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# High earnings through firm influence: the role of hierarchical structures in public procurement

Niclas Frederic Sturm[1*], Cristian Candia[2,3,4,5], Bruno Damásio[1] and Flávio L. Pinheiro[1]

*Correspondence:
nsturm@novaims.unl.pt
[1]NOVA Information Management School (NOVA IMS), Universidade Nova de Lisboa, Lisbon, Portugal
Full list of author information is available at the end of the article

**Abstract**

Public procurement, a critical but often overlooked aspect of governance, plays a pivotal role in steering the acquisition of goods, services and the commissioning of public works. Our study, analyzing over one million public procurement contracts from the Portuguese public administration, applies network science to unravel the complexities of this market. We uncover a market characterized by highly modular and hierarchical networks, with notable service specialization, regional diversity, and entity diversification. Our findings reveal a clear pattern: firms occupying influential positions within the networks consistently achieve higher earnings per bid. This disparity in earnings indicates a market where competition is constrained and entry barriers for new firms are high. Similarly, markets in the Portuguese public procurement system exhibit high levels of concentration, which raises both integrity and supplier risks that should be monitored by policymakers. The empirical framework developed in this article contributes to a growing body of literature that analyzes the levels of competition in public procurement systems. The network-based method applied here facilitates the analysis of firms' positioning within their network of competitors and helps to quantify firm capabilities in a way that moves beyond a monolithic view of firm size and market power.

**Keywords:** Public Procurement; Tenders; Market Organization; Network Analysis; Competition; Complexity

## 1 Introduction

Public procurement, as a critical function of public sector organizations, encompasses the acquisition of goods, services, and works, playing a significant role in steering technological innovation, economic growth, and the realization of socially beneficial outcomes [1–4]. In 2021, these procurement activities represented a substantial portion of Gross Domestic Product (GDP) in member states of the Organisation for Economic Co-operation and Development (OECD), approximately 13% [5]. Traditionally, the focus of research on public procurement has been its role as a policy instrument, with studies often exploring specific contexts such as sustainability [6, 7], innovation [8–11], and market competitiveness [12]. Additionally, recent years have seen a growing interest in the development of indicators



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and frameworks for auditing, aimed at curbing fraud, corruption, and other irregularities in procurement processes [13–18]. Despite these advances, public procurement remains relatively under-explored compared to other governmental instruments, particularly in understanding the inherent organization and structure of procurement markets and their impact on the behavior of market actors [19].

Here, we investigate the structure of competition — the degree to which the inherent organization and interrelations of firms within a market influence their competitive advantage and overall market dynamics — of the Portuguese public procurement market. Since a national economy's procurement market reflects a wide variety of firm behaviors, we focused on the behavior of an active core of firms. We assumed that the co-bidding behavior (i.e., bidding competitively to the same tender) of that active core offers a useful abstraction to reason about the general organization of the public procurement market with its subdivisions. Pertinent to competition structures is whether potential distortions impede market entry or limit opportunities. A general feature of the Portuguese public procurement market is its high concentration, with 2.2% of firms accounting for 80% of total revenues in procurement-related activities.

The legal framework of public procurement in Portugal allows for both competitive procedures, such as open tenders, as well as non-competitive procedures, such as direct awards and prior consultations, whose application is subject to thresholds stipulated in the Portuguese Public Procurement Code (PPC) and directives enacted at the level of the European Union. We have included a more detailed discussion of the institutional framework of public procurement in Portugal, thresholds and special cases in Sect. 1 of the Supplementary Material (SM). Notably, between 2018 and 2022, the proportion of contracts awarded through non-competitive procedures was between 73-78%, while the proportion by contract value was between 30-38% [20], i.e. a significant share of the procurement system is channeled through discretionary procedures. This imbalance in terms of procedures employed motivates a deeper analysis of those parts of the market that are subject to competitive procedures, i.e. open tenders.

Using a large dataset of public procurement contracts, issued by the Portuguese public administration between 2009 and 2022, we characterize firms' competitive ties in open tenders by estimating a network representation of the Portuguese public procurement market. We then provide an empirical analysis of the market organization and how the positioning of firms in the market preludes their success. Characterizing the Portuguese public procurement market in such detail provides a nuanced understanding of its structure and highlights organizational aspects that may require further scrutiny and intervention from policymakers.

Our study contributes a novel perspective on the competitive dynamics in public procurement markets. Whereas previous research has focused particularly on supplier-buyer structures, by, e.g. inferring firm-entity networks [21], or focusing on bidding participation [22], firm-firm interactions allow a dynamic view on the development of markets over time as well as quantify through centrality measures firm influence and competitiveness in a continuous way, overcoming a dichotomous view of firm size.

The structure of the article is as follows: Sect. 2 presents the contextual background of our study, while Sect. 3 outlines the materials and methods employed. Sections 4, 5, and 6 explore firm-firm co-bidding networks, the impact of network centrality measures on public procurement earnings using econometric techniques, and the dynamics of sub-markets

and firm competitiveness, respectively. Finally, Sect. 7 concludes the article, offering insights for future research and policy recommendations.

## 2 The interconnectedness of markets

As Holt [23] suggests, we are entering a "complexity era" in economic systems study, where complex networks offer a robust framework for mapping market structures and agent activities. The high dynamism of markets implies the need for an empirical framework that adequately captures market complexity. Matutinović [24, 39] highlights the role of "functionally interdependent" agents within markets. These interdependencies call for network analysis as an empirical framework. It is important to note that the public procurement market exhibits peculiarities that differentiate it from "ordinary" markets.

Matutinović [25] argues that the self-organization of firms within institutional frameworks, such as those provided by public procurement procedures, inherently shapes the market as a complex system. Public procurement markets, epitomizing the concept of "organized markets" as articulated by Ahrne [26], are prime candidates for analysis through the lens of complex systems, a perspective further supported by the works of [27–30], and [31]. The utility of this approach is evidenced in other markets, such as financial markets, where complexity models have been effectively applied in understanding stock correlations [32], banking network risks [33], and corporate ownership networks [34].

Public procurement markets are commonly classified into developmental stages, starting with the public sector creating new markets and followed by market expansion and consolidation through the state's purchasing power [11, 35]. Hommen categorizes these public procurement markets based on their role in fostering innovation [2]. Within this framework, public procurement markets present a diverse combination of stages, ranging from well-established sectors like construction to emerging areas like digital services. This diversity underscore the complex, multifaceted nature of these markets, influenced by both design [25] and socio-cultural factors [36], and operating between self-organization and central planning [36], as the evolution of their internal workings can be driven by both the market participants/firms and the market organizer, i.e., the state.

The dynamic evolution of the interaction of market participants challenges the assumptions of traditional economic theory, where the interconnectedness of economic agents and their interactions remain inadequately explained [37]. Despite theoretical advancements, empirical investigations into the organization of public procurement markets remain scarce, with few studies delving into this area [8, 38]. Recently, Fountoukidis et al. [21] investigated competitive structures using network analysis, inferring a firm-public entity network. Wittberg and Fazekas [39] quantify low levels of competition in public procurement markets by focusing on the occurrence of single bidding. Deriving market representations through firm-firm interactions opens two important perspectives on competition. First, a market might comprise multiple, inter-related activities, which might not be well-reflected by domain-specific classifications (e.g. the CPV) alone. Then, network centrality measures derived from these co-bidding networks reflect the degree to which competition might be constrained to the presence of dominant firms.

Flynn [40] has advocated for moving beyond the dichotomy of SMEs and large enterprises in the analysis of public procurement markets. A network-based approach allows for gradients of firm influence that facilitates a nuanced analysis of firm position within competitive networks. Market representations based on co-bidding networks allow us to

relate firms' strategic position within the network with their behavior and activities. This helps qualify dichotomous concepts of market power and firm influence.

Our analysis adopts Aspers' notion of "co-constructed" markets [41, 23], where market dynamics are shaped by firms' simultaneous activity in one or multiple segments of the public procurement market. This approach enables us to study the structure of competition in public procurement markets, a phenomenon emerging from collective firm behavior in response to public tenders. By adopting a data-driven methodology [42, 5], we explore market organization through analysis of procurement data, uncovering structural characteristics of the public procurement market and quantifying competitive conditions.

## 3 Materials & methods

We delve into a dataset that comprises more than 1.14 million public procurement contracts sourced from Governmental Open Data Portal base.gov.pt [43], a central repository for public procurement contracts in Portugal from 2009 onward. This portal was created by mandate of the PPC through Law-Decree 18/2008 of January 29th [44].

Each observation represents a procurement contract between one/several firms and one/several public administration entities. Additional information includes the procedure type (e.g., direct award or tender), the value of the contract (initial and final), the dates of contract celebration and execution, and the Common Procurement Vocabulary (CPV) classification of the object of the contract. The CPV is a 5-level hierarchical taxonomy of procurement contract services in the European Union (EU), established by the European Commission in Regulation 213/2008 [45].

We focus our analysis on the co-bidding behavior of firms to open tenders, which restricts our analysis to a subset of 133,870 contracts representing 719,367 bids made by 17,397 firms between 2009 and 2022. We further clean the dataset of incorrect and incomplete records by discarding all contracts that had negative contract values, contracts where neither the public entity nor the supplier(s) were identifiable, and contracts without a date associated with them. Single-bidder contracts have also been discarded, as they provide no information regarding co-bidding behavior. We summarized the individual steps of inferring the co-bidding network in Fig. 1.

Despite the large number of firms involved in the public procurement market, the vast majority exhibit a sporadic and irregular pattern of activity. In fact, as we show in the SM, the market seems to follow the Pareto principle with a small percentage of firms responsible for the majority of market activity. In that sense, our strategy moving forward was to focus our analysis on a subset of $\approx 3000$ firms that represented 85% of public procurement expenditures between 2009 and 2022. This downsizing of the dataset drastically reduces the computational complexity of the follow-up steps while retaining the core of very active firms, which offers a valuable abstraction to reason about the general organization of the public procurement market with its subdivisions. As shown in the SM, alternative thresholds (80% and 90%) would lead to similarly small subsets of firms. Given the ample coverage achieved by this filter, firms not included in this set would, plausibly, organize around the identified market structures, but form only weak connections.

Finally, we focus our analysis in the period between 2011 and 2022, which cover three complete legislatures – the Portuguese parliament's XII, XIII, and XIV. The surveillance institutions implementing the rules of the European Stability Mechanism (ESM), the Troika's structural reform package – an association of the International Monetary Fund

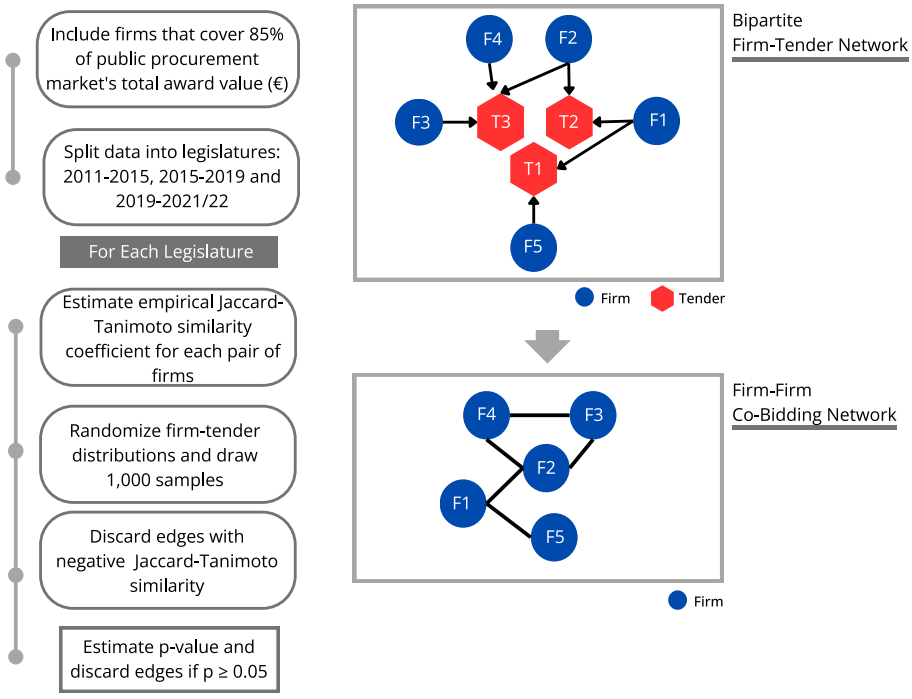


**Figure 1** Methods Diagram. Illustration of the workflow adopted to infer the firm-firm co-bidding network from the original data that provides information on which firms bid to which tender. The steps include data cleaning, temporal aggregation by the legislature, estimating similarity between firms in bidding patterns, and identifying positive and statistically significant similarities. Adapted from [46, 3]

(IMF) with European institutions – marked the XII legislature and coincided with a center-right national government. The two following legislatures represented a shift to a center-left minority government that governed with the support of the left-wing parties. Finally, the last of the three legislatures (XIV) covered the COVID-19 pandemic period and ended prematurely in December 2021. However, we considered the interim period until the constitution of the following. As such, we study each period independently to look for possible dynamics linked with each governance cycle. When needed, we will present comparative results between these three time periods. The period prior to 2011 coincides with the initial establishment of eProcurement in Portugal, in November of 2009, and the introduction of the BASE database. In this early phase, inconsistencies in contract reporting, stemming from the adoption of eProcurement, have been pointed out by the responsible public entity [47]. As such, it is expected that the data may be particularly incomplete and offers an inaccurate representation of the final years of the XI legislature. Therefore, we will not consider procurement activity prior to 2011 in our analysis.

Hence, the final dataset corresponds to the activities of 2865 firms that represent a core of 3.9% of the most active firms, representing 93% of the public procurement expenditures (in contracts of all procedure types) and 404,782 bids to 70,457 public tender contracts between 2011 and 2022. We supplemented the procurement contracts dataset with information about the number of employees per firm from the Orbis/BvD database [48]. Firm-level statistics can be found in the SM.

**Table 1** Summary Statistics for the Firm-Firm Co-Bidding networks per legislature of the Portuguese Parliament

| | Legislature of the Portuguese Parliament | | |
|---|---|---|---|
| | 2011-2015 | 2015-2019 | 2019-2022 |
| *General Network Statistics* | | | |
| *n* Edges (Full Graph) | 37,212 | 38,577 | 34,685 |
| *n* Nodes (Full Graph) | 1987 | 2213 | 2214 |
| *n* Edges (Giant Comp.) | 37,189 | 38,515 | 34,678 |
| *n* Nodes (Giant Comp.) | 1962 | 2182 | 2203 |
| % Node Overlap $t_k \rightarrow t_{k+1}$ | – | 79 | 91 |
| *Node-Level Statistics* | | | |
| Median Degree | 23 | 23 | 23 |
| Q1 Degree | 8 | 9 | 9 |
| Q3 Degree | 55 | 50 | 45 |
| Median Clustering Coef. | 0.42 | 0.40 | 0.41 |
| Q1 Clustering Coef. | 0.30 | 0.28 | 0.29 |
| Q3 Clustering Coef. | 0.60 | 0.60 | 0.63 |
| *Community Statistics* | | | |
| *n* Communities | 32 | 35 | 37 |
| Median Community Size | 32 | 26 | 21 |
| Q1 Community Size | 8.75 | 8.5 | 6 |
| Q3 Community Size | 84.75 | 100.50 | 79 |
| Modularity | 0.71 | 0.77 | 0.80 |

The *Giant Component* is the network that remained after disregarding disconnected components. Node degree, clustering coefficient, and the size of communities in the three networks were summarized using the first quantile (Q1), median, and the third quantile (Q3), respectively. For every legislature's network, the network modularity was computed.

## 4 Firm-firm co-bidding network

We estimate a firm-firm co-bidding network to represent the Portuguese procurement market. To do this, we discarded single-bidder tenders, which do not provide information on co-bidding behavior. Each node represents an active firm in the Portuguese public procurement market, and each edge connects a pair of firms if their co-bidding behavior is statistically significant. In that sense, and following [46], we start by computing, for each pair of active firms, the centered Jaccard-Tanimoto similarity coefficient [51]. The intuition behind this formulation is to identify positive associations in the joint bidding behavior of firms. Centering the coefficient allows for the identification of non-random co-bidding behavior. The coefficient can be formally estimated as:

$$J_{ij}^{c} = \frac{\sum_t b_{it}\, b_{jt}}{\sum_t (b_{it} + b_{jt} - b_{it}\, b_{jt})} - \frac{p_i p_j}{p_i + p_j - p_i p_j} \tag{1}$$

where $b_{it}$ is one if firm $i$ made a bid to tender $t$ and zero otherwise, and $p_i$ is the fraction of tenders in which firm $i$ participated ($p_i = \sum_t b_{it}$). The second term in Equation (1) provides the expected number of observations when the bids from both firms are independent and identically distributed through a Bernoulli process. Hence, the centered Jaccard coefficient allows us to distinguish between positive and negative associations between firms. Finally, we are interested only in associations that are positive and significant; as such, we test the hypothesis that $J_{ij}^{c} > 0$. To that end, we bootstrap a null distribution ($\hat{J}_{ij}$) of the centered Jaccard coefficient by generating an ensemble of 1000 randomizations of the initial associations between firms and tenders. Data was randomized to ensure that the number of bids observed per firm in a year and the CPV bid per firm remained constant. Then, using standard statistical inference methods [52], we estimate the $p$-value by calculating

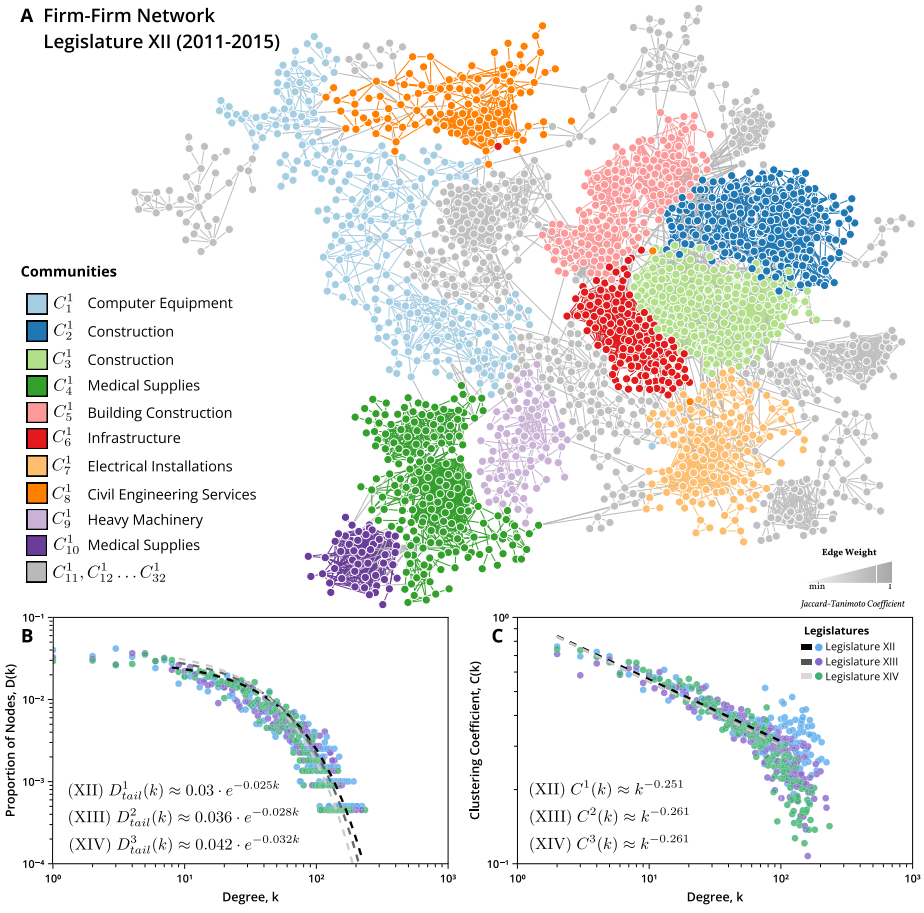


**Figure 2** The Portuguese Public Procurement Market. *Panel A*, depicts a graphical representation of the giant component representing the procurement market network structure during the XII legislature, representing a total of 37,189 competitive ties between 1987 firms. Colors represent the ten largest communities identified using the Louvain algorithm [49]. The *Backbone* algorithm [50] was used for the graphical layout of the graphs. $C_2^1$ and $C_3^1$ are construction communities with regional specialization, similar to the medical supplies community $C_{10}^1$. Networks for the XIIIth and XIVth legislature can be found in the SM. *Panel B*, colored dots show the degree distribution of the three inferred networks and the best-fitted (dashed lines) exponential distribution using a log-likelihood method. In *Panel C*, colored dots show the negative trend between the average clustering coefficient of nodes as a function of their degree $k$ along with the best power-law fits using Ordinary Least Squares (OLS) (dashed line)

the upper tail probability of obtaining a value equal or greater than $J_{ij}^c$ from the cumulative frequency of the null-distribution $\hat{J}_{ij}$. We discard links with $p$-value $\geq 0.05$.

The above-mentioned process was repeated independently for each legislature, resulting in three firm-firm co-biding networks, which we treat as undirected. We inferred the network as weighted, using the observed Jaccard-Tanimoto coefficient as the edge weight. Table 1 presents summary statistics of each of the three networks inferred.

Figure 2–A represents graphically the Portuguese public procurement market during the XII legislature (2011/15). Colors represent the ten largest communities identified using the Louvain algorithm [49], with a modularity of 0.71. See the SM for the networks associated with the XIII (2015/19) and XIV (2019/21) legislature. Notably, we observe a steady increase in the modularity between the XII towards the XIV legislature (from 0.71 to 0.80, see Table 1). Such levels of segmentation are expected and can be explained by

the competition between firms that specialize in providing different goods and services to government entities and with different regional scopes. For instance, the Medical Supplies segment ($C_4^1$ and $C_{10}^1$) is split geographically between firms that supply mainly Continental Portugal and another that focuses on the Islands of Madeira and Azores. Moreover, the segment related to construction activities/services ($C_2^1$, $C_3^1$, $C_5^1$, $C_6^1$) also exhibits different levels of geographic focus.

Figure 2–B illustrates the degree distribution of each network, represented by colored dots, alongside the best-fitted exponential distribution curve. This approach contrasts with alternative distribution models, such as the power-law, which, according to Vuong's Closeness Test [53], show a less accurate fit to our data (further details in the SM). The observed exponential distribution suggests a rapid decay in the probability of a firm having a large number of connections, reinforcing that such networks lack hubs, which are commonly found in scale-free networks, although they do present some level of degree heterogeneity (variance in the degree distribution).

The mechanics underlying the formation of public procurement competition networks further elucidate this phenomenon. New firms connect uniformly with existing firms that engage in the same activities, are located in similar geographic areas or target similar government entities. And this is because their connection stems from bidding for the same contracts, that is, from their choice of what tenders to bid instead of which firms to compete with. This pattern suggests a network formation driven less by preferential attachment to dominant players and more by a random, yet strategic, alignment of firms with similar operational scopes. Such dynamics result in a procurement network that inherently lacks the significant hub structures typically observed in scale-free networks [54].

## 5 Decoding firm influence

How does the absence of prominent hubs in public procurement networks affect individual firm influence within the market? To what extent is a firm's network position correlated with its success in tender earnings? Exploring these questions is pivotal for understanding the nuances of public procurement markets. Here, we employ three network centrality metrics, degree centrality, betweenness centrality, and eigenvector centrality, each computed at the firm level.

These metrics indicate the firm's influence and strategic positioning within the network. More specifically, degree centrality characterizes the competitive position of a firm within the co-bidding network. Betweenness centrality characterizes firms' strategic positioning among its peers. Finally, eigenvector centrality relates a firm's position in the network to that of its competitors.

To facilitate the comparison of centrality measures, we performed a MinMax scaling transformation. We then conduct a panel regression analysis, correlating tender earnings per bid with these centrality measures. Using earnings per bid directly normalizes the outcome by both the level of firm activity and tender opportunities presented to the firm in their areas of economic activity.

Thus, we assess the direct impact of network position on financial performance, controlling for other relevant factors that might influence a firm's success and network influence simultaneously.

Specifically, our analysis uses a three-way fixed effects model focusing on the earnings per bid of a firm.

This model incorporates firm-specific, legislature-specific, and community-specific factors, offering a comprehensive view of the determinants of earnings in the competitive landscape of public procurement. The model's general specifications (Eq. (2)) aim to isolate the effect of network centrality on earnings, providing insights into the strategic benefits of different network positions within the complex web of public procurement. The model is explicitly formulated as follows:

$$\log(\text{earnings-per-bid})_{ijt} = \mathbf{X}'_{ijt}\boldsymbol{\beta} + \theta \text{centrality}^{m}_{ijt} + \alpha_i + \xi_j + \mu_t + \varepsilon_{ijt}, \tag{2}$$

where $\text{centrality}^{m}_{ijt}$ represents the network centrality of a firm and $\mathbf{X}_{ijt}$ is a vector that includes: firm-level characteristics for the $j$-th Community in legislature $t$; the effects of firm earnings in direct (non-competitive) award procedures (log(Direct Award Earnings)); number of contracts participation in procedures other than tenders ($n$); the share of tenders won to tenders bid on (Tender Winning Rate) and the *Herfindahl-Index* per firm for geographic, service, and entity specialization as well as the firm size (log(NumEmployees)) (see SM for more details). Finally, $\alpha_i$, $\mu_t$, and $\xi_j$ capture, respectively, firm, legislature, and community-specific (observed or unobservable) effects, and $\varepsilon_{ijt}$ is an idiosyncratic random disturbance. As usual, clustered standard errors were considered by firm, legislature, and community. Table 2 summarizes the results of the panel regressions.

Our results reveal a positive relationship between all centrality measures and firm earnings in public procurement. More specifically, firms occupying more central positions in the network tend to obtain higher earnings, highlighting the premium associated with strategic network placement. Among the centrality measures, eigenvector centrality and betweenness centrality are the most indicative of higher firm earnings in tenders. Firms sitting at the intersection among a broad range of competitors (as indicated by a high betweenness centrality) and those competing alongside other highly influential firms (as indicated by high eigenvector centrality) are particularly advantaged in terms of earnings per bid.

The positive impact of betweenness centrality suggests an additional nuance: firms positioned as intermediaries between different market segments or serving as links among various firms tend to enjoy higher earnings. This implies a reward mechanism for firms that effectively bridge different parts of the market. However, it is important to note that the influence of degree centrality on earnings is comparatively less pronounced than that of betweenness centrality or eigenvector centrality. Competition thus obtains a more qualitative element in that not mere competitivity rewards a firm but a more selective competitive behavior, as evidenced by the higher coefficients of betweenness and eigenvector centrality. This finding highlights different network positions' varying degrees of impact on a firm's financial success in public procurement tenders.

The tender winning rate has the largest effect, an expected result. A firm that consistently wins tenders seems to possess the necessary capabilities to compete successfully more so than firms that only occasionally win tenders.

Interestingly, excessive specialization of specific entities, as expressed by the entity specialization metric, leads to drastically reduced earnings. The strong effect size could be explained by a smaller pool of potential tender issuers reducing a firm's earnings potential. The geographic specialization estimate is significant only at a 10%-level. The effect direction for geographic specialization points to geographic diversity being an advantage for a firm.

**Table 2** Tender Earnings per Bid Models

| Dependent variable: | log(Earnings per Bid) | | | |
|---|---|---|---|---|
| Model: | (1) *Degree* | (2) *Betweenness* | (3) *Eigenvector* | (4) *Base model* |
| log(Degree Centrality) | 0.215** | | | |
| | (0.049) | | | |
| log(Betweenness Centrality) | | 0.925** | | |
| | | (0.100) | | |
| log(Eigenvector Centrality) | | | 1.11** | |
| | | | (0.130) | |
| log(Direct Award Earnings) | −0.060 | −0.054 | −0.060 | −0.059 |
| | (0.034) | (0.033) | (0.034) | (0.034) |
| Tender Winning Rate | 44.2*** | 44.0*** | 44.4*** | 43.6*** |
| | (2.66) | (2.82) | (2.78) | (2.75) |
| log(*n*) | 0.311* | 0.280* | 0.300* | 0.308* |
| | (0.079) | (0.079) | (0.079) | (0.080) |
| Geo Specialization | −4.55* | −4.04* | −4.34* | −4.72* |
| | (1.20) | (1.06) | (1.09) | (1.21) |
| Service Specialization | −0.954 | 0.805 | 0.010 | −1.33 |
| | (1.23) | (1.28) | (1.25) | (1.24) |
| Entity Specialization | −16.5*** | −13.9*** | −15.9*** | −17.4*** |
| | (1.10) | (1.17) | (1.06) | (1.07) |
| log(**NumEmployees**) | 1.41 | 1.02 | 1.20 | 1.43 |
| | (0.642) | (0.685) | (0.671) | (0.656) |
| *Fixed-effects* | | | | |
| Firm | Yes | Yes | Yes | Yes |
| legislature | Yes | Yes | Yes | Yes |
| Community | Yes | Yes | Yes | Yes |
| *Fit statistics* | | | | |
| Observations | 5882 | 5882 | 5882 | 5882 |
| $R^2$ | 0.771 | 0.776 | 0.774 | 0.770 |
| Within $R^2$ | 0.442 | 0.453 | 0.449 | 0.440 |

*Note:* Significance Codes: *p<0.1; **p<0.05; ***p<0.01; Clustered (by Firm, legislature and Community) Standard Errors are considered.
In Models (1), (2), and (3), we included the network centrality measures mentioned in the main text, as indicated by $\text{centrality}_{ijt}^{m}$ to quantify a firm's influence within the network. Model (4) serves as a benchmark without any centrality measure. Since holding one centrality measure constant while changing another is impossible, we performed three separate regressions for identification purposes, one for each. Moreover, we performed diagnostic tests to validate the fixed-effects approach, which can be found in Sect. 7 of the SM

Finally, the fact that the magnitude of direct award earnings is not significant might be related to the size requirements of participating in open tenders. The average contract award for direct awards in the original dataset is around 34,000€, while that for open tenders is approximately 354,000€, more than ten times as much. This could indicate that only firms of a particular scale participate in tenders and leave direct award awards to a different segment of the public procurement system.

We performed robustness checks by re-estimating the regression for different firm sizes. To this end, we split the firms in our dataset into the top 50% and bottom 50% of firms by size. We found that the network measures have higher coefficients for smaller firms. Degree centrality was not significant for the reduced sample sized. For larger firms, betweenness centrality emerges as the centrality measure with the strongest impact on earnings per bid. This likely reflects strategic positioning as a way to navigate the competitive landscape. A similar reasoning for betweenness centrality can be applied for smaller firms. In their case, however, it is eigenvector centrality that is the centrality variable with the highest coefficient. This could indicate positive spillovers from exposure to more competitive firms, which might drive firm-level efforts to increase efficiency.

In a sensitivity analysis (reported in Sect. 7.4 of the SM), we found varying impact on our results based on the inclusion of fixed effects. When using a two-way fixed effects model (firm & legislature), the coefficients stabilize near those reported here for the three-way model. Interestingly, in the two-way model, the coefficient of eigenvector centrality was higher than that of betweenness centrality. This finding is reversed in the three-way model. Including community fixed effects might thus properly account for potential inter-community knowledge spillover effects.

## 6 Hierarchical organization affects firm competitiveness

In exploring the structure of public procurement networks, Fig. 2–C reveals a pivotal aspect: a negative correlation between the average clustering coefficient and the degree of nodes. This pattern suggests an underlying hierarchical organization in the network, as posited by Ravasz et al. [55]. Such an organization prompts further investigation into how the network is subdivided into distinct communities, each potentially having its unique organizational structure.

In this context, a critical question arises: How do these network subdivisions reflect in the distribution of market power among firms and within communities? To address this, Fig. 3 presents a comparative analysis of the firm-level and community-level *Herfindahl-Index* across different legislatures and in relation to three specialization dimensions: services, entities (public administration contractors), and geography [46, 56]. This analysis aims to uncover the concentration of market power within the network, providing insights into the competitiveness and diversity of the public procurement market.

We show that while firms cover the entire spectrum of specialization across all three legislatures, communities are characterized by Service specialization. This character continuously increases from Legislature XII to XIV. This means that sub-markets are governed by communities organized around a service category. Regarding Entities, most communities appear to have moderate to high levels of diversity. Despite these general considerations, the market naturally includes exceptions, such as a remarkably high level of service specialization (e.g. community $C^1_{32}$, a small community providing only engineering services in the district of Beja) or focus on providing services to individual entities (e.g. community $C^1_{31}$, where firms only provide fabricated products to the national railway company Comboios de Portugal (CP)).

Geographic diversity appears to shift from intermediate levels of diversity in Legislature XII to higher levels in Legislature XIV, indicating an increased geographic spread of firm activity. Notwithstanding, in all periods, we find some markets that exhibit a degree of regional segmentation. This phenomenon is particularly prominent for construction-related activities. Community $C^1_3$ is a construction community mainly active in northern Portugal. An infrastructure community active in northern Portugal also exists in Legislature XIII, community $C^2_6$. Legislature XIV no longer has an identifiable construction community in the north. Instead, we find a smaller community for the country's south, $C^3_{16}$. These changes could reflect an increasing geographic dispersion of firm activities in that market segment. These regional specialization patterns could indicate higher market maturity. Regional segmentation alone can be considered an optional feature of *mature* markets since a regional competitive configuration can still exhibit volatility, with new firms entering and leaving, easily displacing previous winners. In our case, and from the lenses of regional specialization, we see a heterogeneous landscape with some communities with

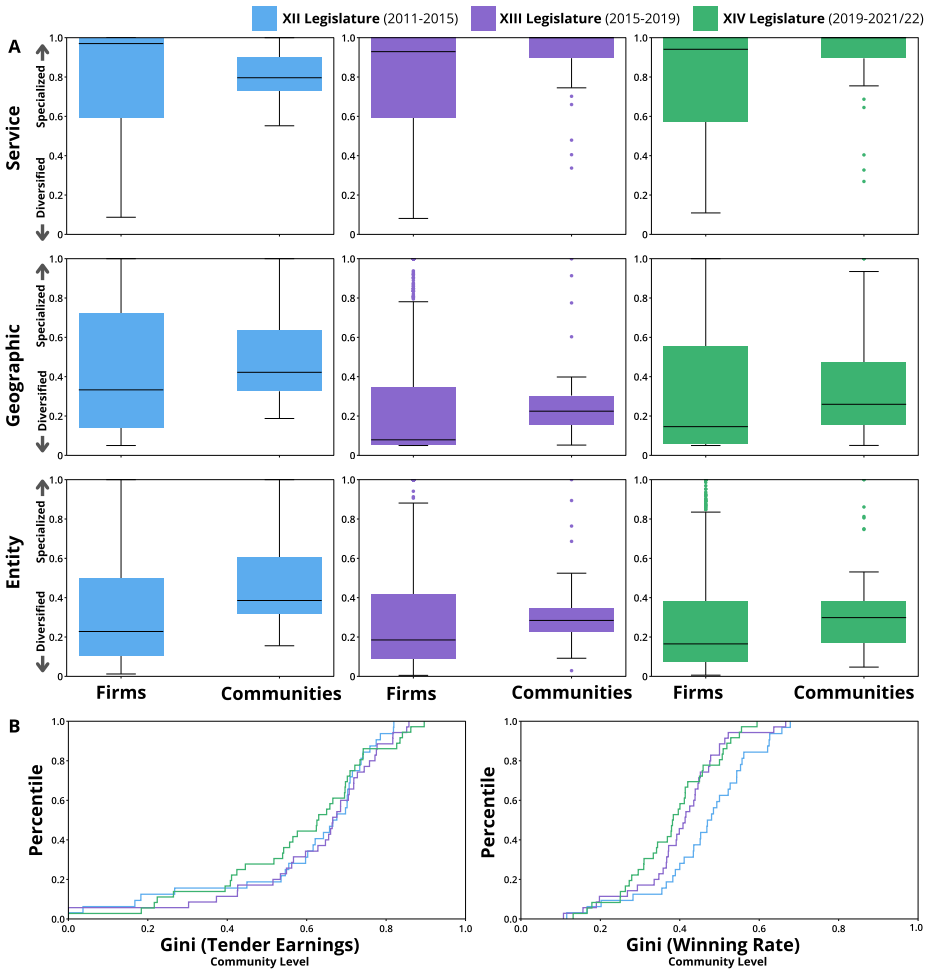


**Figure 3** Communiy and Firm Specialization Behavior. *Panel A*: We used *Herfindahl's Index* ($H^{i,l}_{cat}$) to summarize the community specialization behavior along three axes: Service (as identified by CPV division), Geography (Portuguese Administrative Districts) and Entity (government entity as identified by fiscal number). $H^{i,l}_{cat}$ for communities was computed by taking the average of $H^{i,l}_{cat}$) for each firm in the community. In *Panel B*, we charted the Empirical Cumulative Density Function (ECDF) for the Gini coefficients of tender earnings and winning rates over the three legislatures at the community level

high regional specialization but a trend toward nationwide scope. Indeed, the distribution of earnings and winning rates is also strongly heterogeneous and highly unequal within each community (median Gini coefficient of $\approx 0.6$ for earnings and between and 0.4 and 0.5 for winning rates, see Fig. 3–B). With the exception of the Gini coefficient of winning rates between the XIIth and XIIIth legislature, the distributions do not exhibit significant differences.

The remarkably high, overall level of concentration in the markets indicates deeper-rooted issues with competition in the Portuguese public procurement market. Looking again at Fig. 2, and similarly for the networks of the two subsequent legislatures (in Sect. 5 of the SM), the major communities/markets are those that are "classically" associated with state functions, such as construction, infrastructure and the health sector. Here, strong incumbency effects and knowledge about bid preparation could obstruct the participation of other firms. The Portuguese Competition Authority has initiated two cases in the

time frame considered here, [57] and [58], which highlights both the integrity risks inherent to public procurement as well as risks emerging from high concentration. Recently, the OECD has alerted to integrity risks emerging from the lack of transparency regarding lobbying in Portugal [59]. While those irregularities certainly affect the functioning of the public procurement system, the key transmission mechanism is more fundamental. "Mature" markets, such as the ones mentioned above, pose by virtue of their level of development, higher entry barriers, be it through capital or potentially costly compliance requirements. Repeated interactions with procurement agencies might also make it easier for incumbents to obtain contracts. The way in which these markets then operate raises significant barriers for new entrants.

Hence, a critical question concerns the maturity level of the market and its segments. As far as we know, there is no general theory about when a public procurement market or a market segment reaches maturity. Aspers defines various stages of "unorganized" markets [60], with the final stage being that of *cohesion*. However, in the case of public procurement, it makes more sense to use the concept of "state-governed market making", although public procurement abridges several of the organization processes that generally characterize a market. We suggest three paths that market maturity can follow: technological and knowledge dependence (seen by the high specialization of market segments), geographical specialization (by the high specialization of some segments), and competitive equilibrium.

To establish a measure for the competitive conditions within a market, the tender winning rate of firms in a community can represent a valuable measure of a market's competition structure. As a proxy, the tender winning rates could indicate how established a market has become over time: Fluctuations could signal disruptive processes, while stable winning rates indicate a certain level of stability. In line with a complexity view on market organization, a market's winning rate is the average of the winning rates of its agents, *i.e.* the firms competing within its activity space. Figure 4–A shows the ranges of winning rates for the ten communities considered "stable" across all three legislatures. We find significant variation both over time and between communities.

Figure 4–B and Fig. 4–C show two examples, the Medical Supplies and Heavy Machinery markets. These two examples are particularly interesting since their characteristics allow general observations about the markets' functioning.

The earlier stages of the medical supplies market are indicative of the impact of political changes to the organization of a public procurement market: The *Troika*, which resulted in significant changes to how the healthcare sector was organized in Portugal [61] and a change in government that occurred in 2015 materialize in fluctuations of the average winning in that market, after this the winning rate stabilizes at around 15%, all through the COVID-19 pandemic, which can be seen to increase the size of the bid set as a consequence. Interestingly, the average winning rate of market "insiders" and "outsiders" appear to converge.

The Heavy Machinery market delivers a different impression: It is obvious that firms that are more active in the market, *i.e.* that pertain to the "core" are more successful at winning tenders. The winning rate appears stable with occasional fluctuations, a sign of a mature market. Given the capital intensity of machinery production, this is expected as high initial capital investments are necessary to compete. Additionally, competitors require a certain knowledge base, which is laborious to obtain and sets a firm on a specific path.

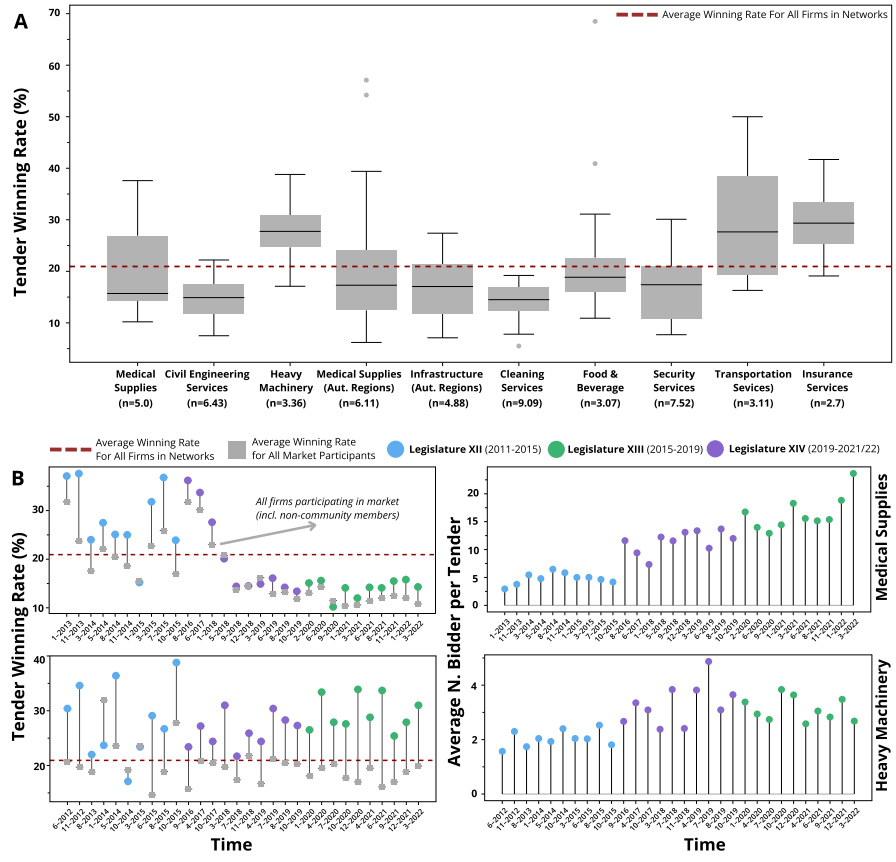


**Figure 4** Market Development. *Panel A* shows the distribution of winning rates of stable communities/markets through legislature XII, XIII, and XIV. We partitioned the contracts for each stable community into ten equally sized and chronological partitions for each of the three legislatures. Within every partition, we computed the average tender winning rate for the community members, the overall winning rate in the network, and the average number of bidders per tender. The marker represents the median, and the whiskers represent the Q1 and Q3 winning rate in that market over time. The average number of bids until the first tender award was computed for each stable community. Communities are ordered in terms of size. *Panel B* compares the temporal development of the winning rate and the average number of bidders per tender in the medical supplies and the heavy machinery market. The grey marker represents the winning rate for all market participants, including those not considered the "core" of the market. The colored marker represents the winning rate of community/market members. The dashed red line shows the average winning rate of all firms in the network

The results reported in Sect. 5 on firm prominence can be corroborated by two further observations about market competitiveness. As a general finding overall communities and legislatures, in-market firms achieve a tender winning rate of 11.7, 13.8, and 11.7 percentage points higher than that of non-market members, respectively, for the three legislatures under consideration. From Panel Fig. 5–A, we deduce that firms outside the network (*i.e.* firms that do not belong to the "core" of a market) have, on average, a lower winning rate than in-network firms. Firm prominence has thus an in-network quality where more "central" firms are more successful and a comparative advantage in relation to firms external to the network, which tend to have less success. Communities with higher winning rates tend to be smaller and exhibit low market entry chances for out-of-network firms. From Legislature XII to Legislature XIV, firm winning rates for out-of-network and in-network firms

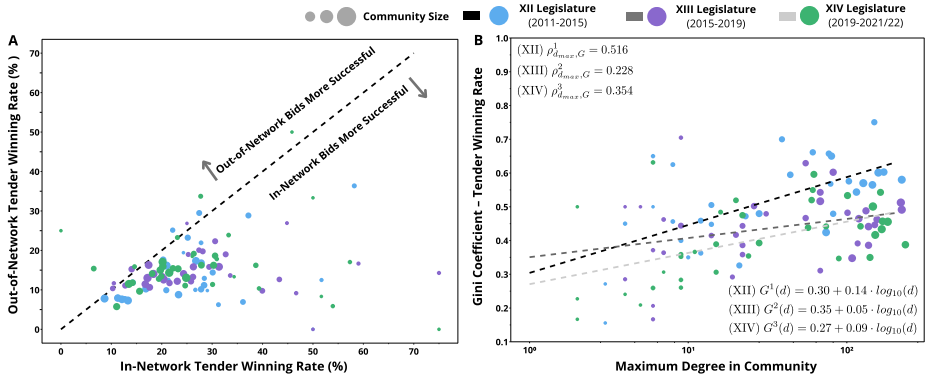


**Figure 5** Market Competitiveness. *Panel A* shows the average tender winning rate of public tender contracts tendered for by firms in a community against the average winning rate of out-of-network firms for the same tenders. The dashed line represents a dividing line. Below the line, in-network firms have higher winning rates as community members. Above the line, out-of-network firms are performing more successfully. In *Panel B*, we find a positive linear association between the maximum degree of a firm in a community and the tender winning rate inequality (expressed by the Gini coefficient) in that community. The correlation is statistically significant for legislatures XII and XIV ($p < 0.05$). Correlation test results are reported in the SM. The association between the maximum degree and the Gini coefficient has been highlighted by OLS fits (dashed lines)

re-approximate. Thus, a dimension of in-network prominence could influence a firm's success in public tenders.

Second, from 5–B, we find that communities that have firms with higher firm prominence (higher node degree) are more unequal in terms of tender winning rates, in other words, the presence of highly competitive firms suppresses the chances of other firms in the market. Indeed, we find a significant correlation between the change in winning rate inequality and the maximum degree of a community. This means that between two legislatures, changes in firm prominence impact the barriers to obtaining public tender contracts, as the winning rate distribution depends on within-community firm prominence.

The concentration observed in these markets can be attributed to different factors. In markets that require a high degree of technological know-how, a certain concentration can be expected as a result of the complexity of the underlying activity. Here, excessive concentration poses a supplier risk for the state. This could affect the supply chain of certain goods and services, e.g., in pharmaceutical markets [62], and also pose increased integrity risks [13] and can lead to higher prices [63]. However, prohibitive entry requirements can also imply high market concentration. These participation barriers can be associated with a number of issues, such as late payments [64, 65] or high costs of bid preparation [66, 67]. The impacts of market concentration, thus, extend beyond mere competition policy and instead could affect crucial areas of the working of the state.

## 7 Conclusion

Addressing the entrenched issue of non-competitive structures in public procurement, our study delves into the Portuguese public procurement market from 2011 to 2022, revealing a complex network of firm interactions and market dynamics. The tender co-bidding networks cover a distinct community structure driven by competitive relationships. These communities, differentiated by service specialization, geographic focus, and government entities, function as distinct markets within the broader public procurement system. Central to this structure is a 'core' group of firms forming dense market segments,

limiting access for peripheral and external firms. This formation and the evolution of sub-markets align with political and legislative shifts, highlighting varied internal dynamics across these sub-markets. Notably, "stable" communities exhibited significant variances in market entry ease and competitiveness, as reflected in their average tender winning rates.

Our findings show a strong correlation between network centrality and tendering success. This suggests that the Portuguese public procurement market may lack a robust competitive structure and accessible market conditions. The high concentration of the Portuguese public procurement market available through open tenders limits economic benefits from their participation, such as job creation and an improved choice of goods and services for the public organization [12, 68].

In this, Portuguese public procurement fits European-wide trends of decreasing levels of competition and increasing market concentration: A report of the European Court of Auditors (ECA) has identified similar trends throughout the European Union [69]. The important nuance identified here through means of network analysis is that beyond the lack of a robust competitive structure there are firms that are highly competitive and successful. Effective regulation of these markets must acknowledge the problem of overall low levels of competition, which are further differentiated between markets, identify how firms may compete more efficiently and how the entry of new competitors can be facilitated.

Our findings imply two key angles of policy reform, (*i*) sector-specific monitoring and (*ii*) policies strengthening the competitiveness of smaller economic operators.

Due to the "dual" nature of public procurement, as both a policy tool and an instrument to achieve cost-efficient outcomes in providing goods and services to citizens, it is important to recognize differences in the type of markets in which the state performs procurement. There are clear benefits to a "one-regulation-fits-all-markets" approach, such as avoiding legal lacunae and casuistic legislation, and yet, a merely regulatory intervention might not be fully capable of effectively removing competitive barriers. This is tied to the diversity of existing market configurations reflecting both firm capabilities and public spending priorities. Undoubtedly, several factors are involved in markets that exhibit low levels of competition. The low participation rate of small and medium-sized enterprises in public procurement has been noted by prior research [70, 71].

The empirical framework developed in this article could assist in the identification of markets where competition is low or market power is highly concentrated. Sectoral monitoring through the empirical framework developed in this study can be accompanied by functional approaches to procurement [3], which, in turn, should be directed at fortifying a healthy supplier base. Failing to account for the existing knowledge base of firms in a region or sector can result in a high percentage of procedure cancellations [72] and — likely — subpar procurement outcomes. This means that for a healthy public procurement system, suppliers not only need to become more competitive, the state also needs to become a better buyer.

The fact that highly competitive firms out-compete their peers is in part a natural outcome of competitive markets, at the same time as network centrality actually has higher impacts on the earnings per bid of smaller firms. This finding contrasts with the high concentration in public procurement markets. The necessary conclusion to be drawn from this is that a large share of firms active in the Portuguese public procurement market do not

withstand competitive pressures. This requires two important qualifications: Both firms positioned in "bridge markets" between different activities or firms exposed to competitive pressures by other, influential firms achieve better earning outcomes.

Finally, we point out limitations of our analysis. Aggregating public procurement procedures by legislature smooths over the nuanced impacts of specific legislation, failing to quantify specific shocks to market segments. Future research should dissect the effects of sector-specific regulations on bidding behavior to better understand sub-market dynamics. Moreover, the methodology of market delimitation through community detection is influenced by the selection of firms in the network, particularly regarding new market entries or exits. Including diverse entities like government bodies and publicly-owned companies in the network could reveal different procurement behaviors and preferences, offering insights into what constitutes "irregular" procurement.

To expand our understanding, future studies should apply network analysis to public procurement markets globally, assessing the applicability of our findings in varied contexts. Incorporating diverse data sources, including qualitative feedback from procurement stakeholders, would enrich the analysis, revealing deeper market dynamics. Analyzing the immediate impacts of legislative changes, instead of aggregating data by legislative periods, would provide more precise insights into policy effects on markets. Longitudinal studies focusing on market entries and exits would illuminate the evolving nature of these markets, guiding more effective market entry strategies and policy reforms. These approaches are crucial for a comprehensive, global understanding of public procurement markets and for shaping impactful policies.

Public procurement is an essential tool in state policy, and our study offers crucial empirical insights for policymakers. These findings enable a deeper understanding of market organization and provide a basis for crafting more precise, effective legislation. Such targeted reforms are vital to ensure that public procurement maximizes its societal impact, fostering a more equitable and dynamic economic landscape.

**Abbreviations**

GDP, Gross Domestic Product; OECD, Organisation for Economic Co-operation and Development; CPV, Common Procurement Vocabulary; EU, European Union; SM, Supplementary Material; ESM, European Stability Mechanism; IMF, International Monetary Fund; PPC, Portuguese Public Procurement Code; OLS, Ordinary Least Squares; ECDF, Empirical Cumulative Density Function; CP, Comboios de Portugal; ECA, European Court of Auditors

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## Supplementary information

**Supplementary information** accompanies this paper at https://doi.org/10.1140/epjds/s13688-025-00543-z.

**Additional file 1.** (PDF 2.8 MB)

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**Author contributions**

NFS and FLP conceived the idea. NFS conducted the data gathering and analysis. BD designed the econometric analysis. CC contributed to the network analysis. All authors contributed to data interpretation and results. NFS, FLP, CC, and BD wrote the manuscript. All authors thoroughly reviewed and approved the manuscript.

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**Data availability**

The dataset supporting the conclusions of this article is available in the Figshare repository, 10.6084/m9.figshare.24476668. Supplementary data used in this article is available from Orbis/BvD but restrictions apply to the availability. The code supporting the conclusions of this article is available at Figshare, under the project name `network_hierarchies_public_procurement`, 10.6084/m9.figshare.25093568. The project requires Python version 3.10, Julia version 1.9.2 and R version 4.3.2. The code was created on Fedora Linux 38 and depends on Unix-like operating systems. Other language-specific software requirements are described in dependency files in the project. The software is available under the CC BY 4.0 license.

## Declarations

**Competing interests**

The author(s) declare no potential competing interests with respect to the research, authorship, and/or publication of this article.

**Author details**

[1]NOVA Information Management School (NOVA IMS), Universidade Nova de Lisboa, Lisbon, Portugal. [2]Computational Research in Social Science Laboratory, School of Engineering and School of Government, Universidad del Desarrollo, Santiago, Chile. [3]Instituto de Data Science, Facultad de Ingeniería, Universidad del Desarrollo, Santiago, Chile. [4]Centro de Investigación en Complejidad Social, Facultad de Gobierno, Universidad del Desarrollo, Santiago, Chile. [5]Northwestern Institute on Complex Systems, Kellogg School of Management, Northwestern University, Evanston, United States.

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**References**

1. Uyarra E, Flanagan K (2010) Understanding the innovation impacts of public procurement. Eur Plan Stud 18(1):123–143. https://doi.org/10.1080/09654310903343567
2. Hommen L, Rolfstam M (2008) Public procurement and innovation: towards a taxonomy. J Public Procur 8(3):17–56
3. Edquist C, Zabala-Iturriagagoitia JM (2020) Functional procurement for innovation, welfare, and the environment. Sci Public Policy 47(5):595–603. https://doi.org/10.1093/scipol/scaa046
4. McCrudden C (2004) Using public procurement to achieve social outcomes. Nat Resour Forum 28(4):257–267. https://doi.org/10.1111/j.1477-8947.2004.00099.x
5. OECD (2023) Government at a glance 2023. OECD. ISBN 9789264557048. https://doi.org/10.1787/3d5c5d31-en
6. Cheng W, Appolloni A, D'Amato A, Zhu Q (2018) Green public procurement, missing concepts and future trends – a critical review. J Clean Prod 176:770–784. https://doi.org/10.1016/j.jclepro.2017.12.027
7. Meehan J, Bryde D (2011) Sustainable procurement practice. Bus Strategy Environ 20(2):94–106. https://doi.org/10.1002/bse.678
8. Bleda M, Chicot J (2020) The role of public procurement in the formation of markets for innovation. J Bus Res 107:186–196. https://doi.org/10.1016/j.jbusres.2018.11.032
9. Edquist C, Vonortas NS, Zabala-Iturriagagoitia JM, Edler J (2015) Public procurement for innovation. Edward Elgar, Cheltenham Glos
10. Georghiou L, Edler J, Uyarra E, Yeow J (2014) Policy instruments for public procurement of innovation: choice, design and assessment. Technol Forecast Soc Change 86:1–12. https://doi.org/10.1016/j.techfore.2013.09.018
11. Edler J, Georghiou L (2007) Public procurement and innovation—resurrecting the demand side. Res Policy 36(7):949–963. https://doi.org/10.1016/j.respol.2007.03.003
12. Caldwell N, Walker H, Harland C, Knight L, Zheng J, Wakeley T (2005) Promoting competitive markets: the role of public procurement. J Purch Supply Manag 11(5–6):242–251. https://doi.org/10.1016/j.pursup.2005.12.002
13. Villamil I, Kertész J, Fazekas M (2024) Collusion risk in corporate networks. Sci Rep 14(1). https://doi.org/10.1038/s41598-024-53625-9
14. Villamil I, Kertész J, Wachs J (2022) Computational Approaches to the Study of Corruption. https://doi.org/10.48550/ARXIV.2201.11880
15. Wachs J, Fazekas M, Kertész J (2020) Corruption risk in contracting markets: a network science perspective. Int J Data Sci Anal 12(1):45–60. https://doi.org/10.1007/s41060-019-00204-1
16. Kertész J, Wachs J (2020) Complexity science approach to economic crime. Nat Rev Phys 3(2):70–71. https://doi.org/10.1038/s42254-020-0238-9
17. Wachs J, Kertész J (2019) A network approach to cartel detection in public auction markets. Sci Rep 9(1). https://doi.org/10.1038/s41598-019-47198-1
18. Fierascu S (2017) The Networked Phenomenon of State Capture: Network Dynamics, Unintended Consequences, and Business-Political Relations in Hungary. PhD thesis, Central European University, Budapest. https://doi.org/10.13140/RG.2.2.22363.92964
19. Grandia J, Meehan J (2017) Public procurement as a policy tool: using procurement to reach desired outcomes in society. Int J Public Sect Manag 30(4):302–309. https://doi.org/10.1108/ijpsm-03-2017-0066
20. IMPIC (2023) Relatório anual de contratação pública em Portugal 2022. Technical report, IMPIC
21. Fountoukidis IG, Antoniou IE, Varsakelis NC (2023) Competitive conditions in the public procurement markets: an investigation with network analysis. J Ind Bus Econ 50(2):347–368. https://doi.org/10.1007/s40812-022-00251-z
22. Fazekas M, Tóth IJ, King LP (2016) An objective corruption risk index using public procurement data. Eur J Crim Policy Res 22(3):369–397. https://doi.org/10.1007/s10610-016-9308-z
23. Holt RPF, Rosser JB, Colander D (2011) The complexity era in economics. Rev Polit Econ 23(3):357–369. https://doi.org/10.1080/09538259.2011.583820
24. Matutinovic I (2010) Economic complexity and the role of markets. J Econ Issues 44(1):31–52. https://doi.org/10.2753/jei0021-3624440102

25. Matutinović I (2006) Self-organization and design in capitalist economies. J Econ Issues 40(3):575–601. https://doi.org/10.1080/00213624.2006.11506936
26. Ahrne G, Aspers P, Brunsson N (2014) The organization of markets. Organ Stud 36(1):7–27. https://doi.org/10.1177/0170840614544557
27. Hidalgo CA (2023) The policy implications of economic complexity. Res Policy 52(9):104863. https://doi.org/10.1016/j.respol.2023.104863
28. Arthur WB (2021) Foundations of complexity economics. Nat Rev Phys 3(2):136–145. https://doi.org/10.1038/s42254-020-00273-3
29. Arthur BW (1999) Complexity and the economy. Science 284(5411):107–109
30. Farmer JD (2012) Economics needs to treat the economy as a complex system. In: Paper for the INET conference "Rethinking economics and politics", vol 14
31. Arthur BW, Durlauf SN, Lane DA (eds) (1997) The economy as an evolving complex system II, vol II. CRC Press, Boca Raton
32. Marti G, Nielsen F, Bińkowski M, Donnat P (2021) A review of two decades of correlations, hierarchies, networks and clustering in financial markets. In: Progress in Information Geometry. Springer, Berlin, pp 245–274. ISBN 9783030654597. https://doi.org/10.1007/978-3-030-65459-7_10.
33. Caccioli F, Barucca P, Kobayashi T (2017) Network models of financial systemic risk: a review. J Comput Soc Sci 1(1):81–114. https://doi.org/10.1007/s42001-017-0008-3
34. Garcia-Bernardo J, Fichtner J, Takes FW, Heemskerk EM (2017) Uncovering Offshore Financial Centers: Conduits and Sinks in the Global Corporate Ownership Network. Sci Rep 7(1). https://doi.org/10.1038/s41598-017-06322-9
35. Edler J, Ruhland S, Hafner S, Rigby J, Georghiou L, Hommen L, Rolfstam M, Edquist C, Tsipouri L, Papadakou M (2005) Innovation and public procurement. Review of issues at stake. ISI Fraunhofer Institute Systems and Innovation Research, Karlsruhe
36. Rutherford G, Kirkpatrick J, Davison A (2023) A relational model of economic organization: relations within, between, and among economic scales. J Econ Issues 57(1):301–318. https://doi.org/10.1080/00213624.2023.2170145
37. Potts J (2000) The new evolutionary microeconomics: complexity, competence and adaptive behaviour. Edward Elgar, Cheltenham
38. Vargo SL, Koskela-Huotari K, Baron S, Edvardsson B, Reynoso J, Colurcio M (2017) A systems perspective on markets – toward a research agenda. J Bus Res 79:260–268. https://doi.org/10.1016/j.jbusres.2017.03.011
39. Wittberg E, Fazekas M (2023) Firm performance, imperfect competition, and corruption risks in procurement: evidence from Swedish municipalities. Public Choice 197(1–2):227–251. https://doi.org/10.1007/s11127-023-01102-8
40. Flynn A (2017) Re-thinking SME disadvantage in public procurement. J Small Bus Enterpr Dev 24(4):991–1008. https://doi.org/10.1108/jsbed-03-2017-0114
41. Aspers P (2009) How are Markets made? MPIfG Working Paper 09/2, Max-Planck-Institut für Gesellschaftsforschung
42. Kitchin R (2014) Big data, new epistemologies and paradigm shifts. Big Data Soc 1(1):205395171452848. https://doi.org/10.1177/2053951714528481
43. base.gov.pt. (2009) Accessed 18 February 2024. https://www.base.gov.pt/base4
44. Assembleia da República (2008) Decreto-Lei n.° 18/2008, de 29 de janeiro. D Repúb 1:753–852. Accessed 18 February 2024. https://diariodarepublica.pt/dr/detalhe/decreto-lei/18-2008-248178
45. European Commission (2008) Commission Regulation (EC) No 213/2008 of 28 November 2007. Off J Eur Union L74:1–375. Accessed 18 February 2024. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R0213
46. Lyra MS, Curado A, Damásio B, Bação F, Pinheiro FL (2021) Characterization of the firm–firm public procurement co-bidding network from the State of Ceará (Brazil) municipalities. Appl Netw Sci 6(1). https://doi.org/10.1007/s41109-021-00418-y
47. Public Procurement in Portugal 2011 (2012) https://www.impic.pt/impic/assets/misc/relatorios_dados_estatisticos/Rel_Anual_Contratos_Publicos_2011_EN.pdf
48. Bureau van Dijk Orbis Database. https://orbis.bvdinfo.com/
49. Blondel VD, Guillaume J-L, Lambiotte R, Lefebvre E (2008) Fast unfolding of communities in large networks. J Stat Mech Theory Exp 2008(10):P10008. https://doi.org/10.1088/1742-5468/2008/10/p10008
50. Nocaj A, Ortmann M, Brandes U (2015) Untangling the hairballs of multi-centered, small-world online social media networks. J Graph Algorithms Appl 19(2):595–618. https://doi.org/10.7155/jgaa.00370
51. Chung NC, Miasojedow B, Startek M, Gambin A (2019) Jaccard/Tanimoto similarity test and estimation methods for biological presence-absence data. BMC Bioinform 20(S15). https://doi.org/10.1186/s12859-019-3118-5
52. Gotelli NJ (2000) Null model analysis of species co-occurrence patterns. Ecology 81(9):2606–2621
53. Vuong QH (1989) Likelihood ratio tests for model selection and non-nested hypotheses. Econometrica 57(2):307. https://doi.org/10.2307/1912557
54. Barabási A-L (2016) Network science. Cambridge University Press, Cambridge. ISBN 9781107076266
55. Ravasz E, Barabási A-L (2003) Hierarchical organization in complex networks. Phys Rev E 67(2):026112. https://doi.org/10.1103/physreve.67.026112
56. Curado A, Damásio B, Encarnação S, Candia C, Pinheiro FL (2021) Scaling behavior of public procurement activity. PLoS ONE 16(12):e0260806. https://doi.org/10.1371/journal.pone.0260806
57. Autoridade da Concorrência (2014) PRC/2014/2. https://www.concorrencia.pt/sites/default/files/processos_e_decisoes/prc/decisoes/AdC-PRC_2014_02-Decisao-VNC-final-net.pdf
58. Autoridade da Concorrência (2016) PRC/2016/6. https://www.concorrencia.pt/sites/default/files/processos_e_decisoes/prc/decisoes/AdC-PRC_2016_06-Decisao-VNC-final-net-Fergrupo-Somafel.pdf
59. Anti-Corruption and Integrity Outlook 2024 (2024) OECD. ISBN 9789264398047. https://doi.org/10.1787/968587cd-en
60. Aspers P (2011) Markets. Polity Press, Cambridge
61. Simões PCdN (2017) Evolução das lógicas institucionais no campo da saúde em Portugal. PhD thesis, Instituto Universário de Lisboa
62. García-Altés A, McKee M, Siciliani L, Barros PP, Lehtonen L, Rogers H, Kringos D, Zaletel J, De Maeseneer J (2022) Understanding public procurement within the health sector: a priority in a post-COVID-19 world. Health Econ Pol Law 18(2):172–185. https://doi.org/10.1017/s1744133122000184

63. Dijkgraaf E, Gradus R (2007) Collusion in the Dutch waste collection market. Local Gov Stud 33(4):573–588. https://doi.org/10.1080/03003930701417601
64. Kaya O (2024) The impact of late payments on SMEs' access to finance: evidence from credit rationing and loan terms. Econ Model 141:106896. https://doi.org/10.1016/j.econmod.2024.106896
65. Connell W (2014) The economic impact of late payments. Technical report 531, European Commission. Directorate General for Economic and Financial Affairs. https://doi.org/10.2765/71358
66. Petersen OH, Hansen JR, Houlberg K (2022) The administrative burden of doing business with the government: learning and compliance costs in business-government interactions. Public Adm 102(1):188–206. https://doi.org/10.1111/padm.12904
67. Petersen OH, Potoski M, Brown TL (2021) Businesses' transaction costs when contracting with governments: the impact of product complexity and public contract management experience. Int Public Manag J 25(5):741–766. https://doi.org/10.1080/10967494.2021.1898500
68. Flynn A (2018) Investigating the implementation of SME-friendly policy in public procurement. Pol Stud 39(4):422–443. https://doi.org/10.1080/01442872.2018.1478406
69. European Court of Auditors (2023) Public procurement in the EU: less competition for contracts awarded for works, goods and services in the 10 years up to 2021. Special report 28, 2023. Technical report, European Court of Auditors. https://doi.org/10.2865/04787
70. Akenroye TO, Owens JD, Elbaz J, Durowoju OA (2020) Dynamic capabilities for SME participation in public procurement. Bus Process Manag J 26(4):857–888. https://doi.org/10.1108/bpmj-10-2019-0447
71. Nicholas C, Fruhmann M (2014) Small and medium-sized enterprises policies in public procurement: time for a rethink?1. J Public Procur 14(3):328–360. https://doi.org/10.1108/jopp-14-03-2014-b002
72. Casady CB, Petersen OH, Brogaard L (2023) Public procurement failure: the role of transaction costs and government capacity in procurement cancellations. Public Manag Rev, 1–28. https://doi.org/10.1080/14719037.2023.2231945


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