and without overt collusion the bidding is likely to be competitive.

Data

Source of Data

The purpose of our empirical analysis is to see if firms are coordinating bids. The data used are publicly available and were obtained from the Kentucky Transportation Cabinet for the years 2005-2007. Information on contracts awarded, which firms purchased bid proposals, which firms actually bid on each project, the amounts of each bid, the winning firm, and the engineer's estimate was obtained from the KYTC Construction Procurement website. These detailed data were only available after 2005 on the KYTC website. Upon request, the Kentucky Transportation Cabinet supplied project location (latitude and longitude for the mid-point of each project) information for the projects in Kentucky from 1996-2009. These data also included information on the type of work including a short description of what the project entailed along with information about the road, location, and number of bids. This was supplemented with another data set from KYTC which contained all awarded contracts in Kentucky from 1994-2010.

Information about plant locations came from various sources including the Plantmix Asphalt Industry of Kentucky (PAIKY) website, the Division of Materials within the Transportation Cabinet, air quality permits obtained from the Division of Air Quality within the Environmental and Public Protection Cabinet, and from individual firm websites. For a few firms, the locations of the asphalt plants were confirmed by telephone. There are a total of 1,985 projects that were let and awarded from 2005-2007. We identified asphalt projects using the KYTC label for each project that briefly summarized the scope of the project. In order to qualify as an asphalt project, the job could not have any other element except asphalt surfacing, resurfacing, rehabilitation, or patching. Asphalt projects that had grade and drain, bridge, or guardrail components were not included in the "asphalt" projects for this analysis, leaving us with 1,075 projects for analysis.[29] These projects accounted for around $600 million in expenditures by the Kentucky Transportation Cabinet.

Firms and Counties

There are 31 major firms that bid on asphalt paving projects in Kentucky during the sample period.[30] The 31 Kentucky firms have a total of 113 asphalt plants in the 120 Kentucky counties for an average of 0.94 plants per county. Figure 1 illustrates the location of each asphalt plant in Kentucky. Table 2 contains the names of the 31 firms, the number of asphalt plants each firm operates, the number of asphalt projects they bid on in Kentucky, the percentage of those bids where the firm was the single bidder, the number of contracts the firm won, and the value of the contracted projects. Considerable variation exists across firms. In the far western corner of Kentucky, H&G Construction bid on 77 projects even though it only has one asphalt plant. They only won 14 of those projects, and they were never the only bidder, always facing competition from Jim Smith Contracting and Murray Paving. Two central Kentucky firms, ATS Construction and Nally & Gibson Georgetown, won all of the projects they bid on.

Service Areas

Political boundaries such as county boundaries and highway district boundaries do not necessarily align with geographic economic markets. In asphalt paving, the feasible service territory is the area where a firm can economically service any asphalt project, i.e. where the firm can reasonably complete an asphalt paving job without the hot-mix asphalt cooling below the temperature threshold. When looking at the distance from plants to projects for projects that firms bid on, there were no instances in the entire sample where a firm bid on a project more than 60 miles from its plant. The service area limit for every firm was thus set at 60 driving miles from each firm's asphalt plant.

All mapping analysis was done in the ArcGIS ArcMap program using the Network Analyst function. We were able to determine and calculate the service areas and driving distances from asphalt plant to project. The software also mapped out these 60 mile service areas. As an example Figure 3 shows H&G Construction's service area in western Kentucky and the projects they bid and did not bid on

[29] Projects with construction components attract a different (and partially overlapping) set of bidders, because the geographic scope of the market for these sorts of projects can be considerably larger than simple asphalt projects.
[30] There were three additional Kentucky firms that showed up once or twice in the bid data, and four Indiana paving companies that were approved for state contract work and bid into Kentucky. One of the Indiana firms, Gohman Asphalt, is a frequent bidder in the Louisville market. We did not include any of these firms in the empirical analysis because of incomplete data.

in their service area. The different 10-mile bands indicate distance from their asphalt plant in Graves County. Notice in Livingston County they bid on a project almost 60 miles away from their plant.

Estimating Bid Functions and Identifying Tacit Collusion

Our goal is to investigate whether firms are using county boundaries as focal points for tacit collusion. To accomplish that, we estimate bid functions for each of the 31 firms in Kentucky. Previous authors (e.g. De Silva, Jeitschko, and Kosmopoulou, 2009) who have examined bidding in highway procurement auctions have combined all the data into one market bidding regression. This approach makes sense if each firm faces similar market conditions in a fairly thick bidding market. As we have argued, however, most Kentucky asphalt paving companies face bidding environments unique to themselves. For that reason, we estimate each firm's bid function separately to see what factors influence each individual firm's decision to bid. Since Kentucky varies in geography and in market density, each firm deals with different factors in its specific service area, so we control for these economic and geographic factors by constructing firm-specific bid functions.

All of the projects in each firm's individual service area are included in the analysis of bidding behavior. Each individual project located in the firm's service area is a unit of observation. The dependent variable is the behavior we are trying to understand—whether a firm bids on a project which it can feasibly carry out. Expected profits are the obvious starting point, so we analyze factors that are likely to affect the expected profitability of a project. These include cost factors such as distance from plant to project, the number of projects a firm has under contract, and the size of the project. Since firms are competing in a repeated game, strategic factors such as how many firms purchased bid proposals and how many rival firms also have the project in their service areas are also included. Lastly, county variables are added to see if firms use county boundaries as focal points to coordinate their bidding.

Distance is a major determinant of costs, and so we would expect the distance variable to be highly important in the firm's bidding decision.[31] After determining projects falling within the firm's service area, we calculated the driving distance from the plant to the project using the OD Cost Matrix function in ArcMap. This mapping function calculates the shortest driving distance from a plant to each project in the service area using maps publicly available from the Kentucky Transportation Cabinet.

[31] See, for example, Bajari and Ye (2003) and De Silva, Dunne, and Kosmopoulou (2003).

Capacity utilization may affect a firm's decision to bid on a project. If a firm is at or close to capacity, the cost of taking on additional work will be increased.[32] We construct this variable by determining the amount of projects the firm is currently working on (falling between the beginning and ending date) on the day of bidding. For example, Mountain Enterprises bid on a project on November 11, 2007. A search of the awarded contract data indicates that the firm had seven projects under contract on that day. This exercise was replicated for each project for each firm.

Heterogeneity between projects is captured using the state engineer's estimate of the cost of the job. This variable serves as an indicator of the scale of the job.[33] It also lends insight into a firm's business model, i.e. the types of projects they are willing to bid on. In thicker markets some firms target large-scale high-value projects while others concentrate on smaller projects. In thinner markets firms tend to bid on all jobs put out for bid by the KYTC.

A second category of variables captures competitive and strategic effects. We create a variable which counts the number of other competitors whose 60-mile service areas contain the specific project. This variable measures the number of potential competitors the firm faces when bidding on a project. Another variable measures the number of rival firms that purchased bid proposals for the project. We include this variable to see if knowledge that other firms have expressed an interest in bidding on the project reduces or increases the probability of bidding. This variable captures a strategic element of bidding that may result when firms have some foreknowledge of who will participate in the auction.

Initially a probit model was used following De Silva, Jeitschko, and Kosmopoulou (2009). Problems with that approach arise, however, because there are a number of firms that tend to bid only in their specific counties. The probits we ran with fixed effects of counties are subject to two problems, both of which potentially bias the results in important ways. First, the fixed effects are estimated on small samples, and they cannot be differenced out in a non-linear model like probit. The fact that fixed effects are inconsistent creates bias for the whole model. The inconsistency arises from the lack of variance going to zero, as the county sample does not grow. Second, perfect classification, where a firm either always or never bids in a county, eliminates the county variables and the software drops these variables out of the model. Some firms are affected a lot by this, others very little. This creates in effect a selection bias because firms are not bidding in some counties, which then drop out of the sample

[32] See, for example, Jofre-Bonet and Pesendorfer (2003) and De Silva, Kosmopoulou, and Lamarche (2009). In an interview, KYTC officials expressed that they do not see capacity constraints as an issue, since they schedule projects specifically not to create capacity problems for likely bidders.

[33] See, for example, De Silva, Jeitschko, and Kosmopoulou (2009).

rather than staying in with some sort of coefficient. Neither of these problems can be eliminated if probit, logit, or any other non-linear model is used. They constitute unfortunate but unavoidable problems in combining limited dependent variables and fixed effects.

Linear probability models are a possible alternative, because they provide a linear approximation to whatever underlying model is present and allow the fixed effects to stay in the model regardless of the pattern of bidding. While the linear probability model is controversial because of its range (fitted values outside 0, 1), there is a tradeoff between this problem and the ones discussed in the previous paragraph. Theoretically, the fixed effects in a probit model apply to the propensity score. If the firm does not bid at all in a county the propensity score, which is abstract and unobserved, is negative infinity. That makes no sense—surely there is some nonzero probability of bidding—but the probit model requires this result. The linear probability model only calculates that the probability of bidding is low, which is more realistic. For this reason we present results using linear probability models to estimate the bidding function for each firm.[34]

The sample for each firm includes any asphalt project put out for bid from 2005-2007 within the firm's 60 mile service area. The dependent variable (y = 1 if the firm bids, y = 0 otherwise) is whether the firm bids on a specific project. The first independent variable consists of 10-mile categorical dummy variables for distance (*Distance)*.[35] The reference category is the distance ring 0 to 10 miles. The next variable is *Jobs Under Contract*, which controls for the number of projects a firm has currently under contract from the KYTC when they bid on a project. The *Engineer's Estimate* is included to control for costs and size of the projects and other heterogeneity associated with each project. *Potential Competitors* indicates how many other firms have the project within their 60 mile service area and could feasibly bid on the project as well. The *Bid Proposal* variable consists of a set of categorical dummy variables indicating how many other firms have purchased bid proposals. Equation (A) expresses this first specification of the bid function:

(A)
$$\begin{aligned} y &= \beta_0 + \beta_1(\text{Distance}) + \beta_2(\text{Jobs Under Contract}) + \beta_3(\text{Engineer's Estimate}) + \\ &+ \beta_4(\text{Potential Competitors}) + \beta_5(\text{Bid Proposals}) + \varepsilon \end{aligned}$$

[34] J.S. Butler and Chris Bollinger added invaluable insights into reasons why the linear probability model is the preferred approach for this particular analysis.
[35] We also estimated bid functions using distance and distance squared. These results were similar to the results with the categorical variables.

In a market environment with geographically dispersed asphalt firms and geographically dispersed paving projects and with no political boundaries defining the location of projects and firms, we would expect the cost variables, especially distance, to be significant determinants of bidding behavior. We would expect the competitive/strategic variables to play a bigger role in thinner markets than in thicker markets. In such an environment with no obvious focal point, it would be difficult for firms to coordinate their bidding.

In a market environment where firms and projects are defined by their location inside or outside certain political boundaries, such as county lines in Kentucky, firms may be able to coordinate their bidding, especially when only a few are involved. In that case location relative to political boundaries would take on greater importance in predicting bidding behavior, and actual distance from plant to project may take on lesser importance. To test for the importance of these political boundary-location effects, we expand the specification of the bid function as follows:

(B)
$$y = \beta_0 + \beta_1(\text{Distance}) + \beta_2(\text{Jobs Under Contract}) + \beta_3(\text{Engineer's Estimate}) + \\ + \beta_4(\text{Potential Competitors}) + \beta_5(\text{Bid Proposals}) + \beta_6(\text{County : All}) + \varepsilon$$

The *County: All* variable is a set of dummy variables that captures the four scenarios depicted in Figure 2. *Project in same county-no rival* (depicted as County A in Figure 2) is the reference category for most firms and is excluded from the regression. This variable indicates that a project is located in a county where the firm has an asphalt plant, and where no rival firms have an asphalt plant. *Project in same county-rival* (depicted as County C in Figure 2) indicates a project that is in the same county, and a rival firm also has an asphalt plant in that county.[36] *Project in adjacent county-rival* (depicted as County B in Figure 2) indicates a project that is in an adjacent county, and a rival firm has an asphalt plant in the county. *Project in adjacent county-no rival* (depicted as County D in Figure 2) indicates that a project is in an adjacent county that does not have an asphalt plant in the county.

If in a thin market firms are able to use county boundaries to coordinate bids, these variables will allow us to identify such behavior. If firms X and Y in Counties A and B in Figure 2 are able to solve the coordination game depicted earlier by only bidding within their own county and thereby achieve the dominant Nash equilibrium, then the *Project in adjacent county-rival* variable will be negative and significant, all else constant. This result would mean that, even after controlling for distance, a firm is

[36] Since some firms only have asphalt plants in counties where rival firms also have asphalt plants, in these cases *Project in same county-rival* is used as the reference category.

less likely to bid on a project simply because it is in a county where a rival has an asphalt plant. This result would therefore support a conclusion that firms are tacitly colluding in bidding and "respecting" one another's turf.

Before actually estimating the two above bid functions, it is instructive to look at an example of actual bidding where the results are so obvious that no regression actually needs to be run. Figure 4 illustrates the bidding behavior of four central Kentucky asphalt contractors. The major urban center, Lexington, is located in Fayette County, which is surrounded by Scott, Bourbon, Clark, and Madison Counties.[37] ATS Construction has two asphalt plants in Fayette County, which are indicated in the first panel of Figure 4. The projects that ATS bid on from 2005 to 2007 are indicated by small red dots, and projects within its service area which it feasibly could have served but did not bid on are indicated by small black circles. With only one exception, ATS bid exclusively on projects located in Fayette County, where its asphalt plants are located.[38] Even though there were dozens and dozens of projects in close proximity to its plants. ATS refrained from bidding on several projects in adjoining counties that were actually closer to its plants than other projects within Fayette County that were farther away.

Nally & Gibson's bidding behavior is illustrated in the second panel of Figure 4. Its asphalt plant is located just north of Lexington in Scott County, and the projects which it did and did not bid on are indicated by red dots and black circles. Nally & Gibson bid exclusively in Scott County. Hinkle Contracting's bidding behavior is illustrated in the third panel. It bid in Bourbon County and in counties north and west of Bourbon County, but never in Scott, Fayette, or Clark counties where the other three companies had asphalt plants. The Allen Company's bidding behavior is illustrated in the fourth panel. Their asphalt plant is located in Madison County, but right on the border with Clark County. The Allen Company bid in both Clark and Madison Counties, but never in Fayette or Bourbon Counties where ATS and Hinkle had plants.

Empirical Results

Now we are ready to discuss the results of the bid function estimations for the 31 firms. There is considerable variation in the estimated bid functions, corresponding to the type of market environment each firm operates in. The entire set of results is voluminous (and available from the authors), but we have selected representative examples to illustrate the different situations: (1) large

[37] The Lexington-Fayette, KY MSA had a population of 687,173 in 2010.

[38] The only project outside Fayette County that ATS bid on was located in Woodford County, where there are no asphalt plants.

urban markets that can support multiple firms, (2) sparsely populated rural areas that can support at most one asphalt supplier, and (3) somewhat more populated areas that can support geographically dispersed oligopolists. We discuss each in turn.

Competitive Markets

There are three market areas where there is enough paving business to support multiple firms: northern Kentucky across the Ohio River from Cincinnati, Louisville, and Lexington. Both northern Kentucky and Louisville are fairly competitive bidding markets, whereas Figure 4 illustrates that in the Lexington MSA asphalt companies have clearly delineated territories where each one bids.

The northern Kentucky region is designated District 6 by KYTC and consists of three densely populated urban/suburban counties (Boone, Kenton, and Campbell) just south of Cincinnati, four suburban/rural counties (Gallatin, Grant, Pendleton, and Bracken) ringing those three counties, and four more rural counties (Carroll, Owen, Harrison, and Robertson) farther south. These counties and the location of different firms' asphalt plants are illustrated in Figure 5. Five firms have a total of 13 plants in these 11 counties, with 11 of the plants being located in the more populated areas closest to Cincinnati. The bids submitted in the seven counties closest to Cincinnati are broken down into multi-bid and single-bid projects in Table 3. Out of 84 projects, 73 (87%) attracted more than one bid at an average winning bid that was 16 percent below the engineer's estimate.

Firm-specific plant location and bidding maps are included in Figure 6 for Barrett Paving, Figure 7 for Bluegrass Paving, and Figure 8 for Eaton Asphalt Paving. The first three columns of Table 4 contain the bid function regression results using both specifications (A) and (B) for each of the three firms. Barrett, Bluegrass, and Eaton compete vigorously and bid extensively in Boone, Kenton, and Campbell Counties. Each bids more selectively in Gallatin, Grant, Pendleton, and Bracken Counties. A fourth firm, Mago Construction, bids extensively in Pendleton and Bracken counties, and selectively in Campbell County, but does not bid in the other counties.

Since Barrett, Bluegrass, and Eaton compete in a fairly dense market in the northernmost counties close to Cincinnati, we analyze their bid functions to see whether econometric estimation supports visual impressions. The Table 4-column (A) results for each of the three firms reveals that distance is a significant predictor of bidding behavior. Barrett and Eaton, with multiple plants, are significantly less likely to bid on projects more than 20 miles from one of their plants. Bluegrass, with only one plant, is less likely to bid on projects more than 10 miles from its plant, with the likelihood of bidding falling even further more than 20 miles out. Bluegrass with its one plant does face capacity issues—the number of jobs it has under contract does significantly reduce the likelihood that it bids on another project. Eaton is less likely to bid on bigger jobs, as measured by the engineer's estimate. Eaton is also less likely to bid if rival firms have purchased bid proposal packets in preparation to bid on a project.

Now we are ready to see whether these three firms coordinate their bids along county boundaries, i.e. tacitly collude, in an effort to suppress competition and raise bid levels. To conduct that test we add county identifiers that indicate own or adjoining county without or with rival asphalt plants. If coordination is occurring we expect these county identifiers to significantly explain observed bidding behavior, perhaps with the distance variables dropping in importance. These regression results are contained in Table 4-Column (B) for the three firms.

The distance variables remain statistically significant and relatively unchanged for all three firms. Their bidding decisions are primarily determined by how far away a project is from one of their plants, especially in the three most populous counties, Boone, Kenton, and Campbell. The county identifiers *Project in adjacent county-rival* and *Project in adjacent county-no rival* are significant for both Barrett and Eaton. For Barrett, these two variables appear to capture Barrett's reluctance to bid in Pendleton County, where Mago has three plants, Harrison County, where only Hinkle Contracting bids, Scott County, where only Nally & Gibson bids, and Owen County, where Eaton, Mago, and Ohio Valley all bid. For Eaton, visual inspection of Figure 8 does not reveal any pattern that would explain the statistical significance of these two variables. Eaton appears to bid without regard to county lines.

The importance of these results is that distance from plant seems to be the primary determinant of bidding for firms in the thick and competitive northern Kentucky market. The addition of county identifiers does not change this fundamental relationship. Fifty-nine out of sixty of the projects put up for bid in Boone, Campbell, Grant, and Kenton Counties from 2005 to 2007 attracted multiple bidders, and averaged 14-17 percent below the engineer's estimate. This is a highly competitive market with no evidence of bid coordination among the market participants.

Natural Monopoly

The far eastern part of Kentucky is mountainous and lightly populated. The road network is sparse and commercial asphalt paving opportunities are not plentiful. For several decades there has been one asphalt paving company, Mountain Enterprises Incorporated (MEI), in eastern Kentucky. It operates a number of plants in different counties, opening and closing them intermittently and staffing them with plant and paving crews that rotate from one location to another. Arguably the market will only support one efficient-sized producer.

Plant locations for Mountain Enterprises are illustrated in Figure 9. As can be seen, a significant portion of its geographic market cannot be feasibly served by any other asphalt supplier. As a result, MEI is the only bidder on the vast majority of projects in its service territory. Table 5 contains bidding information for the seven counties in KYTC Region 12 plus three counties in KYTC Region 11 where MEI is best described as a natural monopoly. Mountain Enterprises was the only bidder in 100 out of 106 projects put out for bid in those counties. It won those auctions with bids that were on average 5.5 % above the state engineer's cost estimate.

Figure 10 illustrates MEI's plant locations and the projects it did and did not bid on, and the fourth column of Table 4 contains the bid function regression results using both specifications (A) and (B). The bid location map shows that Mountain Enterprises routinely bid on all asphalt paving jobs put out for bid by the KYTC in each of the counties it served, and also routinely refrained from bidding on asphalt paving jobs put out for bid in counties on the fringe of its service territory that it did not serve.

This visual impression is supported by the regression results contained in Table 4. The column (A) results indicate that MEI is significantly less likely to bid on projects thirty or more miles from one of their plants. MEI is also significantly less likely to bid on projects where even one rival firm purchased a bid proposal package from KYTC prior to the bid letting. When county identifiers are included in the base regression specification, the distance categorical variables retain significance but diminish in magnitude. MEI continues to avoid bidding on projects where another competitor has purchased a bid proposal package. Finally, *Project in adjacent county-rival* has a large negative and significant effect on the likelihood that MEI submits a bid, indicating that county lines play an important role in bidding decisions even in this geographical market where competitors are few and far between.

Duopoly/Oligopoly

The importance of county boundaries as a focal point that facilitates tacit collusion is very clear in the greater Lexington MSA as discussed earlier and illustrated in Figure 4. For one of the companies, Nally & Gibson, the bid function regression collapses when county identifiers are included. It was the one and only bidder on all projects in Scott County, and did not bid elsewhere. The other companies scrupulously avoided bidding in counties where a rival firm had an asphalt plant. Similar behavior is evident from the bidding in eastern Kentucky of Mountain Enterprises and rival firms. Along the "borders" of its feasible service territory MEI carefully observed county boundaries and bid in counties where it had plants and did not venture out into counties where rival firms had plants. MEI's rivals for the most part reciprocated.

There are a number of other geographically dispersed oligopoly markets in Kentucky that exhibit the same collusive bidding patterns. For example, Nally & Haydon Surfacing operates three asphalt plants and bids in four counties in central Kentucky: Washington, Marion, Taylor, and Green. The location of these plants and counties can be seen in Figure 11, which also illustrates asphalt plants belonging to other firms in the surrounding counties. Figure 12 illustrates Nally & Haydon's bidding behavior—the projects it did and did not bid on. As can be seen, Nally & Haydon bid exclusively in these four counties. Inspection of the bidding maps of surrounding paving companies reveals that no other firms bid in any of the four counties during the 2005 to 2007 period.

The fifth column of Table 4 contains the results of estimating Nally & Haydon's bid function. Specification (A) indicates that distance is a significant predictor of bidding. Capacity constraints and potential competitors also are statistically significant. When county indicators are added to the regression, however, distance becomes less important—coefficient magnitudes and significance diminish. The variables *Project in adjacent county-no rival* and *Project in adjacent county-rival* are both negative and significant. The former result bears closer scrutiny. Nally & Haydon always bid in Taylor County, never facing any competition. It never bid in Metcalfe and Larue Counties, neither of which had asphalt plants but were served (exclusively) by Scotty's Contracting and Stone. When specific county identifiers are substituted for the generic variable, *Project in adjacent county-no rival*, the fit is perfect on *Project in adjacent county-rival* and the county dummies for Taylor, Metcalfe, and Larue Counties.

Inducing Cooperation: The Easy Way and the Hard Way

Our discussion of tacit collusion would not be complete without examples of how rival firms elicit cooperative bidding behavior from one another. One easy and obvious way to eliminate competition is to acquire one's competitors. In the far western corner of Kentucky, H&G Construction competed with Jim Smith Contracting Company and Murray Paving during the 2005-2007 sample period. As Figure 3 shows, H&G bid extensively in the ten far western counties, competing against Jim Smith Contracting in nine of the counties and against Murray Paving in Calloway County. Since Jim Smith

Contracting and Murray Paving shared ownership, H&G Construction was the prototype of a "maverick firm."[39]

The impact of H&G's presence in this geographic market is evident from the bidding outcomes. Jim Smith won 72 contracts at an average of 5.96% below the state engineer's estimate. Murray won 4 contracts at an average of 1.74% below the engineer's estimate. H&G won 14 contracts at an average of 5.64% below the engineer's estimate. By way of contrast, the Rogers Group had asphalt plants and was the only bidder in the three counties—Crittenden, Caldwell, and Trigg— ringing the ten westernmost counties. Jim Smith/Murray Paving did not bid into the Rogers Group's territory, and the Rogers Group reciprocated. As the only bidder in Crittenden, Caldwell, and Trigg counties, the Rogers Group won 50 contracts at an average of 3.24% over the engineer's estimate.

Given the nearly complete overlap of H&G's feasible service territory with Jim Smith/Murray's service territory, no obvious solution to the coordination game suggests itself. Absent overt collusion, a cooperative outcome would not seem to be possible. No solution, that is, unless the merger of the two firms would not trigger a Hart-Scott-Rodino notification. Indeed that was apparently the case, because in October 2007 Jim Smith Contracting announced that it was acquiring H&G Construction—an easy solution to the "problem".[40]

Another way to induce cooperation in a repeated game is retaliation—moving aggressively against a rival that has abrogated a collusive agreement. Adjacent to the counties served by Nally & Hayden (illustrated in Figure 11) are Glass Paving and Scotty's Contracting and Stone. Glass Paving had the only asphalt plant in Hart County, while both Glass and Scotty's had plants in Barren County just south of Hart County. Glass Paving was the only bidder in Hart County, while both firms bid in Barren County. Since it had 12 asphalt plants spread around the region, Scotty's bid extensively in surrounding counties as well.

On July 21, 2006 Scotty's Contracting submitted a bid on a large project in Hart County, where it had previously refrained from bidding. Glass Paving was obviously aware that Scotty's might submit a bid, because it deviated from its usual strategy in Hart County of bidding several percentage points above the engineer's estimate. Glass won the bid by going 10% below the state engineer's estimate for the job, costing it well over $100,000 compared with the usual outcome when it was the only bidder.

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[39] The 2010 USDOJ/FTC Merger Guidelines (p. 18) recognize the existence of mavericks—smaller firms that have an outsized effect on competition as a result of their aggressive market behavior. The Guidelines suggest that acquisition of a maverick rival deserves special consideration.

[40] "Competing Contractors Combine Companies: H&G Construction Brings Strength in Bridge-building to Smith Contracting." *Paducah Sun*, 10/4/07.

Glass had the opportunity to express its displeasure in the next KYTC bid letting. On August 11, 2006 Glass Paving retaliated and bid on projects in Edmonson, Metcalfe and Monroe Counties. Neither Glass nor Scotty's had asphalt plants in these counties, but previously Scotty's had been the only bidder. Glass submitted bids that were 4.3% above, 6.9% below, and 7.3% below the engineer's estimate in Edmonson, Metcalfe, and Monroe, respectively. Scotty's won all three bids, albeit by going much lower that its previous bids in those counties. Apparently the message was received, because Scotty's did not bid again in Hart County for the remainder of the sample period.

Summary and Conclusions

Detection and deterrence of collusion are perhaps the primary challenges of antitrust policy. Economists are frequently called upon to play the role of detective in diagnosing collusion in public procurement auctions. Often such collusion is overt and involves determining a winner and the submission of complementary bids. Alternatively, firms may reciprocally refrain from bidding. When the number of bidders is small and there is an obvious focal point for such coordination, firms may successfully suppress competition without direct communication.

In certain geographic markets, the asphalt paving industry lends itself to such tacit collusion. Given the technology of paving roads, firms have limited feasible service territories. Thinner markets may only be able to support a limited number of suppliers. Certain elements of the institutions of highway procurement auctions also create a market environment that facilitates collusive outcomes.

To determine whether such collusion might occur we collected data on asphalt paving bid lettings by the Kentucky Transportation Cabinet from 2005 to 2007. We estimated bid functions for each of the 31 registered asphalt contractors in Kentucky. Whether a firm bids on a project within its feasible service territory was estimated as a function of cost factors such as distance from plant to project, capacity constraints, and scale of the project and strategic factors such as the number of actual or potential rivals. We included county identifier variables to see if firms use county boundaries as focal points to coordinate their bidding.

Our empirical analysis identified three types of markets: (1) large urban markets with several competitors where bidding is competitive; (2) regions with only one economically viable supplier and commensurately elevated bids; and (3) regions with two or three potential competitors but where firms appear to tacitly refrain from bidding, resulting in single-bidder auctions with prices approaching monopoly levels. In dispersed oligopoly markets, the norm is that firms bid in counties where they have an asphalt plant, and refrain from bidding in counties where a rival firm has an asphalt plant. Since 72 out of 120 counties in Kentucky have one and only one asphalt plant, it is not surprising that county boundaries are such an obvious focal point for firms to coordinate their bidding activity.

The upshot is that 63 percent of asphalt paving contracts attracted only a single bidder from 2005 to 2007. Winning bids for single-bid asphalt projects averaged 2.2 percent above the engineer's estimate, compared with 13.5 percent below the engineer's estimate for auctions that attracted two bidders. Since Kentucky spent over $600 million on asphalt paving contracts during the period, the potential savings to the state from increasing competition are substantial.

Several policy changes suggest themselves. Adam Smith would probably discourage social functions for contractors sponsored by the KYTC on the eve of a bid letting. Requiring bidders to publicly declare their intent to bid by publicizing the list of firms that have purchased official plans allows rivals to adjust their bids downward in response to the threat of entry, and thereby reduces the expected gain and hence likelihood of entry by a non-cooperating bidder. A final change likely to enhance competition in highway procurement auctions would be to remove the focal point that facilitates collusion, namely, do not delineate projects by county lines. The state could go one step further and structure projects so that they are within the potential service territories of multiple asphalt plants.

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Table 1: Summary Statistics of All KYTC Projects in Kentucky – 2005 to 2007

	Number of Projects		Total Value of Projects ($ in millions)		Over or Under Engineer's Estimate (%)	
Number of Bidders	Asphalt Paving	All Other Projects*	Asphalt Paving	All Other Projects*	Asphalt Paving	All Other Projects*
1	680	154	437.8	737.6	2.22	2.38
2	287	223	121.8	800.8	-13.53	-6.02
3	76	211	36.0	488.3	-16.73	-13.22
4	29	153	11.4	174.4	-15.35	-16.02
5	3	83	1.8	144.0	-14.15	-19.52
6		43		49.8		-17.22
7		23		44.0		-21.30
8		12		17.1		-16.07
9		7		4.6		-26.08
12		1		0.7		-11.05
Grand Total	**1075**	**910**	**608.8**	**2,461.1**	**-3.84**	**-10.39**

*These other projects include grade and drain, bridge, mowing, concrete, etc. Some of these projects have asphalt components as part of the project.

Table 2: Firm Bidding and the Value of Winning Contracts

		Asphalt Paving Projects Bid on		Asphalt Paving Contracts Won	
Firms	Number of Plants	Number of Bids	Firm only bidder on project (%)	Number of Projects Won	Contracted Value of Winning Projects ($)
THE ALLEN COMPANY INC	3	54	50	49	15,308,473.15
ATS CONSTRUCTION	2	21	100	21	39,934,777.30
BARRETT PAVING MATERIALS INC	3	63	0	16	4,376,192.58
BLACKTOP INDUSTRIES & EQUIPMENT COMPANY	1	11	0	2	528,974.50
BLUEGRASS PAVING	1	31	0	8	2,227,065.31
COMMERCIAL PAVERS INC	3	53	0	24	18,353,377.60
EATON ASPHALT PAVING CO INC	5	99	3	43	12,210,883.50
ELMO GREER & SONS LLC	10	69	55	66	34,306,098.30
FLYNN BROTHERS CONTRACTING INC	2	31	0	6	2,987,221.00
GADDIE-SHAMROCK LLC	3	29	79	28	26,117,688.71
GLASS PAVING INC	2	20	70	16	10,558,645.85
H & G CONSTRUCTION COMPANY INC	1	77	0	14	6,106,025.76
H G MAYS CORPORATION	3	38	45	32	16,388,222.00
HINKLE CONTRACTING CORPORATION	11	107	92	103	51,571,836.47
JIM SMITH CONTRACTING COMPANY LLC	3	86	14	72	29,068,199.65
KAY & KAY CONTRACTING LLC	1	33	0	3	719,879.00
LEXINGTON QUARRY COMPANY	1	17	76	14	7,117,499.10
LINCOLN COUNTY READY MIX INC	1	28	0	5	2,226,384.48
MAGO CONSTRUCTION COMPANY LLC	12	102	46	88	38,670,973.43
MOUNTAIN ENTERPRISES INC	13	150	87	144	77,543,544.78
MURRAY PAVING	1	4	25	4	1,765,535.60
NALLY & GIBSON GEORGETOWN LLC D/B/A	1	11	100	11	4,804,703.60
NALLY & HAYDON SURFACING LLC	3	30	97	30	12,967,285.12
OHIO VALLEY ASPHALT LLC	3	33	39	27	7,344,865.32
QUALIFIED PAVING LLC	1	17	0	10	7,281,674.44
ROAD BUILDERS & PARKWAY CONSTRUCTION LLC	2	38	76	33	24,192,496.38
ROGERS GROUP INC	5	55	71	50	37,252,115.20
SCOTTY'S CONTRACTING AND STONE LLC	12	119	61	96	69,271,902.25
SHELBYVILLE ASPHALT COMPANY LLC	1	6	17	3	692,378.10
THE WALKER COMPANY OF KENTUCKY INC	2	22	86	21	7,110,045.55
YAGER MATERIALS LLC	1	28	68	21	24,133,747.90

Table 3*:* **Summary of Bidding for Counties in Northern Kentucky**

	Multi-bid projects			Single-bid projects		
COUNTY	Number of Projects	Contracted Value of Projects	% Value Over/Under Engineer's Estimate	Number of Projects	Contracted Value of Projects	% Value Over/Under Engineer's Estimate
Boone	17	$ 4,436,877.11	-16.27			
Bracken	6	$ 976,928.23	-15.28	3	$ 1,415,728.80	-4.08
Campbell	15	$ 3,459,520.00	-17.75			
Gallatin	4	$ 858,039.21	-12.14	2	$ 305,804.00	-3.64
Grant	9	$ 2,970,340.01	-17.15			
Kenton	18	$ 5,562,071.10	-14.74	1	$ 257,550.00	-26.33
Pendleton	4	$ 1,569,399.70	-13.59	5	$ 1,852,404.03	0.08
TOTAL	**73**	**$ 19,833,175.36**	**-15.83**	**11**	**$ 3,831,486.83**	**-4.13**

Table 4: Regression Results for Northern Kentucky Firms, Mountain Enterprises, and Nally & Haydon Surfacing

	Barrett Paving		Bluegrass Paving		Eaton Asphalt Paving		Mountain Enterprises		Nally & Haydon Surfacing	
VARIABLES	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)
Distance (11 to 20 miles)	-0.00590	0.0156	-0.255*	-0.227*	-0.0491	-0.0666	0.0358	0.0452	-0.101	0.0391
	(0.0637)	(0.0572)	(0.133)	(0.134)	(0.0808)	(0.0839)	(0.0363)	(0.0302)	(0.0891)	(0.0679)
Distance (21 to 30 miles)	-0.591***	-0.379***	-0.544***	-0.428**	-0.245***	-0.185*	-0.0853*	-0.0297	-0.409***	-0.219*
	(0.112)	(0.117)	(0.139)	(0.167)	(0.0937)	(0.0972)	(0.0444)	(0.0377)	(0.143)	(0.114)
Distance (31 to 40 miles)	-0.897***	-0.653***	-0.773***	-0.659***	-0.392***	-0.323***	-0.336***	-0.221***	-0.457***	-0.265**
	(0.0579)	(0.0904)	(0.114)	(0.144)	(0.101)	(0.106)	(0.0674)	(0.0566)	(0.144)	(0.116)
Distance (41 to 50 miles)	-0.885***	-0.624***	-0.768***	-0.683***	-0.761***	-0.687***	-0.482***	-0.326***	-0.437***	-0.257**
	(0.0656)	(0.0967)	(0.119)	(0.139)	(0.0750)	(0.0840)	(0.0691)	(0.0582)	(0.142)	(0.114)
Distance (51 to 60 miles)	-0.884***	-0.608***	-0.746***	-0.651***	-0.778***	-0.707***	-0.463***	-0.371***	-0.449***	-0.254**
	(0.0653)	(0.104)	(0.124)	(0.147)	(0.0717)	(0.0793)	(0.0688)	(0.0606)	(0.143)	(0.114)
Jobs Under Contract	-0.00269	-0.00561	-0.157***	-0.151**	0.00779	0.00848	-0.00698**	-0.00363	0.0225**	0.0160*
	(0.0193)	(0.0179)	(0.0582)	(0.0594)	(0.0103)	(0.0102)	(0.00298)	(0.00244)	(0.00950)	(0.00849)
Engineer's Estimate	9.46e-10	1.99e-09	2.10e-07	2.04e-07	-4.82e-08***	-4.49e-08***	-2.04e-08	-1.35e-08	-1.59e-09	-7.19e-10
	(1.48e-09)	(1.82e-09)	(1.38e-07)	(1.33e-07)	(1.78e-08)	(1.63e-08)	(1.51e-08)	(8.92e-09)	(2.21e-09)	(1.82e-09)
Potential Competitors	-0.0149	-0.0169**	0.00292	0.00313	-0.0168**	-0.0172**	-0.0150***	-0.0108*	-0.00405**	-0.00171
	(0.0104)	(0.00835)	(0.0130)	(0.0132)	(0.00802)	(0.00816)	(0.00528)	(0.00601)	(0.00197)	(0.00141)
One competitive bid proposal purchased	0.0373	0.0170	0.111	0.115	-0.241***	-0.0253	-0.491***	-0.320***	-0.619***	-0.432***
	(0.0493)	(0.0475)	(0.0781)	(0.0790)	(0.0803)	(0.0457)	(0.0632)	(0.0574)	(0.116)	(0.119)
Two competitive bid proposals purchased	-0.00684	-0.0206	0.188**	0.196**	-0.108	0.102	-0.548***	-0.277***	-0.681***	-0.501***
	(0.0344)	(0.0446)	(0.0769)	(0.0793)	(0.0779)	(0.0686)	(0.0752)	(0.0789)	(0.108)	(0.112)
Three or more competitive bid proposals purchased					-0.282**	-0.0486	-0.761***	-0.439***	-0.645***	-0.436***
					(0.109)	(0.0940)	(0.137)	(0.113)	(0.113)	(0.119)
Project in same county-rival		-0.0460				-0.109*		0.0151		
		(0.0377)				(0.0656)		(0.0481)		
Project in adjacent county-no rival		-0.276***		-0.0974		-0.300***		-0.0994***		-0.288**
		(0.0736)		(0.134)		(0.0877)		(0.0333)		(0.111)
Project in adjacent county-rival		-0.380***		-0.173		-0.310***		-0.418***		-0.371***
		(0.104)		(0.146)		(0.0878)		(0.0525)		(0.110)
Constant	1.044***	1.179***	0.592***	0.640***	1.162***	1.180***	1.163***	1.108***	1.091***	1.048***
	(0.0526)	(0.0644)	(0.133)	(0.166)	(0.102)	(0.108)	(0.0445)	(0.0373)	(0.0657)	(0.0468)
Observations	182	182	135	135	244	244	279	279	291	291
R-squared	0.803	0.841	0.536	0.547	0.557	0.572	0.828	0.878	0.833	0.862

Robust standard errors in parentheses

Note: The reference cateogry in all specifications is "Project in same county-no rival".

There are some cases where firms only have plants in counties where other rivals have their plants.

In this case "Project in same county-rival" is the reference category.

*** p<0.01, ** p<0.05, * p<0.1

Table 5*:* **Summary of Bidding for Counties in Eastern Kentucky**

	Multi-bid projects			Single-bid projects		
COUNTY	Number of Projects	Contracted Value of Projects	% Value Over/Under Engineer's Estimate	Number of Projects	Contracted Value of Projects	% Value Over/Under Engineer's Estimate
Floyd				10	$ 5,875,309.72	4.87
Harlan				11	$ 7,847,496.45	6.37
Johnson	3	$ 603,329.20	5.98	5	$ 1,714,740.42	4.17
Knott				9	$ 3,140,620.10	5.39
Lawrence	3	$ 877,179.10	-7.53	6	$ 1,842,513.50	7.20
Leslie				10	$10,102,933.72	5.74
Letcher				14	$ 7,069,779.75	9.47
Martin				9	$ 8,943,287.60	2.68
Perry				11	$ 3,891,438.15	5.10
Pike				15	$ 9,491,988.40	3.24
TOTAL	**6**	**$ 1,480,508.30**	**-0.78**	**100**	**$59,920,107.81**	**5.50**

Figure 1: Asphalt Plant Locations in Kentucky

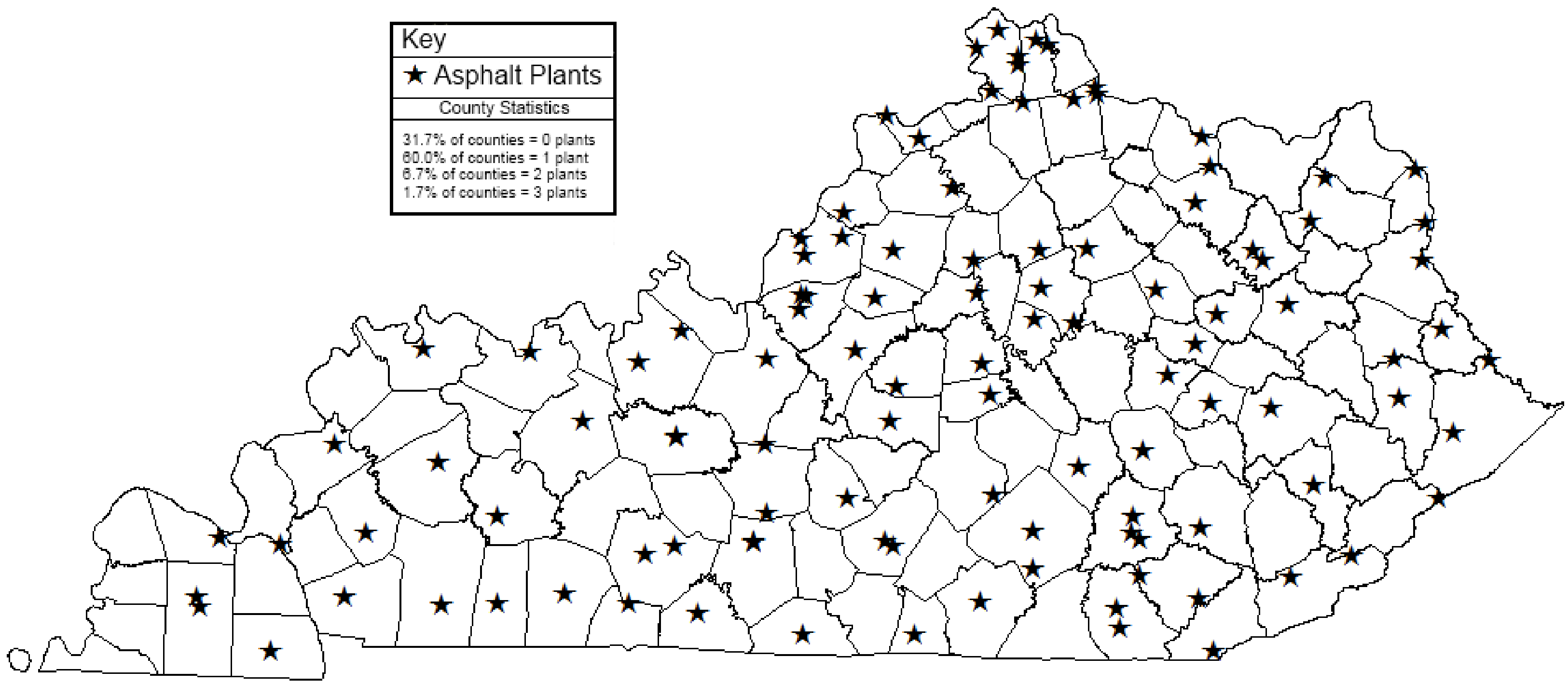


Figure 2: County Boundaries and Bid Coordination

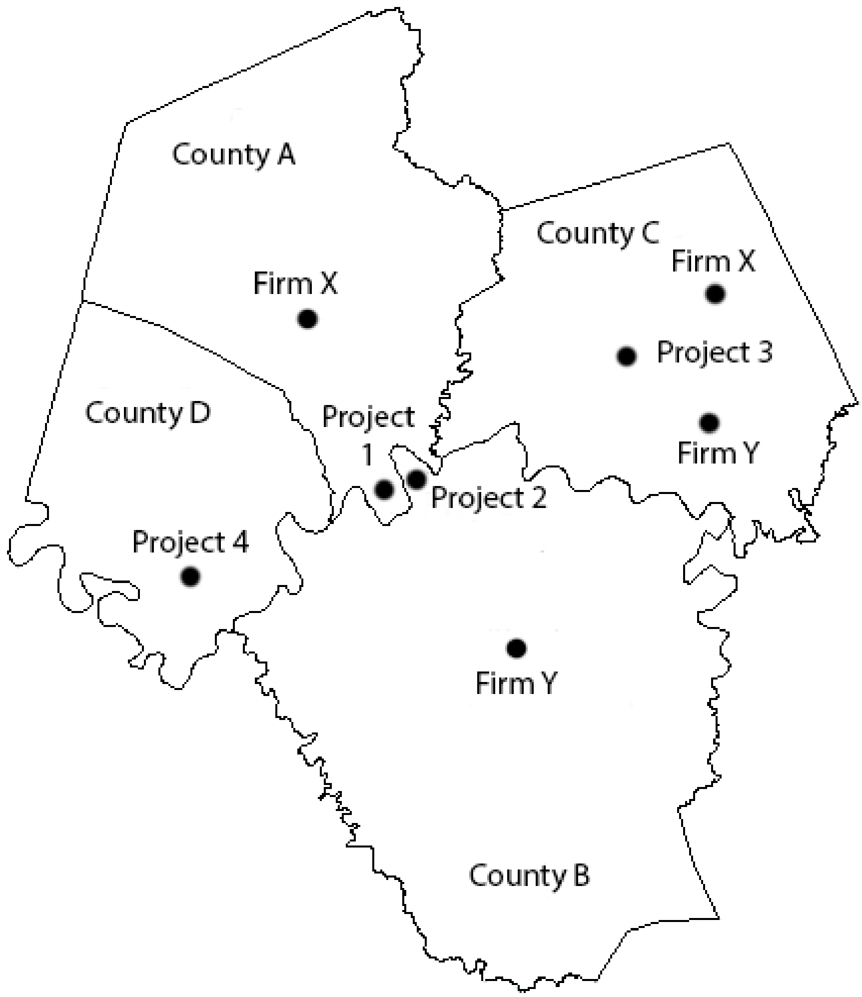


Figure 3: Service area – H&G Construction in Western Kentucky

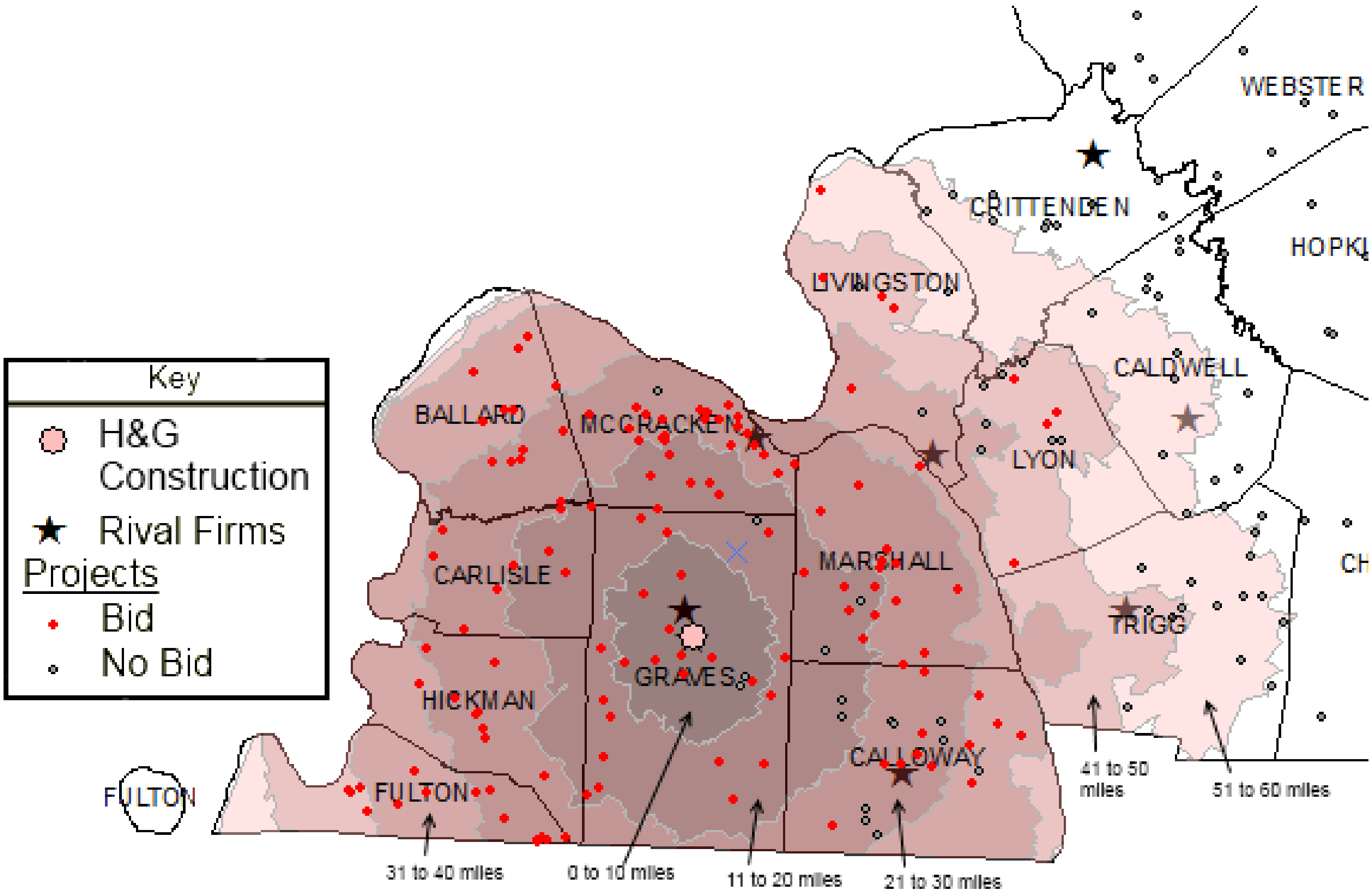
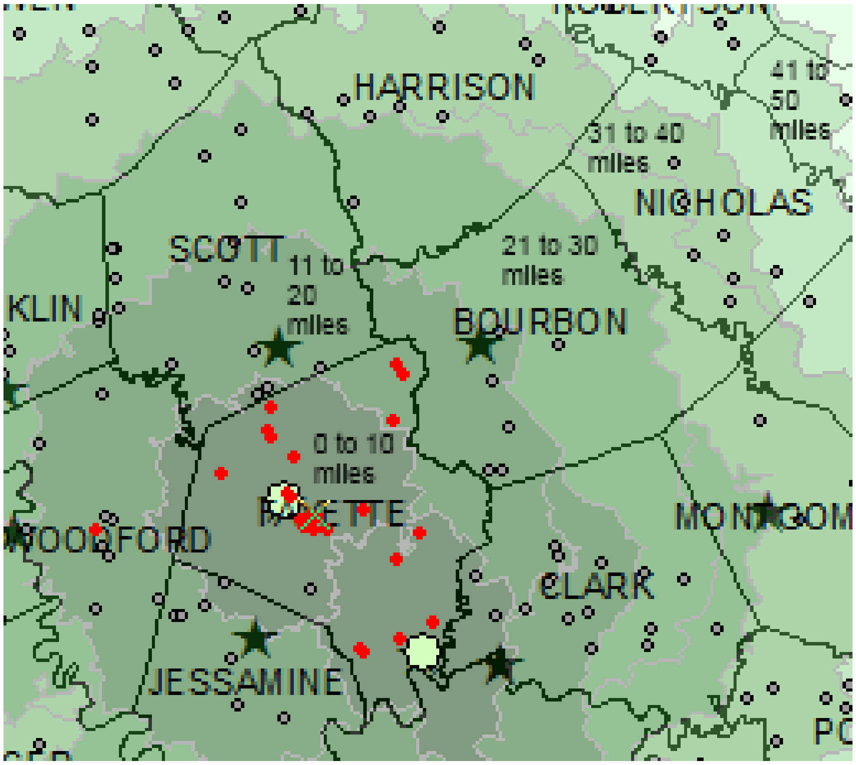
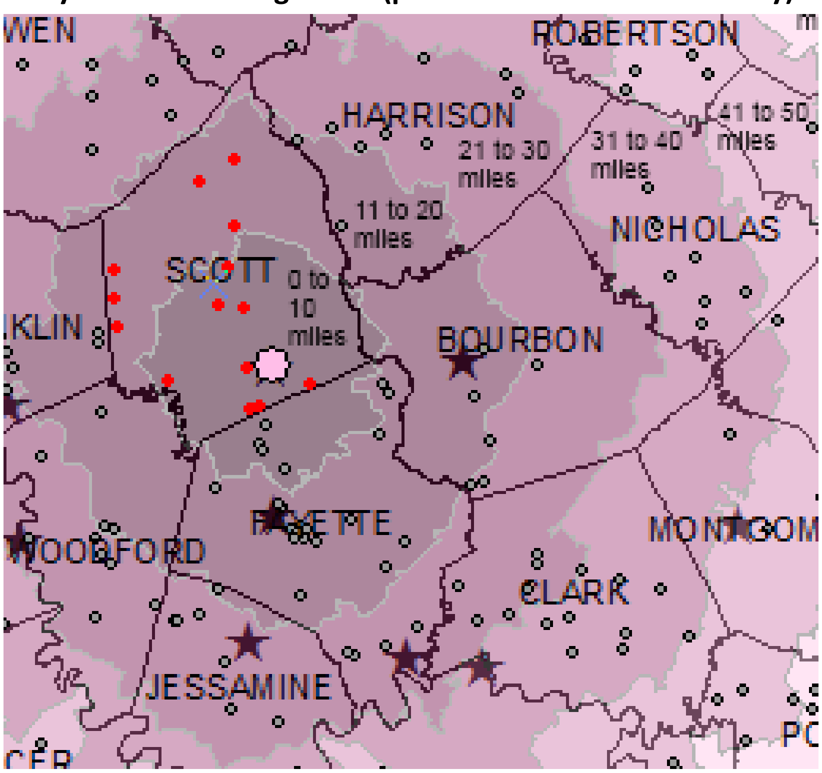


Figure 4: Bidding behavior of four firms in Central Kentucky

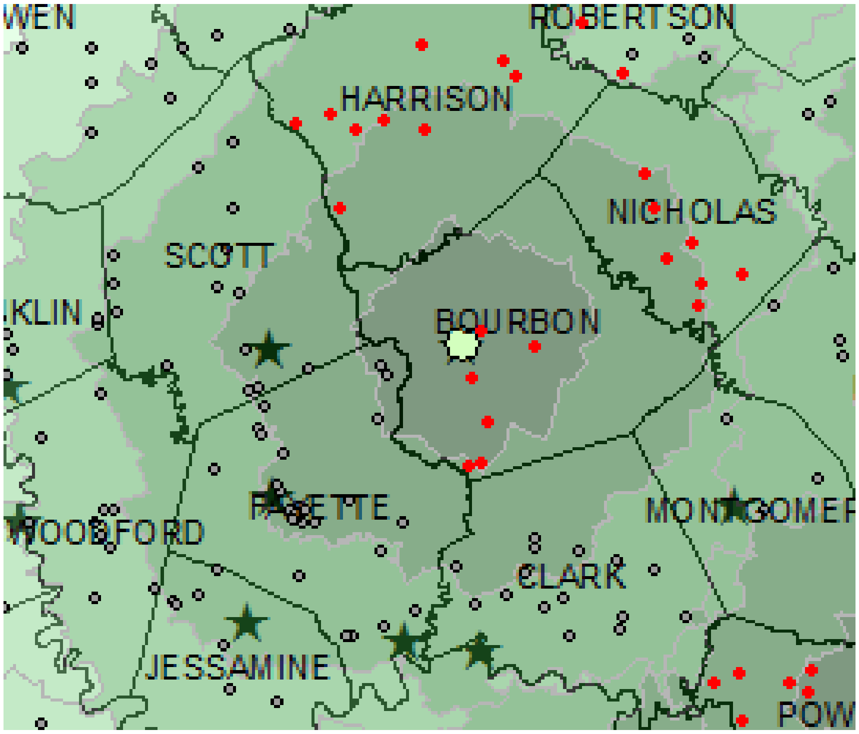
ATS Construction (plant locations in Fayette County)



Nally & Gibson Georgetown (plant location in Scott County)



Hinkle Contracting (plant location in Bourbon County)



The Allen Company (plant location in Clark County)

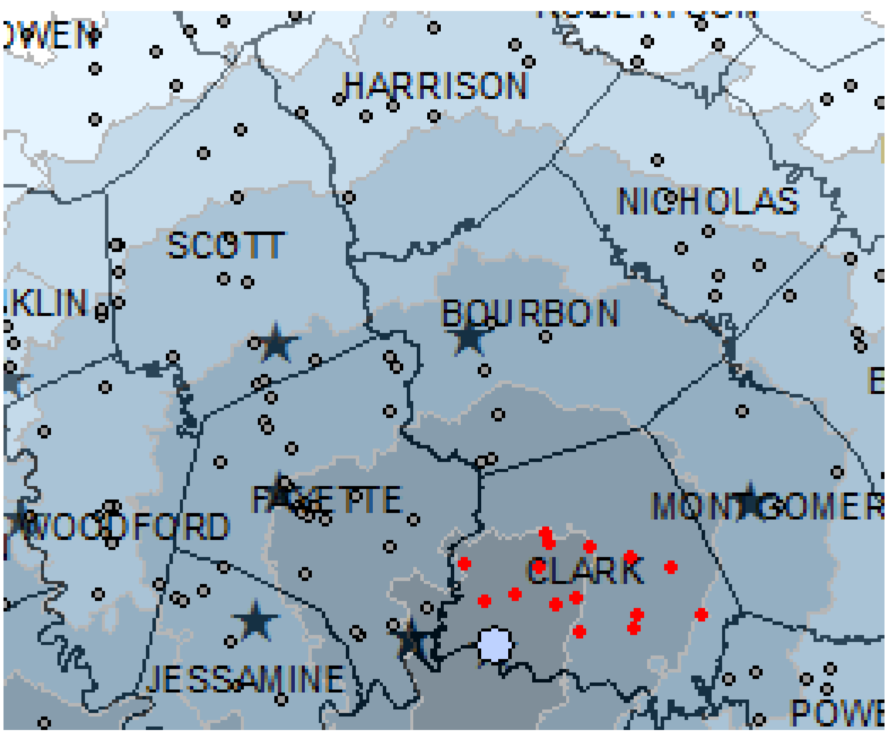


Figure 5: Northern Kentucky (KYTC District 6) Counties, Firms, and Asphalt Plants

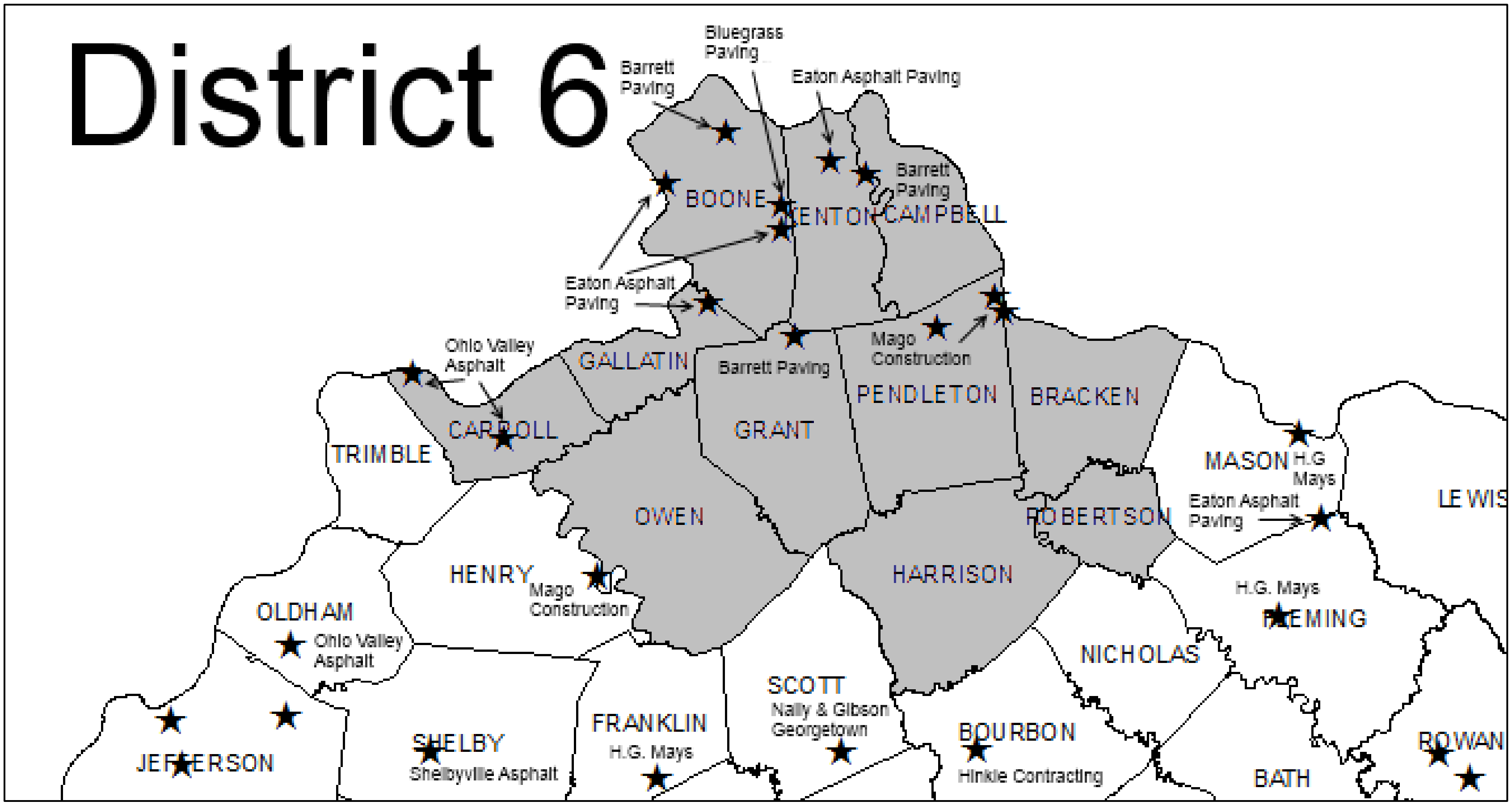


Figure 6: Barrett Paving Service Area

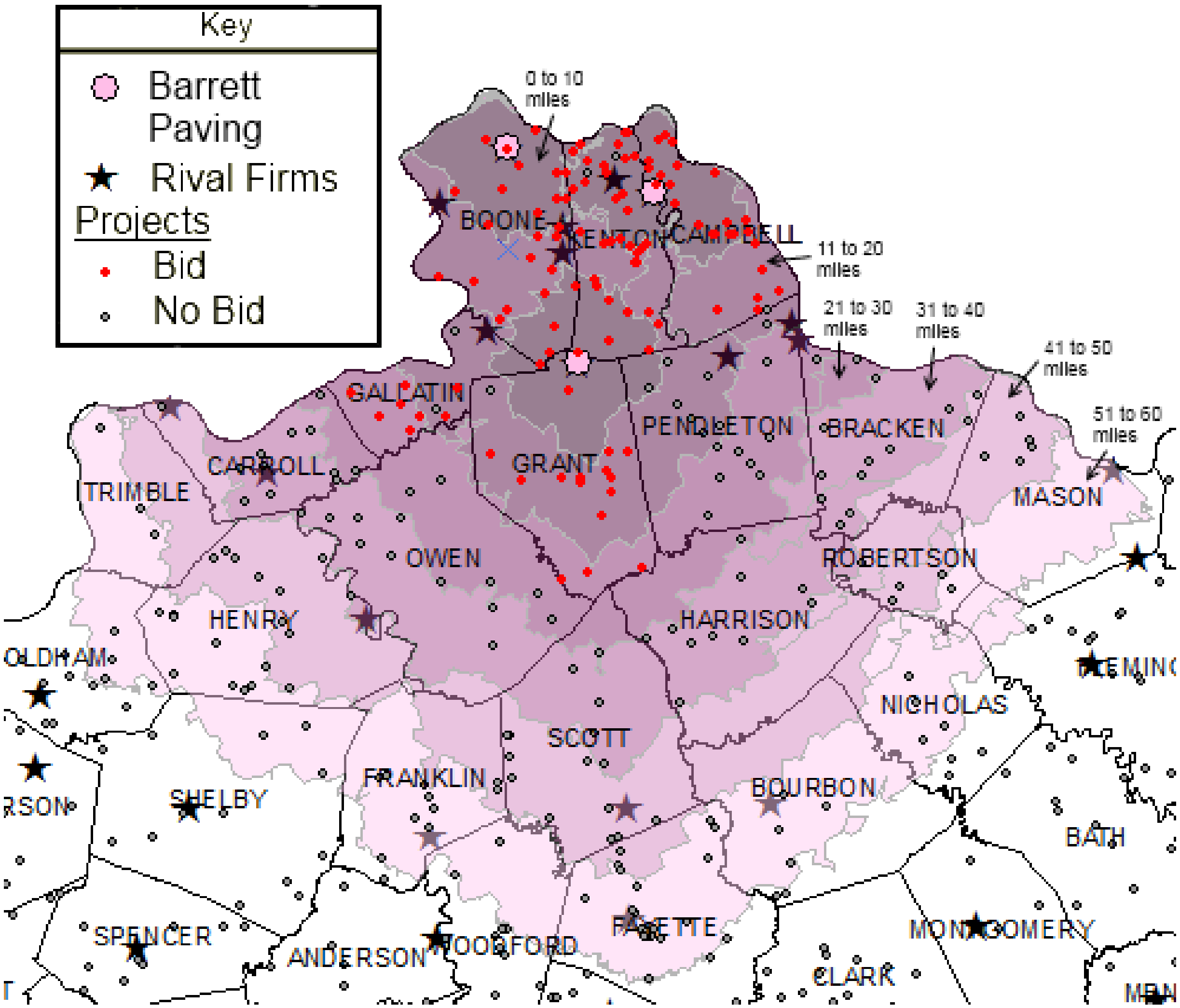


Figure 7: Bluegrass Paving Service Area

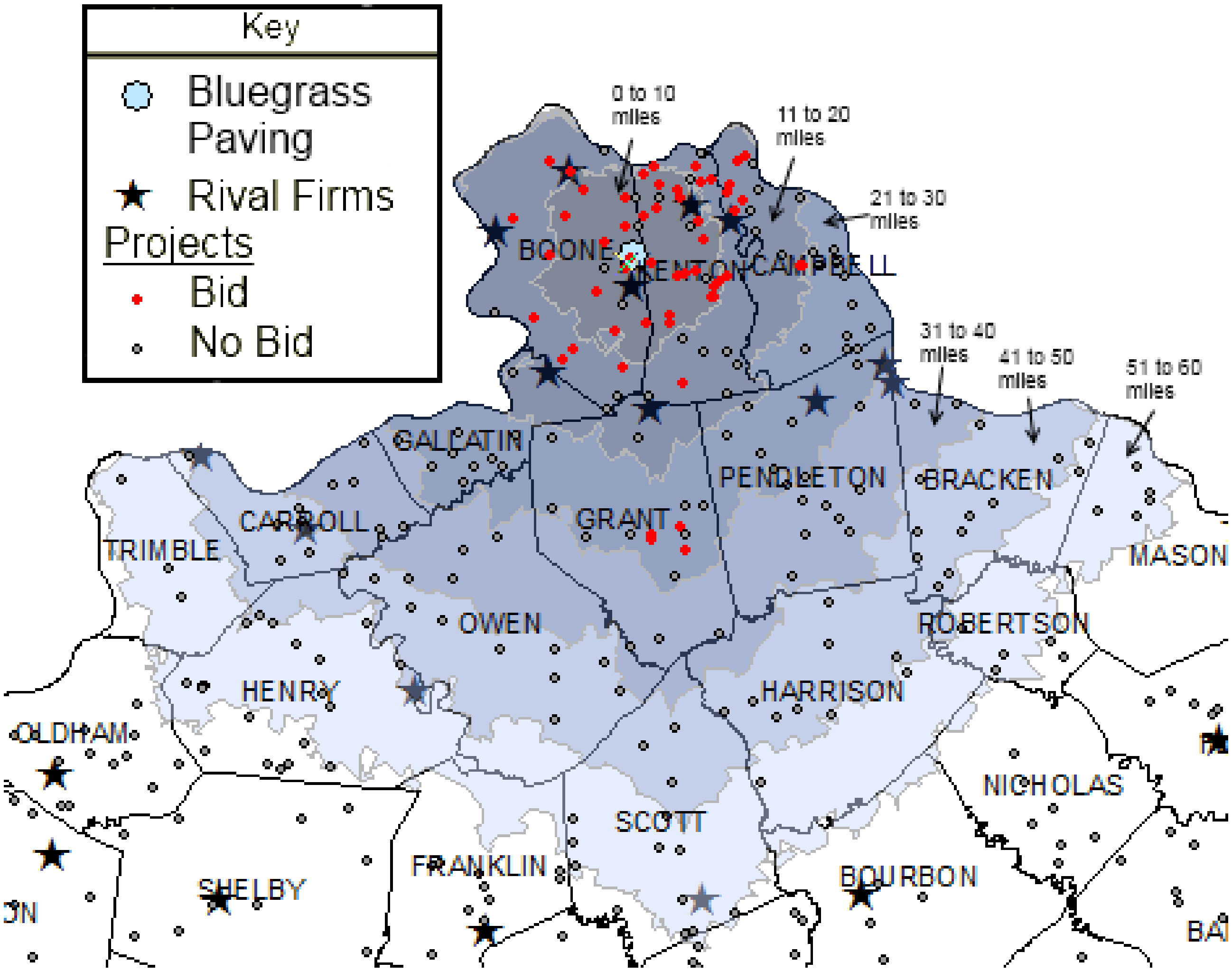


Figure 8: Eaton Asphalt Paving Service Area

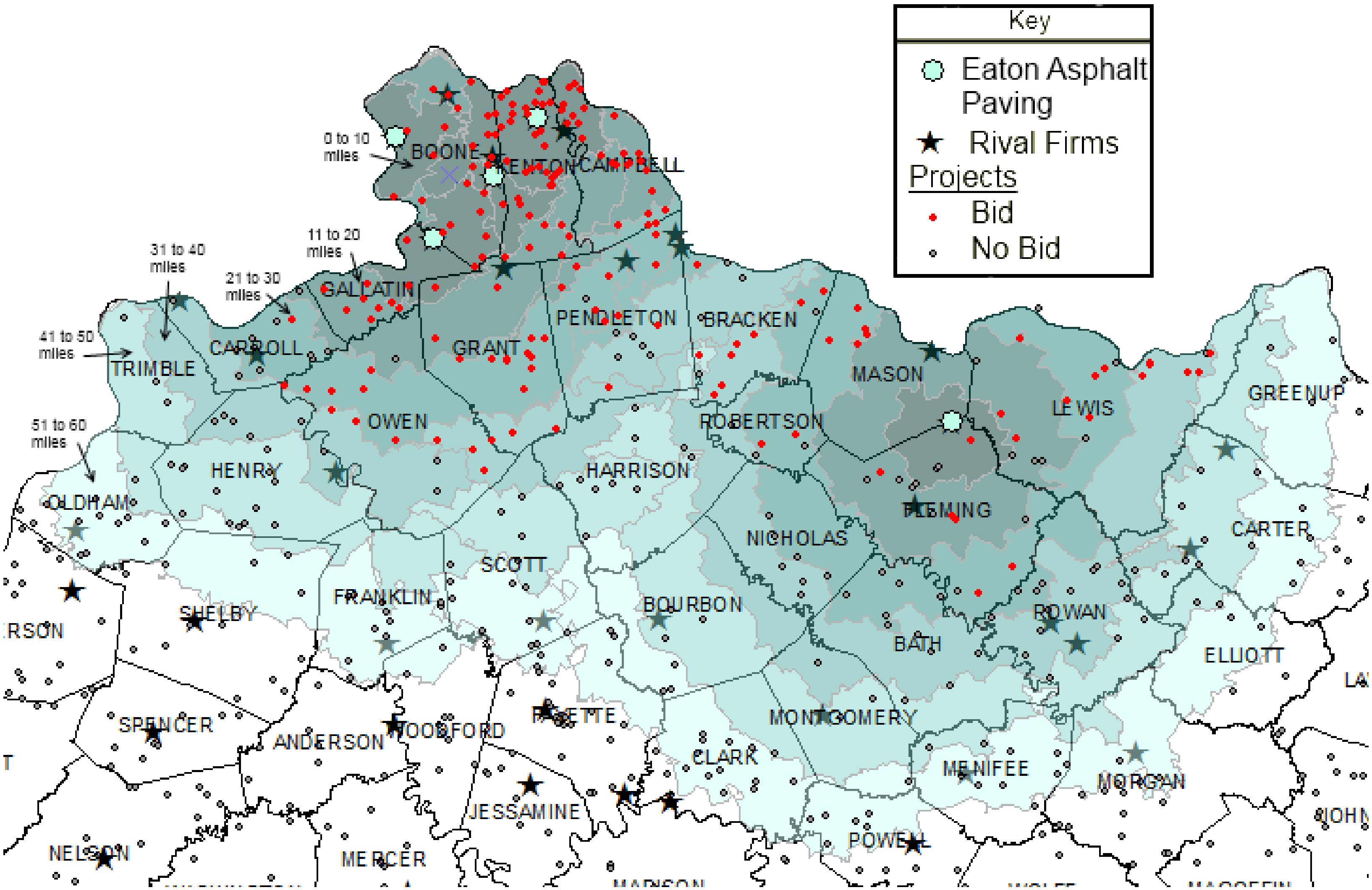


Figure 9: Eastern Kentucky (District 12) Counties, Firms, and Asphalt Plants

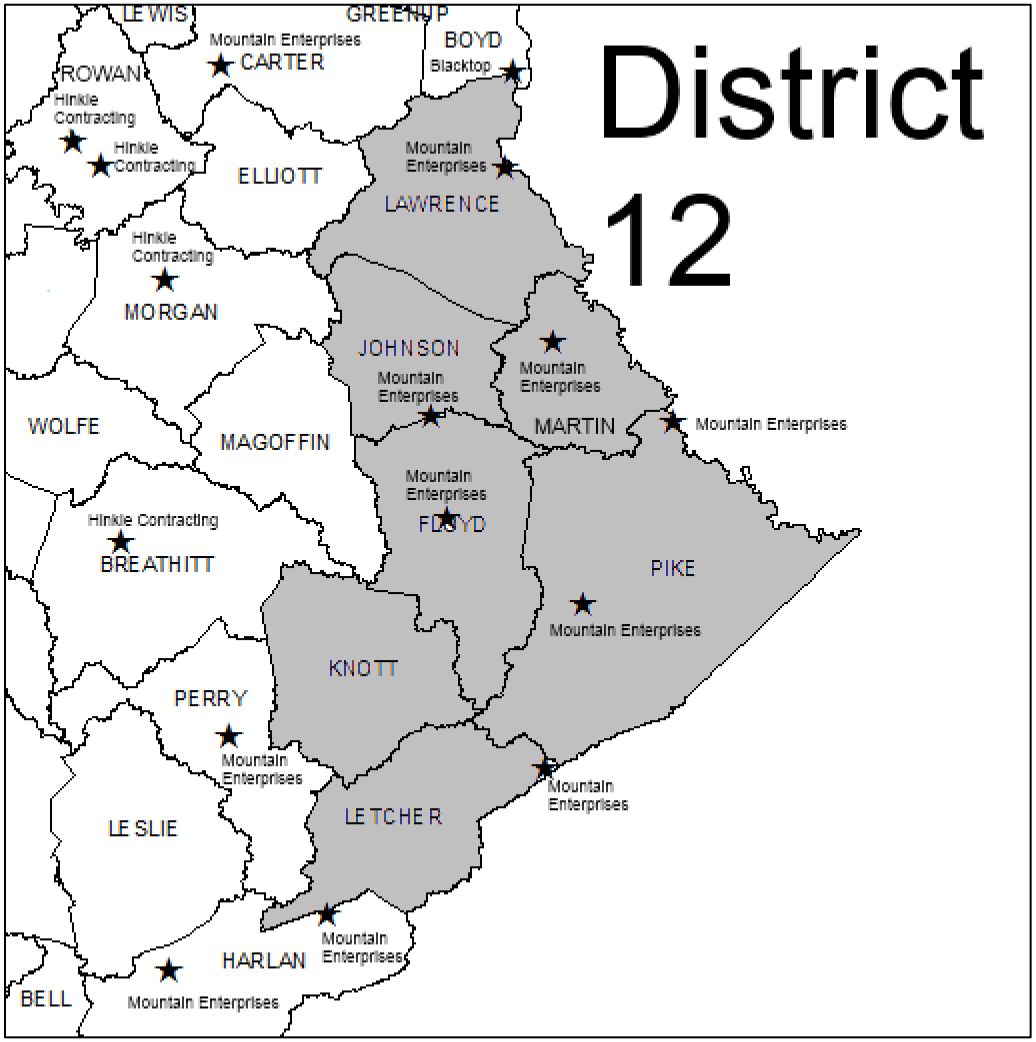


Figure 10: Mountain Enterprises Service Area

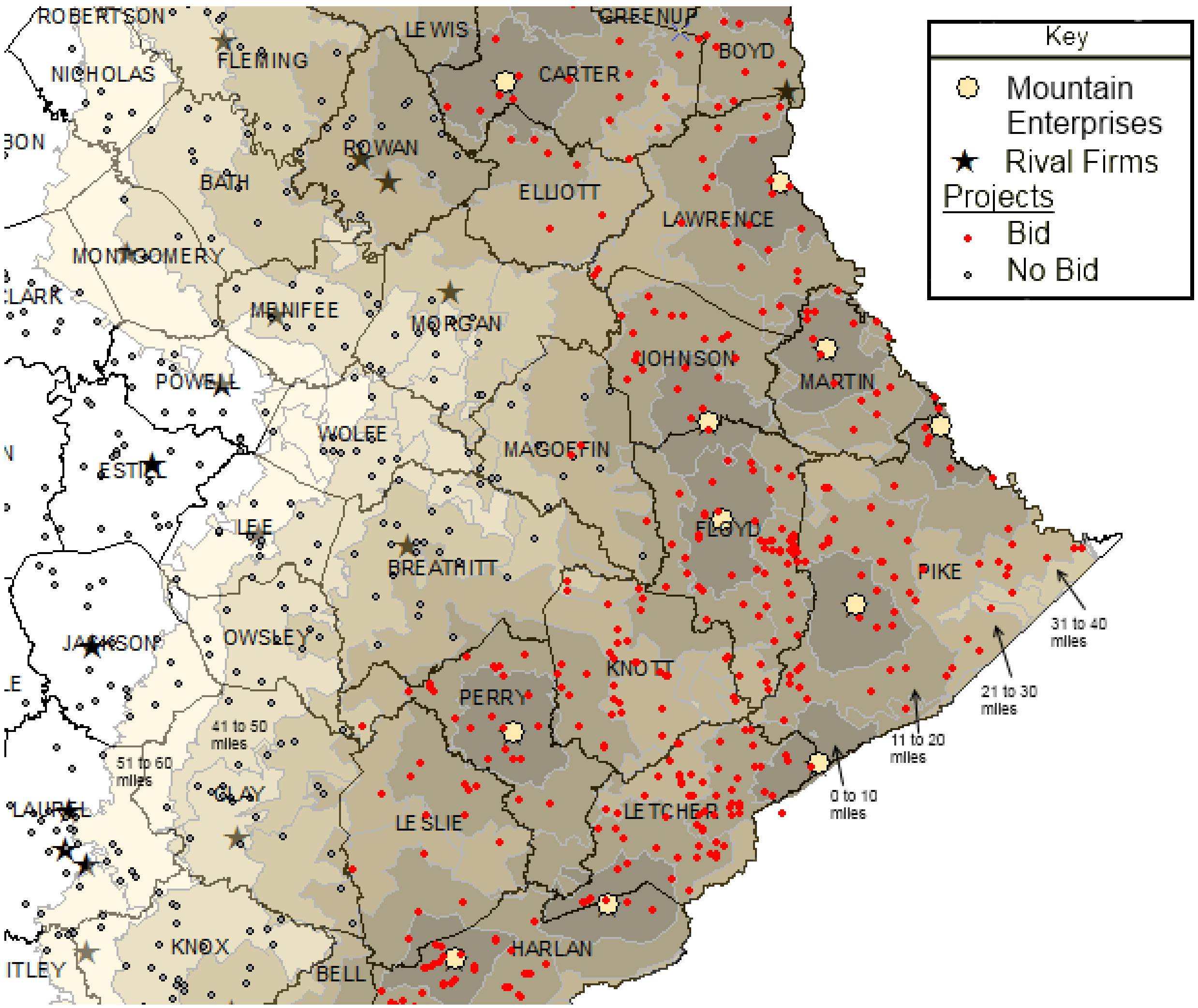


Figure 11: Central Kentucky (District 4) Counties, Firms, and Asphalt Plants

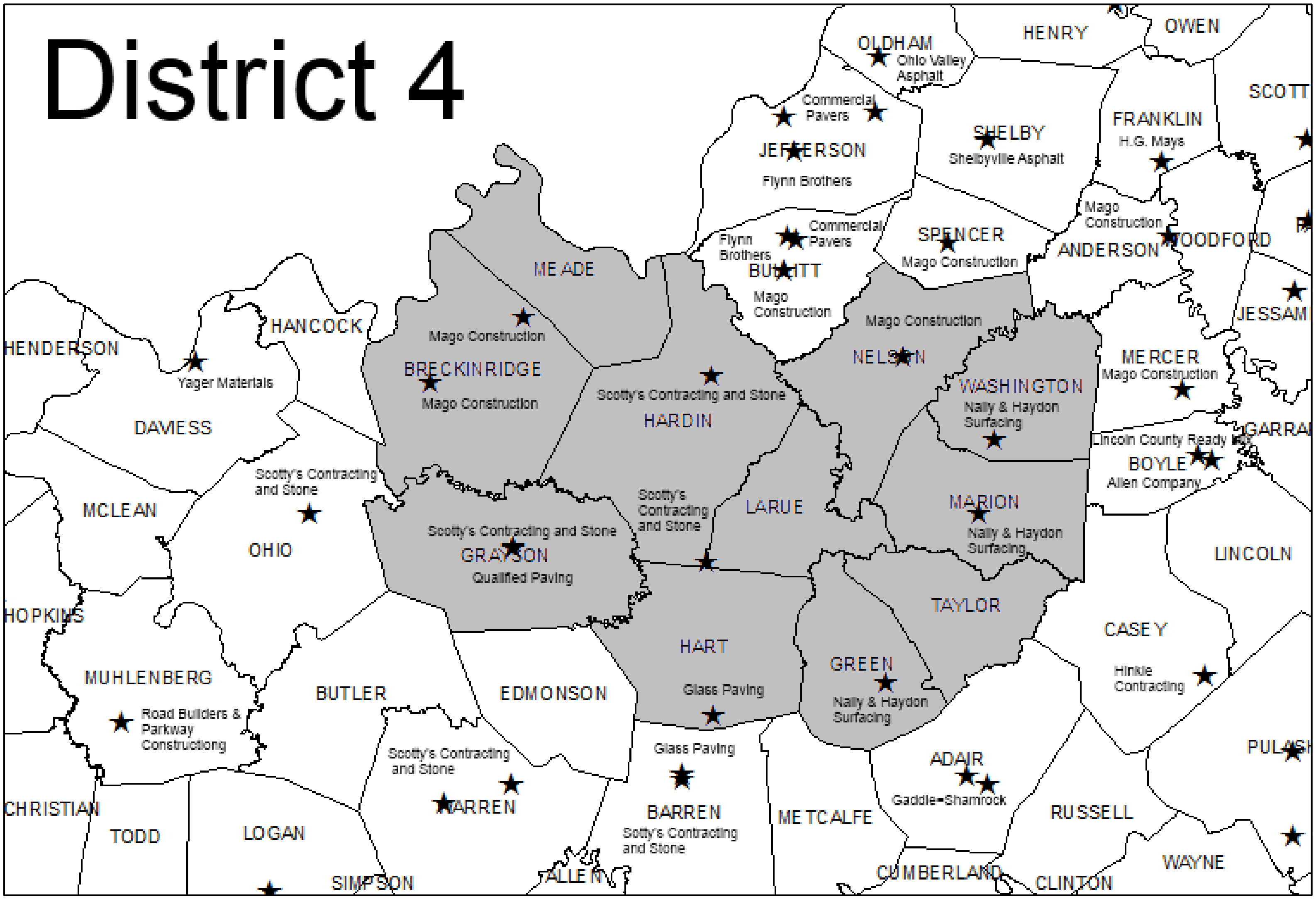


Figure 12: Nally & Haydon Surfacing Service Area