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Economies of scale versus the costs of bundling: Evidence from procurements of highway pavement replacement

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ABSTRACT

Although most public procurements involve decisions concerning bundling, only a limited body of empirical research guides policy on this matter. In this paper, we examine the cost effects of bundling in the competitive tendering of highway pavement replacement with hot-mix asphalt. For this we use linear regression on data from a comprehensive sample of such contracts procured by the Swedish infrastructure manager (IM) during the 2012–2015 period. We find that bundling affects the procurer's cost in multiple and partly counteracting ways. Our results show that economies of scale are strong but diminishing and counteracted by the costs of bundling and bundling-related factors. Overall, the findings support the Swedish IM's current bundle design but also suggest that most of the contracts are still inefficiently small. While not perfectly generalizable to other markets, the findings provide some support for the increased promotion and use of the bundling of small-scale road rehabilitation projects in the USA. Two main implications of the results are that bundling policy should emphasize proximity and similarity rather than whether the work is small in scale and that the scope for efficient bundling should be accounted for when optimizing the timing of pavement replacement.

1. Introduction

As a rough estimate by the World Bank (2020), public procurement amounts to 13–20% of global GDP. In OECD countries, about 30% of total government expenditures is allocated through procurement (OECD, 2019). Hence, effective public procurement policies and practices are imperative for the efficient use of public funds. National legislation and policies stipulate several characteristics of public procurement, often based on the nature and value of what is procured. Still, governmental agencies and individual procurers face a great many decisions regarding a range of issues relating to the design of each procurement process and the subsequent contract.

One decision present in most, if not all, procurements is whether to acquire a set of goods or services separately or bundled as one single contract. Bundling and tying are well-established concepts in microeconomics and marketing. In the standard textbook case, these concepts refer to the case of a seller deciding between selling multiple units of one product, or a combination of distinct products, as one package (e.g. Shy, 1995). While often used interchangeably, *bundling* typically refers to cases in which the proportions of the products are set by the sellers and *tying* to cases in which the buyer chooses the proportions.

Although practically all procurements involve decisions related to bundling, there is a considerable knowledge gap regarding its cost effects. Hence, our aim is to contribute empirical findings on how a procurer can use bundling to improve its cost efficiency. We

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examine the cost effects of bundling in the public procurement of road pavement replacement. Trafikverket, hereafter referred to as the Swedish infrastructure manager (IM), has a well-established and widely implemented policy of bundling, in which multiple and geographically dispersed pavement replacement projects – *objects* – are grouped into larger contracts. About EUR 200,000,000 is spent annually by the IM on pavement replacement for the national road network (Trafikverket, 2020), a considerable amount given the size of the Swedish economy.

We assess the net cost effect of whether and how the IM bundles road pavement replacement objects by examining several potential cost effects related to these decisions. This corresponds to the aim of the study, i.e. to identify favorable preconditions and strategies for bundling. The analysis has three main steps. First, applying multivariate linear regression to winning bids, we estimate the separate and combined cost effects of scale, number of geographically distinct objects, distance between objects, transportation distance, and number of distinct tasks in a contract. Second, we predict the winning bid for a set of cases with varying assumptions as to the number of bundled objects and those bundling-related characteristics found to influence the winning bid. Third, we examine how the examined characteristics of bundling influence the degree of competition. In this step, we estimate the influence of these characteristics on the potential bidders' decision on whether to submit a bid.

While there is a general lack of empirical evidence on the effects of bundling in procurement, recent developments in the USA, in both policy and research, have increased the relevance of examining the specific case of road infrastructure work. Several departments of transportation in the USA are increasingly implementing a pure bundling policy, i.e. with bundles constructed by the seller, to benefit from economies of scale and scope (Xiong et al., 2017). This trend may be linked to the federal Fixing America's Surface Transportation Act (FAST Act, 2015), which explicitly encourages bundling as a policy to save costs and time, specifically for projects involving bridges and smaller-scale or rural projects. We have found few policy documents from other countries treating this topic in English. One exception is the Pavement Design and Rehabilitation Guideline of Toronto Transportation Services (2019), which is more cautious in promoting bundling: "Occasionally, bundling of smaller projects may be feasible to reduce construction costs, especially mobilization charges" (p. 46). Notably, both the FAST Act and the TTS guideline emphasize the use of bundling for small projects.

In parallel with the increasing use of bundling in procurements of road infrastructure work in the USA, research has emerged examining the cost and competition effects of bundling in such procurements. This research, based on data from the Indiana Department of Transportation (INDOT), shows that bundling can provide considerable cost savings through economies of scale (Xiong et al., 2017; Qiao et al., 2019a, 2019b), but also that bundling and increased scale may have an opposite effect on cost by limiting competition (Qiao et al., 2021). Moreover, a general finding of these studies is that the cost and competition effects of bundling vary between the different work categories in the INDOT sample (i.e., Bridge, Road, Traffic, Small structures, and Miscellaneous) and between the many project types in each category.

This study adds to the previous literature in three ways. First, the previous empirical work on the bundling of road infrastructure work in particular derives from only one US state. We contribute observations from another institutional setting, namely Sweden, which is using a framework for the procurement process that is common to the European Union. Findings from multiple cases and institutional settings improves the possibility to assess the extent the insights gained are generalizable or case dependent. Second, analyzing only one type of road work, i.e. pavement replacement, and even only one subtype of such projects, i.e. pavement replacement with the durable hot-mix asphalt, facilitates a high level of detail in modeling and testing the cost effects of bundling. In addition to examining the effect of the main characteristics of a bundle, i.e. the number of bundled objects, the effects of the size and complexity of the bundles, the implications of different geographical spreads between bundled objects, and the transportation distance of potential bidders are addressed. While some of these characteristics are also covered in the previous literature, their potential effects are examined in greater detail here. Third, the paper tests whether the examined characteristics of bundling have nonlinear and combined effects, a matter not covered by the previous literature apart from scale variables.

The remainder of the paper is organized as follows: Section 2 reviews studies with a similar scope as this study. Section 3 describes how the IM in Sweden designs the procurement of pavement replacement. The econometric method is described in Section 4 and the data are presented in Section 5. The results are presented in Section 6 and discussed in Section 7, followed by the conclusions in Section 8.

2. Review of past studies

This study contributes to a still nascent literature on the cost and competition effects of bundling in the public procurement of infrastructure work. As described in the Introduction, the recent contributions of Qiao et al. (2019a, 2019b, 2021), studying data from a single procurer (INDOT), constitute a significant share of the prior empirical research on these issues. Estache and Iimi (2011) conducted one of few previous empirical studies of another application but on a similar theme. Analyzing the public procurement of water supply and sewage projects in developing countries, where the two types of projects are occasionally bundled, they found that bundling has a mixed effect on competition, as the number of bidders increases with bundling but decreases with scale. Overall, the paper established that bundling increases costs through diseconomies of both scale and scope.

As points of reference for this study, it would be useful to highlight some key findings of Qiao and co-authors. Qiao et al. (2019b) found that bundling entails strong economies of scale, with a scale elasticity of cost of 0.52, i.e. a 1% increase in scale increases cost by 0.52%. Moreover, Qiao et al. (2019b) also found that neither the number of objects in a bundle nor the number of bids influences the cost of pavement replacement, contrary to other work categories, whereas the degree of similarity within the projects and bundles was found to have a strong cost-reducing effect. Regarding the competition effect, Qiao et al. (2021) found that, for road work projects in general, participation increases with scale but decreases with the number of objects in a bundle. The results concerning the importance of spatial proximity are mixed: bidding participation is found to increase if bundled objects are in the same county, but there is no effect of objects being in the same corridor. Notably, the average number of bidders is relatively low (3.4) in procurements of pavement replacement compared to the other work categories.

Past studies, also based on US data, have shown that bid levels increase not only with the transportation distance of a bidder (e.g. Lewis and Bajari, 2011), but also with the transportation distance of its rivals (e.g. Bajari and Ye, 2003; Bajari et al., 2014), i.e. bidders respond strategically to information about the costs of their rivals. Similarly, these studies have found that bidding can increase with both the bidders' own and their rivals' degree of capacity utilization (e.g. Bajari and Ye, 2003; Lewis and Bajari, 2011, 2014), although the results concerning this effect are inconsistent (e.g. Bajari et al., 2014). Moreover, Lewis and Bajari (2011) found that the probability of submitting a bid decreases with the transportation distance and that firms with a small (large) production capacity are less (more) likely to participate the larger the contract (measured by the value of the engineer's cost estimate). Overall, these findings strengthen the view that bundling affects multiple important factors determining the bidding strategies in the procurement of pavement replacement.

There is also a substantial literature on bundling by private-sector sellers (e.g. Adams and Yellen, 1976; Schmalensee, 1984; McAfee et al., 1989; Whinston, 1990). These observations may, however, not be directly applicable to public procurement. First, the procurer's bundling decision determines the scale and scope of production carried out by a single supplier, whereas the scale and scope of production is not directly linked to whether multiple objects are sold to one or many costumers. Hence, economies of scale and scope in production may be substantial components of the cost effect of bundling. Second, public procurement may be for larger and more complex contracts than the products and services considered in the traditional bundling literature. Third, while many private-sector purchases are negotiated, public procurement is typically carried out in an auction format, in which bidding strategies are an important factor affecting the procurer's outcome. Such differences indicate the relevance of research focusing on the design of auctions for well-founded and efficient bundling policies in public procurement.

The theoretical literature on the effect of bundling in public procurement auctions, or auctions more generally, is mainly focused on bidding strategies and other game theoretical issues rather than economies of scale and scope. In an auction setting where all potential bidders have similar scale economies in production, an increase in production scale through bundling would have a symmetric level effect on bidding strategies, i.e. the effect is not very interesting from a game theoretic perspective. Thus, the role of economies of scale has not warranted much attention even though its economic magnitude may be substantial, depending on what is procured.

The design of auctions of multiple objects that exhibit economies of scope has attracted more interest. For instance, there is a substantial amount of theoretical research on combinatorial auctions (see Milgrom, 2004). This auction format is a form of mixed bundling invented to account for economies of scope and heterogeneity between sellers. The distinguishing feature is that bidders can submit different bids for different combinations and numbers of objects. This was implemented in the seminal spectrum auction in the USA in 1994, developed by economic theorists Paul Milgrom, Robert Wilson, Preston McAfee, and John McMillan among others (McMillan, 1994). It accounted for the telephone companies' diverse valuations of local licenses and combinations thereof, and sparked considerable interest in researching combinatorial bidding. There is also a strand of literature on how to optimally account for economies of scope in simultaneous or sequential auctions (e.g. Krishna and Rosenthal, 1996; Branco, 1997; Chakraborty et al., 2006).

Another branch of the theoretical auction literature has examined how bundling may reduce the distribution of bidders' valuations and thereby increase the degree of competition, frequently termed *the competition effect*. In papers modeling this effect in the case of a monopolist's multi-object auction, it is typically derived that the effect is moderated by the number of bidders (e.g. Palfrey, 1983; Chakraborty, 1999; Jehiel et al., 2007). Recently, Chen and Li (2018) developed a corresponding model for the case of a monopsonist procurer. As in the case of more general auction theories, they found that bundling can intensify competition by reducing the cost dispersion, but only in the case of two bidders. With more bidders, this reduction in cost dispersion may instead soften competition by limiting the left tail of the cost distribution. The competition effect of bundling is analogous to a multiproduct monopoly seller using bundling as a price-discrimination mechanism, thereby reducing heterogeneity between the buyers and extracting consumer surplus (Adams and Yellen, 1976; Schmalensee, 1984; Fang and Norman, 2006).

3. Swedish procurement of highway pavement replacement

Sweden's IM, Trafikverket, procures all road construction and maintenance activities, including pavement replacement, via competition. Pavement replacement is when an existing road gets a new surface layer, called the wearing course. However, a paved road is a structure with several layers of both gravel and asphalt. A contract for pavement replacement may therefore include the removal and replacement of several layers beneath a road's wearing course.

There are three main techniques for road pavement replacement: hot-mix asphalt concrete, warm-mix asphalt concrete, and cold-mix asphalt concrete. The hot-mix is heated to about 150–170 degrees Celsius, the warm-mix to 100–140 degrees, and the cold-mix does not need to be heated (d'Angelo et al., 2008). Hot-mix asphalt is the most durable and is typically used on roads with high traffic density. This study is focused solely on contracts with hot-mix asphalt. Hot-mix asphalt is typically prepared at stationary asphalt plants, although mobile variants are occasionally set up for large-scale work far from stationary plants. Asphalt plants are usually located near gravel pits, as gravel is the main component of asphalt. As the temperature of the asphalt mix drops during transport, there is a limit to how far the asphalt can be transported before being laid. This is less of an issue for warm-mix and cold mix asphalt (d'Angelo et al., 2008). A defining characteristic of the Swedish market for road pavement work, which is highly concentrated compared with those in neighboring countries (Nyström et al., 2016), is that the companies generally run their own asphalt plants or have subsidiaries with asphalt plants. The exception is the state-run company Svevia, which competed for contracts in the country's southern regions even before establishing an asphalt plant in 2019 (Svevia, 2020).

The IM's budget for pavement replacement is allocated among its six regional offices. According to the IM (Trafikverket, 2016), this distribution is mainly based on the condition of the roads and the share of the road network not meeting the road condition target. A centralized function of the IM monitors the condition of the roads through a pavement management system using input data on multiple road surface measurements, for instance, track depth and the International Roughness Index (IRI), measured by sensor-equipped measuring cars. These measurements are typically made yearly for larger roads and every second or third year for smaller roads. When the budget is allocated, each regional office prioritizes the replacement work in its area following centralized instructions, for instance, to prioritize roads with a high traffic density. Moreover, to avoid both internal and external capacity constraints, the regional offices also account for their other types of infrastructure work when planning their pavement replacement.

When the regional offices' prioritization of pavement replacement activities is accepted and included in the IM's national maintenance plan, each office determines whether and how to bundle this work in its region. This is a case of pure bundling rather than combinatorial bidding in which firms can submit offers for different combinations of objects in the way suggested by Lunander and Nilsson (2004) and empirically examined by Lunander and Lundberg (2012). Trafikverket (2019) described how the bundling decision is mainly determined by the paving method and the distance between the road segments, stating that bundling is more likely for road segments with similar characteristics. This facilitates more uniform requirements within the bundles, for instance, regarding the need for temporary traffic management measures and work at nighttime.

When the IM's regional offices have decided how to bundle their objects, a project leader or a consultant plans and specifies the contracts for each office. Most of the IM's pavement replacement contracts are tendered as unit-price contracts (UPCs) in which all the sub-activities constituting the pavement replacement work are specified in detail and quantified in a Bill of Quantities, using a Swedish standard classification manual for construction. Bids are based on a unit price for each quantity specified in the Bill of Quantities, and the vector multiplication of prices and quantities constitutes the bid. Sometimes, the IM uses a fixed-price contract format with higher degrees of freedom regarding the use of inputs for undertaking an assignment, but such contracts also entail a higher degree of risk[1] (these contracts are not covered in this empirical analysis). In addition to specifications of the pavement replacement per se, the IM's call for bids specifies requirements concerning the bidding firms' credit score, competence, safety standards, etc.

4. Method

This paper examines the cost effects of five aspects closely linked to the procurer's bundling decisions: economies of scale (*Area*), the number of bundled objects in a contract (*Objects*), the geographical spread of objects within the bundle (*Spread*), the transportation distance (*Dist*), and the number of different tasks specified (*Tasks*). In this section, we describe the three steps by which these cost effects are analyzed: how the cost effects are modeled and estimated (step 1); how the net-cost effect of bundling is assessed using cost predictions (step 2); and, lastly, how the impact of bundling on competition is assessed (step 3). A set of testable hypotheses is highlighted, but for brevity only for step 1.

4.1. The separate and combined cost effects of bundling

Since the bidders' cost functions are unknown, we use the flexible translog functional form, proposed by Christensen et al. (1973) and commonly employed in efficiency analysis (Coelli et al., 2005). In our case, this makes it possible for the cost elasticities of the examined bundling characteristics to be nonlinear and to be determined by the other characteristics of the contract included in the model.

We specify the translog cost function of the procurer as:

$$\ln C = \alpha + \sum_{j=1}^{J} \beta_j \ln x_j + \frac{1}{2} \sum_{j=1}^{J} \sum_{k=1}^{J} \beta_{jk} \ln x_j \ln x_k + \sum_{m=1}^{M} \gamma_m z_m + \varepsilon \tag{1}$$

where $\ln C$ is the procurer's log-transformed cost of a contract, x_j is the value of the continuous explanatory variable j $(jk \in J)$, and β_j is the parameter to be estimated for that variable. β_{jk} is the parameter capturing the interaction effect of each pair of variables j and k; when $j = k$, β_{jk} is the second-order effect of that variable. The equality of β_{jk} and β_{kj} is assumed (see Berndt and Christensen, 1973). Furthermore, z_m is the value of dummy variable m (zero or one) and γ_m is the parameter to be estimated for that variable; α is a constant and ε is an error term, assumed to be normally distributed with a mean value of zero.

With the translog cost function (1), the elasticity of cost with respect to each continuous variable is

$$\epsilon_j = \frac{\partial \ln C}{\partial \ln x_j} = \beta_j + \sum_{k=1}^{J} \beta_{kj} \ln x_k \tag{2}$$

i.e. the elasticity of variable j is the sum of the first-order effect and all products of the log-transformed value of variable k and the interaction effect between variables j and k (or the second-order effect when $j = k$).

Translog function (1) is estimated using ordinary least squares (OLS) regression, using the conventional 95% confidence level when

[1] The International Federation of Consulting Engineers provides detailed information about unit-price contracts, which engineers call design–bid–build contracts. The Federation also describes fixed-price contracts, which are referred to as design–build contracts, as well as other types of contracts (see https://www.fidic.org).

testing for the statistical significance of the estimated effects. With the many terms included in a full translog model, multicollinearity is a frequent issue. The degree of multicollinearity is assessed based on the variance inflation factor (VIF). If multicollinearity is high, the adequacy of reduced models is considered. For this, the joint significance of all terms of each continuous variable is tested. The variables that are not significant according to this test, accounting for first- and second-order effects as well as the interaction effect, are excluded.

The IM's use of bundling is not a randomized process. If the IM consistently only bundles pavement replacement work of a particular kind, it may cause a selection bias on the estimated cost effects of the bundling variables. We have not been able to find an instrument variable, i.e. a variable associated with the bundling decision but not the cost, for correcting this potential bias. This implies that the cost may be influenced by most characteristics of the procurements.

Several exogenous sources of variation in whether or not a certain pavement replacement object is bundled have been established, suggesting that selection bias is not a major issue. First, at the time of the bundling decision, the total pool of pavement replacement objects to be tendered is exogenously determined by factors such as the condition of the road network, the IM's prioritization of road segments for treatment, and the regional boundaries. Second, according to the IM, their policy is to have similar pavement replacement objects within the bundles. Hence, whether a certain object is bundled is dependent on whether there are other similar objects in the region, or a part of the region, that same year. Third, the IM does not have a strict centralized instruction on bundling. Instead, whether and how to bundle objects is ultimately decided by project leaders at the IM's six regional offices. Arguably, it is unlikely that the implementation of bundling is perfectly uniform across the IM.

While several more cost effects are estimated, seven testable null hypotheses are highlighted for this first step of the analysis. The hypotheses are primarily based on general economic principles and prior findings rather than being derived from theory on auctions and bundling specifically. The first hypothesis is about whether the contracts exhibit economies of scale. As described in Section 4, road pavement replacement contracts cover quantities of multiple tasks, and the economies of scale are likely specific to each task. However, in this paper, we seek to examine the contracts' cost properties in terms of the total contract scale. Scale is defined in terms of the total area of a contract including both the new wearing course and the area of any additional new sub-surface coatings. These quantities often account for most of the contract value. Moreover, the quantities of most of the other tasks included in the Bill of Quantities may be proportional to the quantity of new pavement. Hence, the total scale of the contract is defined as:

$$Area = \sum_{a=1}^{A} \psi_a q_a \tag{3}$$

where q_a is the number of square meters of bitumen-bound layers in category a in the Bill of Quantities and ψ is a function transforming the (few) quantities specified in tonnes into square meters. In the estimated model (1), dummy variables are included to control for the difference in production cost between the aggregated layers.

Previous research has established substantial scale economies, i.e. that the average cost decreases with the quantity. These economies may emanate from several parts of the pavement replacement work. For instance, there may be fixed-cost components in the winning bidder's use of personnel and plant, in the on-site preparations and temporary traffic management solutions, and in the production of the asphalt and in the production and purchasing of input materials.

Hence, the following hypothesis on the economies of scale will be tested (where $\in_{AREA}$ is the elasticity of cost with respect to the variable *Area*):

$H1_0$: $\in_{Area} = 1$ ($\partial \ln c = \partial \ln Area$).

$H1_A$: Road paving replacement contracts exhibit either economies or diseconomies of scale.

It should be noted that one firm may win and carry out all objects even if they are procured separately. However, with separate procurements, the bidders cannot fully account for the economies of scale or other cost effects of carrying out multiple objects jointly. This follows from the bidders' uncertainty at the bidding stage regarding what combination of objects they will ultimately carry out. With bundling, this combination is specified by the procurer, and with combinatorial bidding, the bidders can submit different bids for different combinations of objects.

In most instances, the number of objects is the defining characteristic of a bundle. In the examined case, an object is defined as a spatially contiguous pavement replacement measure, which follows the definition used by the procurer in the Bill of Quantities. For a given scale of contract, additional objects are expected to give rise to a cost of either transporting machinery and personnel between the different sites or of needing additional machinery and personnel, and possibly also to an increased cost of coordinating the work:

$H2_0$: $\in_{Objects} = 0$

$H2_A$: The number of objects in a contract influences the cost.

If the paving activity exhibits economies of scale, this is expected to diminish when work is divided between different sites, as the scale of each contiguous paving activity is reduced. The number of objects could also be expected to reduce the scope for potential economies of scale at the asphalt plant if the objects are not carried out during the same period:

$H3_0$: $\beta_{Area*Objects} = 0$

$H3_A$: The interaction between the number of objects and the scale influences the cost.

The geographic spread between the pavement replacement objects in a contract is one of several sources of heterogeneity within these bundles. This aspect is highlighted as it complements the dichotomous definition of an object based on its contiguousness. For a given scale and number of objects, a larger geographical spread between the objects is expected to increase the cost of allocating machinery and personnel to each object and of coordinating all the work specified in the contract:

$H4_0$: $\in_{Spread} = 0$

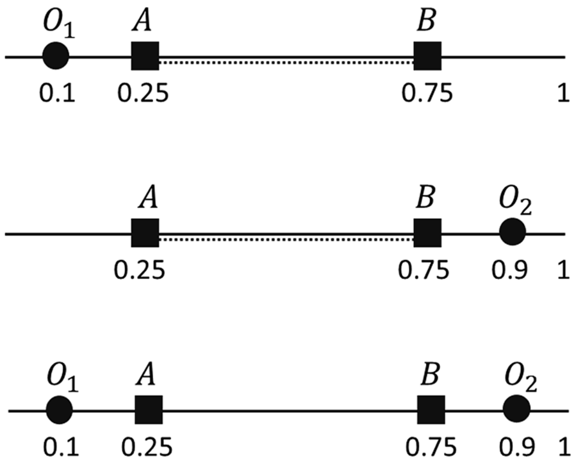

Fig. 1. Separate contracts versus bundling. Square: asphalt plant. Dot: pavement replacement object. Dotted line: mark-up.

$H4_A$: The spread between bundled objects influences the cost.

It will also be examined whether the geographical spread between the objects in a contract influences the cost elasticity with respect to scale. If the objects are near one another, it may still be possible to benefit from potential economies of scale at the sites:

$H5_0$: $\beta_{Area*Spread} = 0$

$H5_A$: The interaction of the spread between bundled objects with the scale influences the cost.

Adding spatially dispersed objects to a contract influences the transportation distance between the work sites and the potential bidders' asphalt plants. While there may be a fixed-cost component in loading the asphalt into the trucks, there is also a marginal cost of transportation in terms of fuel and work hours. Hence, the cost is expected to increase with the transportation distance of the firms:

$H6_0$: $\epsilon_{Dist} = 0$

$H6_A$: The transportation distance influences the cost.

As the location of the asphalt plants is common knowledge, the potential bidder with the minimum transportation distance may incorporate part of its locational advantage in a markup. Then, the procurer's cost is more strongly associated with the second-shortest transportation distance among the potential bidders than with the minimum distance, with bidders incorporating the locational advantage into their bids. To examine this, hypothesis 6 is tested with respect to both the shortest and the second-shortest distances, in separate models. The Akaike and Bayesian information criteria are used to select between these models before testing the other hypotheses.

If the bidders with locational advantages use them by marking up their bids, bundling may be used as a means of increasing competition by reducing the differences in the (transportation) costs of the potential bidders. Fig. 1 illustrates this potential competition effect of bundling, also discussed in the Introduction, borrowing the basic framework from Hotelling's (1929) classical representation of product differentiation. The locations of two construction companies' asphalt plants are represented by points on a line of length one and the per-unit transportation cost is set to one. Fig. 1 depicts a case in which companies A and B have asphalt plants at 0.25 and 0.75, respectively, and the IM has identified a need for two pavement replacement objects (O). If the objects are procured separately, the companies have an advantage in distance of 0.5 for one of the objects, and a corresponding disadvantage for the other. If the locational advantage is public knowledge, the company adds a profit mark-up of 0.5 to its bids for the contracts, all else being equal. If the IM instead bundles the two objects, the two companies have identical transportation distances, which leaves no room for a mark-up on the bids. Still, there is inefficiency in that the total transportation distance is 0.8 with bundling, compared with 0.3 if each object was allocated to the closest company.

If a group of objects is not completely homogenous, procuring the objects as a bundle increases the complexity of the contract compared with having a separate contract for each object. As described in Section 2, the literature suggests that the degree of similarity within a bundle has a cost-reducing effect. The generic classification system in the Bill of Quantities makes it possible to examine the effect of a corresponding measure but of dissimilarity, or complexity, defined as the number of non-paving tasks specified in the Bill. The procurer's cost is expected to increase as a greater number of distinct tasks is to be carried out and coordinated within the contract:

$H7_0$:.$\epsilon_{Tasks} = 0$

$H7_A$: The number of distinct tasks in a contract influences the cost.

4.2. The predicted net-cost effect of bundling

As a second step of the analysis, the procurer's cost, i.e. the winning bid, is predicted for a set of illustrative cases of bundles with varying characteristics. Using the margins command in Stata (Williams, 2012), the winning bid is predicted for each observation (contract) and each case, given the estimates of the fitted model. The mean value of the predictions for each case is presented. Following the standard approach, the variables that do not vary between the cases are kept constant at their observed values.

Table 1
Sample vs. population: Region and year.

	2012	2013	2014	2015	Total
North	6 (7)	12 (12)	8 (8)	5 (9)	31 (36)
West	15 (17)	21 (21)	28 (29)	17 (25)	81 (92)
Central	7 (7)	12 (12)	6 (6)	5 (6)	30 (31)
East	10 (12)	11 (11)	9 (9)	6 (7)	36 (39)
Stockholm	11 (14)	15 (16)	16 (16)	8 (11)	50 (57)
South	18 (17)	24 (24)	7 (14)	13 (14)	62 (70)
Total	67 (75)	95 (96)	74 (82)	54 (72)	290 (325)

4.3. *The influence of bundling on competition*

Even though bundling may affect the potential bidders' decision on whether to submit a bid, the main models will include the number of bids as a control for the degree of competition. The potential indirect cost effect of bundling through the effect on competition is examined by comparing the parameter estimates of the main models with models excluding the number of bids. Whether bundling affects the degree of competition in terms of the number of bidders is also examined by estimating the following probit model explaining the probability of a potential bidder submitting a bid:

$$Pr(y=1|x_j,z_m,d_n)=\Phi\left(\sum_{j=1,j\neq\delta}^{J}\beta_j x_j+\sum_{m=1}^{M}\gamma_m z_m+\sum_{n=1}^{2}\eta_n d_n+\theta d_1 d_2\right) \tag{4}$$

where y equals one if the potential bidder submits a bid, and zero otherwise, and Φ is the standard normal cumulative distribution function. This model includes all but one of the J continuous variables in the cost model: the variable capturing the transportation distance of the closest or second-closest potential bidder ($\delta \in J$) is replaced with variables for the transportation distance of the potential bidder (d_1) and its rival with the shortest transportation distance (d_2), and for the interaction between these distances. The following definition of a potential bidder is used: a firm that has submitted a bid for at least one of the contracts in the sample. The probit model is estimated using maximum likelihood.

5. Data

5.1. *Datasets and sampling*

The IM has provided a list of its contracts for pavement replacement procured in the 2012–2015 period. This material also includes information about the regional office, year of the procurement, paving method, winning bidder, and submitted bids. A total of 540 contracts are listed, amounting to EUR 758 million in terms of the winning bids. Of these contracts, 354 are for hot-mix asphalt (64% of the total contract value), with 325 being UPCs and 29 fixed-price contracts. Detailed information is specified in a standardized Bill of Quantities for each UPC but not for the fixed-price contracts.[2] Since this makes it impossible to control for heterogeneity, the analysis focuses on UPCs. Using information found in the Bill of Quantities (e.g. file name, region, year, specified locations, and, in most cases, the winning bid), 291 of the 325 UPCs have been linked to Bills of Quantities with a uniform format. One of these contracts is omitted as an outlier, having a 30% higher contract cost per square meter than any other contract. Unlike the other contracts, this omitted contract involved considerable amounts of earth work.

In addition to the Bill of Quantities, the IM has also provided data on the identity of the bidding companies, bid levels, and winning bidders. The owner of each of 90 asphalt plants, the exact coordinates of each plant, and information on whether the plants were active during the examined period have been registered.

Table 1 shows the distribution of the sample by year and region versus the population of these contracts procured during the same period (in parentheses). Overall, the distribution suggests that the sample selection process was not considerably skewed over these two dimensions.

Fig. A1 in the Appendix shows the locations of the pavement replacement objects in the sample in the Swedish national road network. For this map, the road segments in objects have been estimated as the shortest distance along the national road network between start and end coordinates of the objects. Three observations about these contracts and the sampling process can be highlighted. First, there is an area in southwest Sweden (i.e. Värmland region) with no pavement replacement observations. The procurers responsible for the hot-mix paving replacement in this area did not follow the IM's standardized form for Bill of Quantities, i.e. the activities are not assigned the standard classification codes, making it impossible to harmonize the data on contracts in this area with the other data. Second, the sample covers pavement replacement on Sweden's two largest islands. Some objects are on the island of Gotland where there is only one firm with an asphalt plant. There are also objects on the island of Öland, but a bridge connects this island to the mainland. Third, there are more asphalt plants in the denser parts of the road network, while asphalt plants in the north

[2] It would be interesting to improve our understanding of the consequences of selecting between UPC and fixed-price contracts. Since much less information is available about the latter category, this is left for a separate study.

Table 2
Descriptive statistics.

Variable	Name	Unit	Median	Mean	SD	Min	Max
Winning bid	*Winbid*	EUR, million	0.9	1.2	0.9	0.1	4.7
Unit cost (EUR/m^2)		EUR	6.8	7.2	2.2	3.0	15.0
Area of pavement replacement in a contract	*Area*	100,000 m^2	1.43	1.82	1.34	0.1	6.93
Number of objects in a contract	*Objects*	*n*	4.0	5.0	4.1	1.0	27.0
Spatial spread between objects in a contract*	*Spread*	km	33.5	38.2	27.0	2.4	134.2
Number of non-paving tasks	*Tasks*	*n*	8.0	10.5	8.5	2.0	70.0
Distance of closest firm	*Dist1*	km	23.1	26.2	17.2	1.5	119.2
Distance of second-closest firm	*Dist2*	km	34.3	39.6	33.8	6.0	325.7
Number of bidders	*Bids*	*n*	4.0	4.0	1.0	2.0	6.0

* Spread: Descriptive statistics only for contracts with at least two objects ($n = 247$).

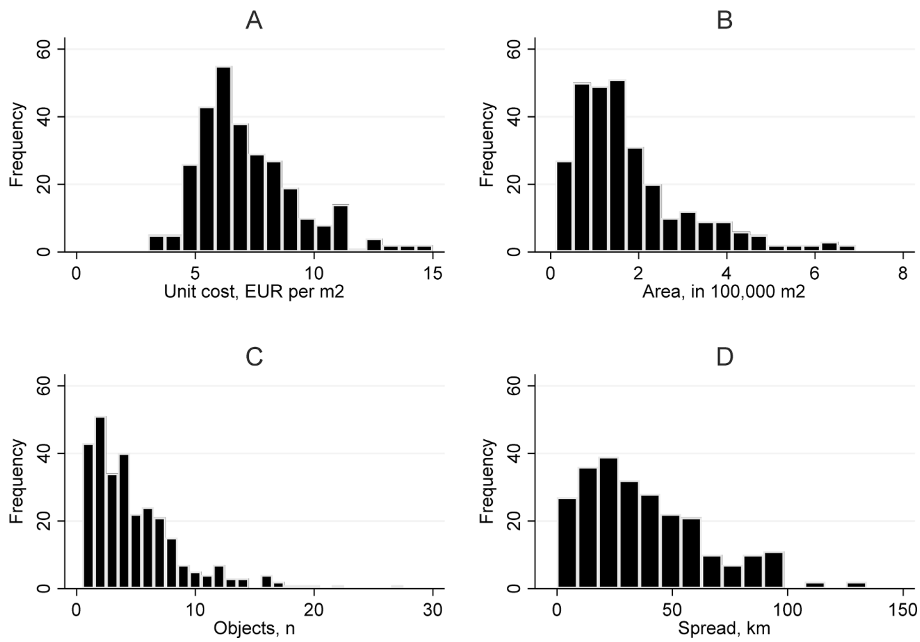

Fig. 2. Distributions of the unit cost (A), area (B), number of objects in a contract (C), and spread between objects in a contract (D) within the sample.

are generally located near the coastline, with substantial transport distances to inland contracts.

5.2. The cost variable

For inferences regarding procurement costs and efficiency, it would be preferable to have the sum of final payments be the cost variable. However, given the current state of the IM's data management, it is impossible to obtain data on the final payments or to match them with the other contract data (Nilsson et al., 2021a, 2021b). Hence, our analysis is based on bidding data. Being limited to using data on bids rather than the final payment is in line with most of the previous studies of similar cases (e.g. Bajari and Ye, 2003; Lewis and Bajari, 2011; Qiao et al., 2019a, 2019b), even though there are some exceptions (e.g. Bajari et al., 2014). It could also be argued that the procurer's internal cost of labor should be considered when examining the cost and efficiency effects of bundling policies. As for most public procurers, it is currently impossible to retrieve and match data on IM's internal costs with the contract data. Still, for such standard infrastructure contracts, the internal procurement cost typically corresponds to a fraction of the contract value.

Two factors mainly determine the validity of making inferences regarding the cost effects of the IM's bundling policy based on winning bids rather than the final payments. First, the validity depends on whether there is a systematic association between bundling and the magnitude of ex post changes in the payments. Second, it depends on how much final payments deviate from the winning bids. Flyvbjerg et al. (2003) presented several well-known examples of large cost overruns in infrastructure megaprojects and, moreover, showed that the actual cost is 28% higher, on average, than the estimated cost of construction for major transport infrastructure in the USA. Similarly, Nilsson (2022) described how the scope and cost of seven corresponding projects in Sweden escalated dramatically, with cost overruns of 98–395%, after the initial decision to build, particularly during the planning phase. With many risk factors, such as soil and bedrock characteristics, construction projects are prone to adjustments and renegotiations even in the construction phase (e.

g. Anderson et al., 2007; Creedy et al., 2010).

Although road maintenance is less complex than road construction, the IM reports that final costs exceed the sums in the contracts by 18% in overall road maintenance contracts (Nilsson et al., 2019). Against this background, we would have preferred to have data on the final cost. Still, we have not found any prior evidence regarding the association between cost overruns and the examined bundling-related variables. Moreover, the variance in cost overruns is likely relatively low for the examined sample of contracts, covering only a particular kind of maintenance work. If there is an association between cost overruns and bundling, a low variance in cost overruns would limit the magnitude of the resulting estimation bias.

Several previous studies examining the cost effects of procurement policies base their empirical strategy on a symmetric bidding function, and include all submitted bids in their analysis (e.g. Porter and Zona, 1993; Athey et al., 2011; Krasnokutskaya and Seim, 2011). Given the research question of this study, we argue that the winning bid is preferable as a dependent variable as it eliminates a source of selection bias. In most auctions, the bidder's participation decision is endogenous (e.g. McAfee and McMillan, 1987; Levin and Smith, 1994). When estimating the effect of a procurement policy on bidding strategies, data on the submitted bids do not capture effects on participation. With the winning bid as the cost variable, there is no need to remedy this source of selection bias (e.g. using Heckman correction). Moreover, from the perspective of a procurer, the procurement cost is associated with the winning bid. Hence, using winning bids instead of all submitted bids improves the validity of inferences about procurement costs and efficiency.

Table 2 presents descriptive statistics on the cost variable, i.e., the winning bid, and the continuous explanatory variables included in the empirical model. The winning bids are within the range of EU 0.1–4.7 million (exchange rate: EUR 1 = USD 1.19 = SEK 10.34 as of 21 October 2020), indicating a considerable degree of heterogeneity in the scale of the contracts. The average winning bid is EUR 1.2 million and the total contract value of the sample is about EUR 348 million. As the data contain information on the winning bids for all 325 unit-price contracts, the average of the sample can be compared to the average for this population. The average of the sample is about 0.8% less than the population average, suggesting that the sample is representative of the population of contracts procured in this period, in terms of contract value and thereby also scale.

The average unit cost is EUR 7.2 per square meter. Fig. 2 panel A shows that the distribution is moderately right skewed. The minimum value of the unit cost may appear improbably small for hot-mix pavement replacement, but, as previously described, the areas of all bitumen-bound layers are included in the total contract area, i.e. this measure of unit cost is lower for contracts with substantial amounts of the less costly sub-structure layers. Similarly, the maximum value indicates how the sample contains contracts in which a considerable share of the cost is explained by the extent of supplementary work, for instance, the removal of existing layers.

5.3. Explanatory variables

As defined in Section 4, the scale of a contract is captured by a single variable, *Area*, which is the total area of new bitumen-bound layers. As presented in Table 2, the average scale of a pavement replacement contract is 182,000 square meters. For reference, the average area per object is approximately 57,000 square meters (121,000 square meters for single-object contracts). As indicated by the broad spread of the winning bids, there is considerable variation in the scale. Fig. 2 panel B shows that the distribution is considerably right skewed but contains no extreme outliers.

There is considerable variation in whether and to what extent the pavement replacement objects (*Objects*) are bundled. Fig. 2 panel C shows that the sample includes about 40 contracts for only one object but also several contracts for more than 10 objects. As presented in Table 2, the average contract is for a bundle of five objects. There is also considerable variation in how far apart the bundled objects are. Hence, we introduce a measure of the spatial spread (*Spread*) corresponding to the diameter of a circle around the centroid of a bundle. *Spread* is calculated as the mean distance between the centroids of each object and the centroid of the bundle times two. If there are only two objects in the contract, *Spread* is equal to the actual distance between the objects. The centroid of an object is the average coordinate between the start and end position of the object, which is information found in the Bill of Quantities, and the centroid of the bundle is the average coordinate of all objects' centroids. The mean spatial spread of contracts with at least two objects (247 contracts) is 38.2 km. In the most spread-out bundle, the objects are on average 134.2 km apart. Fig. 2 panel D show the distribution of *Spread* within the sample.

Table 2 shows how the medians of the minimum (*Dist1*) and second-shortest (*Dist2*) transportation distance of the potential bidders for a contract are about 23 and 34 km, respectively. In particular, the latter of these two variables has considerable variation and a large maximum, implying that one potential bidder had a strong locational advantage in some of the procurements. A bidder's transportation distance is defined as the straight-line distance from its closest asphalt plant to a contract's centroid. In most cases this is a good approximation of the mean transportation distance to the objects in a contract. However, for cases in which the bidder's distance to the centroid is less than the spatial radius of a bundle (*Spread*/2), i.e. if the asphalt plant is located somewhere between the objects, the transportation distance is instead defined as the spatial radius of the bundle.

The number of distinct non-paving tasks (*Tasks*) specified in the Bills of Quantities ranges from 2 to 70, meaning that there is considerable heterogeneity in terms of our measure of complexity. Still, the median number of tasks is only four. The number of bids (*Bids*) is included to capture differences in the degree of competition, which may correlate with the characteristics of the IM's bundling. As discussed in Section 5, this is our preferred control for competition, even though the decision to submit a bid may be endogenous to the use of bundling. The average number of submitted bids is four and none of the procurements had less than two bidders.

In addition to the variables in Table 2, a set of dummy variables is included as controls. One dummy variable controls for whether part of the specified work is to be carried out during the subsequent year (13% of the contracts). Dummy variables are also included to control for regional and yearly differences, including inflation (see Table 1).

Table 3 provides complementary information about the main components of the examined contracts, namely the distribution of

Table 3
Prevalence of asphalt categories in contacts.

Layer		No. of contracts	Sum, million m^2	Share of total area
A	Bitumen-bound bearing layers, category A	54	2.9	5.6 %
B	Bitumen-bound bonding layers, category A	84	3.3	6.2 %
C	Bitumen-bound adjustment layer, category A	194	9.0	17.2 %
D	Bitumen-bound wear layers, category A	245	20.7	39.4 %
E	Wear layers, category A of surface treatment with bituminous binder and gravel	3	0.1	0.2 %
F	Heating coatings, category A	108	16.4	31.2 %
G	Stabilization layers, category A	1	0.1	0.2 %

Table 4
List of the hypotheses.

Null hypothesis		Alternative hypothesis
H1:	$\epsilon_{Area} = 1$	The road paving replacement contracts exhibit either economies or diseconomies of scale.
H2:	$\epsilon_{Objects} = 0$	The number of objects in a contract influences the cost.
H3:	$\beta_{Area^*Objects} = 0$	The interaction between the number of objects and the scale influences the cost.
H4:	$\epsilon_{Spread} = 0$	The spread between bundled objects influences the cost.
H5:	$\beta_{Area^*Spread} = 0$	The interaction of the spread between bundled objects with the scale influences the cost.
H6:	$\epsilon_{Dist} = 0$	The transportation distance influences the cost.
H7:	$\epsilon_{Tasks} = 0$	The number of distinct tasks in a contract influences the cost.

seven categories of bitumen-bound layers occurring in the sample. These data are covered in the Bills of Quantities. The distribution is shown in terms of frequency among the 290 contracts in the sample, the total area per category when summing over all contracts, and each category's share of the total area of all categories. Some of the contracts involve the replacement of all the layers in the road structure, but most contracts are only for the replacement of the adjustment and wear layers. Even though the members of the sample were only selected because the IM labeled them as hot-mix pavement replacement, several contracts also involve category E or F, corresponding to cold and warm-mix asphalt, respectively. On average, category D amounts to 39.4% of the total paving area. Dummy variables for the occurrence of layers A, B, C, E, and F are included in the empirical model, whereas layer D is omitted as a baseline case. With only one observation, layer G is also omitted.

Table A1 in the Appendix shows the correlations of the explanatory variables, except for the year and road layer dummies, for brevity. The correlations give some insights into how the IM bundles objects. First, the correlation between the number of objects and scale is only weakly positive, indicating that bundles containing several objects generally contain smaller-scale objects than do contracts containing one or a few objects. Second, the correlation between the number of objects and the number of unique non-paving tasks in a contract is weakly negative, indicating that mainly similar and less complex objects are bundled. Third, contrary to our a priori expectation, but in line with the moderate geographical spread within the bundles, the correlations between the number of objects and the variables for transportation distances are weakly negative. This association indicates that the IM has avoided bundling objects that are near an asphalt plant.

Overall, the correlations suggest that the set of control variables contributes to limiting omitted-variable bias, with non-negligible correlations with at least one of the bundling variables. Among the strongest correlations are those related to which of the IM's six regional offices procured the contract, suggesting considerable differences in both preconditions and practices. The contracts are generally larger in Region East and smaller in Region Stockholm. Region North bundles fewer objects per contract and Region Stockholm bundles more, and, contrary to our expectation, the spread within the bundles is smaller in the large and sparsely populated Region North and larger in the densely populated Region South. However, as expected, Region North is strongly correlated with the second-shortest distance of a potential bidder (positively) and the number of potential bidders (negatively).

6. Results

In a first step, the first-order, second-order, and interaction cost effects of the examined contract characteristics are estimated (Section 6.1). In a second step, winning bids are predicted based on the estimates from step 1, under varying assumptions as to both the number of bundled objects and the characteristics found to influence cost (Section 6.2). In this way, the net-cost effect of bundling is assessed. The third step tests whether and how the examined contract characteristics influence the degree of competition (Section 6.3).

6.1. *The separate and combined cost effects of bundling*

Table 4 lists the hypotheses presented in Section 4 regarding the separate and combined effects of the highlighted contract characteristics. As described in Section 4, the hypotheses are tested by estimating the procurer's translog cost function (equation (1) using OLS.

The results of the full translog with the variables described in Section 5 are provided in the Appendix (Table A2). Before examining the degree of multicollinearity and the possible adequacy of the reduced models, the first step is to investigate which of two variables

Table 5
Joint significance *F*-test of continuous variables (all terms).

Variable	*p*-value	Variable	*p*-value
ln*Area*	0.000***	ln*Dist2*	0.002**
ln*Objects*	0.001***	ln*Bids*	0.000***
ln*Spread*	0.798	ln*Tasks*	0.007**

Note: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 6
Results.

Variables	Coef.	S.E.	Variables	Coef.	S.E.
ln*Area*	0.768***	(0.027)	ln*Bids**ln*Tasks*	0.150	(0.083)
ln*Objects*	0.091***	(0.024)	*Twoyears*	0.013	(0.045)
ln*Objects*ˆ2	0.063**	(0.023)	*LayerA*	−0.015	(0.044)
ln*Dist2*	0.037	(0.030)	*LayerB*	0.002	(0.033)
ln*Dist2*ˆ2	0.093***	(0.028)	*LayerC*	−0.085*	(0.036)
ln*Tasks*	0.119***	(0.034)	*LayerE*	0.117*	(0.053)
ln*Bids*	−0.197***	(0.044)	*LayerF*	0.007	(0.031)
ln*Area**ln*Objects*	−0.033	(0.026)	*Central*	0.315***	(0.083)
ln*Area**ln*Dist2*	0.020	(0.034)	*North*	0.241**	(0.082)
ln*Area**ln*Tasks*	0.001	(0.043)	*South*	0.097	(0.059)
ln*Area**ln*Bids*	−0.063	(0.060)	*West*	0.046	(0.054)
ln*Objects**ln*Dist2*	0.077**	(0.026)	*East*	0.191**	(0.066)
ln*Objects**ln*Tasks*	−0.028	(0.031)	*Year2013*	−0.083*	(0.035)
ln*Objects**ln*Bids*	−0.175*	(0.069)	*Year2014*	−0.020	(0.038)
ln*Dist2**ln*Bids*	−0.116	(0.082)	*Year2015*	−0.080	(0.045)
ln*Dist2**ln*Tasks*	0.065	(0.037)	*Constant*	13.937***	(0.075)
Observations, 290; R^2, 0.916; Adjusted R^2, 0.905					

Model III. Dependent variable: ln(Winbid). Variables normalized by their means prior to log transformation. Robust standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

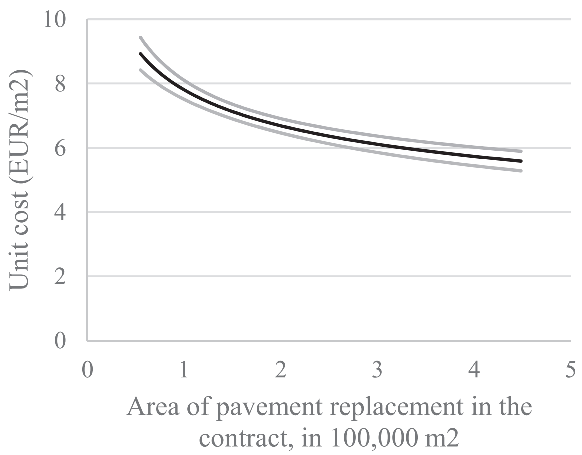

Fig. 3. The estimated cost effect of scale (*Area*). Predicted unit cost (black). 95% CI (grey).

capturing the transportation distance to include in the models: the minimum distance or the second-shortest distance. Comparing the AIC and BIC of a full translog specification (models I and II) with either of these variables, the model including the second-shortest distance (Model II) is preferred.

The VIF for this specification of the full translog model (i.e. Model II) is 14, which indeed suggests that multicollinearity is an issue. Testing the joint significance of all terms of each continuous variable (Table 5), we cannot reject that all the parameters associated with the spatial spread within a bundle, *Spread*, are zero. Hence, all terms including *Spread* are eliminated from the model. Moreover, the second-order terms of variables that are not close to statistical significance are also eliminated (*Area*: $p = 0.704$, *Bids*: $p = 0.384$, and *Tasks*: $p = 0.899$).

Table 6 presents the results of the reduced model when including the second-shortest rather than the minimum transportation distance (Model III). Even with inclusion of interaction variables, the coefficients can be interpreted as the elasticity at the sample mean, as all continuous variables have been divided by the sample mean prior to the logarithmic transformation. Post-estimation

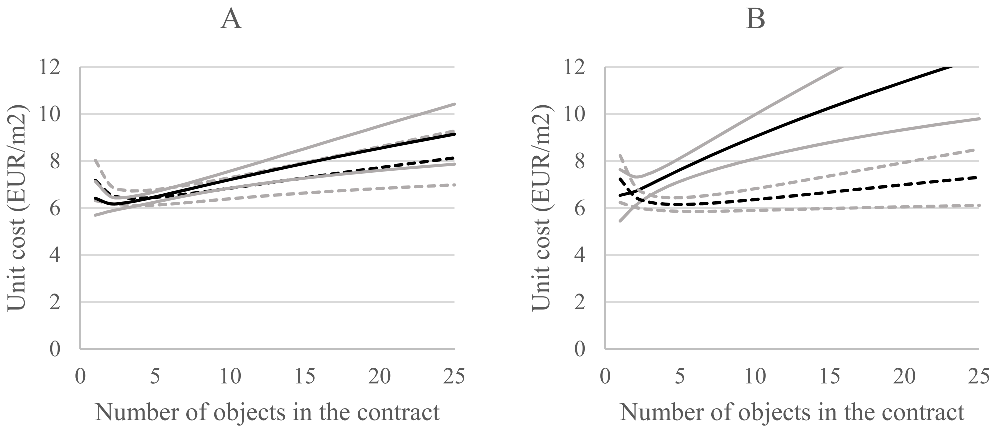

Fig. 4. The estimated cost effect of the number of objects (*Objects*). (A) Transportation distance (*Dist2*) at 20 km (dashed line) and 50 km (solid). (B) Number of bidders set at 2 (solid) and 6 (dotted). Predicted unit cost (black). 95% CI (gray).

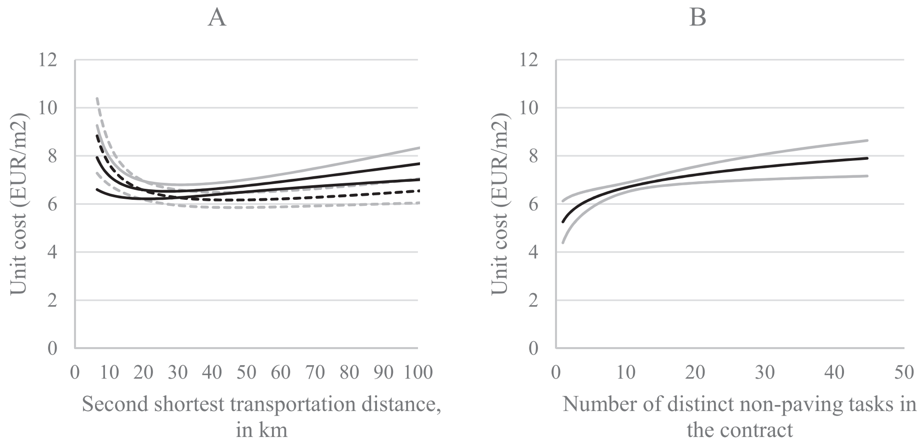

Fig. 5. (A) Estimated cost effect of the transportation distance (*Dist2*). Number of objects set at 2 (dashed line) and 7 (solid). (B) Estimated cost effect of the number of distinct non-paving tasks (*Tasks*) in the contract. Predicted unit cost (black). 95% CI (grey).

testing suggests that this reduced model meets the assumptions for OLS (e.g. Breusch–Pagan homoscedasticity test, $p = 0.46$; Ramsey RESET omitted-variable test, $p = 0.63$). Still, following the standard practice, robust standard errors are used. The VIF is 2.34, implying that multicollinearity is not an issue with this reduced model. The model explains 92% of the observed variation in the winning bids.

Focusing first on the issue of economies of scale, only the first-order effect of the scale (*Area*) is statistically significant, meaning that this coefficient constitutes the estimate of the total cost elasticity with respect to scale. With a 95% confidence interval of 0.715–0.821, the coefficient estimate for scale is significantly smaller than 1, i.e. the null hypothesis *H1* is rejected in favor of the alternative hypothesis of economies of scale. According to the point estimate, the elasticity of cost with respect to scale is 0.768 (at the mean of *Dist2*). This estimate suggests that increasing the scale by 1% increases the cost by about 0.768%, which corresponds to a return to scale of 1.30 ($1/\epsilon_{Area}$).

The results include significant second-order and interaction effects that may be most easily interpreted when presented graphically. Hence, the main results are visualized using predictions of the unit cost. These cost predictions involve a retransformation from the log scale ($C_i = \exp(\widehat{\ln C_i} * 0.5\widehat{\sigma^2})$, where $\widehat{\ln C_i}$ is the predicted natural logarithm of cost and $\widehat{\sigma^2}$ is the variance of the root mean squared error. Fig. 3 shows the predicted unit cost for most of the range of scale (*Area*), visualizing how the estimates imply strong but diminishing economies of scale. For reference, the average scales of a contract and an object are approximately 182,000 and 57,000 square meters, respectively, when summing over all layers.

Both the first- and second-order effects of the number of objects in a contract (*Objects*) are significant at the 95% level. Moreover, the number of objects has a significant interaction effect with both the transportation distance (*Dist2*) and the number of bids (*Bids*). Hence, the null hypothesis *H2* is rejected. At the sample mean of the variables in the model (e.g. *Objects* = 5), the point estimate suggests that increasing the number of objects by 20% (one additional object) increases the cost by 1.8% (20*0.091). This cost elasticity with respect to the number of objects is nonlinear and increases with the number of objects.

Fig. 4 shows how the cost elasticity with respect to the number of objects also increases with the transportation distance and

Table 7
Description of cases.

Case	Panel in Fig. 5	Description	OBJECTS	DIST2	TASKS
Baseline	A, B, C, D	Baseline (mean values)	5	40	10
N6	A	Baseline + 1 object (20%)	6	40	10
D48	B	N6 + 8 km transp. dist. (20%)	6	48	10
D80	B	N6 + 40 km transp. dist. (100%)	6	80	10
T12	C	N6 + 2 tasks (20%)	6	40	12
T20	C	N6 + 10 tasks (100%)	6	40	20
D48T12	D	N6 + 8 km transp. dist. + 2 tasks	6	48	12
D80T20	D	N6 + 40 km transp. dist. + 10 tasks	6	80	20

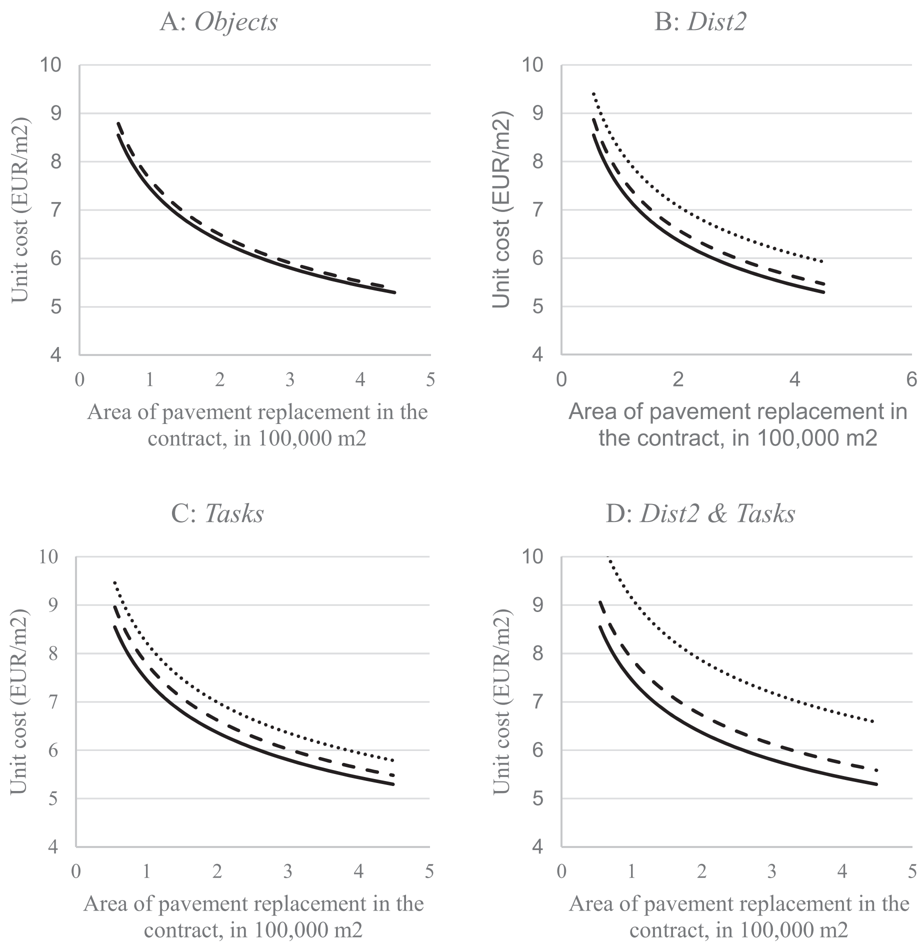

Fig. 6. The predicted net-cost effect of adding one object to an average contract. Solid line: baseline (*Objects* = 5; *Dist2* = 40; *Tasks* = 10). Dashed line: one additional object (A) and a 20% increase in *Dist2* (B) or *Tasks* (C) or both (D). Dotted line: one additional object and a 100% increase in *Dist2* (B) or *Tasks* (C) or both (D).

decreases with the degree of competition; the cost-increasing effect of bundling diminishes if the transportation distance is short (panel A) and if the degree of competition is strong (panel B). The interaction effect with the scale is not significant, i.e. the null hypothesis *H3* cannot be rejected. As tested initially, the null hypotheses *H4* and *H5*, regarding the effect of the geographical spread between the objects, cannot be rejected.

The first-order effect of the second-shortest transportation distance is not significant at the mean. Still, the second-order effect and interaction effect with the number of objects are significant at the 95% confidence level. Hence, the null hypothesis *H6* is rejected. These results imply that the transportation distance increases cost when the distance and the number of objects are at some point above their average.

Fig. 5 panel A shows the estimated effect of transportation distance on the unit cost, with the number of objects set to two (25th percentile) and seven (75th percentile), respectively. Notably, the negative association between transportation distance and unit cost over the lowest end of the range, all else being equal, implies that the total cost of transportation decreases with distance, i.e. there is a negative marginal cost of transportation. This result is likely due to the model specification, with an interplay of second-order and interaction effects, rather than to a true empirical association.

The first-order cost effect of the number of non-paving tasks specified in the contract (*Tasks*) is significant at the 95% level. Hence, the null hypothesis *H7* is rejected. According to the point estimate, increasing the number of tasks by 10% increases the cost by 1.19%, which supports hypothesis 7. The number of tasks is in the range of 2–70, which suggests that grouping multiple objects in one contract could give rise to a substantial percentage change in this variable, and thereby to a substantial cost increase. Correspondingly, Fig. 5 panel B shows a strong (but diminishing) association between the unit cost and the number of tasks.

While the primary aim of this paper is to examine the cost effects of the bundling variables, the other cost parameter estimates presented in main results table (Table 6) are also commented on. In addition to influencing the cost effect of bundling, the degree of competition for a contract is found to have a substantial first-order effect. According to the point estimate, the procurer's cost is reduced by 4.9% if the number of bidders is increased by one from the mean of four (25%*0.197). Moreover, the results show that the cost is influenced by the inclusion of other asphalt categories than asphalt category D (omitted as a baseline). The cost is about 8% $(\exp(\gamma)-1)$ lower if a contract includes asphalt category C, i.e. if some of the total area of pavement replacement in the contract belongs to this category instead of category D. Similarly, the cost is about 12% higher in contracts including asphalt category E.

The results also show that costs differ between the IM's regional offices. The point estimates suggest that the cost is 21–37% higher in the Central, North, and East regions versus in Stockholm (baseline), whereas the cost in the South and West regions is not significantly different from the baseline. The explanations for these differences may be both endogenous (e.g. procurement practices) and exogenous (e.g. characteristics of the ground, climate, and traffic).

Finally, the results suggest that the IM's cost was about 8% lower in 2013 than in 2012. The difference in cost is not statistically significant when comparing either 2014 or 2015 with 2012. Whether the contract duration was two years instead of one year was not found to influence the cost.

6.2. The predicted net-cost effect of bundling

The net-cost effect of bundling, under various circumstances, is examined by predicting winning bids based on the estimates in Section 6.1, including the first- and second-order effects as well as the interaction effects. The predictions are made under varying assumptions as to both the number of objects and the two characteristics of the bundles found to significantly influence the procurer's cost, apart from the scale. These two characteristics are the second-shortest transportation distance (*Dist2*) and the number of distinct non-paving tasks (*Tasks*). Rather than making one or several assumptions as to scale, winning bids are predicted for the range of 50,000–450.000 square meters. In the sample of contracts, 85% of the scale observations are within this range. Moreover, the predictions of the winning bids are presented in terms of unit cost, i.e. divided by the scale. In this way, the cost effects of transportation distance and the complexity of the bundle can more easily be related to the economies of scale.

Table 7 lists the eight cases considered. The first case is a baseline in which all the included variables are at the mean. In Case N6, the bundle is increased from five to six objects without affecting the transportation distance and the number of (non-paving) tasks. Fig. 6 shows the predicted unit cost given the scale of the contract and the cases presented in Table 7. As previously noted, the average scales of a single object and a contract are approximately 57,000 and 182,000 square meters, respectively. Increasing the number of objects from five to six without affecting the transportation distance and what kind of tasks are to be performed (Case N6) gives rise to a small increase in the unit cost versus the baseline. Hence, under these assumptions, the cost savings from economies of scale clearly dominate the costs of bundling even when including small-scale objects, for most of the scale range.

In Cases D48 and T12, the transportation distance and the number of tasks, respectively, are increased in proportion to the increase in the number of objects, i.e. by 20% (to 48 km and 12 tasks). This means that the costs of bundling increase but are still dominated by economies of scale over most of the range of scale when adding one at least average-size object. However, the net effect of the costs and benefits shifts to negative at some level and combination of the scale of the object, transportation distance, and the number of different tasks. For instance, if the added object implies that either the transportation distance (D80), number of tasks (T20), or both (D80T20) increase(s) to twice the respective mean(s), the costs of bundling would dominate the economies of scale in most conceivable cases. These cases are included for illustrative purposes, as adding a sixth object to a contract is unlikely to have such a major influence on these contract characteristics.

To summarize, the analysis of these cases illustrates that the economies of scale are substantial, particularly below the average scale of the contracts in the sample (about 182.000 square meters), but also above. While costs are found to increase with each additional object included in a contract, this is outweighed by economies of scale if the added object is not very minor. Instead, the two other identified cost effects of bundling, stemming from the transportation distances and the number of different tasks to be performed, are the main determinants of the net-cost effect of increasing the scale of a contract. If adding one additional object of an average scale causes only a moderate increase in either the transportation distance or the number of tasks, the impact on cost is generally less than the benefit from economies of scale, particularly for contracts below the average scale. However, if adding an additional object has a major impact on the transportation distance or the number of different tasks, or both, the increase in scale would have to be substantial for bundling to be advantageous.

6.3. The influence of bundling on competition

Given the substantial cost effect of the degree of competition, found in Section 6.1, it is plausible that bundling has indirect cost

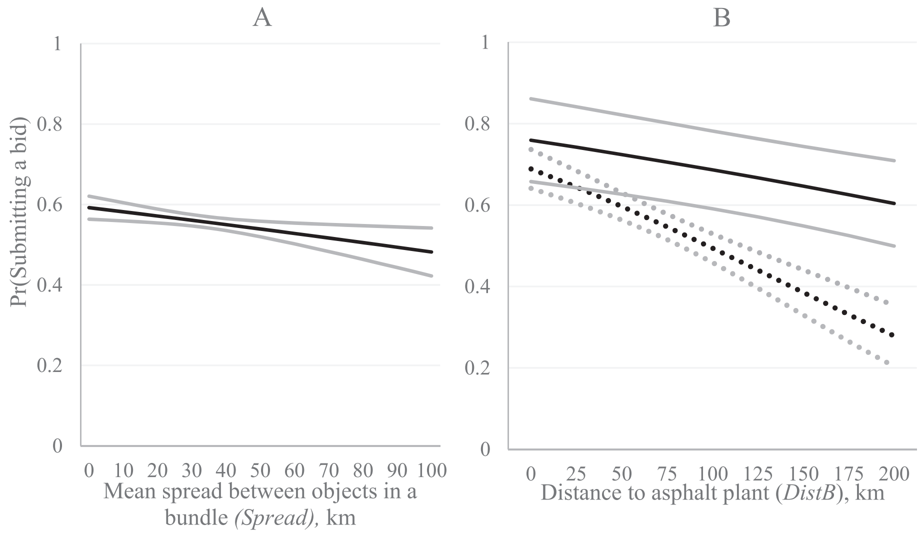

Fig. 7. Determinants of the probability of a potential bidder submitting a bid. (A) The average spread within bundle (*Spread*). (B) The transportation distance (*DistB*) given the shortest distance of a rival (*DistR*): 10 km (dotted) and 100 km (solid).

effects through affecting bidders' participation. This issue is of particular interest as facilitating adequate competition is a common issue in public procurement. For instance, about 20% of the public procurements in the Tenders Electronic Daily, TED, a procurement database for the European Union, attracted only one bidder (excluding framework agreements and negotiated procedures; European Commission, n.d.).

The first way to improve our understanding of how bundling affects competition is to exclude the variable for number of bidders from the reduced model. The results of this are shown in Table A2 in the Appendix (Model IV) and establish that removing the number of bids as a control variable has a limited impact on the coefficient estimates and does not change the sign of any estimate.

The impact of bundling on competition is also examined by estimating the probit function on the potential bidders' participation decision presented in equation (4). In this model, the participation decision is defined as a function of all but two of the variables included in the cost function but without log transformation and without interaction and second-order effects. The variable for the number of bids is replaced with a corresponding exogenous measure, namely the number of firms having an asphalt plant within 150 km ($PBids \in \mathbb{Z} \cap [1,7]$, mean = 5.2). Moreover, the variable for the second-shortest transportation distance is replaced with variables for the transportation distance of each potential bidder and their closest rival, and the interaction between these two distances. Given the national coverage of most of the firms on the market, all seven firms having submitted at least one bid for a contract in the sample are treated as potential bidders in each of the 290 procurements. This gives 2030 observations of the decision of whether to submit a bid, of which 1135 resulted in the submission of a bid.

The main findings of this step of the analysis are visualized in Fig. 7, whereas the full results are presented in Table A3 in the Appendix. The effects of the contract size and the number of objects on the propensity to submit bids are not significant. In contrast, the spread of the bundle has a significant effect on participation. As shown in Fig. 7 panel A, the probability of submitting a bid is found to decrease with the spread, which goes against the hypothesized competition effect of levelling the playing field. Moreover, Fig. 7 panel B illustrates that this probability decreases with the bidder's transportation distance, and the magnitude of this effect is found to increase the closer a potential rival bidder is to the contract sites. The impact of closeness to an asphalt plant, both one's own and that of a competitor, is obviously important and warrants serious analysis when contracts are bundled.

7. Discussion

Bundling influences the efficiency of the examined procurements of pavement replacement in multiple and counteracting ways. In line with findings regarding similar contracts in the USA (e.g. Xiong et al., 2017; Qiao et al., 2019b), economies of scale are found to be substantial but diminishing. While the point estimate of the scale elasticity of cost of approximately 0.77 is higher than the corresponding elasticity of 0.52 in US paving replacement contracts (Qiao et al., 2019b), it still implies a considerable potential for efficiency improvements by way of increasing average contract size. The elasticity is found to be constant with respect to both scale and the other variables. Still, in monetary terms, the scale economies shrink with contract size, whereby the benefit of increasing average size is particularly great for contracts currently smaller in size.

This does not mean that the IM should increase the scale of a pavement replacement contract by extending the contract to adjacent road segments where the pavement is in good condition. Instead, the IM's main instrument for determining the scale is bundling: a contract can be made larger by grouping multiple geographically spread-out pavement replacement objects. A caveat is that the average distance between objects and an asphalt plant should not be too great; otherwise, there is a risk that the level of competition in the bidding contest may drop.

Fig. A1. Geographical distribution of objects (dark grey lines) and asphalt plants (triangles) in the sample over the Swedish national road network (light gray lines).

The results show that increasing the scale of a contract through bundling has cost effects counteracting those of economies of scale. First, contrary to findings regarding similar project types reported by Qiao et al. (2019b), the number of objects in a bundle is found to increase the IM's cost, and more so the larger the transportation distance of the potential bidders. At the sample mean, an additional object is found to increase the cost by 1.8%. Second, bundling may increase the transportation distances of the potential bidders. In line with previous findings regarding similar procurements in the USA, the transportation distance is found to increase the cost (at above average transportation distances). Third, bundling may increase the complexity of the contract, which is also found to increase the cost, in line with the finding of Qiao et al. (2019a) that bundles of similar objects are less costly. The geographical spread between the objects in a bundle is not found to influence the cost, all else being equal (including transportation distance).

The descriptive statistics show that the IM generally bundles a few nearby, small, and similar objects. The practice of making bundles of nearby similar objects is in line with the efficiency results presented here, indicating that the IM has a fair understanding of the cost structure of the procured work. Still, the results also show that the diminishing economies of scale are still substantial and at the average scale of the IM's contracts, suggesting that efficiency could be improved if the IM increased the size of these contracts using bundling. Similarly, the results suggest that the US and Canadian guidelines on bundling similar types of road work, mentioned in the Introduction, may be improved by emphasizing transportation distance and the similarity of objects rather than whether the objects

Table A1
Correlation matrix.

	Area	*Obj*	*Spread*	*Dist1*	*Dist2*	*Tasks*	*PBids*	*Bids*	*2 year*	*Cent*	*North*	*Sthlm*	*South*	*West*
Obj	0.14	1.00												
Spread	0.31	0.26	1.00											
Dist1	0.26	–0.08	0.51	1.00										
Dist2	0.14	–0.18	0.04	0.54	1.00									
Tasks	0.26	–0.10	0.06	0.33	0.37	1.00								
PBids	–0.22	0.11	–0.01	–0.19	–0.41	–0.41	1.00							
Bids	0.06	0.15	–0.10	0.03	0.01	0.06	–0.03	1.00						
2 year	0.10	0.03	–0.11	0.02	0.15	0.15	–0.01	–0.09	1.00					
Cent	0.32	0.00	0.09	0.04	0.03	0.31	–0.44	–0.05	–0.06	1.00				
North	–0.03	–0.27	–0.27	0.17	0.52	0.45	–0.42	0.06	0.13	–0.12	1.00			
Sthlm	–0.22	0.37	–0.12	–0.24	–0.25	–0.25	0.25	0.27	–0.15	–0.16	–0.16	1.00		
South	–0.15	–0.12	0.39	0.18	–0.01	–0.13	–0.22	–0.09	–0.18	–0.18	–0.18	–0.24	1.00	
West	–0.19	–0.07	–0.27	–0.20	–0.14	–0.23	0.45	–0.15	0.24	–0.21	–0.22	–0.28	–0.32	1.00
East	0.44	0.08	0.18	0.12	–0.03	0.04	0.18	–0.01	0.01	–0.13	–0.13	–0.17	–0.20	–0.23

are small-scale projects.

The descriptive statistics also show considerable discrepancies between the Swedish IM's regional offices in terms of the characteristics of the bundles. This observation suggests that there is scope for efficiency improvements through further dissemination of efficient bundling practices. Relatedly, Smith et al. (forthcoming) compared cost efficiency in procurements of highway replacement across the Swedish IM's regions and procurement engineers, finding considerable cost differences, even with important characteristics of the treated road sections being accounted for.

The complementary analysis of determinants of the bidders' probability of submitting bids provides mixed results regarding how bundling influences competition. On one hand, this probability decreases with both the transportation distance and the spread between objects; on the other hand, neither the scale, number of objects, nor number of tasks is found to influence the probability of submitting a bid. These results are partly contrary to the corresponding findings from the USA. Whereas Qiao et al. (2021) also found that spatial proximity increases the bidding participation, the participation is found to increase with the scale and decrease with the number of objects in the examined US case. The degree of competition, as in the number of submitted bids, is found to be negatively associated with the cost, which supports considering these potential indirect cost effects when designing the bundles of road pavement replacement work.

In line with previous findings regarding the importance of the transportation distance of bidders and rivals (e.g. Bajari and Ye, 2003; Bajari et al., 2014), we find that the procurement cost is better explained by the second-shortest than the minimum transportation distance. Moreover, the distance of the closest rival is found to strongly influence the probability of a bidder's decision on whether to submit a bid, given its own transportation distance. These results offer some support for the competition effect derived in theoretical work on bundling in auctions (e.g. Palfrey, 1983; Chakraborty, 1999; Jehiel et al., 2007; Chen and Li, 2018), i.e. that bundling may be used to reduce differences in the bidders' valuation of a contract and thereby increase competition.

Some additional comments are warranted about the implications of the results. First, the results are based on observed data. The results should not be generalized to extreme variants of bundling, far from what is observed and analyzed here. Second, the dynamics of competition should be considered. If a large share of the annually tendered pavement renewal contracts in a region were allocated to one bidder, the losing bidders might not stay active in the region for the next round of procurement. Third, one issue not considered in our analysis is whether the group of potential bidders could be expanded if contracts were smaller than the current practice, thereby facilitating the participation of smaller firms. We have only analyzed the bidding of firms that were competing for these contracts given the procurement policies during the period. However, as we have found strong economies of scale even when a bundle is divided between multiple work sites, it is unlikely that small and medium-sized firms would be competitive even if individual contracts were made smaller. This aspect is further supported by the fact that establishing a new asphalt plant requires substantial sunk investment costs.

8. Conclusion

This paper examines how bundling affects procurement costs in the case of road pavement replacement. This is one example of many possible applications of public procurements that involve decisions about bundling. Since there is limited empirical research guiding procurers on the subject, the generalizable recommendations from the research concern the extent of similarity to other applications where bundling may be a possibility.

We have found that bundling has multiple and counteracting effects on the procurer's cost. In line with findings from the USA, the economies of scale are shown to be substantial but diminishing in pavement replacement. Complementing the prior literature on this topic, we have shown that these economies of scale are not affected by whether work is divided between geographically spread-out project sites, i.e. using bundling. Moreover, we have shown counteracting cost-increasing effects associated with the number of bundled objects, transportation distance, and number of different tasks in a contract. The paper has also presented evidence that the transportation distance of the competitors is an important determinant of companies' participation and bidding strategies, suggesting that bundling may be used to reduce the difference in the bidders' valuations and thereby increase competition.

Table A2
Results.

	I		II		III		IV	
Notes:	*Dist1*		*Dist2*		*Dist2*		*Dist2*	
					Reduced		III – *Bids*	
	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.	Coef.	S.E.
ln*Area*	0.787***	(0.032)	0.777***	(0.030)	0.768***	(0.027)	0.771***	(0.027)
ln*Area*ˆ2	0.011	(0.024)	0.009	(0.023)				
ln*Objects*	0.060	(0.033)	0.069*	(0.032)	0.091***	(0.024)	0.085**	(0.026)
ln*Objects*ˆ2	0.055	(0.031)	0.045	(0.028)	0.063**	(0.023)	0.058*	(0.024)
ln*Spread*	0.002	(0.037)	0.011	(0.027)				
ln*Spread*ˆ2	–0.002	(0.006)	–0.002	(0.005)				
ln*Dist*	–0.007	(0.041)	0.038	(0.037)	0.037	(0.030)	0.050	(0.030)
ln*Dist*ˆ2	0.013	(0.018)	0.095**	(0.029)	0.093***	(0.028)	0.098***	(0.027)
ln*Bids*	–0.212**	(0.064)	–0.232***	(0.064)	–0.197***	(0.044)		
ln*Bids*ˆ2	–0.082	(0.147)	–0.124	(0.143)				
ln*Tasks*	0.128**	(0.041)	0.122**	(0.038)	0.119***	(0.034)	0.125***	(0.036)
ln*Tasks*ˆ2	0.003	(0.028)	–0.004	(0.029)				
ln*Area**ln*Obj*	–0.015	(0.039)	–0.033	(0.037)	–0.033	(0.026)	–0.033	(0.028)
ln*Area**ln*Spread*	–0.009	(0.009)	–0.002	(0.007)				
ln*Area**ln*Dist*	0.052	(0.029)	0.029	(0.038)	0.020	(0.034)	0.008	(0.038)
ln*Area**ln*Bids*	–0.075	(0.076)	–0.084	(0.075)	–0.063	(0.060)		
ln*Area**ln*Tasks*	–0.019	(0.053)	–0.014	(0.051)	0.001	(0.043)	0.020	(0.045)
ln*Obj**ln*Spread*	0.016	(0.037)	0.020	(0.028)				
ln*Obj**ln*Dist*	0.069	(0.053)	0.065	(0.044)	0.077**	(0.026)	0.081**	(0.028)
ln*Obj**ln*Bids*	–0.121	(0.103)	–0.104	(0.102)	–0.175*	(0.069)		
ln*Obj**ln*Tasks*	–0.117*	(0.051)	–0.095	(0.049)	–0.028	(0.031)	–0.031	(0.033)
ln*Spread**ln*Dist*	–0.008	(0.009)	0.001	(0.008)				
ln*Spread**ln*Bids*	–0.021	(0.020)	–0.013	(0.020)				
ln*Spread**ln*Tasks*	0.017	(0.010)	0.017	(0.010)				
ln*Dist**ln*Bids*	0.032	(0.075)	–0.118	(0.086)	–0.116	(0.082)		
ln*Dist**ln*Tasks*	0.070	(0.039)	0.052	(0.046)	0.065	(0.037)	0.056	(0.037)
ln*Bids**ln*Tasks*	0.226*	(0.097)	0.189	(0.098)	0.150	(0.083)		
Twoyears	–0.000	(0.051)	0.009	(0.048)	–0.080	(0.045)	–0.075	(0.043)
LayerA	0.029	(0.049)	–0.006	(0.048)	0.013	(0.045)	0.028	(0.046)
LayerB	0.030	(0.036)	0.007	(0.037)	–0.015	(0.044)	–0.040	(0.044)
LayerC	–0.070	(0.039)	–0.087*	(0.038)	0.002	(0.033)	0.012	(0.033)
LayerE	0.088	(0.070)	0.104	(0.061)	–0.085*	(0.036)	–0.098**	(0.036)
LayerF	0.013	(0.032)	0.007	(0.032)	0.117*	(0.053)	0.136**	(0.050)
Central	0.223*	(0.087)	0.305***	(0.085)	0.007	(0.031)	0.022	(0.031)
North	0.133	(0.082)	0.228*	(0.089)	0.315***	(0.083)	0.328***	(0.081)
Sthlm	0.051	(0.060)	0.087	(0.059)	0.241**	(0.082)	0.244**	(0.087)
West	–0.007	(0.055)	0.044	(0.055)	0.097	(0.059)	0.101	(0.061)
East	0.086	(0.072)	0.171*	(0.071)	0.046	(0.054)	0.058	(0.055)
2013	–0.060	(0.036)	–0.077*	(0.038)	0.191**	(0.066)	0.207**	(0.068)
2014	–0.024	(0.041)	–0.022	(0.041)	–0.083*	(0.035)	–0.075*	(0.036)
2015	–0.093*	(0.047)	–0.079	(0.047)	–0.020	(0.038)	–0.021	(0.038)
Constant	13.995***	(0.083)	13.952***	(0.080)	13.937***	(0.075)	13.935***	(0.075)
Observations	290		290		290		290	
R^2	0.915		0.917		0.916		0.910	
Adjusted R^2	0.901		0.904		0.905		0.901	
AIC	–20		–27		–41		–31	
BIC	134		127		76		217	

Dependent variable: ln*(Winbid)*. Robust S.E. in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Our findings offer support for how the Swedish IM uses the bundling of road pavement replacement work and for the increasing use of such bundling by IMs in the USA. We have shown that the Swedish IM generally bundles nearby and similar objects. While this is in line with the results of the efficiency analysis of this study, the results suggest that the Swedish IM could benefit from making the bundles even larger, as the scale of many contracts is within the range of substantial returns to scale. Similarly, we have questioned the restrictive emphasis on small-scale projects found in US and Canadian guidelines for the bundling of similar work. While road surface deterioration is largely exogenous, the IM often has some flexibility regarding the threshold for when to initiate repairs. Possibly, this flexibility could be used to facilitate the bundling of similar and geographically proximate pavement replacement tasks. However, there may be a social cost to prolonged time with poor road surfaces that is not accounted for here. Hence, there is scope for future research to examine how the timing of procurements can be optimized with respect to economies of scale and other factors.

While the main implications of the present results are generally in line with the few prior studies of similar procurements, some discrepancies have been identified regarding the cost and competition effects of the examined bundling-related factors. Contrary to prior research, we have found a cost effect of including additional objects in a bundle, even with factors such as scale, transportation distance, and complexity held constant, and no effect of either number of objects or scale on the participation of potential bidders.

Table A3
Regression results: Probability of a potential bidder submitting a bid.

Variables	Coef.	S.E.	Variables	Coef.	S.E.
Area	0.000	(0.004)	*LAYERF*	–0.286**	(0.095)
Objects	0.006	(0.013)	*CENTRAL*	–0.389	(0.236)
Spread	–0.006**	(0.002)	*NORTH*	0.051	(0.275)
DistB	–0.009***	(0.001)	*SOUTH*	0.013	(0.168)
DistR	0.004	(0.004)	*WEST*	–0.578***	(0.146)
DistB # DistR	0.000***	(0.000)	*EAST*	–0.166	(0.174)
PBids	–0.153**	(0.047)	*FIRM2*	–3.200***	(0.309)
Tasks	–0.004	(0.008)	*FIRM3*	–2.023***	(0.162)
Twoyears	–0.017	(0.128)	*FIRM4*	–0.224	(0.166)
LayerA	0.377**	(0.136)	*FIRM5*	–0.565***	(0.152)
LayerB	–0.201*	(0.091)	*FIRM6*	–1.734***	(0.158)
LayerC	–0.014	(0.093)	*FIRM7*	–0.019	(0.187)
LayerE	–0.062	(0.291)	*Constant*	3.033***	(0.369)
Observations: 2030; Pseudo (McFadden) R^2: 0.519					

Model P.I. Dependent variable: *Pr(Submitting a bid)*. Robust S.E. in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

There is scope for further research on the moderating determinants of these effects. Moreover, what is not considered in this study are the long-term effects of bundling on competition. The empirical analysis is based on observations of bidding strategies by companies active on the market as it is, i.e. a market characterized by the procurer's current bundling policy. As discussed, the found strong economies of scale, regardless of whether or not the scale is divided between multiple spread-out locations, indicates that small and medium-sized firms would likely not be competitive even if the procurer changed to an unbundling policy. The long-term effects of how the already limited pool of competitors would be affected by further increases in the bundle sizes, decreasing the number of contracts up for competition in each year, is more difficult to assess a priori and could be a productive subject for future research.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

See Fig. A1 and Tables A1-A3.

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