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Centralized Procurement and Delivery Times: Evidence from a Natural Experiment in Italy

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Centralized Procurement and Delivery Times: Evidence from a Natural Experiment in Italy*

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Abstract

We study how delivery times and prices for hospital medical devices respond to the introduction of centralized procurement. Our identification strategy leverages a legislative change in Italy that mandated centralized purchases for a sub-set of devices. The statutory centralization generated a reduction in prices and an increase in delivery times for centralized purchases relative to non-centralized purchases. We use data on quantities and on suppliers to discuss the mechanisms potentially underlying our findings.

JEL classification: D44; H51; H57; I18

Keywords: Public Procurement; Centralization; Medical Devices; Delivery Times; Bulk Purchasing;

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1 Introduction

Previous papers have documented that centralization of procurement has resulted in lower prices (see, for instance, Bandiera et al., 2009 and Dubois et al., 2021). However, these lower prices may come at the cost of longer delivery times or lower quality in other dimensions (see OECD, 2011). If prices fall but delivery times become longer, or quality somehow decreases, then the overall impact of centralization is ambiguous and may even be negative.

This paper studies the impact of statutory centralized procurement for hospital medical devices on prices and delivery times. To do so, we collected comprehensive data on each order of medical devices for 16 hospitals located in the Italian Region *Lazio*.[1]

For each order, we have access to detailed information on the type of medical device, including the brand and exact model. The medical devices in our sample are standardized and purchased on a regular basis by all hospitals. Like other datasets, such as the one used by Grennan and Swanson (2020), ours includes information on the unit price paid for the medical device, the quantity purchased, and the identity of the supplier. Uniquely, our dataset also provides information on both the order and delivery dates. We define the delivery time as the difference between the delivery date and the order date.[2]

Our identification strategy takes advantage of the staggered implementation of statutory centralization for different medical devices. Starting in 2016, hospitals were required to buy a sub-set of devices using a central buyer, while other devices could be directly purchased by hospitals. We estimate the impact of statutory centralization using a difference-in-differences research design, in which we compare changes in prices and delivery times for centralized devices to the changes for non-centralized devices. This empirical strategy rests on the assumption that centralized and non-centralized devices share a parallel trend before 2016. We test and do not reject the existence of a common trend between centralized and non-centralized devices before 2016.

Consistent with the papers mentioned above, we find that centralized procurement reduces prices. Our main contribution is to document that, as prices decrease, delivery times increase. Nevertheless, the effect of centralized procurement on delivery times is relatively small. More specifically, after January 2016, we find a reduction in prices of approximately 15% and an increase in delivery times of roughly 20% for centralized devices, compared to non-centralized devices. The average delivery time in the pre-

[1] In this paper, we define hospitals as all those health units that provide health services. These health units are of three different types: a) units that provide healthcare services such as services for pathological addictions, clinics for specialist examinations, home care, assistance, vaccinations, blood tests (*Aziende Sanitarie Locali*), b) healthcare facilities where patients can be hospitalized (*Aziende Ospedaliere*) and c) hospitals where healthcare services are provided and where the clinical research is carried on (*Istituti per il ricovero e cura a carattere scientifico*). From this point forward, we use the term "hospitals" to indicate all these public buyers.

[2] Delivery times of medical devices became particularly relevant during the COVID-19 pandemic. According to ANAC (2020), public buyers in the healthcare sector, when asked, declared that delays in delivery of medical devices represented 60% of all the issues reported in the procurement process.

centralization period is 12 days, and this increase in delivery time amounts to a change of only 2.5 days. To our knowledge, our results are the first in the literature to examine the effect of centralization on delivery times.

Next, we explore possible mechanisms that could generate our main findings. Although we investigate several possible mechanisms, our primary focus is on the importance of contract size. We can thus examine whether the reduction in prices due to centralization is associated with bulk purchasing. Centralization implies that the demand that otherwise would have been placed separately by individual hospitals at multiple different suppliers is pooled and placed with a smaller number of sellers. To explain how we investigate this mechanism, we first define the difference between contracts and orders.

Contracts are legally binding agreements between buyers and sellers, and orders are the real transactions between buyers and suppliers at the conditions established in the contract. These real transactions are registered in the accounting systems. When a contract C for the supply of Q quantities of a medical device D for a certain period T is awarded to supplier S, at the time of the award the real transaction between the buyer and the supplier of quantities Q of medical device D that are auctioned in contract C is not taking place. Units of the medical device D are effectively purchased when, during time T, the buyer issues orders O to the supplier S for a certain number of units $Q' <= Q$ of the medical device at the conditions established at the time of the award of the contract. Thus, during time T, there might be several orders associated with one contract.

In this paper, we can match our order-level data with contract-level data provided by the Italian Anticorruption Authority (ANAC) using the contract identifier. Although we observe only quantities effectively purchased (Q') in our orders, and we do not observe the quantities Q auctioned in the contracts, we can aggregate all quantities Q' bought in one or more orders associated with a contract for a particular device D by contract identifier to construct a measure of contract size. This measure of contract size is a proxy for Q. We find that the overall contract size, i.e., the quantities in a contract for a particular device, is 200% larger for centralized devices compared with devices in the control group. We also find that the monthly quantities ordered by individual hospitals do not change, whereas the number of suppliers decreases significantly. In addition to generating bulk discounts, we conjecture that these findings may explain the observed increase in delays, as the suppliers must execute larger contracts.

Note that our finding that the sizes of individual hospital-device orders are not increasing has implications for the welfare effects of the lengthening of the delivery times. The increase in delivery times that we document is relatively small, and so we might not be concerned that hospitals and their patients are being harmed in any way. However, even a delay of 2 days could have important consequences if it leaves hospitals short of crucial medical devices. Our finding that the monthly demand by individual hospitals for centralized devices does not increase implies that one of two things must be true. Either hospitals were ordering too many quantities of medical devices at each order before the policy change so that they did not use all of their stock prior to the receipt of the next shipment, or they are now experiencing shortages.

Finally, we assess the robustness of our results by repeating our analysis in a larger sample of medical devices that are less homogeneous. Our main conclusions are unchanged: centralized procurement generates a reduction in price with a small increase in delivery time.

This paper relates to the literature on centralized procurement (Bandiera et al., 2009; Albano and Sparro, 2010; Schotanus et al., 2011; Walker et al., 2013; Baldi and Vannoni, 2017; Castellani et al., 2018; Ferraresi et al., 2021; Dubois et al., 2021; Lotti and Spagnolo, 2021). Bandiera et al. (2009) and Dubois et al. (2021) empirically show that centralized procurement reduces prices, while Lotti and Spagnolo, 2021 show that the effect of centralized procurement on prices might be larger, due to spillovers to the purchases of items not subject to centralized procurement. Baldi and Vannoni (2017) and Ferraresi et al. (2021) look specifically at public procurement in healthcare. Ferraresi et al. (2021), in particular, show that aggregate expenses of local public health units in Italy decreased after the creation of local procurement agencies that aggregate the demand of local public health units. Relative to these papers, we study the impact of centralization not only on prices, but also on the execution of contracts by exploiting the availability of the actual orders and delivery times to hospitals.

Our paper also contributes to the broader literature examining procurement in healthcare. Grennan (2013) documents that measures aimed at decreasing hospital costs, such as increased transparency or centralized procurement, are not always effective. The effectiveness of these policies depends on the extent to which they soften competition and the bargaining ability of hospitals. Grennan and Swanson (2020) study whether improving the information available to hospitals (the buyers) may be helpful in lowering prices. Whereas these articles consider a setting where prices are negotiated between US hospitals and suppliers (business-to-business transactions), we apply the analysis to a set of public hospitals (business-to-government transactions). Furthermore, the main focus of these papers is on prices and not on delivery times.

Bucciol et al. (2020) show that the impact of reference price policies depends on the bargaining ability of public hospitals. Reference prices could only slightly decrease public expenditure: efficient hospitals pay higher prices when the reference prices are in place, and inefficient hospitals can instead pay lower prices. Thus, the policy might not be effective and could have unintended consequences driven by the demand side of the market. In this paper, we analyze a different policy aimed at reducing prices paid for medical devices, and we look at mechanisms underlying our results on both the demand and supply sides of the market.

The paper also relates to the literature analyzing the impact of pricing policies on dimensions other than prices. Maini and Pammolli (2020) point out that international reference pricing policies in the market for drugs may be a deterrent to entry. Similarly, we analyze the impact of a different pricing policy in healthcare not only on prices but also on delivery times.

This paper contributes to the literature that examines the role of discretion in public procurement (see, for instance, Coviello et al., 2018, Decarolis et al., 2020a and Bandiera et al., 2020). It reinforces the findings of that literature by showing that limiting discretion in procurement might reduce procurement prices but might increase delays in the delivery of public goods.

Finally, this paper relates to the literature on *ex-post* procurement performance (Coviello et al., 2018; Giuffrida and Rovigatti, 2019; Decarolis et al., 2020b, Decarolis and Palumbo, 2015). Whereas those papers focus on public works and services, we focus on the delivery of homogeneous goods in the healthcare sector.

The paper is structured as follows. Section 2 explains the legislative background. Section 3 presents the data. In section 4 we present the identification strategy and the main difference-in-differences results. Section 5 discusses some of the possible mechanisms behind the decrease in prices and increased delivery times following the mandatory centralization of procurement. Section 6 shows that the increase in delivery times following the centralization policy also applies to all other macro-categories of goods that are not necessarily homogeneous. Section 7 concludes.

2 Institutional background

2.1 Centralization of purchasing

According to Consip, the Italian national procurement agency, more than 35,000 contracting authorities can autonomously award contracts for goods, services, or public works in Italy. The resulting price dispersion incentivized the Italian government to implement reforms in the public procurement sector to reduce the number of contracting authorities. Law 66/2014 (*Decreto Legge 66/2014*) established a list of demand aggregators (*Soggetti Aggregatori*) that can award contracts for goods and services on behalf of local public administrations, thus acting as contracting authorities. Since 2014, there have been 35 demand aggregators in Italy recognized by law. These demand aggregators are a) Consip as the national procurement agency, b) 21 regional procurement agencies, c) nine municipalities, and d) one province.[3] Although the list of demand aggregators was publicly released in 2014, it was not clear for which categories of goods and services public ad-

[3]The entire list is available at: `https://www.acquistinretepa.it/opencms/opencms/soggetti_aggregatori_new/chi_siamo/`

ministrations could use the demand aggregators, so the use of that tool was discretionary until January 2016.

A decree of the Italian Prime Minister on 24 December 2015, which went into force on 1 January 2016, indicated specific categories of goods and services for which the demand aggregators must be used as well as the contract value thresholds above which the demand aggregators must be used. A second decree, written on 11 July 2018 and in force as of 16 July 2018, established additional categories of goods and services for which demand aggregators must be used along with the contract value threshold above which the demand aggregators must be used. As our sample period ends in June 2018, we only consider the effects of the first decree. Both decrees give power to ANAC to not release a contract ID (*Codice Identificativo di Gara*) if the public buyer wants to autonomously award a contract for a good or service subject to the use of demand aggregators and if the contract value is higher than the contract value threshold for which the use of demand aggregators is mandatory. This power is waived in cases of emergencies and urgent need.

Figure 1 presents the list of goods that are subject to the use of demand aggregators, together with the contract value thresholds and the year of the regulation (Dpcm). The list includes simple devices, such as syringes and needles, dressings, sutures, and gloves, as well as devices with more technologically advanced components, such as stents, hip replacements, defibrillators, and pacemakers. Drugs and vaccines are also included. Below the thresholds indicated, public administration bodies are entitled to award contracts using discretionary procedures such as direct bargaining with one supplier or restricted procedures. EU contract value thresholds (community thresholds) for stents, hip replacements, defibrillators, and pacemakers are subject to small periodic changes and may be updated after some time. For public hospitals, the EU threshold was €207,000 before January 2016 and increased to €209,000 after (EU Regulation 2015/2170).[4]

2.2 The degree of homogeneity of medical devices

Following Bandiera et al. (2009, 2020) we focus our attention on standardized products. Specifically, we concentrate on homogeneous products such as syringes and needles of certain loads, dressings of different sizes, and sutures of different gauges.[5] For example, rather than lumping together all syringes, we differentiate between syringes of 10 and 50 ml to avoid measurement error, as our analysis considers the unitary price of the items as one of the relevant outcomes.

In order to construct our sample of homogeneous products, we exploit the classification of devices implemented by the National Agency for Regional Health Services (AGENAS). This governmental agency supports the government and the implementation of its policies in the healthcare sector through research, monitoring, and evaluation. Their classifications

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2170&from=en

[5] Bandiera et al. (2009) analyze goods such as laptops, paper, office chairs, and fuel.

were released in waves starting in 2012 and helped the ANAC implement other policy changes, such as reference prices, for a sub-set of homogeneous items.

Figure 1: Goods subject to the use of centralized procurement

Commodity study	Threshold (€)	Dpcm
SPECIFIC HEALTHCARE EXPENDITURE - GOODS		
Medicines	40,000	2016
Vaccines	40,000	2016
Stent	Community threshold	2016
Incontinence aids	40,000	2016
Hip replacement	Community threshold	2016
General dressings	40,000	2016
Defibrillators	Community threshold	2016
Pacemaker	Community threshold	2016
Needles and syringes	40,000	2016
Gloves (surgical and non-surgical)	40,000	2018
Sutures	40,000	2018

Source: Italian national procurement agency (*Consip*) `https://www.consip.it/media/approfondimenti/consip-nel-sistema-nazionale-degli-acquisti-pubblici`. The first column indicates the category of goods, *Threshold* indicates the contract value above which the use of centralized procurement is mandatory, and *Dpcm* indicates the year of the regulation. The document is translated into English from Italian.

Figure 2 provides an example of six homogeneous classes of devices for syringes and needles, as classified by AGENAS. The column *CODICE CND* represents an alphanumeric classification identifying the specific device. The column *DESCRIZIONE* contains the related description of the alphanumeric code, and the column *SPECIFICHE TECNICHE* identifies the device and provides the technical specifications. Of the three levels of homogenization, the most detailed is the one providing the technical specifications of the device.

Recalling the list in Figure 1, we exclude homogeneous drugs from our analysis because they have been subject to reference prices since 2014. Stents and hip replacements are excluded because they are more complex and technologically advanced devices, although AGENAS classified them in 2012. We exclude defibrillators, pacemakers, incontinence aids, gloves, and vaccines because they have never been classified. After these exclusions, our analysis includes syringes, needles, dressings, and sutures in the class of simple and homogeneous devices. Finally, our analysis will exclude 39 classes of dressings, syringes, and needles that, since March 2016, have also been subject to the reference prices, given the possible confounding effect that this additional policy might have on our estimates.

Figure 2: Excerpt from the list of homogeneous medical devices

	CODICE CND	DESCRIZIONE	SPECIFICHE TECNICHE
1	A01010101	Aghi ipodermici per siringa	in acciao inox lubrificato, punta a triplice affilatura, calibro G18 ÷ G 25, senza ftalati, latex free, **senza dispositivo di sicurezza**
2	A01010101	Aghi ipodermici per siringa	in acciao inox lubrificato, punta a triplice affilatura, calibro G18 ÷ G 25, senza ftalati, latex free, **con dispositivo di sicurezza**
3	A010102	Aghi a farfalla	in acciao inox lubrificato, punta a triplice affilatura, calibro G19 ÷ G25, lunghezza mm 18-20, senza ftalati, latex free, **senza dispositivo di sicurezza**, con tubo di raccordo da 30 cm ca.
4	A010102	Aghi a farfalla	in acciao inox lubrificato, punta a triplice affilatura, calibro G25 ÷ G27, lunghezza mm 10 ca., senza ftalati, latex free, **senza dispositivo di sicurezza**, con tubo di raccordo da 30 cm ca.
5	A010102	Aghi a farfalla	in acciao inox lubrificato, punta a triplice affilatura, calibro G25 ÷ G27, lunghezza mm 10 ca., senza ftalati, latex free, **senza dispositivo di sicurezz**a, con tubo di raccordo da 60 cm ca.
6	A010102	Aghi a farfalla	in acciao inox lubrificato, punta a triplice affilatura, calibro G19 ÷ G25, lunghezza mm 18-20, senza ftalati, latex free, **con dispositivo di sicurezza**, con tubo di raccordo da 30 cm ca.

Source: National Agency for Regional Health Services (AGENAS) `https://www.agenas.gov.it/images/agenas/ricerca/agenas_ccm_corrente_finalizzata/LEA/beni_servizi/all_8.pdf`.
Notes: *CODICE CND* presents the alphanumeric classification identifying the specific device. The related description of the alphanumeric code is given in the column *DESCRIZIONE*, and the column *SPECIFICHE TECNICHE* provides the technical specifications for each device.

3 Data and descriptive statistics

Order-level data: the primary data used in this paper come from a unique administrative database, *Spending Analysis*, which contains the universe of hospital medical device purchase orders issued by hospitals located in the Italian region of *Lazio*. *Spending Analysis* is maintained by *LAZIOcrea S.p.A.*, a for-profit data company that supports the region in technical and administrative activities. The region of Lazio granted access to the data. All orders made by hospitals in the region are automatically recorded. These data are a key source of spending tracking for auditors employed by the region of *Lazio*.

The initial data cover 6,696 purchases by 16 hospitals of 50 different medical devices in the categories of syringes, needles, dressings, and sutures. The sample covers all hospitals in the region between January 2015 and June 2018. For each order, we observe detailed information on the type of medical device, including the brand and the exact model within the brand, manufacturer, and their classifications in detailed groups generated by AGENAS. Our regressions will treat 10- and 20-ml syringes as two different devices. We also observe the price paid for the medical device, the quantity purchased by the hospital, and the identity of the suppliers. The data also contain unique hospital identifiers. However, the data include no information on hospital characteristics (e.g., number of beds and doctors).

Delivery data: a key outcome in our analysis is the delivery time. We compute delivery time as the difference between the delivery date and the order date. While order dates are included in our order-level data, the exact delivery dates of the purchased items are collected in a separate dataset that we match using order identifiers. To the best of our knowledge, this is the first paper that considers delivery times in the procurement of medical devices.

Contract-level data: we link our order-level data with data on the procurement contract between hospitals and suppliers. These data are collected by the ANAC. The data contain contracts with a value above €40,000. The contract value threshold of €40,000 is the threshold above which the Italian public buyers must report to the ANAC the details of the procurement contracts.

Our final sample contains data on 3,720 orders.[6] These data contain order-level information, such as delivery times, quantities ordered, unitary price of the item, and contract-level information, such as the value of the contract, the number of firms that participated in the call for tender, and the format of the tender (open or restricted).[7]

Panel A of Table 1 reports summary statistics. The average (unitary) price is €1.4. Ordered quantities, on average, are 2,457, and the average time of delivery is 10 days. Panel B illustrates that the average total value of the contracts is €589,328, and the average total quantities ordered in each contract are 97,218. The contract-level data indicate that, on average, two firms compete to provide a medical device, and contracts are awarded 60% of the time using an open tender.

Table 1: Summary statistics at the order-level (Panel A) and contract-level (Panel B)

VARIABLES	Mean	SD	p10	p50	p90	N
Panel A: Order-level						
Unitary price (€)	1.380	1.587	0.180	1.010	3.035	3,720
Quantity	2,457	8,260	72	360	5,300	3,720
Delivery time (days)	10.33	9.901	2	7	20	3,720
Panel B: Contract-level						
Value of contract (€)	579,328	1,716,000	50,800	115,000	900,000	94
Total quantities used in the contract	97,218	198,163	1,224	20,250	243,000	94
Firms competing for the contract	2.056	2.060	1	1	5	54
Open auction (0/1)	0.585	0.495	0	1	1	94

Notes. *Unitary price* is the per unit price provided in the purchase orders (in €). *Quantity* is the quantity ordered. *Delivery time* is the number of days elapsed between the day of the order and the day of delivery. *Open auction* is a dummy equal to 1 if the order is associated with a contract awarded with an open auction. *Mean* is the average of the variable; *SD* is the standard deviation of the variable; *p10* is the 10th percentile; *p50* is the 50th percentile. *p90* is the 90th percentile. *N* is the number of observations.

Relationship between contracts and orders: the relationship between contracts and orders is represented in Figure 2. We present one example of a contract for 75,000 50-ml syringes. The value of the contract is €60,000, and the contract is valid for 6 months from the award date (30 March 2016). Although unitary prices are decided at the contract-awarding stage, we do not observe them. We also do not observe the total quantities in the contract.[8]At the awarding stage, the buyer does not effectively buy the

[6]In Section 4.3, we repeat our analysis considering all the order-level data, not only those orders associated with contracts with a value above €40,000.

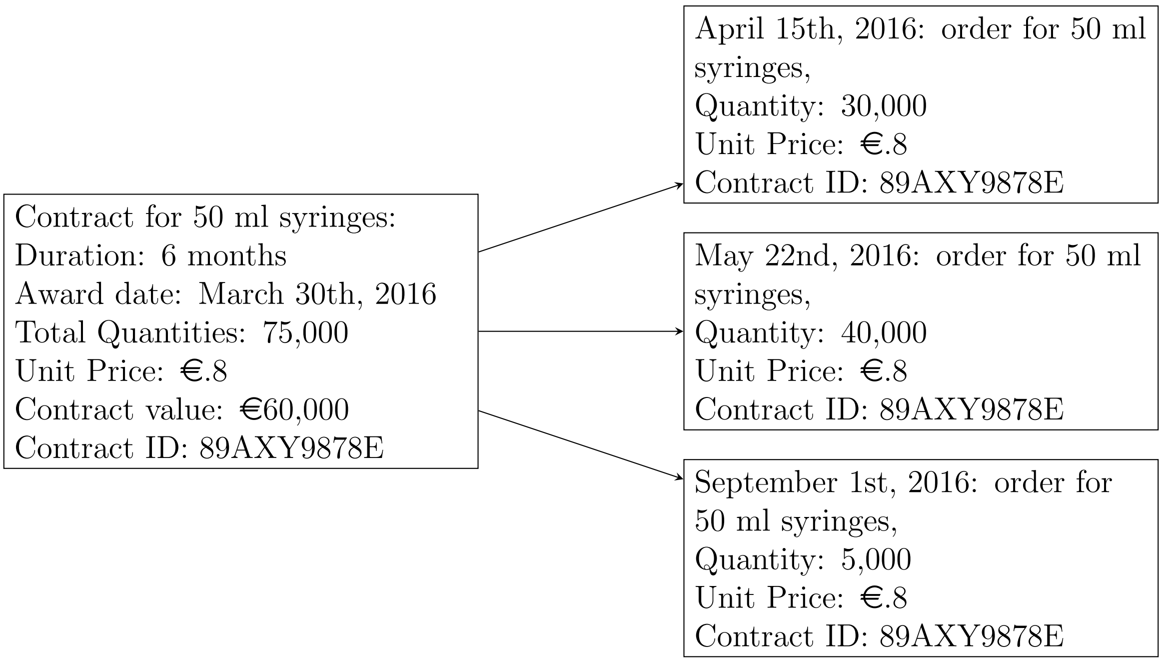
[7]For a detailed description of the contract-level data, see Castellani et al. (2018).

[8]We do not observe contract renegotiations that might imply different unitary prices with respect to those agreed at the contract-awarding stage

units of the device that are in the contract. The contract information that we observe are the contract identifier and the value of the contract.

After 30 March 2016, orders are issued. The orders are purchase requests that are transferred from a buyer to a supplier. These requests provide the specifics of the requested medical device and are also stored in the accounting system of the region. The access to the administrative database gives us order-level information. All information on orders are observed, such as the date of the order, the characteristics of the medical device, the unitary price, the quantities ordered, and the contract identifier. We can match the orders with the related contracts using the contract identifier that we observe in both datasets.

Table 2: Relationship between contracts (left) and orders (right)

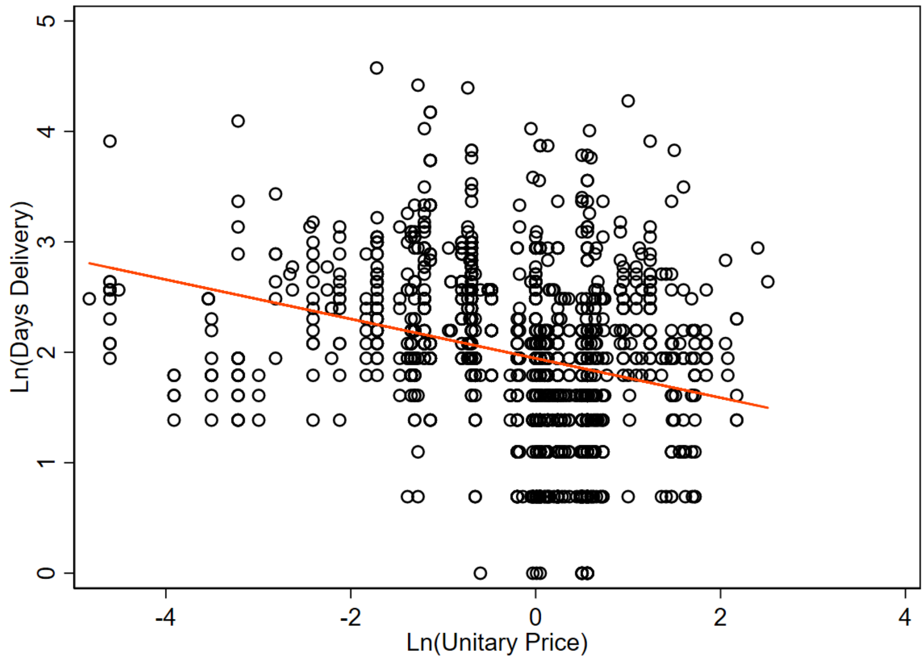


Correlation between delivery time and prices: Figure 3 plots the correlation between delivery times and prices. It illustrates the negative correlation between the logarithm of delivery times and the logarithm of prices in the pre-centralization period. The coefficient is -17.83 and is statistically significant at 1%. Prices explain approximately 8% of the variation in delivery times.

4 Empirical strategy and results

As mentioned in the previous section, we run our analysis on medical devices belonging to the broad categories of syringes, needles, dressings, and sutures. The devices in the category of syringes, needles, dressings belong to the set of centralized devices, and the devices in the category of sutures belong to the set of non-centralized devices. Sutures were excluded from the first decree issued on 24 December 2015, which specified the list of centralized devices.

Figure 3: Correlation between unitary prices and delivery times (in log) before January 2016



Notes: $R^2 = 7.8\%$, coefficient equal to -17.83, significant at 1% (t-statistic equal to -10.82).

The treatment, i.e., the decree of the Prime Minister issued on 24 December 2015 specifying syringes, needles, and dressings as centralized devices, might not have been randomly assigned. We take this policy change as exogenous for few reasons. The first reason is that the purchases of devices that we analyze come from a single Italian region, while the central government issued the policy change. Thus, the policy is exogenous to the region. Second, sutures (our non-centralized devices) were already identified in 2012 as devices with a high impact on public expenditure, together with syringes, needles, and dressings (our group of centralized devices). All these categories were subject to a policy introducing reference prices in 2012. Surprisingly, compared to the reference price policy implemented in 2012, sutures were left out by the mandated centralization in January 2016, although both policies aimed at limiting public expenditure in the healthcare sector. Sutures were then subject to the use of demand aggregators only in July 2018, after the end of our sample period. As presented in Figure 1, the contract value thresholds above which the contracts for the procurement of sutures have to be awarded through the use of demand aggregators since July 2018 are also the same as the one established in the decree of the Prime Minister issued on 24 December 2015 for syringes, needles, and dressings.

To estimate the effect of centralization on delivery times and prices, we estimate the following model:

$$\begin{aligned} Ln(Y_{odcht}) &= \beta_0 + \beta_1 Centralized_d \times Post_t + \beta_2 Centralized_d + \beta_3 Post_t + \beta_4 Ln(Quantity)_{odcht} \\ &\quad + \beta_5 Ln(ContractValue)_c + \theta_d + \gamma_h + \delta_t + \epsilon_{odcht}, \end{aligned} \tag{1}$$

where Y_{odcht} are the unitary price and the days of delivery for order o, of device d, for contract c in hospital h in quarter t; *Centralized* is a dummy equal to 1 for devices subject to centralization; *Post* is a dummy equal to 1 if the order is issued after January 2016; θ_d are 50 device fixed effects; γ_h are 16 hospital fixed effects; δ_t are 14 quarter fixed effects.[9] The estimates also include the log of Q_{odcht} and $ContractValue_c$, which are the ordered quantities and the total value of the contract, respectively. In this equation, the parameter of interest is β_1, which can be interpreted as the difference between the change in the log of the Y_{odcht} in the group of medical devices subject to the centralization policy and the change in the log of the Y_{odcht} in the group of medical devices not subject to the centralization policy from before to after January 2016. We cluster standard errors at the device-hospital level.

Table 3 reports our main results from the estimation of Equation (1). In columns 1 and 4, we report the estimates obtained using our basic difference-in-differences model. In columns 2 and 5, we include device fixed effects, hospital fixed effects, and time (quarter) fixed effects. In columns 3 and 6, we include the logarithm of the quantities ordered and the logarithm of the value of the contract as additional controls.

The estimated coefficient $Centralized_d \times Post_t$ indicates that centralized devices are cheaper (columns 1, 2, and 3) but are delivered with a delay relative to controls (columns 4, 5, and 6) after the introduction of mandatory centralized procurement. Specifically, considering the model with all the controls (columns 3 and 6), centralization causes a reduction in prices of approximately 15% and an increase in delivery times of roughly 20% for treated devices. The average delivery time in the pre-centralization period is 12 days. Thus, the increase in delivery time amounts to a change of 2.5 days.

Figure 4 captures the dynamic effect of centralization on affected devices relative to controls. This figure is obtained estimating the following variant of Equation (1):

$$\begin{aligned} Ln(Y_{odchj}) &= \sum_{j=-3}^{10} \theta_j Centralized_d \times Quarter_j + \beta_4 Ln(Quantity)_{odchj} \\ &\quad + \beta_5 Ln(ContractValue)_c + \theta_d + \gamma_h + \delta_j + \epsilon_{odchj}, \end{aligned} \tag{2}$$

[9] Appendix A.1 shows the categories of devices in the group of centralized devices (Figure A.1) and in the group of non-centralized devices (Figure A.2).

Table 3: Difference-in-differences for unitary prices and delivery times

Dep.Variable	(1) Ln(Price)	(2) Ln(Price)	(3) Ln(Price)	(4) Ln(Days)	(5) Ln(Days)	(6) Ln(Days)
Centralized×Post	-0.1958	-0.1351*	-0.1450**	0.2723***	0.2064***	0.1971***
	(0.172)	(0.073)	(0.073)	(0.094)	(0.077)	(0.074)
Centralized	-1.1418***			0.7254***		
	(0.185)			(0.098)		
Post	0.0966			-0.1270		
	(0.085)			(0.079)		
Ln(Quantity)			-0.0137			-0.0011
			(0.010)			(0.021)
Ln(ContractValue)			-0.0467			-0.0439***
			(0.041)			(0.013)
Observations	3,720	3,720	3,720	3,720	3,720	3,720
Device FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	1.012	1.012	1.012	12.09	12.09	12.09

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the unitary price of orders and days of delivery (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

where j are quarters from the reform; *Centralized* is a dummy for devices centralized; θ_d are device fixed effects; γ_h are hospital effects; δ_j are quarter effects. The model omits quarter -1, which we consider as the reference quarter.

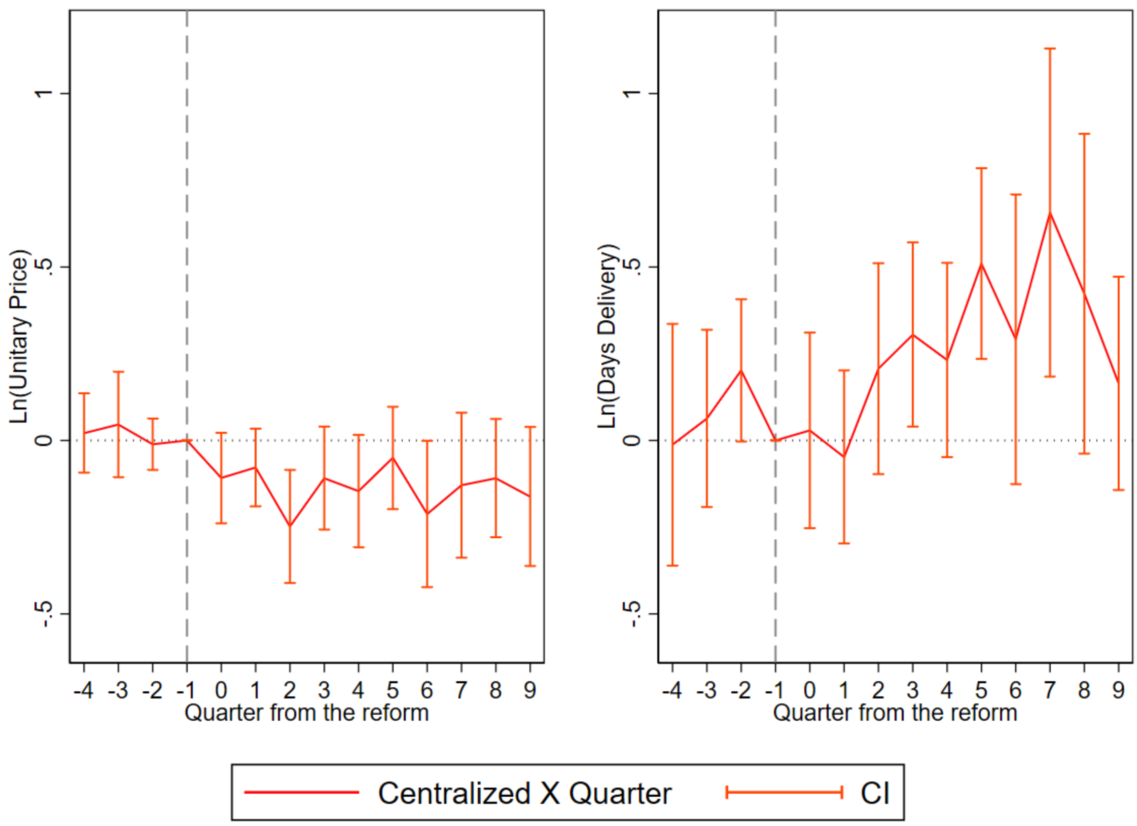
The estimated coefficients of the variable $Centralized_d \times Quarter_j$ are plotted in Figure 4. As expected, after 2016, unitary prices drop more sharply for devices impacted by the centralization policy. On the contrary, delivery times rise more for treated devices. Vertical bands indicate that the majority of the lagged effects of centralization are statistically different from 0.

4.1 No anticipation of the legislative change and parallel trends

From Figure 4, we observe that there is no evidence of anticipatory effects. That is, all but one of the coefficients of $Centralized_d \times Quarter_j$ before January 2016 are not statistically different from 0. The only exception is for the third quarter of 2015, when we estimate Equation (2) using days of delivery as our outcome. In Table A.1, we report the magnitude of the coefficients and their standard errors. The lack of statistical significance of most of the pre-2016 individual coefficients and the high p-value of the joint test indicate that the parallel trend assumption is not rejected.

The parallel trend assumption is also tested in Table A.2. In this table, the assumption is tested parametrically in a model where delivery times and prices are regressed on a linear

Figure 4: Dynamic effects of centralization on unitary prices and delivery times



time trend (*Quarter*), a linear time trend interacted with *Centralized*, and the same set of fixed effects discussed in Equation (2) in the sample before 2016. The estimated coefficients of the interaction term are small and not statistically significant, regardless of the set of fixed effects that we include in our model.

4.2 Non-linear effects of the policy

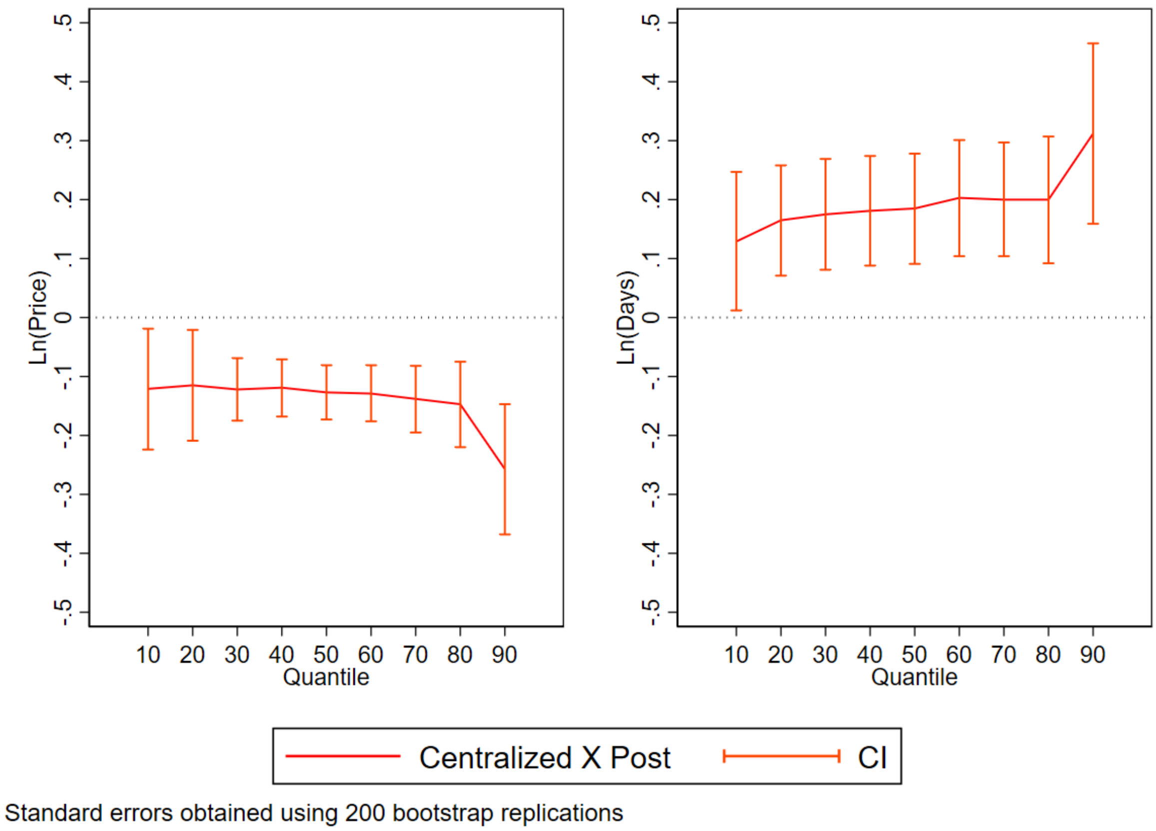
We look at the effects of centralization at different points of the price and delivery time distributions. To do so, we estimate a quantile difference-in-differences model. We thus estimate the following equation:

$$\begin{aligned} Q_q(Ln(Y_{odcht})) \quad = \quad & \beta_{0,q} + \beta_{1,q} Centralized_d \times Post_t + \beta_{2,q} Centralized_d + \beta_{3,q} Post_t \\ & + \beta_{4,q} Ln(Quantity)_{odcht} + \beta_{5,q} Ln(ContractValue)_c \\ & + \theta_d + \gamma_h + \delta_t + \epsilon_{odcht}, \end{aligned} \tag{3}$$

where q is the q-th quantile, with $q = 10, ..., 90$; Y_{odcht} are prices and days of delivery for order o, of device d, for contract c, in hospital h in quarter t; *Centralized* is a dummy equal to 1 for devices centralized; *Post* is a dummy equal to 1 if the order is issued after January 2016. We also control for the logarithm of quantities ordered and we control for the logarithm of the contract value. The model is estimated including device fixed effects (θ_d), hospital fixed effects (γ_h), and quarter fixed effects (δ_t). The coefficient of interest is $\beta_{1,q}$.

Figure 5 reports the estimates of the coefficient $\beta_{1,q}$ at each quantile. Results are consistent with the main difference-in-differences estimates, but we observe a stronger effect of centralization at higher quantiles of the price and delivery times distribution, especially at the 80th and 90th quantiles. Table A.3 in Appendix A.3 presents the magnitude of the coefficients and the standard errors.

Figure 5: Estimated coefficient $\beta_{1,q}$ with a 95% confidence interval for the variable $Centralized_d \times Post_t$. The estimates are obtained from the estimation of Equation (3)



4.3 Robustness checks

We run a series of robustness checks. In Table A.4, we run the same econometric model as in Equation (1) dropping orders issued in the year 2018. We thus restrict the observations to one year before and two years after the policy change. The results are similar to our main estimates.

As we mentioned before, we do not have information on the unit prices at the awarding stage of a contract. In addition, we are not aware of possible renegotiations of these contracts. Table A.5 shows the same analysis, but data on prices are collapsed by contract, device, hospital, and product code. The effect of centralization on prices is stronger than our main estimates, and the number of observations is much lower. This result shows that our main estimates might represent a lower bound of the effect of centralized procurement on prices.

Table A.6 reports the results for our main difference-in-difference estimation, using the logarithm of the quantities purchased as an outcome. The effect of centralized procurement on the quantities ordered for the set of centralized devices with respect to the set of non-centralized devices is not statistically different from 0.

In our main estimates, three categories of medical devices are subject to centralization: syringes, needles, and dressings. The only devices in the control group are sutures. Table A.7 shows the effect of the policy on purchases of syringes and needles compared to purchases of sutures. The results are similar to our main estimates for prices, but a weaker effect of centralization is observed for delivery times. Table A.8 presents instead the effect of the policy on purchases of dressings relative to the purchases of sutures. The results show stronger effects of centralization on both prices and delivery times.

Table A.9 shows the effect of centralization on prices and delivery times, including the orders associated with contracts whose value is below €40, 000. This estimation has clear sample selection issues, as the buyers are not obliged to report contracts below €40,000 to the ANAC. We observe a stronger effect of centralization on prices but a weaker effect on delivery times.

5 Mechanisms driving the decrease in prices and the increase in delivery times

We now study the different mechanisms that could underlie our results. We propose several possible mechanisms: a) bulk purchasing, b) increased competition, and c) a lower number of suppliers serving the same level of demand.

5.1 Bulk purchasing

National and regional procurement agencies typically aggregate the demand of different buyers (in this case, hospitals), and thus they award contracts for larger quantities. In this way, the price is reduced. For this reason, the Italian legislation defines these procurement agencies as demand aggregators (*Soggetti Aggregatori*). For this mechanism to explain the results, when we collapse the data at the contract-device level (a contract might involve the award of different devices), we should find that the quantities of medical devices auctioned in a contract significantly increase in the group of centralized devices relative to the group of non-centralized devices after the introduction of mandatory centralization. Unfortunately, we do not observe quantities Q effectively auctioned in a contract, but only the quantities purchased in each order Q'. Nevertheless, we can aggregate all quantities ordered for a particular device by contract identifier to construct a measure of contract size. This transformation allows us to examine whether the reduction in prices due to centralization is associated with bulk purchasing.

Results are presented in columns 1 and 2 of Table 4. Column 1 reports the estimation results without fixed effects, while column 2 reports the estimation including device fixed effects. We observe a 200% increase in the quantities purchased per contract in the treated group with respect to the control group of devices after January 2016, in a model controlling for device effects.

We want to rule out the possibility that the increase in quantities in contracts for centralized devices is also accompanied by a change in the monthly demand of hospitals for these devices. Using our order-level data, i.e., the only data containing quantities purchased, in columns 3 and 4, we show that the monthly quantities for a particular device ordered by hospitals do not change. The results are robust to the inclusion of device, hospital, and month effects.

We conclude that hospitals are not buying more and that bulk purchasing is a driver of the decrease in prices. Bulk purchasing might also drive the increase in delivery times, provided that suppliers do not adjust their production capacity. Suppliers execute larger contracts after the introduction of mandatory centralization.

Table 4: Difference-in-differences for the quantities purchased

	(1)	(2)	(3)	(4)
Dep.Variable	Ln(Tot.Q.ContractDevice)		Ln(Tot.Q.HospitalMonth)	
Centralized×Post	2.5912***	2.0019***	-0.2821	-0.0800
	(0.541)	(0.624)	(0.257)	(0.126)
Centralized	0.2988		0.8664***	
	(0.414)		(0.316)	
Post	-2.5809***	-2.5011***	0.2415*	
	(0.357)	(0.495)	(0.131)	
Observations	182	182	1,474	1,474
Device FE	No	Yes	No	Yes
Hospital FE	No	No	No	Yes
Time FE	No	No	No	Yes
Mean Y Centralized Pre	56414	56414	8071	8071

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on the logarithm of the purchased quantities. *Tot.Q.ContractDevice* represents the total purchased quantities associated with the contract. *Tot.Q.HospitalMonth* represents the total quantities ordered in a month by an individual hospital. *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device level (columns 1 and 2) and at the device-hospital level (columns 3 and 4). Significance at 10% (*), 5% (**), and 1% (***).

5.2 Competition at the contract-awarding stage

We exploit the availability of information at the contract-level to check whether the price decrease might be driven by tougher competition at the contract-awarding stage. To this end, we collapse the data at the contract level. We check three main outcomes: a) the number of participants (not always reported in the data), b) the probability of open auctions, and c) the value of the contract (in log).

Table 5 presents the results. We find more competition at the awarding stage, with the number of bidders increasing by approximately one and a half bidders, but the effect is not significant due to a lower number of observations. We also find that the probability that contracts are awarded through open auctions increases by approximately 10%. The increase is about 19% of the probability of open auctions in the treated group before the policy. Finally, we observe a large increase in the values of contracts awarded. The effect is not significant, although the magnitude of the effect is large.

Table 5: Difference-in-differences for contract-level outcomes: number of bidders, probability of competitive awards, and logarithm of contract value

	(1)	(2)	(3)
Dep.Variable	Nbr.Bidders	OpenAuctions(0/1)	Ln(ContractValue)
Centralized×Post	1.4234	0.0979	0.9020
	(1.071)	(0.243)	(0.701)
Centralized	-0.7091	-0.2765*	-0.7630
	(0.546)	(0.140)	(0.514)
Post	0.5333	-0.1039	-0.9013
	(0.868)	(0.211)	(0.636)
Observations	54	94	94
Device FE	No	No	No
Hospital FE	No	No	No
Time FE	No	No	No
Mean Y Centralized Pre	1.091	0.542	475447

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on number of bidders, probability of competitive awards and log of the value of the contract. *Nbr.Bidders* represents the number of bidders in the contract. *OpenAuction(0/1)* is a dummy equal to 1 if the contract is awarded through an open auction. *Ln(ContractValue* is the logarithm of the value of the contract. *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. Robust standard errors in parentheses. Significance at 10% (*), 5% (**), and 1% (***).

5.3 Supply concentration

The final mechanism that might explain the significant increase in delays is the degree of concentration of the supply in a given unit of time. The concentration of the supply, especially when the demand does not change, means that buyers purchase the same quantities and order goods from a lower number of suppliers, making these suppliers more likely to be capacity constrained in the short period.

To study this mechanism, we analyze the number of orders and the total quantities purchased per month in each market. These two variables indicate whether there has been a change in the monthly level of demand for syringes, needles, and dressings with respect to sutures. At the same time, we investigate the number of suppliers per month. To prove the hypothesis that there might be an increasing backlog for each supplier, we should find that demand does not change in a given unit of time, but the number of suppliers decreases.

Table 6 reports our findings. The number of monthly orders and the total quantities purchased per month do not change, but we observe a significant decrease in the number of suppliers in the set of centralized devices relative to the set of non-centralized devices. The decrease represents approximately 15% of the number of suppliers observed in the centralized set of devices in the period before the policy change.

Table 6: Difference-in-differences for number of orders, quantities and number of suppliers per month

	(1)	(2)	(3)
Dep.Variable	N.OrdersMonth	Ln(Tot.Q.Month)	N.SuppliersMonth
Centralized×Post	-1.9833	-0.0551	-2.2833***
	(7.345)	(0.255)	(0.777)
Centralized	14.4167**	3.0026***	11.2500***
	(6.685)	(0.213)	(0.712)
Post	-18.5000***	-0.2485	-0.9167***
	(4.953)	(0.159)	(0.287)
Observations	84	84	84
Device FE	No	No	No
Hospital FE	No	No	No
Time FE	No	No	No
Mean Y Centralized Pre	65.42	266343	14.67

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on monthly number of orders, monthly total quantities ordered (in log), and number of suppliers. *N.OrdersMonth* represents the number of orders per month. *Tot.Q.Month* represents the total quantities ordered per month. *N.SuppliersMonth* represents the number of suppliers per month. *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. Robust standard errors in parentheses. Significance at 10% (*), 5% (**), and 1% (***).

6 External validity of the main results

The increase in delivery times is verified on a small set of homogeneous devices. Our original sample represents only 2% of the entire sample. The reduced sample size makes it difficult to give external validity to the evaluation of pricing policies in healthcare.

This section investigates whether the main results hold more generally in the entire set of centralized categories. Figure 1 lists the entire set of centralized medical devices, with gloves and sutures only centralized after the end of our sample period and thus included in the control group. To run the estimation, we first match all contract identifiers available from the ANAC website with the contract identifiers in the purchase order data. We then keep only those orders associated with a contract.

The main difference with our main specification in Equation (1) relies on the definition of a device. In our main sample, we use the classification from Figure 2 provided by AGENAS to identify the devices and their related fixed effects, using key information from all the three columns. Figure 2 presents, for example, six different devices. When we estimate the model in Equation (1), we should thus have six fixed effects. Instead, if we use the more general device identifiers (as we do in this section) to define a device, we are restricted to the information in the first column of Figure 2. Thus, in the estimation, we only have two different devices and thus only two device fixed effects (one for the device with code A01010101 and one for the device with code A010102). In this analysis, each category of devices is thus less homogeneous, and this aspect might cause measurement error in our estimates.

Table 7 reports the results for unitary prices. We observe that our main findings also hold for non-homogeneous devices, with a decrease in unitary prices of approximately 19% in our main specification (column 3). This set of non-homogeneous medical devices includes even more complex medical devices (pacemakers, stents, prosthesis), drugs, and vaccines in the treated group. Thus, it is not surprising to see that the average unitary price is much higher than the one observed in our main sample reported in Table 3. We observe that the effect of centralization on the delivery times using this larger number of orders is slightly lower than the one observed in the sample that we use in our main estimation (14% versus 20%). The results are also robust to the inclusion of device, hospital, and quarter effects (columns 2 and 5). The results are also robust to the inclusion of quantities ordered and the value of the contract in the set of controls.

Although the results on unit prices must be taken with caution, the findings in this section are important in light of the developments of the contract executions for vaccines against COVID-19 in Europe. Since mid-January, suppliers of vaccines faced production issues that led them to cut the supply to some European countries. This fact is consistent with our findings that centralized and, by definition, larger contracts are exposed to disruptions from the supply side if the contracts are not well designed.

Table 7: Difference-in-differences for unitary prices and delivery times: the sample includes all devices in Figure 1, regardless of their degree of homogeneity. The controls are those devices in Figure 1 which became centralized at the end of our sample period (year 2018).

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Centralized×Post	-0.3261	-0.2024	-0.1819*	0.1292**	0.1431***	0.1424***
	(0.273)	(0.154)	(0.099)	(0.059)	(0.048)	(0.048)
Centralized	1.7433***			-0.0923		
	(0.431)			(0.066)		
Post	0.3127			-0.0572		
	(0.255)			(0.052)		
Ln(Quantity)			-0.4558***			0.0122**
			(0.019)			(0.006)
Ln(ContractValue)			-0.0090			-0.0026
			(0.015)			(0.008)
Observations	133,395	133,349	133,349	133,395	133,349	133,349
Device FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	234.4	234.4	234.4	10.71	10.71	10.71

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on unitary prices and delivery times (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

7 Conclusion

We studied the effect of mandatory centralized procurement on prices and delivery times of hospital medical devices. Our identification strategy leveraged the staggered implementation of centralized procurement for a sub-set of the medical devices regularly purchased by the Italian hospitals in our sample. We used a unique dataset on the purchases of these medical devices. We document that unitary prices decreased, and delivery times increased for those devices subject to the centralization policy with respect to other unaffected devices.

We use data on quantities and the identity of suppliers to explore a possible mechanism that could generate our findings. Although we observe quantities only in our order-level data, we aggregate all quantities ordered for a particular device by contract identifier to construct a measure of contract size. We can thus show that the reduction in prices due to centralization is associated with bulk purchasing. We also find that the monthly quantities ordered by individual hospitals do not change, while the number of suppliers decreases significantly. Assuming that suppliers do not adjust their production capacity, these findings may explain the increase in delivery times, as the suppliers must execute larger contracts.

OECD (2011) noted the potential issue of delivery times in centralized procurement, underlining that *"it may be a risky strategy if the winning supplier for some reason finds itself having delivery problems and is unable to fulfill its obligations"*. In particular, the paper criticizes the approach used by the Italian public procurement agency, which awards contracts with one single winner taking the entire contract.[10] Our results offer a more complete assessment of the impact of centralization on the procurement of medical devices and confirm the positive impact of centralization on procurement costs with some effects on delivery times that should be considered in the evaluation of the effectiveness of centralized procurement policies.

[10] "*The experience of Consip (Italy), which practices a single-supplier approach to centralized purchasing and argues that its prices and other terms, in general, are very competitive, is in line with this reasoning. On the other hand, a potential drawback of this approach is that it may hinder SMEs from participating because they lack sufficient production capacity. [...] Framework agreements with multiple suppliers have the advantage of providing a more reliable sourcing than single-supplier agreements. If one supplier has delivery problems, there are others to turn to. It also provides a greater product variety due to the fact that the suppliers' products are not completely homogeneous – this is a value-enhancing factor, given the fact that procuring entities may have diversified preferences. Another advantage is that the risk of a successive market concentration is smaller.*"

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A Appendix

A.1 Identification strategy

Figure A.1: Centralized

Figure A.2: Non-centralized

A.2 Test parallel trend

Table A.1: Coefficients of the model estimated in Equation 2

	(1)	(2)
Dep.Variable	Ln(Price)	Ln(Days)
$Q1_{2015}\times$Centralized	0.0212	-0.0123
	(0.058)	(0.178)
$Q2_{2015}\times$Centralized	0.0459	0.0635
	(0.078)	(0.130)
$Q3_{2015}\times$Centralized	-0.0112	0.2020*
	(0.038)	(0.105)
$Q1_{2016}\times$Centralized	-0.1084	0.0287
	(0.067)	(0.144)
$Q2_{2016}\times$Centralized	-0.0776	-0.0476
	(0.057)	(0.127)
$Q3_{2016}\times$Centralized	-0.2479***	0.2072
	(0.083)	(0.155)
$Q4_{2016}\times$Centralized	-0.1089	0.3051**
	(0.076)	(0.135)
$Q1_{2017}\times$Centralized	-0.1463*	0.2320
	(0.083)	(0.143)
$Q2_{2017}\times$Centralized	-0.0505	0.5102***
	(0.075)	(0.140)
$Q3_{2017}\times$Centralized	-0.2119*	0.2917
	(0.108)	(0.213)
$Q4_{2017}\times$Centralized	-0.1291	0.6570***
	(0.107)	(0.241)
$Q3_{2018}\times$Centralized	-0.1086	0.4235*
	(0.087)	(0.235)
$Q4_{2018}\times$Centralized	-0.1619	0.1642
	(0.102)	(0.157)
Ln(Quantity)	-0.0141	-0.0003
	(0.010)	(0.020)
Ln(ContractValue)	-0.0465	-0.0375***
	(0.041)	(0.012)
Observations	3,704	3,704
DeviceID FE	Yes	Yes
Hospital FE	Yes	Yes
Time FE	Yes	Yes
Mean Y Centralized Pre	1.009	12.11
P-value Joint Test Pre 2016 Coefficients	0.622	0.430

Notes: Coefficient (standard error in parentheses) of the interaction term between *Centralized* and a dummy for quarter on the unitary price of orders (column 1) and days of delivery (column 2) in logs. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. *P-value Joint Test Pre 2016 Coefficients* is the p-value of the joint test of $Q1_{2015} \times Treatment = Q2_{2015} \times Treatment = Q3_{2015} \times Treatment$. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.2: Test of a common linear trend for unitary prices and delivery times for the group of centralized and non-centralized devices before January 2016.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Centralized×Quarter	-0.0044	-0.0187	-0.0153	0.0271	0.0177	0.0324
	(0.039)	(0.021)	(0.022)	(0.054)	(0.056)	(0.062)
Centralized	-0.1713			-5.2819		
	(8.587)			(11.814)		
Quarter	-0.0027			-0.0072		
	(0.021)			(0.050)		
Ln(Quantity)			-0.0282*			0.0040
			(0.017)			(0.029)
Ln(ContractValue)			-0.0259			-0.0855***
			(0.043)			(0.018)
Observations	1,397	1,397	1,397	1,397	1,397	1,397
DeviceID FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	1.012	1.012	1.012	12.09	12.09	12.09

Notes: Coefficient (standard error in parentheses) of the interaction term between *Centralized* and a linear trend (*Quarter*) on the unitary price of orders (columns 1-3) and days of delivery (columns 4-6) in logs. Only observations prior to the policy change are included. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

A.3 Robustness

Table A.3: Quantile difference-in-differences estimation

	(1)	(2)
Dep.Variable	Ln(Price)	Ln(Days)
q10	-0.121**	0.129**
	(0.0524)	(0.0599)
q20	-0.115**	0.165***
	(0.0479)	(0.0478)
q30	-0.122***	0.175***
	(0.0270)	(0.0480)
q40	-0.119***	0.181***
	(0.0247)	(0.0474)
q50	-0.127***	0.185***
	(0.0234)	(0.0476)
q60	-0.129***	0.203***
	(0.0244)	(0.0501)
q70	-0.138***	0.200***
	(0.0288)	(0.0493)
q80	-0.147***	0.200***
	(0.0371)	(0.0547)
q90	-0.257***	0.312***
	(0.0564)	(0.0779)
Observations	3720	3720
Device FE	Yes	Yes
Hospital FE	Yes	Yes
Time FE	Yes	Yes
Controls	Yes	Yes

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization for centralized devices *Centralized*×*Post* at different quantiles for unitary prices and delivery times (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. The quantile estimation also includes the same controls as in the main estimates such as the logarithm of the quantities ordered (*Ln(Quantity)*and the logarithm of the value of the contract (*Ln(ContractValue)*). SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.4: Difference-in-differences for unitary prices and delivery times. The first six months of 2018 are excluded.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Centralized×Post	-0.2048	-0.1448**	-0.1519**	0.2394**	0.1977***	0.1911***
	(0.169)	(0.073)	(0.074)	(0.093)	(0.074)	(0.070)
Centralized	-1.1418***			0.7254***		
	(0.185)			(0.098)		
Post	0.1066			-0.1273*		
	(0.082)			(0.076)		
Ln(Quantity)			-0.0160			-0.0035
			(0.012)			(0.020)
Ln(ContractValue)			-0.0493			-0.0437***
			(0.043)			(0.013)
Observations	3,308	3,308	3,308	3,308	3,308	3,308
DeviceID FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	1.012	1.012	1.012	12.09	12.09	12.09

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on unitary price and days of delivery (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.5: Difference-in-differences for unitary prices and delivery times: unitary prices collapsed by contract, device, hospital, and product code

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Centralized×Post	-0.2660	-0.3548***	-0.3073**	0.2723***	0.2064***	0.1971***
	(0.273)	(0.091)	(0.119)	(0.094)	(0.077)	(0.074)
Centralized	-1.7058***			0.7254***		
	(0.210)			(0.098)		
Post	0.1564*			-0.1270		
	(0.087)			(0.079)		
Ln(Quantity)			-0.0390*			-0.0011
			(0.020)			(0.021)
Ln(ContractValue)			-0.0233			-0.0439***
			(0.038)			(0.013)
Observations	484	473	473	3,720	3,720	3,720
Device FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	0.795	0.795	0.795	12.09	12.09	12.09

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on unitary prices and delivery times (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.6: Difference-in-differences for the logarithm of quantities ordered

	(1)	(2)
Dep.Variable	Ln(Quantities)	Ln(Quantities)
Centralized×Post	-0.1041	-0.0008
	(0.198)	(0.070)
Centralized	1.7399***	
	(0.270)	
Post	0.2736***	
	(0.085)	
Observations	3,720	3,720
Device FE	No	Yes
Hospital FE	No	Yes
Time FE	No	Yes
Mean Y Centralized Pre	4071	4071

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on quantities ordered (in log). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.7: Difference-in-differences for unitary prices and delivery times: centralized set of devices includes syringes and needles only.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Centralized×Post	-0.1431	-0.1426*	-0.1593*	0.2032**	0.1332	0.1221
	(0.159)	(0.083)	(0.086)	(0.098)	(0.080)	(0.076)
Centralized	-1.6459***			0.8275***		
	(0.209)			(0.097)		
Post	0.0966			-0.1270		
	(0.085)			(0.079)		
Ln(Quantity)			-0.0184*			0.0014
			(0.010)			(0.023)
Ln(ContractValue)			-0.0712			-0.0484***
			(0.050)			(0.015)
Observations	3,023	3,023	3,023	3,023	3,023	3,023
Device FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	0.403	0.403	0.403	13.03	13.03	13.03

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on unitary price and days of delivery (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.8: Difference-in-differences for unitary prices and delivery times: centralized set of devices includes dressings only.

Dep.Variable	(1) Ln(Price)	(2) Ln(Price)	(3) Ln(Price)	(4) Ln(Days)	(5) Ln(Days)	(6) Ln(Days)
Centralized×Post	-0.2102	-0.1847**	-0.2043**	0.3998***	0.3627***	0.3586***
	(0.303)	(0.081)	(0.086)	(0.119)	(0.098)	(0.098)
Centralized	-0.1639			0.5271***		
	(0.248)			(0.109)		
Post	0.0966			-0.1270		
	(0.085)			(0.079)		
Ln(Quantity)			-0.0184			0.0043
			(0.015)			(0.035)
Ln(ContractValue)			-0.1005**			-0.0204
			(0.046)			(0.013)
Observations	2,284	2,284	2,284	2,284	2,284	2,284
Device FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	2.192	2.192	2.192	10.28	10.28	10.28

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on unitary price and days of delivery (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.9: Difference-in-differences for unitary prices and delivery times. Orders associated with contracts below €40,000 are included.

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Centralized×Post	-0.0773	-0.1874***	-0.1901***	0.1874**	0.1341**	0.1343**
	(0.151)	(0.064)	(0.066)	(0.085)	(0.062)	(0.062)
Centralized	-1.5066***			0.6869***		
	(0.189)			(0.089)		
Post	0.1310*			-0.1041		
	(0.070)			(0.076)		
Ln(Quantity)			-0.0408***			0.0125
			(0.011)			(0.015)
Ln(ContractValue)			0.0087			-0.0018
			(0.020)			(0.008)
Observations	6,696	6,696	6,696	6,696	6,696	6,696
Device FE	No	Yes	Yes	No	Yes	Yes
Hospital FE	No	Yes	Yes	No	Yes	Yes
Time FE	No	Yes	Yes	No	Yes	Yes
Mean Y Centralized Pre	0.957	0.957	0.957	11.76	11.76	11.76

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on unitary price of orders and days of delivery (in logs). *Post* is a dummy variable equal to 1 if the orders are issued after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

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