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Buyers' Ability in Public Procurement: A Structural Analysis of Italian Medical Devices*

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Abstract

Using an original dataset of standardised medical devices purchased by Italian local Public Buyers (PBs), we investigated the ability of each PB in running the related procurement process. For each purchase, the difference between each items' price and its marginal cost was measured. We define PBs' ability as the PBs' fixed effect on such difference.

We show that: average prices vary substantially among PBs; this variation is largely captured by the PBs' fixed effect; the PBs' ability depends on institutional characteristics and size; mandatory reference prices determine higher average purchasing prices for high-ability PBs and lower prices for low-ability PBs.

JEL Classification: D44; D73; H57; I18.

Keywords: Public Procurement; Medical Devices; Buyer's Ability; Reference Price.

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1 Introduction

The European Union market for medical devices is the second largest market of medical devices in the world, after the United States.[1] However, compared to the United States, where expenditures are mainly managed by the private health sector, in the European Union approximately 79% of healthcare costs are paid for by national governments (OECD-EU, 2016).[2] Such relevant differences between the EU and US health systems also include the purchasing of medical devices. In the United States, this purchasing usually relies on direct trade between private hospitals and suppliers, characterised by strategic discretion and flexibility. However, in EU countries, such activity is heavily regulated and the public officials' discretional choice regarding the awarding mechanisms and the contract's management is largely restricted by law (Lian and Laing, 2004; Spagnolo, 2012). Thus, in the private health sector, the managers' bargaining ability in buying medical devices is expressed in business-to-business's direct negotiations with suppliers (Grennan, 2013 and 2014). In contrast, in the public health sector, the public buyers' ability must cope with business-to-government's regulated procedures, often relying on open auction mechanisms.

In Italy – as in many other national health systems in Europe – the purchasing of medical devices is managed at a local level. Recently, the national press highlighted that, for the same standard item (i.e., a simple syringe), different public hospitals and local health units often pay very different prices.[3] In a period of tight public budgets, this evidence has fueled an extensive public debate.

The objectives of this paper, by exploiting an original Italian dataset, are firstly to empirically investigate the ability of public buyers (PBs, i.e., local public hospital and health units) as a determinant of price differences in the procurement of standard medical devices. Secondly, to assess the impact of "reference prices", as a policy which has imposed a cap on the price of each procured medical device and has been adopted in the aim of reducing public procurement expenditure.[4] For each purchase we measure the difference between the item's price – resulting from the procurement

[1]In 2015 the EU market for medical devices was worth 110bn euros, or about 7.9% of total health expenditures in the same year (OECD-EU, 2016).

[2]Public health is a relevant goal pursued in the Europe 2020 strategy. The European Commission stated that "Promoting good health is an integral part of the smart and inclusive growth objectives for Europe 2020. Keeping people healthy for longer has a positive impact on productivity and competitiveness" (Communication dated 29 June 2011 'A budget for Europe 2020').

[3]See, among many articles, P. Russo "Garze e siringhe d'oro: le spese pazze delle ASL" (Bandages and gold syringes: the crazy expenditures of Italian local health agencies) in La Stampa, July 3rd 2012, and E. Vendramini "I costi standard sono giusti? Dipende" (Are reference prices fair? It depends) in Il Sole 24 Ore, October 30th 2015.

[4]In 2011, the Italian Authority for Public Contracts – i.e., the national regulator for public procurement at the time our dataset refers to – was tasked to set a "reference price" for each of the several classes of functionally equivalent medical devices in the aim to lower the prices paid by public buyers in purchasing such items. These reference prices, active from July 2012 to May 2013, worked as a cap to unitary prices in procurement auctions for medical devices.

procedure – and its marginal production cost we have structurally estimated. We define the PB's ability as the PB fixed effect on (the opposite sign of) such difference for each item procured. We ran our empirical analysis on an original dataset including 75 classes of standard medical devices sold to 135 Italian local PBs in the period January-December 2013.

Our empirical approach is guided by two important features. The medical devices we investigate are standardised and relatively cheap (indeed, renegotiation rarely occurs), and they can be grouped into classes of functionally homogeneous products (i.e., in each class, quality differentiation would not be an issue). On these grounds, we first estimate unobserved marginal cost for each procured medical device. Then, using an official classification provided by the Italian technical advisor for health policies, we group functionally homogeneous medical devices in classes; and for each class, we set a benchmark marginal cost. Thus, we compute the difference between the observed price for each medical device and its benchmark marginal cost. From there, we infer a proxy for the PB's ability in running each purchase. We further investigate the determinants of such PB's ability by exploiting information from local public hospitals' and health units' balance sheet open data. Finally, we assess the impact of the "reference prices" policy and its exogenous termination on the PB's ability.

Based on real market data, our analysis is a key step toward bridging real procurement outcomes with each public buyer's features and choices of procurement procedures. Our main findings can be summarised as follows. Firstly, the average prices of standard medical devices paid by different Italian PBs vary substantially. Secondly, the differences across the PBs' purchasing prices are explained by PB fixed effects, which in turn relate to the PB's institutional characteristics and size. In particular, the PB's size (measured either by overall personnel costs or by overall health-related costs) has a general positive and significant effect on the ability to run the procurement process. Furthermore, we find that it is the ratio of non-health over total personnel cost that drives the overall positive and significant effect of size on the PB's ability. In contrast, once having controlled for size, overall procurement expenses for health-related goods push ability down, which is consistent with the adopted definition of PB's ability. Our results also highlight significant differences in the ability to procure between PBs of different organisational structures. Local public health units record higher prices in purchasing standard medical devices over public hospitals – the latter have a more centralised procurement management than the former – and they are also more closely related to regional offices where the health policy is decided.

Regarding the adoption of a reference price as a cap to medical devices' prices, we found that this policy has a non-linear effect on the PBs' ability. It has a significantly negative effect on high-ability PBs (i.e., it increases average prices) and a positive effect on low-ability PBs. Overall, in the presence of reference prices, the dispersion of PB's ability is reduced and observations are more concentrated toward an average value. In fact, when reference prices were in force, all of the main determinants of PB's ability decrease their magnitude or lose overall significance.

Our paper mainly contributes to three strands of economic literature on procurement. The first is on the procurement of medical devices. Grennan (2013, 2014) investigates such purchasing on a detailed US database of coronary stents. He empirically studies the negotiation process between private hospitals and private suppliers, and the resulting price discrimination (Grennan, 2013). His focus on the private hospitals' bargaining ability shows that this ability has a large private-hospital specific component that explains 79% of price variations in purchasing (Grennan, 2014). Focusing on Europe, Sorenson and Kanavos (2011) present and discuss medical device procurement policies and practices in several European countries, highlighting large heterogeneity in procedures therein adopted and little in the way of analysis on their effects. Laing and Lian (2004) compare public and private health procurement in the UK, showing suboptimal outcomes in the former. Kastanioti et al. (2013) discuss procurement practices and policies recently set forth in the Greek procurement of health technologies, particularly regarding reference price setting and centralised tenders, and discuss the first measurable outcomes (in terms of cost savings) resulting from these policies. We contribute to this literature by providing empirical results for the Italian procurement of standard medical devices, with a focus on the determinants of the public buyers' ability in managing a very regulated process and on outcomes from the adoption of a reference price regime.

The second strand of literature we contribute to is on the role played by public buyers in procuring goods or services, and on the linked policies. Considering procurement performance as related to competence of public workforce, a recent paper by Decarolis et al. (2018) empirically assesses such causal effect on US bureaus. Using an instrumental variable strategy and combining data on office-level competencies and on procurement performance (i.e., cost and time overruns), the authors find that cooperation within the office matters the most to improve the bureaus' outcome. Considering the price paid for standardised goods and services by different classes of Italian public buyers, Bandiera, Prat and Valletti (2009) found that expenditure would reduce by 21% - corresponding to a saving in between 1.6 and 2.1% of the Italian GDP - if all the public buyers were to pay the same prices as the one at the tenth percentile. These authors also found that at least 82% of such estimated waste was to be related to burocratic ineffieciency. On a large dataset on Russian procurement in 2011-2015, Best et al. (2018) estimate that 60% of within-product purchase-price variation across 16 million purchases is due to the bureaucrats and organisations administering procurement. Moreover, investigating a specific procurement policy – i.e., bid preferences for domestic firms – they show that the design of such optimal procurement policy depends on the effectiveness of the procurers at implementing the policy itself. To these papers, we add a novel approach to measure the public buyers' ability in managing procurement purchases and its determinants.

Moreover, Di Tella and Schargrodsky (2003) investigate the medical procurement prices of standard medical devices following the introduction of a strict monitoring policy on Buenos Aires hospitals' purchasing. They estimate a 10% reduction on average prices paid by hospitals because of the crackdowns.[5] Similar to Di Tella and Schargrodsky (2003), we investigate the effect of a policy to reduce the public procurement expenditure of standard medical devices. However, this differs from those authors as we specifically measure the impact of the reference price policy on the PBs' ability in the purchase of medical devices and its effect on public expenditures.

Finally, we contribute to the empirical auctions literature by extending the application of the seminal paper by Guerre et al., (2000). The innovative features of our analysis are necessary to investigate a dataset of heterogeneous goods awarded in procurement sealed bid auctions. In so doing, we provide an original development to empirically investigate real procurement auctions with such characteristics (i.e., auctions for the awarding of different standard goods, in a procurement setting where a sealed bid mechanism is adopted.).

The remainder of the paper is organised as follows: Section 2 describes the institutional setting (2.1), our dataset (2.2) and presents some typical reduced-form estimates (2.3). Section 3 describes the structural theoretical framework, firstly introducing the definition of PB's ability (3.1) and then showing the marginal cost estimate for the medical devices included in our dataset (3.2). Section 4 derives the PB's ability (4.1) and estimates its determinants (4.2). Section 5 replicates the same analysis exploiting the event of reference price termination as a quasi-natural experiment. Therefore, the PBs' ability (5.1) and its determinants (5.2) are compared before and after this event. Finally, Section 6 concludes by summarising our findings and providing policy implications. In the Appendix, we report further details on the estimations and some robustness checks.

2 Environment

2.1 Institutional Setting

The Italian healthcare system is a regionally based national health service that provides universal coverage largely free of charge. The main sources of its financing are national and regional taxes that are supplemented by co-payments for pharmaceuticals and outpatient care. The system consists of three levels of action: national, regional and local. The highest level is responsible for ensuring the general goals and fundamental principles of the national health system. Regional governments are responsible for ensuring the delivery of services through a network of population-based local public health units ("Aziende Sanitarie Locali", ASL) and local public

[5] They also find a significant (and negative) effect of public managers' wages on the prices paid by hospitals, a result consistent with the theory of corruption by Becker and Stigler (1974), i.e., better paid managers will be less tempted to engage in corrupted processes.

hospitals.[6]

Procurement for standardised medical devices in Italy is decentralised at the local level. In 2013, the year covered in our dataset, approximately 350 local public buyers (PBs, local public hospitals and health units) had procurement responsibilities.[7] According to the Italian public procurement law, goods and services should be awarded through public tenders and direct negotiation can be used under some precise circumstances.[8] As for medical devices, in 2013 scoring-rule auctions were often employed for complex services while first-price auctions, together with direct negotiation, were almost always adopted for simpler and more standard goods.

To enter a public procurement auction for medical devices, potential suppliers must satisfy a minimum set of common requirements (i.e., to present standard tender documents and have the financial and technical qualifications required). Moreover, in this respect, each PB has some discretion in requiring additional qualifications and procedures. As a result, each PB in charge of procurement for medical devices can play a role in "burdening" the suppliers' entry in the awarding procedure with costly requirements and, within the finite set of mechanisms defined by law, in choosing the awarding mechanism to adopt.

In 2012, the Italian Authority for Public Contracts (AVCP)[9] was assigned the task of setting reference prices for classes of functionally equivalent medical devices purchased by local public hospitals and health units. The aim of this policy was to help standardising prices paid for the same item by different PBs. Each reference price consists of a cap on unitary prices for a class of medical devices.[10] The policy on reference prices also includes a safeguard clause. If the auction with the reference price's application is annulled, the PB could then proceed with a new auction where the reference prices are no longer applied. Reference prices were mandatorily applied on the public purchasing of medical devices from July 1st 2012 to May 2nd 2013. On the latter date, the Administrative Tribunal of Rome (TAR) replying to the appeal jointly submitted by some suppliers cancelled out the reference prices, a decision motivated by the fact that the listed devices in some classes were both functionally

[6]To cover local demand, in some regional areas, there are also private hospitals accredited with providing health services with the same characteristics as the public ones.

[7]Source: http://www.salute.gov.it/portale/documentazione/p6_2_8_1_1.jsp?id=13.

[8]The Italian Code of Procurement – Italian Legislative Decree no. 163/2006, art. 125, in force at the time our dataset refers to – states that direct negotiations could be used only for goods and services with a reserve price below 211.000€ and only for urgent needs arising because (i) of an unexpected early termination of a previously existing contract, (ii) the period is between the end of the previous contract and the awarding of the following tender, (iii) the previous contract has expired and any participants showed up in the following tender, or (iv) unpredictable events.

[9]In 2014, the competences of the Italian Authority for Public Contracts (AVCP) were transferred to the Anticorruption Authority (ANAC).

[10]It is important to note that a class of medical devices could refer to complex products, such as stents and prostheses, or for much simpler ones, such as syringes and needles. Our empirical investigation is performed on a dataset including only the latter medical devices, i.e., the standard ones.

and technically too heterogeneous to refer to the same price. One contribution of our analysis is to empirically exploit the discontinuity originated by the reference prices' adoption and elimination to test the impact of such exogenous policy change on the PB's ability.

2.2 Data

We assembled four sources of data to obtain our final dataset. The first source is an unexploited dataset consisting of the transcripts of competitive auctions for standard medical devices conducted by Italian PBs, from January 1st to December 31st, 2013. These transcripts have been provided by the Italian Authority for Public Contracts. For each auction we have information regarding the ID of the PB organising the awarding procedure and the mechanism adopted (i.e., first-price auction, scoring-rule auction, or direct negotiation); the medical device purchased (i.e., class of device and code), its quantity, the unitary price paid and the number of bidders in each auction[11]. In these transcripts, it is also recorded if the PB has discretionally set a restriction to bidders regarding entry into the auction in the form of (i) a pre-qualification phase that has to be passed by bidders before taking part in the auction, or in the form of (ii) a pre-selection phase that precisely indicates which bidders are allowed to participate. Finally, in our dataset, we know if the awarding auction includes lots of two or more different medical devices, and if the PB carries a joint tender for a number of other PBs. In the latter, we observe the identity of the leading PB which is is the one responsible for the procurement process, as well as all the above information regarding the auction, number of bidders, winning price and quantity purchased.

In our dataset, the awarded contracts by each PB, $h = 1, \ldots, H$, have an average value of 126,425€ with an average unitary price of 1.37€. The average number of bidders, $s = 1, \ldots, S$, is 4. Within each class of functional homogeneous medical devices, $d = 1, \ldots, D$, we observed price variations across the PBs' purchases. For example, the class defined as "syringes with three-piece eccentric cone, luer type; capacity 20 ml, graduate, with a triple-sharpened needle, mounted gauge G 19–G 23 and a length of 40 mm" shows unitary prices ranging between 0.05 and 0.17€.

Secondly, we collected information from each PB's financial statement[12] on the total value of the production, total costs, costs for the personnel split in health-related personnel (i.e. doctors, nurses and healthcare assistants), non-health related personnel (i.e. clerks) and costs for the procurement of health-related goods and services. Balance sheets capture PBs' heterogeneity and information included i.e. data on costs and outcomes could be used to measure the PB's efficiency. Summary

[11] Data on the number of bidders in each auction are missing for 564 observations.

[12] According to Italian law, each local PB's financial statement, which includes the balance sheet and profit and loss account, has to be disclosed and follow a standard format jointly set by the Ministry of Health and the Ministry of Economy and Finances. Financial statements were downloaded from official websites.

statistics about PBs' financial statements are reported in Table 1. We also observe the region in which the PBs are placed and if they are located in a rural or a metropolitan area.

Table 1: *PBs' summary statistics. Data in million euros.*

	Obs.	Mean	s.d.	Min	Max
Total value production	131	538	455	41	2706
Costs: total	129	506	399	41	2533
Costs: personnel (Total)	130	124	97	3	689
Costs: personnel (health)	126	101	78	1	543
Costs: procurement (health)	131	74	101	1	788

Thirdly, as a result of the decentralised nature of the Italian health system, different political decisions at the regional level may have an impact on PB's ability. To this end, we collect information on the total regional spending devoted to health and on the regional population. The ratio between these two variables, the per-capita health expenditure, is a dimensionally invariant measure of the amount of resources each region decides to devote to health. On average, the per-capita health expenditure is equal to 1,891€ .[13]

Finally, Italian PBs experience very large delays in their payments (Guglieri and Carbone, 2015). Clearly, delays have an impact on the PB's ability to obtain a "better deal" because suppliers may discount an expected late payment by initially asking a higher price. We collected data for average days payable outstanding at the PB level.[14] Delays vary extensively, with minimum and maximum values of 55 and 1,603 days respectively, and a median value of 160 days. When studying the impact on PB's ability, delays on the same year may present a simultaneity problem. To address this issue, we use delays in 2012 to study PB's ability in 2013.

2.2.1 Data cleaning

The unit of observation in our dataset is the price paid by each PB's in procuring each medical device. Starting from the larger AVCP original dataset which includes 2,149 observations in the period January–December 2013, we consider only classes of medical devices – defined following AGENAS[15] – for which we have at least ten

[13] To check if regional per-capita health expenditure is driven by economies of scale, we compare per-capita health expenditure for regions above and below the median population using a Kolmogorov-Smirnov test. We find no significant difference.

[14] We have missing information on 12% of our observations. In this case, we use the regional average as a proxy. Regional average delay is highly correlated with local delays (correlation 0.73). Data were provided by Assobiomedica, the Italian association of medical devices producers.

[15] AGENAS, the Italian National Agency for Regional Health Services that provides technical support for regional health departments in Italy produced two lists for classes of homogenous products. The first one, published in 2009, was used to set the reference prices that later on were ruled

observations, thus reducing our dataset to a total of 1,776 observations.

In managing the procurement of medical devices, the PBs can choose, within the limits described in the Italian law, the awarding mechanism in the form of first price auctions, direct negotiations and scoring rules. Thus, our database includes all these procedures. However, scoring rule auctions (making suppliers compete also on quality elements) may introduce a source of within-category device-heterogeneity. As a result, we excluded from our database observations belonging to scoring rule auctions, ending up with 1,549 observations.

Considering the awarding mechanisms adopted to procure medical devices, the final 1,549 observations in our dataset belong to a total of 808 first price auctions (FPAs) and 741 direct negotiations. For both these mechanisms, the PBs can affect the bidders' entry by imposing requirements and qualifications to participate in the auction and/or by implementing a larger or smaller level of advertising regarding the awarded procedure.[16] Note that we end up with a larger number of prices for medical devices than the number of awarding auctions. This is due to some auctions including the awarding of more than one medical device. All in all, in our dataset we recorded the purchases of 133 different PBs from 89 suppliers and for 76 classes of medical devices.

2.3 Preliminary evidence

This sub-section serves two tasks on the understanding of our unit of observation, i.e. unitary price. Firstly, it checks if prices vary separately with the medical device, with the PB and with the identity of the supplier. Secondly, it aims to compare some commonly reduced-form estimates and detect the most appropriate one to describe unitary prices.

On the first task, we ran a set of one-way analysis of variance (ANOVA) tests to see if unitary prices on average change with the medical device, with the PB and with the supplier (one dimension per time). The three tests are reported in Column (1) of Table 2 with p-values within squared parentheses and they always reject the null hypothesis indicating that prices indeed vary with all the three dimensions, especially with the device categories (as implied by the higher value of the test). We then checked if unitary prices change with each dimension, even after controlling for the other two. For this purpose we adopted the same test as before, where prices are now cleaned from their average by two dimensions. For instance, in one case we considered the difference between prices and average prices by PB plus average prices by supplier,

out by the Lazio Regional Administrative Tribunal (TAR). The second one, published in 2013, is a more detailed list created to address the tribunal's concerns about excessive intra-class product heterogeneity. In our empirical analysis, we adopt the latter AGENAS list for the classes of medical devices.

[16] See Kelman (1990) and Bandiera, Prat and Valletti (2009) for discussion about the PBs' discretion on auctions' entry requirement. For the effect of advertising on procurements' auction outcomes see Coviello and Mariniello (2014).

and we tested if this difference changes with the medical device. This way we study if, after removing PB- and supplier- specific linear fixed effects, there is still something that varies with the devices. Column (2) of Table 2 reports that the tests always reject the null hypothesis, indicating that prices still vary with each dimension, once we remove fixed effect of the other two. In another case reported in Column (3), we repeated the ANOVA exercise using the ratio, instead of the difference between price and average price paid. The purpose was to see if, for instance, after removing PBs' and suppliers' specific multiplicative fixed effects, there is still something that varies with the devices. All in all, this evidence suggests that prices are determined by all the three dimensions, and it is possible to isolate the contribution of each. Our results are confirmed using a non-parametric Kruskal-Wallis test in place of the ANOVA test (output available upon request).

Table 2: *One-way ANOVA tests*

	(1)	(2)	(3)
	Price	Price - avg. price	Price / avg. price
Device	9.66	6.73	7.48
	[0.000]	[0.000]	[0.000]
PB	2.32	1.60	1.60
	[0.000]	[0.000]	[0.000]
Supplier	3.83	2.31	1.31
	[0.000]	[0.000]	[0.033]

Note. "Price - avg. price" and "Price / avg. price" subtract and divide to the price its average by the two remaining dimensions (e.g., the average by PB and the average by supplier when running the test on the device dimension); p-values in squared parentheses.

On the second task, a standard approximation requires unitary prices to be explained by costs, quantity purchased and measures of market power. Since we run our analysis on medical devices grouped into classes of functionally homogeneous products, a vector of device dummies is a good proxy for their costs. Quantity purchased is used to control for the presence of economies of scale. To account for market power we consider two variables, the number of different suppliers recorded in our dataset for each category of medical devices (to account for potential competition) and the number of bidders (to account for effective competition in the tender).

Using a linear regression model of prices on device dummies, number of suppliers and number of bidders, we find that 71% of the medical device dummies are significant at the 5% significance level, with $R^2 = 0.31$. Using a log-log model, the fit increases to $R^2 = 0.89$, with 89% of the medical device dummies being significant (see Columns (1)-(2) of Table 3). This evidence suggests that the log-transformation is better suited to describe prices. Moreover, a joint F-test strongly rejects the hypothesis that all device-dummy coefficients are equal. A distribution of the estimated coefficients is reported in Appendix Figure A.2. Moving from a fixed-effect (FE) to a random-effect (RE) model has no relevant impact on these results. Thus, in what follows we stick to FE regressions with log-prices as a dependent variable.

As a variant of the specification, in Column (3) we replace the variable on the number of bidders with the interaction between number of bidders and a dummy for first price auction (FPA). The reason is that in direct negotiations, the other type of awarding mechanism adopted, the median number of bidders is just 1 (and the average is 1.5). As in the other cases, our measures of market power are significant and negative.

When including PB fixed effects in addition to medical device fixed effects (Column (4)), we observe that 76% of medical devices and 56% of the PBs' dummies are significant at the 5% significance level. Moreover, a joint F-test strongly rejects the null hypothesis that all PB-dummy coefficients are equal. A distribution of the estimated PB-dummy coefficients is reported in Appendix Figure A.3. The regression is estimated on the entire dataset, by removing from the specification the (log) number of bidders.

Finally, we allow device dummies to interact with quantities purchased to control for potential economies of scale. We use a log-log model of prices on quantities, device dummies and device-quantity interactions[17]. We find almost no variation in the fit of our model ($R^2 = 0.90$) with respect to the same specification but with quantity and quantity-device interactions removed ($R^2 = 0.89$). Furthermore, 91% of the log-quantity and device dummy interactions are not significant at the 5% significance level. Results are reported in Column (5). We obtain similar results using a linear regression model. In conclusion, our analysis suggests that, in our dataset, no economies of scale are present in the levels of quantity purchased by our PBs.

[17] Given that products are different, we do not consider it is appropriate to use a single measure of quantity.

Table 3: *Selected preliminary regressions*

	(1) Price	(2) ln(Price)	(3) ln(Price)	(4) ln(Price)	(5) ln(Price)
Suppliers	-0.268***				
	(0.083)				
Bidders	0.017				
	(0.036)				
ln(Suppliers)		-6.018***	-6.074***	-4.669***	
		(0.598)	(0.596)	(1.007)	
ln(Bidders)		-0.067**			
		(0.026)			
ln(Bidders) × FPA			-0.080***		
			(0.027)		
Reference price	-0.215	0.043	0.042	0.027	
	(0.225)	(0.044)	(0.044)	(0.048)	
log(Quantity)					0.0224
					(0.089)
Constant	2.245***	9.296***	9.391***	7.007***	-0.547
	(0.663)	(1.102)	(1.100)	(2.029)	(0.579)
Device fixed effects	YES	YES	YES	YES	YES
PB fixed effects	NO	NO	NO	YES	NO
log(qty)× Device FE	NO	NO	NO	NO	YES
R^2	0.307	0.889	0.889	0.922	0.898
Observations	992	992	992	1549	1549

Note. Robust standard errors, except Column (5): clustered standard errors using PB ID; *** p<0.01, ** p<0.05, * p<0.1.

3 Theoretical framework

3.1 Definition of the PB's ability

Consider a market in which there is a PB $h \in \{1, H\}$ in charge of managing requests to purchase medical devices belonging to class $d \in \{1, D\}$, such as hypodermic needles for syringes with given characteristics.[18] The PB's goal is to purchase the required quantity q_{dh} of the standard medical device at the lowest price. On the supply side, there are S suppliers, and each supplier $s \in \{1, S\}$ is willing to sell the requested

[18] According to Italian law, requests to procure medical devices cannot refer to a specific brand existing in the market, but they should describe the required medical device in a very detailed and technical way, so as not to favour a specific supplier.

medical device. We assume that, for a medical device of type d, each supplier's profit function, π_{ds}, with constant return to scale is given by

$$\pi_{ds} = q_{dh} \cdot (p - c_d(\theta_s))$$

where p is the medical device's awarding price, $c_d(\cdot)$ is the cost function to produce the medical device d, and $\theta_s \in [\underline{\theta}, \overline{\theta}]$ is the supplier type, known only by the supplier. We assume that θ_s is distributed according to a cumulative distribution function $F(\theta)$, which is common knowledge among suppliers and not observed by the econometrician. Assuming a cost function with unidimensional private information θ_s and no economies of scale, makes it possible to use unitary prices in the presence of lots. In other words, no cross-subsidisation between different medical devices in the same lot is admitted. Finally, some suppliers may not be active for a specific tender. We define $N_{dh} \leq S$ as the number of active suppliers in a specific tender run by a local PB h, for class d of medical devices.

The observed unitary price paid, p_{dhs}, can be written as the sum of the supplier's marginal cost $c_{ds} = c_d(\theta_s)$ plus a mark-up μ_{dhs}, as follows:

$$p_{dhs} = c_{ds} + \mu_{dhs}. \tag{1}$$

Under full information, the PB's utility is maximised if $p_{dhs} = c_d^{MIN}$, where c_d^{MIN} is the marginal cost of the most efficient supplier. To maximise its utility, a PB has both to award the contract to the most efficient supplier (i.e., the one with the lowest marginal cost) and obtain a price as close as possible to such supplier's marginal cost. However, in a realistic framework, several elements might prevent a PB obtaining such a price. Indeed, the PB can have limited information on the suppliers' cost structure, or the PB can be able to attract a small number of competitors in the awarded mechanism chosen, etc. Some of these elements are exogenous with respect to the PB's choices, while others can be totally or partially controlled by the PB.

In order to investigate the PBs' ability in the purchasing of different classes of medical devices, we need to set a benchmark supplier $s = 0$ with marginal costs $c_{d0} = c_d(\theta_0)$. Defining $\Psi_{dhs} = \mu_{dhs} + (c_{ds} - c_{d0})$, then Equation (1) can be rewritten as:

$$p_{dhs} = c_{d0} + \Psi_{dhs}. \tag{2}$$

We define the PB's ability as a persistent effect on Ψ_{dhs} recorded across all the tenders (i.e. FPAs and direct negotiations) to procure medical devices. Such effect refers to the PB's choice of the awarding mechanism, the definition of the reserve price, the promotion of the suppliers' participation to the tender, etc. The higher the PB's persistent effect, the higher the price paid on average by that PB, (the lower the PB's utility) and the lower the PB's ability in managing the procurement process.

To estimate this effect, we assume that Ψ_{dhs} can be broken down into a PB specific effect γ_h and a residual component γ_{ds}. The preliminary analysis of Sub-section 2.3

discusses this assumption. Assuming linear separability (i.e., $\Psi_{dhs} = \gamma_h + \gamma_{ds}$), implies that γ_h can be estimated consistently from Equation (2) using a regression of prices on medical devices and PB dummies. In this case, the choice of the benchmark supplier is irrelevant, being its effect captured by the medical device's category fixed effect.

However, our preliminary analysis in Sub-section 2.3 suggests that a log-log structure and hence a multiplicative separability (i.e., $\Psi_{dhs} = \gamma_h \cdot \gamma_{ds}$), better fits our data. Accordingly, Equation (2) can be rewritten as:

$$\ln(\Psi_{dhs}) = \ln(p_{dhs} - c_{d0}) = \ln(\gamma_h) + \ln(\gamma_{ds}) \tag{3}$$

thus requiring a structural estimation of marginal costs and a careful choice of c_{d0}.

In Sub-section 3.2, we focus on how to derive the benchmark marginal cost for each class of medical devices and in Section 4, we estimate each PB's fixed effect γ_h, also exploring the correlation between the PB's ability and the PB's balance sheet data.

3.2 Marginal Cost Estimate

To estimate the marginal cost for each class of medical devices awarded, we only use observations on first-price auctions (FPA). In so doing, we follow the methodology proposed in the seminal paper by Guerre et al., (2000; henceforth GPV). Specifically, to consider the features of the setting we are investigating, we proceed by implementing the GPV methodology with some changes. The first change we implement is related to the fact that we observe the awarding of different medical devices. Thus, all offers in our dataset are transformed to the ones each supplier would have submitted in a FPA for the provision of a common (standardised) medical device. Another difference from GPV where the highest price wins the auction, is that in our dataset we observed prices of procurement auctions, according to which the lowest price wins the auction. Finally, in the sealed bid auctions collected in our dataset, each bidder is required to submit its offer in a closed envelope within a deadline. Thus, bidders do not directly observe who is submitting the offer in that specific auction, i.e. bidders may receive a noisy signal on the level of competition they will face.

We present the former two changes in Sub-sections 3.2.1 and 3.2.2 below and the latter change in Appendix A.1.

3.2.1 Device heterogeneity

Medical devices are not identical goods and differ in their observable characteristics, therefore allowing for categorising by class. It is reasonable to expect that the price distribution shifts inside each class of medical device. Unfortunately, the number of observations in our dataset is too small to compute the conditional distribution of bids for each class d. To tackle this issue, we assume that the bidders' private valuation (i.e. their marginal cost) is multiplicative separable in the supplier's type

θ_s and in a technological parameter α_d specific for each class of medical device. This separability is preserved by equilibrium bidding (Haile et al., 2003). For example, suppose the marginal cost of a medical device of class d is twice the marginal cost of a medical device of class d'. With this assumption, the same ratio between the marginal costs of d and d' applies to all suppliers. In this case, also in equilibrium and for each supplier, the price of d will be two times the price of d'.

Accordingly, we assume that in an auction for medical device d, marginal costs (i.e. the bidders' private values) are given by:

$$c_d(\theta_s) = \alpha_d \cdot \theta_s \tag{4}$$

with the bidder-specific private information θ_s independent from the device-category parameter α_d. The assumption of multiplicative separability in the cost function has already been used in the literature (e.g. to model adaptation costs in Bajari et al., 2014) and it is consistent with the preliminary results presented in Sub-section 2.3.

Let a category $d = 0$ be such that $\alpha_d = 1$. Then, equilibrium price mantains the same separable structure as marginal costs:

$$p_d(\alpha_d, \theta_s, N_{dh}) = \alpha_d \cdot p_0(\theta_s, N_{dh})$$

where $p_d(\cdot)$ is the equilibrium bidding function for device d. Given this functional form, the technological parameter α_d can be obtained using a regression of observed log-bids on the medical devices' fixed effects (the dummy variable D_d) and on the number of bidders in each FPA (N_{dh}), as follows (output available upon request):

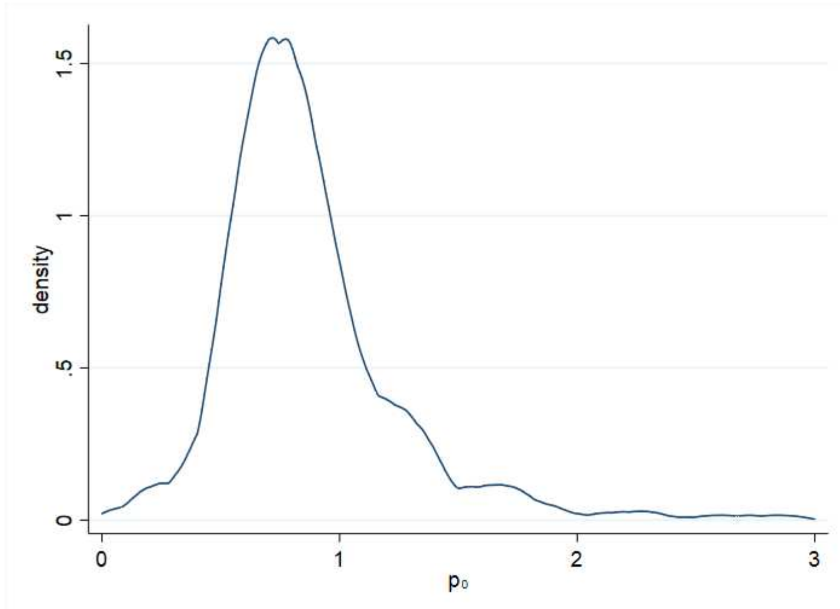
$$\ln(p_{dhs}) = \sum_{d=1}^{D} \left(\ln(\alpha_d) \cdot D_d + \beta_{dh} \cdot \ln(N_{dh})\right) + \varepsilon_{dh}.$$

All observed unitary prices p_{dhs} paid by PBs, that is, the winning bids, are then normalised dividing by α_d. We define homogeneous price p_{0hs} as follows:

$$p_{0hs} = \frac{p_{dhs}}{\alpha_d}. \tag{5}$$

This price p_{0hs} is used from now on to make all observations of our dataset comparable and get a consistent estimate of the bid each supplier would have submitted in a FPA for the provision of a medical device of class 0, with $\alpha_0 = 1$ and with the level of competition N_{0h}. The distribution of p_{0hs} is presented in Figure 1.

Figure 1: *Distribution of homogeneous prices*



3.2.2 Procurement rule and winning price

In a procurement framework, the lowest bid wins. The resulting Nash equilibrium bid $p(\theta_i)$ of the i-th bidder of type θ_i is given by the following:

$$p(\theta_i) = \theta_i + \int_{\theta_i}^{\overline{\theta}} \left(\frac{1 - F(y)}{1 - F(\theta)} \right)^{n-1} dy. \tag{6}$$

Similar to GPV, Equation (6) can be inverted to express the unobserved marginal cost θ_i as a function of the observed prices and observed through kernel estimate price distribution.

However, in our dataset, for each auction we do not observe all bids. We only observe the winning prices. For standard FPAs, Athey and Haile (2002) propose using the winning prices of multiple auctions to identify private values, because the winning price is the maximum order statistic of the bids' distribution for a given level of participation. In a procurement framework, winning prices can be considered as the first (i.e. minimum) order statistic of the bids' distribution.

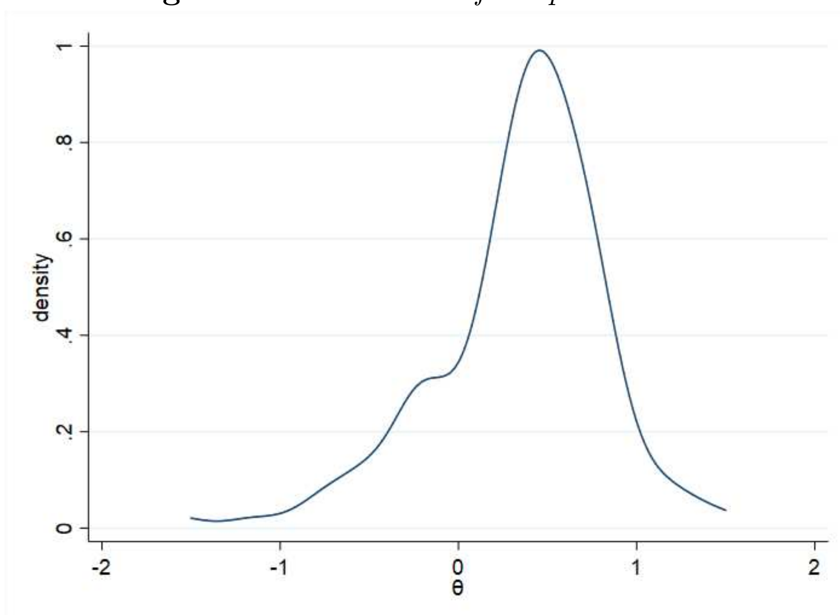
The structural equation that states unobserved marginal costs as a non-parametric function of observed winning prices, winning prices' distribution, and level of competition is the following:

$$\theta_s = p_{0hs} - \frac{N_{0h}}{N_{0h}-1} \frac{1 - G_{(1)}\left(p_{0hs}|N_{0h}\right)}{g_{(1)}\left(p_{0hs}|N_{0h}\right)} \tag{7}$$

where $N_{0h} = \{3, 8\}$ is the noisy signal about the level of competition bidders receive for the auction considered, $G_{(1)}\left(p_{0hs}|N_{0h}\right)$ is the cumulative density function of all transaction prices, conditional on N_{0h}, evaluated at p_{0hs}, and $g_{(1)}\left(p_{0hs}|N_{0h}\right)$ is its relative probability density function. Derivation of Equation (7) is presented in Appendix A.3.

The resulting distribution of θ_s is plotted in Figure 2.

Figure 2: *Distribution of the private value*



Since we impose no constraint to Equation (7), it is apparent that some estimates of the marginal cost θ_s are negative. However, this is not a problem for our subsequent analysis as we concentrate on a central value of the distribution. Indeed, our analysis requires choosing a benchmark supplier, equal across all medical devices. Then prices paid by different PBs are compared with marginal costs of that supplier. We decided to use the median value θ_0 of θ_s to define such supplier and, accordingly, we use Equation (4) to obtain the benchmark marginal cost c_{d0} for each class d, as follows:

$$c_{d0} = \alpha_d \cdot \theta_0.$$

We consider the median marginal cost for two reasons: (i) deviations from a median value provides an easy interpretation of the price-cost differences $(p_{dhs} - c_{d0})$ used to derive PB's ability, as it measures how much the winning supplier differs from a median one; (ii) the median value is a "safer" choice since the distribution of the marginal costs is structurally estimated and not directly observed by the econometrician.

The choice of the benchmark marginal cost has consequences on Equation (3) and in particular on the PB specific effect γ_h, that this way measures the effect relative to the benchmark supplier. In our case, γ_h describes the PB effect relative to the median supplier. Changing benchmark marginal costs does not alter our subsequent analysis; since it is constant with respect to the PB, the PB specific effect γ_h may change in size but preserves the same ranking.[19]

To investigate the PB's ability across the markets of different medical devices, we consider c_{d0} along with the price paid by the PB. In our dataset, benchmark marginal costs are always above zero and excluding 5% of our observations, below the actual prices paid by public buyers.

4 Public Buyer's ability

4.1 Estimation

We now investigate each PB's specific fixed effect to run procurement procedures. Considering the price paid for each medical device and having estimated each medical device's benchmark marginal cost c_{d0} , we can get $\Psi_{dhs} = p_{dhs} - c_{d0}$. We then proceed by estimating the PB specific component γ_h using the following OLS regression:

$$\ln(\Psi_{dhs}) = \ln(p_{dhs} - c_{d0}) = \sum_{h=1}^{H} (\widetilde{\gamma}_h \cdot A_h + \phi_h \cdot A_h \cdot R) + \epsilon_{dhs}. \tag{8}$$

The specification in Equation (8) includes the PB dummies A_h, and the dummy variable R equal to 1 when the reference price regulation was in force and 0 otherwise. This variable interacts with the PB dummies to capture any change in the PB fixed effect attributable to the reference price.

We exclude from this estimation those PBs for which we have fewer than 10 observations, that is, those PBs that have managed less than 10 different auctions in the period considered. We end up with 60 PBs and 1,257 observations on awarded medical devices. In the analysis we use standard errors clustered at the level of medical devices, to control for potential serial correlation.

Our ultimate goal is to provide an estimate for the PB's parameters $\widetilde{\gamma}_h = \ln(\gamma_h)$, where γ_h is the PB's specific fixed effect in managing the procurement process as defined in Equation (3). The higher the coefficient, the lower the ability of the PB. In the regression, almost all the dummies are significant, suggesting that each PB is

[19] We tried with the 33-th and 67-th percentiles of the distribution of private values. Our results, available upon request, are qualitatively confirmed.

endorsed with its own specific ability in managing the procurement process. Estimates are available upon request. Appendix Figure A.4 shows a map with the average value of $\widetilde{\gamma}_h$ by Italian region.

4.2 Determinants

To study the correlation of the PB's ability with the PB's known characteristics and with the auction's mechanisms, we run regressions of the proxy for each PB fixed effect estimated in Equation (8) on a set of explanatory variables, as follows:

$$-\widetilde{\gamma}_h = \beta_0 + \beta_1 \cdot M_h + \beta_2 \cdot H_h + \beta_3 \cdot P_h + \beta_4 \cdot C_h + \epsilon_h. \tag{9}$$

In these regressions the unit of analysis is the single PB. We consider weighted regressions, where the weight is the number of auctions the PB managed in our sample period. This way we attribute more importance to observations referring to the PBs that more frequently organised tenders to award medical devices.[20]

The specification includes four groups of variables: M_h refers to the adopted auction mechanism (the fraction of direct negotiations), H_h refers to potential scale economies in purchasing (the logarithm of the health personnel cost or the logarithm of health material purchases), P_h refers to the distribution of costs (the fraction of non-health personnel over total personnel costs and the fraction of health material purchases over total health costs) and the average number of days the PB takes to pay its suppliers (the logarithm of the days payable outstanding as of 2012),[21] and C_h refers to control variables on the nature of the PB (the dummy ASL, identifying medium-small health units, different from hospitals), its location in a metropolitan/rural area, in the North/Center-South of the country, as well as the per-capita health expenditures in the region the PB belongs to. This last variable is interacted with the dummy for Center-South because we observed country-wide disparity, with Northern regions spending more than Southern ones.

Note that in Equation (9) we inverted the sign of the dependent variable to facilitate its interpretation. In so doing, higher coefficients indicate the ability to run the procurement procedure. As the dependent variable is an estimate itself, we make use of bootstrapped standard errors based on 1,000 iterations.

Table 4 reports the output of our regressions, where the specification takes two variants depending on which variable is considered for H_h (either health personnel cost or health material purchases). We do not consider the two variables in the

[20] In the dataset used for this analysis (1,257 observations), the number of auctions attributed to a single PB ranges from 10 to 95, with an average of 20.95.

[21] We consider year 2012, i.e. one year before our sample period, to avoid potential reverse causality with the dependent variable. The source for this information is www.assobiomedica.it.

same specification because they both proxy for the size of the PB and indeed they are highly correlated (the correlation is 0.79). A regression equation using both variables could find it difficult to precisely identify the contribution of each. Since a priori we have no preference for either variable, we look at them in two separate models. Table 4 shows the output of IV regressions rather than standard OLS ones (shown in Appendix Table A.3). The reason is that we are concerned that there may be simultaneity on the mechanism variable M_h: the procurement mechanism is not randomly allocated with respect to the PB, and the PB's decision on which auction mechanism to implement may influence and at the same time be influenced by the PB's ability itself. This could create endogeneity and produce inconsistent estimates. In all the columns we therefore instrument the mechanism variable (fraction of direct negotiations) with two variables, the fraction of multi-device auctions and the average quantity of devices auctioned.[22] Both instruments inform on the size of each auction. This is important as smaller auctions face fewer legislative constraints in using direct negotiation. This set of instruments is found to be relevant and exogenous according to the standard relevance and exogeneity tests. Moreover, the Hausman-Wu test suggests that endogeneity is indeed present, at least in Columns (1) and (2), and it is therefore advisable to use IV models (see the bottom of Table 4). In what follows we comment only on coefficients that are significant at least at a 5% level.

Our benchmark regressions are shown in Columns (1) and (2). As a robustness check, Columns (3) and (4) replicate the same analyses using a proxy for the PB fixed effect defined differently. Rather than from Equation (8), coefficients $\widetilde{\gamma}_h$ originate from the following equation:

$$\ln(p_{dhs}) = \sum_{h=1}^{H} (\widetilde{\gamma}_h \cdot A_h + \phi_h \cdot A_h \cdot R) + \sum_{d=1}^{D} (\delta_d \cdot D_d) + \epsilon_{dhs}. \tag{10}$$

Equation (10) differs from Equation (8) in two ways. Firstly, the dependent variable is made of prices only and therefore excludes marginal costs. Secondly, the specification now includes medical device dummies. The purpose is to obtain estimates of the PB fixed effects that are not affected by our procedure to infer marginal costs. The resulting estimates of $\widetilde{\gamma}_h$ are generally smaller in size but highly correlated (0.61) with those obtained in our benchmark analysis. The key findings from Columns (1) and (2) are qualitatively preserved in Columns (3) and (4).

Our analysis shows that direct negotiations have a negative and significant impact on the PB's ability. The reason could be that, in line with the Italian law on public procurement, direct negotiations are used when the awarded item is endorsed with specific characteristics that the competition will not allow to address. This explains the higher prices paid by the PB, and thus a negative impact on the PB's ability.

[22] To make quantities of different products comparable, we use deviations from the average observed quantity for each category of medical devices.

We also find that the PB size effect, measured using either health personnel cost or health purchases, is positive and significant. Considering the variables on the distribution of costs, we find a positive and strong significant effect on the ratio of non-health personnel over total personnel cost. There is a negative effect of health purchases over total health expenditures, which seems to indicate that the PB's ability may increase further when more resources are devoted to health personnel rather than health purchases, or even better to non-health personnel. That is, comparing two PBs with the same size of expenditures, the one recording larger costs for non-health personnel does show more ability in procuring medical devices.

Turning to the control variables, we see a negative overall effect for small local health units (as measured with the coefficient on the ASL dummy) and the number of outstanding days for payment. This latter evidence suggests that efficiency in making quick payments is related to the ability to reach prices closer to the marginal costs. No other variable in the specification turns out to be significant.

Table 4: *Determinants of PB's ability (IV regressions)*

	(1)	(2)	(3)	(4)
	Benchmark		Without costs	
Fraction of direct negotiations	-1.492**	-1.860**	-0.497***	-0.602***
	(0.621)	(0.740)	(0.189)	(0.223)
ln(health personnel costs)	0.379***		0.205***	
	(0.046)		(0.019)	
ln(health purchases)		0.298***		0.174***
		(0.049)		(0.021)
Non-health/total personnel cost	6.058***	5.468***	1.541***	1.275***
	(0.571)	(0.633)	(0.170)	(0.191)
Health purchases/total health exp.	-1.507***	-2.970***	-0.546***	-1.361***
	(0.480)	(0.474)	(0.132)	(0.156)
ln(days payable outstanding)	-0.687***	-0.722***	-0.187***	-0.202***
	(0.123)	(0.131)	(0.035)	(0.037)
ASL	-0.680***	-0.696***	-0.256***	-0.254***
	(0.136)	(0.148)	(0.040)	(0.042)
Metropolitan area	-0.032	-0.149	-0.226***	-0.255***
	(0.244)	(0.289)	(0.074)	(0.087)
Center-South (CS)	-1.128	-1.355	-0.568	-0.689
	(1.784)	(1.847)	(0.566)	(0.595)
Health expenditure p.c.	-1.103	-1.175	0.922***	0.839***
	(1.112)	(1.162)	(0.278)	(0.292)
Health expenditure p.c. x CS	1.063	1.101	0.554*	0.590*
	(0.982)	(1.020)	(0.308)	(0.323)
Constant	0.654	3.660	-6.092***	-4.716***
	(2.555)	(2.452)	(0.664)	(0.640)
Relevance test (p-value)	0.000	0.000	0.000	0.000
Sargan test (p-value)	0.477	0.750	0.193	0.476
Hausman-Wu test (p-value)	0.005	0.004	0.084	0.054
Observations	1,257	1,257	1,257	1,257

Note. Bootstrapped standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

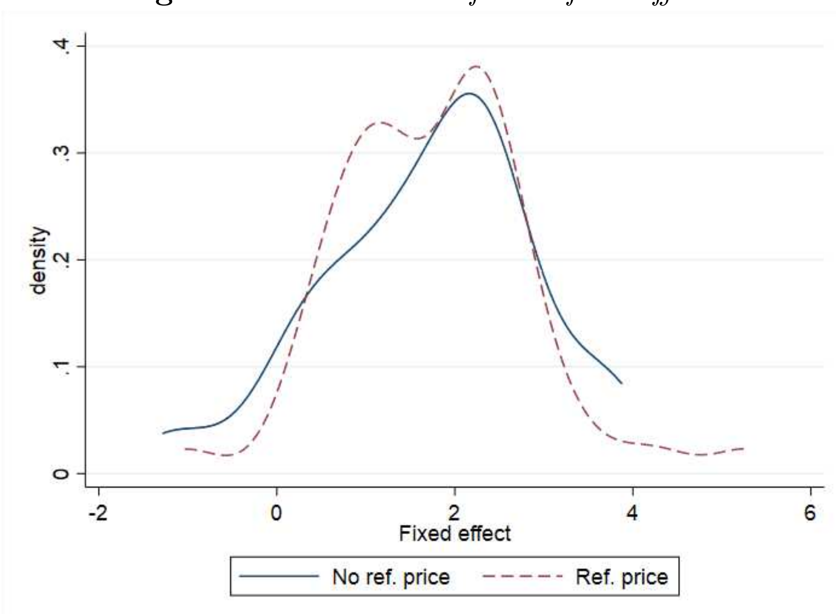
5 Reference Prices and Public Buyer's ability

5.1 Estimation

In this section we empirically investigate the effects of the reference price policy for the classes of medical devices on the PB's ability to carry out the procurement process. We remind ourselves here that our dataset covers the period from January 1st to December 31st 2013. From the beginning to May 2nd, the PBs were forced by law to apply the reference price defined by the Italian Authority for Public Contracts (AVCP) for each class of homogeneous medical devices they awarded.

Firstly, we replicated the same regression as in Equation (8), but only on the subset of 45 PBs that managed awarding procedures both before and after the termination of the reference price policy.[23] Figure 3 compares the distribution of the PB fixed effects, as measured by $\widetilde{\gamma}_h$, with the PB fixed effects in the presence of the reference prices, given by $\widetilde{\gamma}_h + \phi_h$. Under the reference price policy, we observed that the distribution of the fixed effects is more concentrated towards central values of the distribution. This is not surprising as it suggests that the reference price policy imposed additional regulation to the management of the auctions, thus limiting each PB to exert its own ability.

Figure 3: *Distribution of PB's fixed effects*



To help understand what is going on, we divided the sample of PBs in two groups depending on whether their ability is above or below the median and ran the following regression:

$$\ln(\Psi_{dhs}) = \sum_{h=1}^{H} \widetilde{\gamma}_h \cdot A_h + \rho \cdot R + \epsilon_{dhs}. \tag{11}$$

[23] In so doing we work on a dataset of 979 observations, i.e., prices paid by PBs both before and after the termination of reference price.

Equation (11) differs from Equation (8) for the inclusion of a common rather than PB-specific effect on the reference prices. Results are reported in Table 5. We obtain that, although reference prices show no overall impact on the final net price of the marginal cost, their effect changes widely depending on the initial level of ability of the PB. In fact, reference prices have a strong and negative impact on PBs with low ability and a strong positive impact on PBs with high ability. That is, with the reference price the (log) distance between prices and marginal costs shrinks for low-ability PBs and increases for high-ability PBs. As a reference, the average of the dependent variable is -1.727.

Table 5: *Impact of the reference price*

	(1)	(2)	(4)
Sample	All	Low ability	High ability
Reference price	-0.151	-0.751***	0.521**
	(0.180)	(0.236)	(0.238)
PB fixed effects	YES	YES	YES
R^2	0.523	0.466	0.571
Observations	938	474	464

Note. Standard errors clustered by medical device in parentheses; *** p<0.01, ** p<0.05, * p<0.1

These results highlight a non-linear effect of the reference price policy on the final outcome of the awarding procedures in our dataset. We interpret the effect in connection to changes in the reserve price.

Considering the PBs endorsed with high ability, i.e. those that purchase at a price close to the marginal cost, the reference price could increase the reserve price, creating a focal point for participants in the awarding procedure and reducing the ability of the PB to extract all the rent from the most efficient supplier. On the other hand, considering the PBs endorsed with low ability, the reference price policy could have a positive effect for PBs endorsed with low ability because it would decrease the adopted reserve price, as compared to the one adopted without reference price and allow the PB to pay a lower price.

5.2 Determinants of the PB's ability under reference prices

We conclude our analysis by repeating the IV regression in Equation (9) using as dependent variable a proxy for the PB's ability under the reference prices:

$$-\left(\widetilde{\gamma}_h + \phi_h\right) = \beta_0 + \beta_1 \cdot M_h + \beta_2 \cdot H_h + \beta_3 \cdot P_h + \beta_4 \cdot C_h + \epsilon_h. \tag{12}$$

Our aim is to learn if the PB's ability correlates with different variables when the reference price is at play. Table 6 shows the relevant outputs, comparing estimates on ability under the reference price ($-\left(\widetilde{\gamma}_h + \phi_h\right)$) with those without reference price ($-\widetilde{\gamma}_h$). This latter scenario stems from Equation (9), but the output differs from Table 4 because here we only consider PBs facing at least one auction with a reference price and one auction without a reference price in our sample. Appendix Table A.4 shows the corresponding estimates based on OLS regressions.

From the comparison of Column (1) with Column (3), and Column (2) with Column (4), we find systematic evidence that under the reference price policy many key effects that were significant become non-significant (health purchases over total health expenditures), or reduce their size (the fraction of direct negotiations, health personnel cost, health purchases and non-health over total personnel cost). The same applies to most control variables. Our explanation is that the reference price policy limits the discretion of the PBs in designing the awarding process, with the result that each PB's specific ability (or inability) no longer significantly affects the procurement's outcome.

Table 6: *Determinants of PB's ability with ref. price (IV regressions)*

	(1)	(2)	(3)	(4)
	No Ref. price		Ref. price	
Fraction of direct negotiations	-3.095***	-3.080***	-1.670***	-1.693***
	(0.615)	(0.610)	(0.384)	(0.381)
ln(health personnel cost)	0.581***		0.262***	
	(0.069)		(0.068)	
ln(health purchases)		0.558***		0.239***
		(0.067)		(0.066)
Non-health/total personnel cost	13.387***	13.827***	5.184***	5.288***
	(1.734)	(1.752)	(1.611)	(1.650)
Health purchases/total health exp.	-3.178***	-5.697***	0.235	-0.848
	(0.773)	(0.935)	(0.707)	(0.919)
ln(days payable outstanding)	0.213	0.215	0.149	0.153
	(0.160)	(0.161)	(0.103)	(0.103)
ASL	-0.837***	-0.837***	-0.182	-0.181
	(0.161)	(0.160)	(0.135)	(0.135)
Metropolitan area	-0.523**	-0.507**	0.218	0.214
	(0.254)	(0.252)	(0.202)	(0.201)
Center-South (CS)	-7.353***	-7.553***	-7.179***	-7.339
	(2.272)	(2.277)	(1.916)	(1.928)
Health expenditure p.c.	5.468***	5.276***	0.269	0.165
	(1.710)	(1.697)	(1.078)	(1.062)
Health expenditure p.c. x CS	4.339***	4.438***	3.172***	3.244***
	(1.251)	(1.254)	(1.021)	(1.027)
Constant	-19.386***	-17.331***	-4.041	-2.858
	(4.331)	(4.148)	(2.938)	(2.741)
Relevance test (p-value)	0.000	0.000	0.000	0.000
Sargan test (p-value)	0.204	0.242	0.513	0.445
Hausman-Wu test (p-value)	0.000	0.000	0.000	0.000
Observations	979	979	979	979

Note. Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

6 Conclusions

Public procurement of medical devices represents a large share of the national public budgets in European countries. In this paper, we have empirically investigated the price differences in the purchasing of standard medical devices by Italian public buyers (i.e. PBs: local hospitals and health units), with a focus on the PB's ability in managing such procurement during the period from January 1st to December 31st 2013. Furthermore, we have studied the effects of a reference price policy on the medical devices' final prices paid by PBs, a policy adopted to increase efficiency in such public spending. In our analysis, for each purchase we measured the difference between the medical device's price (resulting from the procurement procedure) and its benchmark marginal production cost (resulting from our structural estimation). We defined the PB's ability as the PB's fixed effect on such difference, for each item procured.

Our results highlight that the Italian PBs pay substantially different prices for standard medical devices. In particular, the quartile-based coefficient of variation of the prices paid equals 58.31% .[24] Such differences across the procurement prices can be explained by the PB fixed effects which we then investigated as related to institutional characteristics, geography and size. We found that the PB size (measured by the overall personnel costs, corresponding to the sum of health personnel and non-health personnel costs, or by the size of their health-related procurement) has a general positive and significant effect on the PB's ability to run the procurement process. Our empirical analysis showed that it is the non-health personnel cost that drives the overall positive and significant effect on the PB's ability. This result somehow supports centralisation of public procurement for medical devices, i.e. a few large PBs collecting non-health personnel and addressing (possibly skilled) efforts in the purchasing activities.

We then observed that the adoption of a mandatory reference price as a cap to medical devices' winning prices has a significant negative effect for high-ability PB's purchasing (i.e. higher procurement prices are recorded as compared to the period in which reference prices were absent) and a positive effect on low-ability PB's purchasing. All in all, according to our observations, mandatory reference prices seem to have been ineffective in fostering the efficiency of public procurement for standard medical devices in Italy. Specifically, our back-of-the-envelope calculation shows that the total prices paid increased by 1.2% due to the presence of the reference price policy. However, this overall evidence hides the 59.49% price decrease for low-ability PBs and the 24.22% price increase for high-ability PBs. [25]

Our findings suggest that policy makers aimed at increasing efficiency (i.e. value for money) in the procurement for standard medical devices should first carefully take into consideration each PB's ability in running the procurement process. Such consideration of the PB's ability would be even more relevant when moving from the procurement of standard to complex items. A further implication from our observations suggest policy makers should avoid the implementation of policies addressing all the PBs in the same way. Our findings for standard medical devices in Italy indi-

[24] To make all observations comparable, the quartile-based coefficient of variation is computed using homogenous prices, as defined by Equation (5) – applied to the entire dataset.

[25] Based on price predictions from Table 4, with or without the reference price. Low-ability and high-ability PBs are defined as in Table 4.

cate that the PB size and institutional characteristics determine the PB's ability in purchases, i.e. PBs with larger non-health personnel teams and better connections to decision-makers show higher ability in procurement. Specifically referring to the impacts of a reference price policy on the PB's ability, our findings suggest a move toward a discriminatory approach, that is, to implement mandatory requirements only for the PBs which perform below a defined benchmark.

All in all, our observations and policy implications provide a primary focus on the public procurement of standard medical devices, addressing the sources and the effects of the buyer's ability in such purchasing. Given the high value of European public procurement in the health sector and the core relevance of such sector for the Europe 2020 strategy, new empirical investigations are expected to shed light on further improvement for expenditure efficiency in this setting.

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A Appendix

A.1 Noisy signal on competition in auctions

Tenders in our dataset are sealed bid auctions in which bidders are supposed not to know ex-ante how many competitors they will face. Consider the two extreme cases. First, if the level of competition is perfectly known in advance by all the bidders, then when $N_{0h} = 1$ the unique participant must bid a price $B^{(1:1)}$ equal to the reserve price r. Accordingly, if $\Pr\left(B^{(1:1)} = r \mid N_{0h} = 1\right) < 1$, then the hypothesis that N is fully observed ex-ante can be rejected. In our dataset we observe the reserve price in 21% of FPAs: among them, we only observe this for three observations when $N = 1$, and in two of them there is $B^{(1:1)} < r$. Second, if N_{0h} is totally unknown by the participants, then the distribution of the bids should not vary with N_{0h} : running in our dataset a Kendall's rank correlation coefficients test leads us to rejects this hypothesis.[26]

We thus assume that, in our setting, bidders receive a noisy signal of the level of competition they will face in the auction. Using Kendall's test on auctions with similar competition, we obtain that the bids' distribution results are different in auctions, respectively, with $N_{0h} = 1$, with $N_{0h} \in [2, 4]$ and with $N_{0h} \in [5, S]$ participants: within each of these three subsamples, the bids' distribution does not change with the number of bidders, but across those subsamples, it does.

In the following we sketch how we derive the noisy signal on competition. Define with $G_{\underline{n},\overline{n}}$ the observed distribution of bids with a number of participants $n \in [\underline{n}, \overline{n}]$. Starting with $\underline{n} = 1$, for each $\overline{n} \in [2, N]$ we compare whether $G_1 ... G_k ... G_n$ originates

[26] Kendall's score: -20757. Test of H_0: the normalised prices and number of bidders are independent, p-value<0.01.

from the same distribution using the Kendall's rank correlation coefficients test. If we accept the hypothesis that all samples originate from the same distribution, then we continue adding G_{n+1} to the comparison. If we reject the hypothesis, we stop and restart comparing $G_{n,n+1}$. In Table A.1, the first two columns report the lowest and highest number of bidders, respectively $\underline{n}$ and $\overline{n}$, considered in the test, and the third column reports the Kendall's rank correlation coefficients' p-value.

Table A.1: *Noisy signal*

$\underline{n}$	$\overline{n}$	Kendall's p-value
1	2	0.00
2	3	0.29
2	4	0.16
2	5	0.03
5	6	0.89
5	7	0.23
5	8	0.96
5	9	0.85
5	11	0.87
5	12	0.88
5	13	0.57
5	15	0.70
5	16	0.55
5	21	0.65
5	22	0.87
5	29	0.82
5	30	0.94

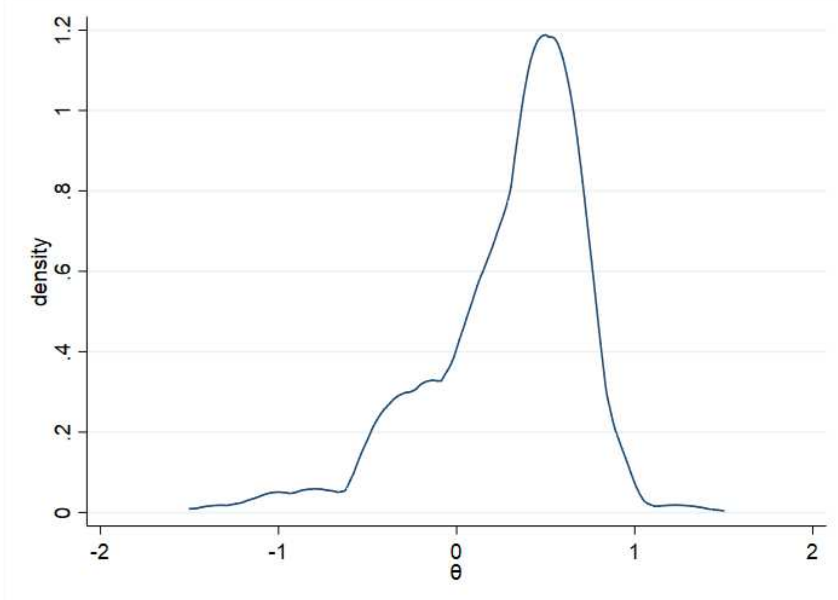
Because we cannot derive the equilibrium bidding condition for $N_{0h} = 1$, we discard these observations. We define the subsample for $N_{0h} \in [2, 4]$ as the one with *low competition,* and we use the median value $N_{0h} = 3$ as the noisy signal on the competition firms would face. Similarly, we do the same for the subsample for $N_{0h} \in [5, S]$, defined as a *high competition* subsample, using the median value $N_{0h} = 8$ as the noisy signal.

A.2 Different definition of competition

Marginal cost estimate needs knowledge of the number of participants to the bid. In Sub-section 3.2.1 we split the sample in two groups, signaling low participation (between 2 and 4 participants) and high participation (5 or more participants). As a robustness check, we remove the distinction in two groups and consider a unique signal in case of two or more participants in an auction; in that case, the median value used to compute equilibrium is $N_{0h} = 5$ while the subsample is defined as *2+ competition*.

An application of Equation (7) to this alternative framework gives rise to the density function of the bidder's private value shown in Figure A.1:

Figure A.1: *The distribution of the private value in the 2+ competition subsample*



The distribution is in line with the benchmark one in Figure 1, as it gives rise to similar marginal cost estimates, and provides similar estimates of a PB's ability.

A.3 Marginal cost estimate

The GPV approach to estimate marginal costs using observed bids has to be modified, since our data consist of winning offers of procurement auctions: the functional form of the bid is different. In a procurement auction, the lowest bid wins, and therefore the probability of victory given a bid p_i is equal to $\Pr(p_i \leq p) = (1 - F(\theta))^{n-1}$. Following Holt (1980), in a procurement auction, the (Nash) equilibrium bid $p(\theta_i)$ of the $i - th$ bidder of type θ_i is given by:

$$p(\theta_i) = \theta_i + \int_{\theta_i}^{\overline{\theta}} \left(\frac{1 - F(y)}{1 - F(\theta)} \right)^{n-1} dy. \quad (13)$$

This strategy is obtained solving the first order differential equation in $p(\cdot)$:

$$1=\frac{f(\theta)}{1-F(\theta)}\frac{1}{p'(\theta)}(n-1)\cdot(p(\theta)-\theta) \tag{14}$$

with boundary condition $p\left(\overline{\theta}\right)=\overline{\theta}$. The equilibrium strategy in Equation (13) is strictly increasing in θ and, as in a standard FPA, expresses the equilibrium bid as a function of the bidder's type θ.

Define with $G(p)$ the cumulative distribution function of all observed bids p, with $g(p)$ the density function. As noted by GPV, $G(p)=\Pr(p_i\leq p)=\Pr\left(\theta_i\leq p^{-1}(p)\right)=F\left(p^{-1}(p)\right)=F(\theta)$. $G(p)$ is absolutely continuous and has a density function equal to $g(p)=\frac{f(\theta)}{p'(\theta)}$. Thus, Equation (14) can be rewritten as:

$$\theta_i=p_i-\frac{1-G(p_i)}{(n-1)\cdot g(p_i)}. \tag{15}$$

A further difference from GPV is that we observe winning bids only. As in Athey and Haile (2002) winning bids are considered equal to the maximum order statistic of $G(p)$ given the level of competition n, in the procurement auction case they should be considered equivalent to the first order statistic with density function $g_{(1)}(p)$ and cumulative distribution function $G_{(1)}(p)$ equal to:

$$\begin{aligned} g_{(1)}(p) &= n\cdot g(p)\cdot(1-G(p))^{n-1} \\ G_{(1)}(p) &= 1-(1-G(p))^{n}. \end{aligned}$$

Thus,

$$\frac{1-G_{(1)}(p)}{g_{(1)}(p)}=\frac{[1-G(p)]^n}{n\cdot g(p)\cdot[1-G(p)]^{n-1}}=\frac{n-1}{n}\frac{1-G(p)}{(n-1)\cdot g(p)}. \tag{16}$$

Replacing Equation (16) into Equation (15) yields the structural Equation (7):

$$\theta_i=p_i-\frac{n}{n-1}\frac{1-G_{(1)}(p_i)}{g_{(1)}(p_i)}.$$

A.4 Alternative explanation: corruption

We now explore whether an explanation alternative to PB's ability may describe the variability we observe on the ability to manage the procurement process. We focus on corruption because misbehavior can potentially lead to similar effects on the final prices for procured medical devices. According to Bandiera et al. (2009), each awarding procedure in public procurement could be affected by the PB's lack of knowledge or experience in running it (i.e., passive waste), as well as by the PB's actions supporting corruption and favoritism (i.e., active waste). Unfortunately, in the setting we investigate, we have no way to cleanly disentangle these two dimensions.

However, we follow Bandiera et al. (2009) and consider a variant of the regression in Equation (8), where we include in the specification the interaction between PB dummies ($A_h, h = 1, ..., H$) and producer dummies ($S_j, j = 1, ..., J$), as follows:

$$\ln(\Psi_{dhs}) = \sum_{h=1}^{H} \left(\widetilde{\gamma}_h \cdot A_h + \phi_h \cdot A_h \cdot R + \sum_{j=1}^{J} \lambda_{hj} \cdot A_h \cdot S_j \right) + \sum_{d=1}^{D} \delta_d \cdot D_d + \epsilon_{dh}.$$

We also include medical device dummies ($D_d, d = 1, ..., D$) to control for the characteristics of the auctioned products. The purpose of this OLS regression is to understand if the repeated relation between a specific PB and a specific producer (i.e., the PB's repeated purchasing from the same seller) has a systematic impact on the PB's ability. Note that, as highlighted by the literature on relational contracting (Levin, 2003; Asanuma, 2002), a repeated relationship could be a signal of corruption or favoritism (i.e., when a producer bribes the PB to avoid competition or obtain gains through the auction; Rose-Ackerman, 1999), leading to a benefit for all the involved parties (i.e., mitigate potential hold-up problems and incentives for ex-post renegotiation arising from contractual incompleteness; Gil and Marion, 2011). Accordingly, as an outcome from our regression, significantly positive coefficients λ_{hj} would be a signal of corruption or favoritism, while significantly negative coefficients λ_{hj} would be a signal of a valuable relationship.

The introduction of the interactions between PBs and producers (403 parameters) induces only a modest improvement in the fit of the model, whose R^2 statistic ranges from 0.87 to 0.96. This indicates that repeated relations can describe no more than 9% (0.96-0.87) of a PB's ability. Moreover, our estimates show that just 50 out of the 403 coefficients are significantly positive, and only 20 are significantly negative. Taken together, this evidence leads us to note that corruption seems infrequent in our data and plays a marginal role in explaining the PB's ability.

A.5 Further tables and figures

Figure A.2: *Distribution of device-dummy coefficients from Column (2), Table 3*

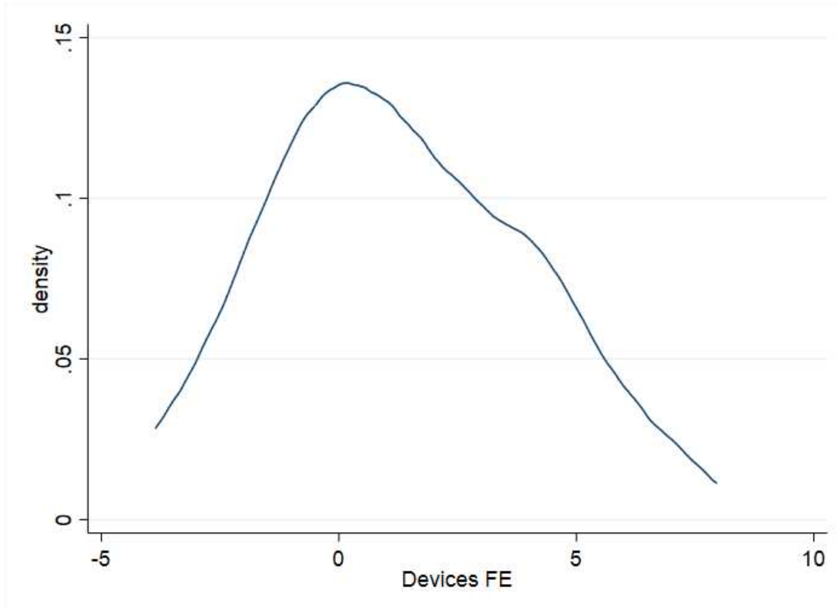


Figure A.3: *Distribution of PB-dummy coefficients from Column (4), Table 3*

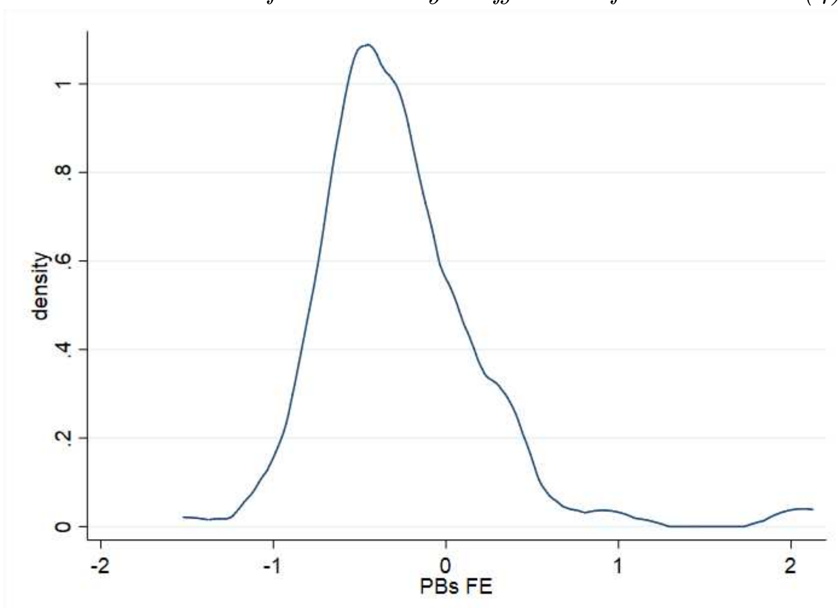


Table A.3: *Determinants of PB's ability (OLS regressions)*

	(1)	(2)	(3)	(4)
	Benchmark		Without costs	
Fraction of direct negotiations	0.104	0.149*	-0.133***	-0.110***
	(0.077)	(0.078)	(0.036)	(0.037)
ln(health personnel cost)	0.387***		0.206***	
	(0.038)		(0.017)	
ln(health purchases)		0.353***		0.187***
		(0.035)		(0.016)
Non-health/total personnel cost	6.106***	5.708***	1.551***	1.334***
	(0.405)	(0.419)	(0.132)	(0.132)
Health purchases/total health exp.	-0.901**	-2.465***	-0.408***	-1.237***
	(0.381)	(0.371)	(0.112)	(0.144)
ln(days payable outstanding)	-0.543***	-0.557***	-0.155***	-0.162***
	(0.094)	(0.095)	(0.029)	(0.030)
ASL	-0.381***	-0.345***	-0.188***	-0.168***
	(0.083)	(0.082)	(0.030)	(0.029)
Metropolitan area	0.568***	0.603***	-0.090***	-0.070**
	(0.097)	(0.096)	(0.032)	(0.031)
Center-South (CS)	-2.454	-2.736*	-0.870*	-1.028*
	(1.619)	(1.619)	(0.525)	(0.531)
Health expenditure p.c.	-2.889***	-3.203***	0.515**	0.342
	(0.889)	(0.878)	(0.237)	(0.237)
Health expenditure p.c. x CS	1.980**	2.116**	0.762***	0.839***
	(0.875)	(0.875)	(0.285)	(0.288)
Constant	1.549	3.721*	-5.888***	-4.701***
	(2.276)	(2.131)	(0.661)	(0.609)
R-squared	0.204	0.200	0.243	0.234
Observations	1,257	1,257	1,257	1,257

Note. Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Table A.4: *Determinants of PB's ability with ref. price (OLS regressions)*

	(1)	(2)	(3)	(4)
	No Ref. price		Ref. price	
Fraction of direct negotiations	-0.269***	-0.260***	0.968***	0.973***
	(0.075)	(0.074)	(0.083)	(0.083)
ln(health personnel cost)	0.443***		0.132***	
	(0.041)		(0.048)	
ln(health purchases)		0.433***		0.121***
		(0.040)		(0.047)
Non-health/total personnel cost	6.974***	7.414***	-0.804	-0.775
	(0.642)	(0.665)	(0.921)	(0.950)
Health purchases/total health exp.	-1.323***	-3.290***	1.967***	1.427***
	(0.399)	(0.400)	(0.306)	(0.430)
ln(days payable outstanding)	0.019	0.021	-0.032	-0.031
	(0.106)	(0.106)	(0.065)	(0.064)
ASL	-0.125	-0.131	0.482***	0.486***
	(0.086)	(0.087)	(0.082)	(0.083)
Metropolitan area	0.449***	0.460***	1.125***	1.128***
	(0.096)	(0.096)	(0.078)	(0.078)
Center-South (CS)	-7.909***	-8.014***	-7.697***	-7.775***
	(1.452)	(1.456)	(1.049)	(1.048)
Health expenditure p.c.	0.010	-0.086	-4.827***	-4.904***
	(0.907)	(0.911)	(0.575)	(0.568)
Health expenditure p.c. x CS	4.831***	4.886***	3.631***	3.668***
	(0.777)	(0.779)	(0.554)	(0.553)
Constant	-7.421***	-6.097**	7.130***	7.761***
	(2.518)	(2.450)	(1.915)	(1.791)
R-squared	0.206	0.205	0.462	0.461
Observations	979	979	979	979

Note. Bootstrapped standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.

Figure A.4: *PB fixed effects across Italian regions*