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DISCUSSION PAPER

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

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

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Abstract

We examine the impact of centralization on medical-device procurement by hospitals. We leverage a comprehensive dataset on device orders from Italy and take advantage of a legislative change that mandated centralized purchases for a subset of devices. Consistent with previous studies we find that centralization reduces prices for centralized devices relative to non-centralized purchases. Uniquely, our dataset contains information on order and delivery dates, allowing us to also study the impact on delivery times. We find that statutory centralization resulted in a small increase in delivery times. Using data on quantities, the identity of suppliers and their balance sheets, we examine 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

Centralization of procurement has been shown to benefit taxpayers by lowering prices (see for example the seminal paper by Bandiera et al., 2009 and, more recently, Dubois et al., 2021). However, these lower prices may come at the cost of longer delivery times, for instance because of suppliers' inability to quickly adjust capacity to meet demand (see OECD, 2011), or because of increased distance between buyers and sellers. If prices fall, but delivery times become longer, then the overall impact of centralization is ambiguous and may even be negative.[1] Despite this, to our knowledge, the causal relationship between centralization and delivery times has not been examined.

In this paper, we study the impact of statutory centralized procurement for hospital medical devices on prices and delivery times. To do so, we collected administrative data on each order of medical devices for all hospitals located in the Italian Region *Lazio*. For each order, we have access to detailed *granular* information on the type of medical device, including the brand and exact model. The medical devices in our main 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 administrative information on both the order and delivery dates. Together, these allow us to compute delivery time with high precision as the difference between the delivery date and the order date.

Our identification strategy takes advantage of the staggered implementation of statutory centralization for different medical devices. Starting in 2016, all 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 treated devices that were subject to the legislation to the changes for control devices that were not. This empirical strategy rests on the assumption that treated and non-treated devices share a parallel trend before 2016. We test and do not reject the existence of a common trend between treated and non-treated devices before 2016. Furthermore, in order to corroborate the quasi-experimental variation in treatment status between devices, we test whether hospital and order characteristics are systematically different for treated and control devices before the policy change. Our findings suggest that characteristics are balanced across treatment and control devices, providing support for the required identifying assumptions.

Consistent with previous results in the literature, we find that centralized procurement reduces prices. Our main contribution is to document that delivery times are also affected.

[1]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.

Centralized procurement increases delivery times, however, this effect is fairly small. More specifically, after January 2016, we find a reduction in prices of approximately 15% and an increase in delivery times of roughly 19% for centralized devices, compared to non-centralized devices. The average delivery time in the pre-centralization period is 12 days, and so this increase in delivery time amounts to a change of only 2.3 days.

Next, we explore possible mechanisms that could generate our findings. Our primary focus is on the impact of contract size. This is because centralization usually implies that contracts that otherwise would have been placed separately by individual hospitals at multiple different suppliers are pooled and placed with a smaller number of sellers. To investigate the impact of centralization on contract size in our context, we take advantage of the fact that we can match our order-level data with contract-level data provided by the Italian Anticorruption Authority (ANAC). The latter contain background information on the terms of agreement between buyers and sellers. Summing up the orders associated with contracts allows us to construct a device-specific proxy for the total contract size and we study the impact of centralization on this variable. Our findings show that the introduction of centralized procurement caused a 200% increase in the quantities purchased per contract in the treated group with respect to the control group of devices after January 2016. We also find that the number of suppliers decreases significantly. These findings are despite the fact that demand, in the form of monthly quantities ordered by individual hospitals, does not change. These results suggest that the lower prices we find may be the result of bulk discounts or increased bargaining power for hospitals (see Dubois et al., 2021). In addition to lower prices, the increase in contract size could explain the longer delays we observe if the remaining suppliers could not quickly adjust capacity or if procured devices had to travel longer distances. We investigate both of these possible explanations for increased delays using balance-sheet data and suppliers' addresses of incorporation. We find evidence that capacity may have played a role, but no such support for increased distance.

Finally, we assess the robustness of our results by repeating our analysis in a larger sample of medical devices that includes medicines, vaccines, stents, hip prostheses, pacemakers, incontinence aids, and gloves. These devices are subject to a similar centralization policy and the main advantage of including them is the resulting increase in sample size. The main limitation compared to our preferred sample and estimates is that these devices are less standardized, which limits our ability to add granular controls for the purchased goods. Using this sample, our main conclusions are unchanged: centralized procurement generates a reduction in price with a small increase in delivery time. We conclude that our results generalize to a broader set of medical devices.

To summarize, our results confirm the positive impact of centralization on procurement achieved through lower prices as shown in Bandiera et al. (2009), Dubois et al. (2021) and subsequent papers. At the same time, they are particularly novel as they allow us to ascertain that centralization is associated with an increase in delivery times. The increase in delivery times that we document is fairly small, and so one might not be too concerned that hospitals and their patients are being harmed in any meaningful way. However, even a delay of two or three 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 requesting too many 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.

Related literature: 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) provide empirical evidence 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. Grennan and Swanson (2019) analyze the price dispersion observed for several categories of medical devices and disentangle whether the observed dispersion can be attributed to the bargaining ability of the buyer, search costs and brand preferences. In a more recent paper, Grennan et al. (2021) look at the effect of hospital managerial practices on the costs of medical devices. 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. See also Bucciol et al. (2020) and Dubois et al. (2021).

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.

Finally, this paper relates to the literature on *ex-post* procurement performance (see for instance Coviello et al., 2018; Giuffrida and Rovigatti, 2019; Decarolis et al., 2020). Whereas those papers focus on public works and services, we focus on the delivery of standardized goods in the healthcare sector. Moreover, relative to these papers, we are the first to analyze delivery times computed from administrative data and not from self-reported data.

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 standardized. Section 7 concludes.

2 Institutional background

In Italy more than 35,000 public administrations regularly award procurement contracts to suppliers for goods, services, and works, and are strictly regulated by the Italian procurement law. Procurement contracts specify the terms and conditions at which hospitals can place orders for required medical devices. Contracts are adjudicated via public auctions. Despite strict procurement regulation, significant within-device price dispersion existed. For instance, in 2010 the Italian Minister of Economy and Finance remarked on the fact that the same 5ml syringes cost 5 cents at hospitals in Sicily but just 3 cents in Tuscany.[2] This price dispersion for identical devices led the government to enact Law 66/2014 (*Decreto Legge 66/2014*), which established a set of purchasing entities allowed to serve as demand aggregators (*Soggetti Aggregatori*), that can award contracts for goods and services on behalf of local public administrations. Since 2014, there have been 35 demand aggregators in Italy recognized by law. These demand aggregators are a) Consip, the national procurement agency (described in Bandiera et al., 2009), b) 21 regional procurement agencies, c) nine municipalities, and d) one province.[3]

Initially, Law 66/2014 did not specify explicitly for which categories of devices public administrations were required to use demand aggregators. As a result, the use of these purchasing entities was discretionary, such that hospitals could either continue to sign contracts directly with suppliers or could operate through aggregators. A decree of the

[2] See https://www.quotidianosanita.it/governo-e-parlamento/articolo.php?articolo_id=806.

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

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. Figure 1 presents a list of the goods that became subject to the use of demand aggregators following the 2015 decree.

Figure 1 also reports for each device the contract value (thresholds) for which the law applies and the exact year in which the 2015 decree became binding (Dpcm). Contracts with values below the specified threshold can be awarded using discretionary procedures such as direct bargaining with one supplier or restricted procedures. *Community* denotes European Community thresholds for large lots, which apply for stents, hip replacements, defibrillators, and pacemakers. These devices are procured under European Community Rules. The community threshold has been updated over time. For public hospitals, the community threshold was €207,000 before January 2016 and increased to €209,000 after (EU Regulation 2015/2170).[4] For other devices, procured under Italian rules, the threshold is €40,000. We focus on contracts for more than €40,000, since below this threshold it is not mandatory for contracting authorities to communicate contract information with ANAC.

Following Bandiera et al. (2009, 2021) we focus most of our attention on *standardized* products.[5] In our context, we take standardized to mean those products that are classified by the National Agency for Regional Health Services (AGENAS) as being standardized. Figure 2 provides information on six standardized classes of devices for syringes and needles, as classified by the National Agency for Regional Health Services (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 standardization, the most detailed is the one providing the technical specifications of the device. This is the one we use in our analysis, allowing us to include device-specific fixed effects. Finally, from the list of devices in Figure 1, we exclude medicines from our analysis even though they can be considered standardized, because they have been subject to a reference-price policy since 2014. We investigate the robustness of our results to the inclusion of the less standardized products in Section 6 of the paper.

This leaves us with the following devices in our main sample: syringes and needles of various loads, dressings of different sizes, and sutures of different gauges. We restrict attention further to products of the same model (or size). For instance we will treat 10 and 50 ml syringes as two different devices. As we will discuss in further detail below, we consider syringes, needles and dressing as treated devices and sutures as controls, since

[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.

the former group were affected by the policy in 2016, while sutures only became subject to the policy in 2018.

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: Excerpt from the list of standardized 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

In this section we describe our data. We combine two datasets, one that contains order-level information, and one that contains contract-level data. 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.

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. 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. The region of Lazio granted us direct access to the data set.

The data cover 6,695 orders between January 2015 and June 2018 from all 16 of the hospitals in the region for 62 different medical devices in the categories of syringes, needles, dressings, and sutures, that are the focus of our analysis. 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 50 ml syringes as two different devices. Notably, we also observe the exact price paid for each order of the specific medical device, the quantity purchased by the hospital, the identity of the suppliers, and order and delivery dates. The data also contain unique hospital identifiers. The data include information on hospital characteristics such as type and address, but only limited details on their operations. This includes information on official spending for each medical device as reported by the Health Ministry, but no information on personnel or performance.

The hospitals in our sample are all the health units that provide health services in the region. 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*).

A key outcome variable for our analysis is the delivery time, which we compute as the difference between the delivery date and the order date. To the best of our knowledge, this is the first paper that considers delivery times in the procurement of medical devices. Other papers on procurement that report delivery times usually obtain these measures through surveys, which might open up issues related to self-reporting.

Contract-level data: We link our order-level data with data on the procurement contracts between hospitals and suppliers. These data are collected by the ANAC and contain contracts valued at more than €40,000. Above this threshold Italian public buyers must report to the ANAC the details of the procurement contracts. The data set provides information on the value of the contract. Although unitary prices are decided at the contract-awarding stage, we do not observe them.[6]

We also do not observe the total quantities in the contract. At the contract-awarding stage, the buyer does not immediately purchase the specified total quantity, but does so through a series of orders. 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 stored in the accounting system of the region. We can match the orders with their associated contract using the contract identifier that we observe in both datasets (i.e., the CIG code). Aggregating the order quantities associated with a contract for a particular device allows us to construct a proxy for the total quantity auctioned in the contract. We use this measure in Section 5 to investigate possible explanations for our findings.

Our final sample contains data on 3,719 orders that can be associated with 94 contracts.[7] Table 1 reports summary statistics. Panel A of Table 1 reports statistics for variables in our order-level data. The average (unitary) price is €1.4. Ordered quantities, on average, are 2,457 units, and the average time of delivery is 10 days. Panel B illustrates summary statistics at the contract-level for the 94 contracts associated with the orders. The average total value of the contracts is €579,328, and the average total quantities ordered in each contract are 97,210. 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. We do not have data on individual bids for any of the 94 contracts we observe, or information on the number of firms that participate in the auction in 40 of the contracts.

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	3.070	3,719
Total quantity	2,457	8,261	72	360	5,400	3,719
Delivery time (days)	9.764	9.044	2	7	19	3,719
Panel B: Contract-level						
Value contract (€)	579,328	1,716,000	50,800	115,000	900,000	94
Total quantities used in the contract	97,210	198,160	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.

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

[7] 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.

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. Devices in the first three categories belong to the set of centralized devices (i.e. treatment devices), while sutures are considered non-centralized (i.e. control devices), since they were excluded from the first centralization decree issued on 24 December 2015.

To identify the effect of centralization on delivery times and prices, we estimate the following difference-in-differences 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} is either the unitary price or 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, which we include to control for spending cycles (see Liebman and Mahoney, 2017). 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, since some hospitals could still have preferences over specific devices.

Table 2 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.

Our main findings relate to the estimated coefficient $Centralized_d \times Post_t$, which indicates that after the introduction of mandatory centralized procurement, centralized devices are cheaper (columns 1, 2, and 3), but are delivered with a delay relative to controls (columns 4, 5, and 6). 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 19% for treated devices. The average unitary price in the pre-centralization period is about €1 and so the decrease in prices amounts to a decrease of about €.15. The average delivery time in the pre-centralization period is 12 days and so the increase in delivery time amounts to a change of roughly 2.3 days.

Table 2: 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	-0.1966	-0.1361*	-0.1459**	0.2521***	0.1947**	0.1852**
	(0.172)	(0.073)	(0.073)	(0.095)	(0.081)	(0.076)
Centralized	-1.1418***			0.6928***		
	(0.185)			(0.095)		
Post	0.0974			-0.1435*		
	(0.085)			(0.078)		
Ln(Quantity)			-0.0134			-0.0192
			(0.010)			(0.022)
Ln(ContractValue)			-0.0465			-0.0455***
			(0.041)			(0.013)
Observations	3,719	3,719	3,719	3,719	3,719	3,719
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	11.59	11.59	11.59

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% (***).

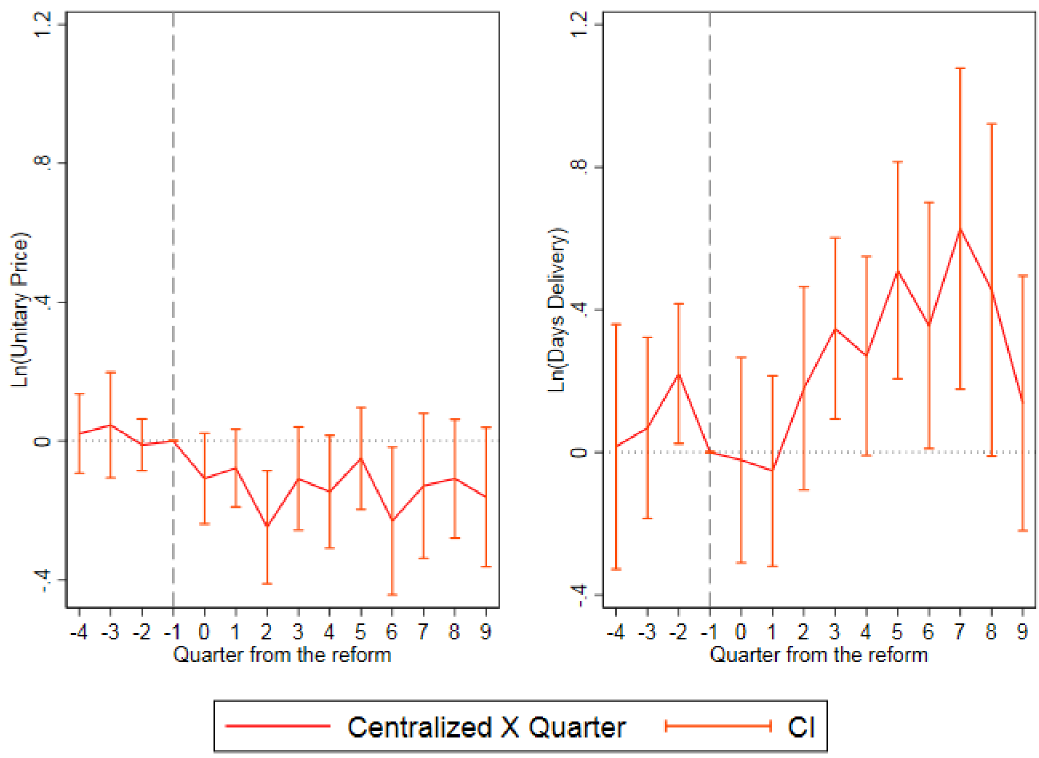
Figure 3 captures the dynamic effect of centralization on affected devices relative to controls. This figure is obtained estimating the following variant of Equation (1):

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

where j represents the number of quarters since 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 3. 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. These findings provide evidence that the effects of centralization are persistent two years after the reform .

Figure 3: Dynamic effects of centralization on unitary prices and delivery times



Notes: Plot of the coefficients (red line) and the associated confidence intervals (orange line) of the interaction term between the dummy *Centralized* equal to 1 of the device is centralized and a dummy indicating whether the order is issued x quarters from the reform, with x=-4,-3,-2,0,1...,9. The base group is the quarter before the policy change. The coefficients are estimated running a regression of logarithm of unitary prices (on the left) and delivery times (on the right) on the interaction term $Centralized \times Quarter$. The estimation includes device, hospital and quarter effects. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

4.1 Evidence in support of the identifying assumptions

In this section we provide evidence in support of the identifying assumptions required for the difference-in-differences research design.

Figure 3 shows that there is no evidence of anticipatory effects in our data. 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 formally 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 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.

The difference-in-differences design also requires knowledge of what determined treatment status. This is because one might be concerned that the decree from the Prime Minister issued on 24 December 2015 specifying syringes, needles, and dressings as centralized devices, might not have been random in which case assignment to treatment could not be considered as exogenous. However, we feel confident in treating this policy change as exogenous for the following reasons. First, the device purchases that we analyze are from a single Italian region, while the policy change was implemented by the central government. Therefore, the policy is exogenous to the region. Second, sutures (our non-centralized devices) were 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, another policy aimed at limiting public expenditure in the healthcare sector. Importantly, although they were not part of the first decree, sutures became subject to the use of demand aggregators in July 2018, after the end of our sample period. At this point, as indicated in Figure 1, the contract value thresholds above which sutures contracts have to be awarded through the use of demand aggregators are the same as those established in 2015 for syringes, needles, and dressings.

To corroborate the quasi-experimental variation in treatment status between devices we test whether the characteristics of hospitals (the buyers) and contracts are systematically different for treated and control devices before the policy change. That is, we run standard balance tests between these characteristics and the treatment status of the specific device purchased in a given order (before the reform). If the treatment status is not correlated with hospital characteristics, then the coefficient of a regression of hospital characteristics on treatment status should not be statistically different from zero.

We identify seven hospital characteristics. The first five are indicator variables: (i) whether the order is issued by a hospital in the province of Rome, (ii) whether the order is issued in the last quarter of the year (since procurement has been proven to be cyclical, see Liebman and Mahoney, 2017), (iii) whether the order identifier is associated with a single device or multiple devices, (iv) whether the order is associated with a contract that must also be advertised at the European level (see Section 2), and (v) whether the order is associated with a contract of lower size (i.e., the contract value lies between €40,000 and €50,000). The sixth is a categorical variable indicating whether the hospital is a unit providing healthcare services, a healthcare facility where patients can be hospitalized, or a hospital where clinical research is carried out as described in Section 3. Finally, we also include the expenses (in log) for every hospital for each brand of a device in the year before the policy change.[8]

Our findings are reported in Table 3. They confirm that these characteristics are balanced between treated and control devices prior to the implementation of the policy.

Table 3: Balance tests for hospital and contract characteristics

	(1) Rome(0/1)	(2) OrderLastQuarter(0/1)	(3) Bundle(0/1)	(4) EUContract(0/1)	(5) SmallContract(0/1)	(6) Hosp.Category(0/1)	(7) Log(ExpDeviceHospital)
Centralized	-0.0020	-0.1750	-0.0744	-0.0179	0.0541	0.4433	0.4222
	(0.005)	(0.125)	(0.061)	(0.154)	(0.035)	(0.269)	(0.398)
Observations	1,397	1,397	1,397	1,397	1,397	1,397	184
Device Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospital Effects	No	No	Yes	Yes	Yes	Yes	Yes
Quarter Effects	Yes	Yes	No	Yes	Yes	Yes	No

Notes: The table reports the estimated coefficients from the regression of hospital and contracts characteristics on treatment status (*Centralized*) and controlling for device, hospital and quarter effects. *Rome (0/1)* indicates whether the order is issued by a hospital in the province of Rome. *LastQuarter (0/1)* indicates whether the order is issued in the last quarter of the year. *Bundle (0/1)* is a dummy indicating whether the order identifier is associated with a unique request or whether the request is part of a bundle of requests. *EUContract (0/1)* is a dummy equal to 1 if the order is associated with a contract that must be advertised also at the European level. The threshold for advertising the contract at the EU level was 207,000 in 2015 for local buyers in the health sector awarding contracts related to goods and services. *SmallContract (0/1)* is a dummy equal to 1 if the order is associated with a contract with value between €40,000 and €50,000. *Hosp.Category* is a categorical variable indicating whether the hospital is a unit providing healthcare services, a healthcare facility where patients can be hospitalized or a hospital where clinical research is carried on as described in Section 3. *Log(ExpDeviceHospital)* indicates the total expenses (in logs) of an hospital in the year 2015 for a given brand of a particular device. *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% (***).

4.2 Non-linear effects of the policy

Next, we look at the effects of centralization at different points of the price and delivery-time distributions. The idea is to see whether there are some instances where delivery times increased significantly. To do so, we estimate the quantile difference-in-differences model developed in Athey and Imbens (2006) (i.e. the Changes-in-Changes model). Specifically, we estimate the following equation:

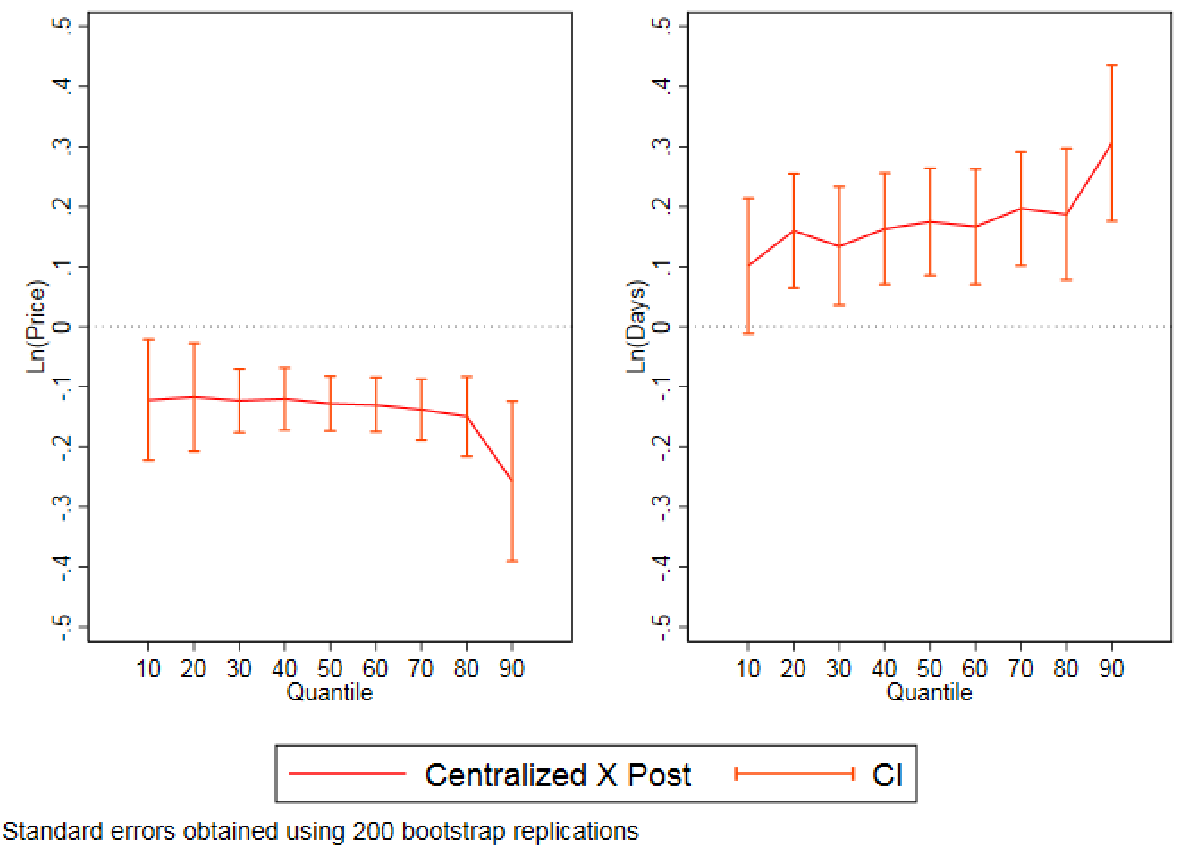
$$\begin{aligned} Q_q(Ln(Y_{odcht})) &= \beta_{0,q} + \beta_{1,q} Centralized_d \times Post_t + \beta_{2,q} Centralized_d + \beta_{3,q} Post_t \\ &\quad + \beta_{4,q} Ln(Quantity)_{odcht} + \beta_{5,q} Ln(ContractValue)_c \\ &\quad + \theta_d + \gamma_h + \delta_t + \epsilon_{odcht}, \end{aligned} \tag{3}$$

[8] We collected this data from the Italian Ministry of Health. The dataset contains for the entire country the yearly total expenses registered by brand of a given device and by hospital and it is publicly available here: `https://www.dati.salute.gov.it/dati/dettaglioDataset.jsp?menu=dati&idPag=81`

where q is the q-th quantile ($q = 10, ..., 90$); Y_{odcht} is either prices or 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). Standard errors, in this model, are computed using the bootstrap method with 200 replications. The coefficients of interest are $\beta_{1,q}$.

Figure 4 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. This corresponds to an increase in delivery times of about three and six days with respect to the average delivery time in the 80th quantile and 90th quantile observed for centralized devices in the period before the policy change. Table A.3 in Appendix A.2 presents the magnitude of the coefficients and the standard errors.

Figure 4: Change-in-Change effects of centralization on unitary prices and delivery times



Note: 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 Additional results and robustness checks

Next, we run a series of robustness checks. First, 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. Results are presented in Table A.4 and are similar to our main estimates.

Table A.5 repeats our analysis using data on prices collapsed by contract, device, hospital, and product code. This analysis helps to address the potential issue that we do not observe prices at the contract level but we do observe prices at the order level.

Tables A.6 and Table A.7 break our results down for the different treatment devices. Recall that in our main estimates, three categories of medical devices are subject to centralization: syringes, needles, and dressings. Table A.6 shows the effect of the policy on purchases of syringes and needles compared to purchases of sutures (our control). The results are similar to our main estimates for prices, but a slightly weaker effect of centralization is observed for delivery times. Table A.7 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.

In our main dataset, we only used orders associated with contracts with values above €40,000. Table A.8 shows instead 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 all details on contracts below €40,000 to the ANAC. Our main results hold, although we observe a stronger effect of centralization on prices, but a slightly weaker effect on delivery times.

5 Mechanisms

The analysis so far has provided robust evidence that the introduction of centralized procurement reduced prices and increased delays by a small amount. In this section we use additional data on quantities purchased, suppliers' identities and locations, and balance-sheet data on capacity and revenue in an effort to explain our findings.

Our primary focus is on the impact of the size of contracts. As a result of centralization, contracts that, prior to the regulation, would have been placed separately by individual hospitals are now combined and placed together under centralization. Larger contacts may provide buyers with more bargaining power and/or generate economies of scale and bulk discounts, helping to explain the observed lower prices (see Dubois et al., 2021 for a discussion). In addition to lower prices, the increase in contract size could explain the longer delays we observe if suppliers could not quickly adjust capacity or if procured devices had to travel longer distances to reach hospitals because centralization caused a reduction in the number of suppliers.

To investigate these issues we start by estimating the causal effect of centralization on contract size. We make use of our data on quantities ordered. As discussed in Section 3, we do not have information on the total quantity specified in the contract, but we do observe the exact quantities purchased in each order. We therefore aggregate all quantities ordered for a particular device by contract identifier to construct a proxy for total contractual quantity. This new variable allows us to test whether centralized procurement generated a systematic increase in contract size.

Results are presented in columns 1 and 2 of Table 4 and suggest that the introduction of centralized procurement generated a systematic increase in contract size. Column 1 reports the estimation results without fixed effects, while column 2 reports results from estimation including device fixed effects. With device fixed effects included we find that the introduction of centralized procurement caused a 200% increase in the quantities purchased per contract in the treated group with respect to the control group of devices after January 2016.

Table 4: Difference-in-differences for the quantities purchased and number of monthly suppliers

	(1)	(2)	(3)
Dep.Variable	Ln(Tot.Q.ContractDevice)		N.SuppliersMonth
Centralized×Post	2.5906***	2.0015***	-2.2833***
	(0.541)	(0.624)	(0.777)
Centralized	0.2994		11.2500***
	(0.414)		(0.712)
Post	-2.5803***	-2.5006***	-0.9167***
	(0.357)	(0.496)	(0.287)
Observations	182	182	84
Device FE	Yes	Yes	No
Hospital FE	No	No	No
Time FE	No	No	No
Mean Y Centralized Pre	56414	56414	14.67

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on the logarithm of the total purchased quantities and on the number of monthly suppliers. *Tot.Q.ContractDevice* represents the total purchased quantities associated with the contract for a device. *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. 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% (***).

One way that centralization could cause contract size to increase is by concentrating purchases at a smaller number of suppliers. To investigate this we make use of information on the identity of the suppliers available from our order-level dataset and study the effect of centralization on the number of suppliers per month for treatment devices as compared to control devices. Results are reported in column 3 of Table 4. Our results suggest that the market becomes more concentrated after centralization. Specifically, we find that the number of suppliers in a given month decreases after centralization. The decrease represents approximately 15% of the number of suppliers observed in the centralized set of devices in the period before the policy change.

Next we provide evidence to rule out the possibility that the increase in contract size for centralized devices is driven by an increase in demand from hospitals. In other words, we want to confirm that hospital demand stays constant, but contract size increases nonetheless. Using our order-level data, in columns 1 and 2 of Table 5, 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. Columns 3 and 4 of Table 5 provide further confirmation that total demand has not increased. We aggregate up and analyze the number of orders and the total quantities purchased per month for each device. 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.

Together, these results confirm that contracts are larger and are concentrated at a smaller number of sellers, and this despite the fact that hospital-level demand did not change. As discussed in Dubois et al. (2021) these may generate price reductions due to either or both of two complementary mechanisms: (i) enhanced hospital bargaining power, or (ii) bulk discounts related to economies of scale.[9]

The remaining question is whether the increased contract size caused by centralization might also explain the longer delays we observe. This is what we turn to next. Increased contract size could generate longer delays either if suppliers could not quickly adjust capacity or if procured devices had to travel further distances between suppliers to hospitals. The latter event could occur for instance because, as already shown, the centralized orders are filled by a smaller number of suppliers. We examine these two possibilities in what follows.

We start by investigating the impact of centralization on shipping distance. With fewer suppliers, shipping times might increase, possibly explaining the observed increase in delays. We use the distance between the supplier and the legal address of the health unit (expressed in kilometres). Results are presented in Table 6 . We find that the coefficient of the interaction term $Centralized \times Post$ is not significant. This result is robust to the inclusion of device, hospital and time (quarter) effects (used in our main analysis). The coefficient is also small compared to the average distance observed in the period before the centralization for the centralized set of devices, which is of 382km. Overall, our findings regarding distance suggest that increased shipping time is unlikely to explain the increase in delays that we observe.

[9]We rule out the possibility that price reductions can be explained by the use of different auction formats under the centralization regime, as we do not find any evidence that centralization had an effect on the award method (i.e., open versus restricted auction) used to purchase the medical devices in our sample. These results are available upon request.

Table 5: Difference-in-differences for monthly demand by hospital, monthly number of orders and monthly demand

Dep.Variable	(1) Ln(Tot.Q.HospitalMonth)	(2)	(3) N.OrdersMonth	(4) Ln(Tot.Q.Month)
Centralized×Post	-0.2825	-0.0808	-1.9500	-0.0506
	(0.257)	(0.126)	(7.347)	(0.256)
Centralized	0.8664***		14.4167**	3.0026***
	(0.316)		(6.685)	(0.213)
Post	0.2419*		-18.5333***	-0.2530
	(0.131)		(4.956)	(0.160)
Observations	1,473	1,473	84	84
Device FE	No	Yes	No	No
Hospital FE	No	Yes	No	No
Time FE	No	Yes	No	No
Mean Y Centralized Pre	8071	8071	65.42	266343

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on monthly total quantities ordered per hospital (in log), monthly number of orders and monthly overall demand (in log). *Tot.Q.HospitalMonth* represents the total quantities ordered in a month by an individual hospital. *N.OrdersMonth* represents the number of orders per month. *Tot.Q.Month* represents the total quantities ordered 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% (***).

Table 6: Distance of firms

Dep.Variable	(1) Distance (km)	(2) Distance (km)
Centralized×Post	-49.9606	-11.6595
	(30.603)	(15.618)
Centralized	-161.7538**	
	(62.401)	
Post	10.5856	
	(11.174)	
Observations	3,710	3,710
Device FE	No	Yes
Hospital FE	No	Yes
Time FE	No	Yes
Mean Y Centralized Pre	382.5	382.5

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the distance of suppliers from hospitals. *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. *Distance* is the distance between the address of the supplier and the address of the health unit. Significance at 10% (*), 5% (**), and 1% (***).

An alternative explanation for the longer delays is that, as contract sizes increased, the suppliers satisfying these contracts could not adjust capacity quickly enough and so had trouble filling orders on time. We investigate this possibility in two ways. First, we test whether delays are more likely to occur at smaller firms, since these are the ones that should be affected by capacity constraints. We measure size indirectly by assuming that firms that supply multinationally are large, while those that sell only in Italy are small. Using this measure, we find that, in our sample, 72% of orders are placed at small firms. We estimate the following difference-in-difference-in-difference model:

$$\begin{aligned} Ln(Y_{odchst}) \;=\; & \beta_0 + \beta_1 Small_s \times Centralized_d \times Post_t + \beta_2 Small_s \times Post_t \\ & + \beta_3 Small_s \times Centralized_d + \beta_4 Centralized_d \times Post_t \\ & + \beta_5 Small_s + \beta_6 Centralized_d + \beta_7 Post_t + \beta_8 Ln(Q)_{odchst} \\ & + \beta_9 Ln(ContractValue)_c + \theta_d + \gamma_h + \delta_t + \epsilon_{odchst}, \end{aligned} \tag{4}$$

where Y_{odcht} is either the unitary price or the days of delivery for order o, of device d, for contract c in hospital h by supplier s in quarter t. *Small* is a dummy equal to 1 if the firm is a small local firm as opposed to a multinational firm. Results are reported in Table 7 and confirm our hypothesis. Our findings suggest that the decrease in prices (columns 1 to 3) and the increase in delays (columns 4 to 6) are largely driven by firms who are potentially more exposed to capacity constraints, i.e. the firms who only sell locally.

Table 7: Difference-in-differences for unitary prices and delivery times

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Small×Centralized×Post	-0.7991**	-0.3259***	-0.3171***	0.0899	0.3782**	0.3870**
	(0.329)	(0.110)	(0.119)	(0.223)	(0.180)	(0.173)
Small×Post	0.3777***	0.3486***	0.3069**	0.1995	0.0460	0.0119
	(0.142)	(0.095)	(0.121)	(0.162)	(0.104)	(0.098)
Small×Centralized	1.2196***	0.2609	0.2124	-0.0210	-0.2086	-0.2487
	(0.434)	(0.192)	(0.216)	(0.166)	(0.164)	(0.159)
Centralized×Post	0.4781*	0.1327*	0.1336*	0.0701	-0.3241**	-0.3260**
	(0.281)	(0.075)	(0.075)	(0.160)	(0.144)	(0.142)
Small	-0.4419***	-0.3989***	-0.3834***	-0.0384	0.3009***	0.3159***
	(0.121)	(0.120)	(0.128)	(0.130)	(0.101)	(0.094)
Centralized	-2.1596***			0.7167***		
	(0.391)			(0.105)		
Post	-0.2118*			-0.2225***		
	(0.126)			(0.074)		
Ln(Quantity)			-0.0186*			-0.0083
			(0.010)			(0.024)
Ln(ContractValue)			-0.0457			-0.0373***
			(0.041)			(0.013)
Observations	3,719	3,719	3,719	3,719	3,719	3,719
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	11.59	11.59	11.59

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. *Small* is a dummy equal to 1 if the firm is a small local firms as opposed to a multinational. Significance at 10% (*), 5% (**), and 1% (***).

Since this approach to measuring size is somewhat crude, in a second step we merge in balance-sheet data for suppliers to investigate whether firms adjusted capacity following centralization. We match our supplier IDs with balance sheet data collected by *Cerved*. Cerved contains the yearly financial statements of all public and privately-owned Italian firms that are required to file a balance sheet.[10] We match all the suppliers from the procurement-market database described in Section 3 if they received at least one order from hospitals in the region before and after 2016. Using these data we define a firm's *exposure to the legislative change* $CentrExp_i$ as the value of medical devices subject to the centralization experiment supplied by firm i in 2015, as a percentage of the firm's total value of production in 2015. The average exposure of firms in our sample is .02% and the standard deviation is .04%. We use this variable to estimate the causal impact of exposure to centralization on two outcomes: capacity and revenues from procurement. We proxy for capacity using physical assets (i.e. capital). Specifically, we estimate the following model:

$$y_{it} = \alpha + \delta ExpCentr_i \times Post_t + \beta ExpCentr_i + \gamma Post_t + \varepsilon_{it}, \tag{5}$$

where y_{it} is the outcome variable of interest (capital, revenues from procurement) in levels, and $ExpCentr_i * Post$ is created by interacting firm i's *exposure to the legislative change* variable defined, with a dummy that equals 1 after the legislative change in 2016. We also include year and firm fixed effects. Estimation results are reported in Table 8.

Our main finding is that there is no significant change in capital for more exposed firms after 2015. The estimated coefficient δ is not statistically significant across specifications (Table 8, columns 1 and 2). From columns 3 and 4 we can see that this is despite the fact that more exposed firms have more procurement revenues. The revenue effects are sizeable: A one-standard-deviation increase in $ExpCentr_i$, when multiplied by the coefficient in Table 8, column 4, yields $117.36 * (0.04) = 4.7$, corresponding to an increase of 4,700 euros in the annual value of procurement supplied for the hospitals in the region, or 15% of the average value of procurement of centralized devices supplied.

6 External validity of the main results

The analysis so far has focused on the standardized devices described in Section 2 and belonging to four categories: syringes, needles and dressings (centralized devices) and sutures (non-centralized devices). However, these devices represent only a sub-sample of the full set of devices available in our original dataset of hospital orders discussed in Section 3. Attention was further restricted to devices satisfying threshold and size

[10]These data are used, for example, in Guiso et al. (2005).

Table 8: Effects of centralization on revenues and capacity

	(1)	(2)	(3)	(4)
Dep. Variable	Capital (in €1,000)	Capital (in €1,000)	Revenues (in €1,000)	Revenues (in €1,000)
ExpCentr×Post	25,860.0531	-144.7616	207.4489***	117.3529**
	(23,010.496)	(3,551.669)	(71.945)	(42.063)
ExpCentr	-76,379.8577*		-200.4432	
	(42,390.859)		(167.308)	
Post	-2,787.6015		-11.5224	
	(2,485.569)		(8.253)	
Observations	78	78	78	78
Firm FE	No	Yes	No	Yes
Year FE	No	Yes	No	Yes
Mean Y	6895	6895	31.42	31.42

Notes: Coefficient (standard error in parentheses). *Capital* represents firms' total physical assets (in €1,000).*Revenues* is the total value of orders for centralized devices received by a firm in a year (in €1,000). *ExpCentr* represents the exposure to the legislative change computed as the ratio between the firm's value of centralized medical devices supplied pre-reform and the firm's pre-reform value of production. *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 supplier level. Significance at 10% (*), 5% (**), and 1% (***).

constraints.[11] In this section we investigate whether our main results hold more generally in the larger set of devices subject to the mandatory centralization reform. The objective is to confirm that our results extend beyond the original sample of standardized of devices.

To the set of control products we add gloves, since, like sutures, their purchases were only centralized after the end of our sample period. To the treatment products we add medicines (drugs), vaccines, stent, incontinence aids, hip replacements, defibrillators, and pacemakers. As discussed in Section 3, we match this larger sample of orders with the contract identifiers available from the ANAC website using the contract identifier. We then keep only those orders associated with a contract. For medicines, vaccines, incontinence aids, dressings, needles, syringes, gloves and sutures we only keep those orders associated with contracts with a value above €40,000. For stent, hip replacement, defibrillators and pacemakers we keep those orders associated with contracts above the EU threshold (community threshold) since only those contracts are mandated to be centralized. Finally, we exclude those medicines (drugs) subject to the policy of reference pricing since 2014. This is to replicate the matching process used to produce our core estimates.

From an econometric point of view, we estimate a slightly different model compared to our main specification in Equation (1). This is because in the larger set of devices we cannot employ the granular definition of devices used in our main data. 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. In the example in Figure 2 there are six different types of syringes and so when estimating Equation

[11]Recall that in our main analysis we kept only those types of syringes, needles, dressings and sutures classified by Agenas and associated with contracts above 40,000 €.

(1), we include six device fixed effects, one for each type. Instead, in this section we use the more general device identifiers to define a device based only the device alphanumeric code in the first column of Figure 2 (i.e., *CODICE CND*). Therefore, instead of device fixed effects, we can now include just two (one for the syringes with code A01010101 and one for the syringes with code A010102).

Table 9: Difference-in-differences for unitary prices and delivery times for non-standardized devices

Dep.Variable	(1) Ln(Price)	(2) Ln(Price)	(3) Ln(Price)	(4) Ln(Days)	(5) Ln(Days)	(6) Ln(Days)
Centralized×Post	-0.3264	-0.2041	-0.1828*	0.1336**	0.1502***	0.1499***
	(0.273)	(0.154)	(0.099)	(0.059)	(0.048)	(0.048)
Centralized	1.7434***			-0.0769		
	(0.431)			(0.064)		
Post	0.3130			-0.0660		
	(0.255)			(0.051)		
Ln(Quantity)			-0.4550***			0.0058
			(0.019)			(0.006)
Ln(ContractValue)			-0.0091			-0.0017
			(0.015)			(0.008)
Observations	133,363	133,317	133,317	133,363	133,317	133,317
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	10.50	10.50	10.50

Notes: The sample includes all devices in Figure 1, regardless of their degree of standardization. The controls are those devices in Figure 1 which became centralized at the end of our sample period (July 2018). 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% (***).

Table 9 reports the results for unitary prices and delivery times. We observe that our main findings also hold for non-standardized devices, with a decrease in unitary prices of approximately 18% in our main specification (column 3). This set of non-standardized medical devices includes even more complex medical devices (pacemakers, stents, prosthesis), drugs, and vaccines in the treated group. It is therefore not surprising to see that the average unitary price is much higher than the one observed in our main sample reported in Table 2. We observe that the effect of centralization on delivery times using this larger number of orders is positive and statistically significant. The effect is slightly lower than the one observed in the sample that we use in our main estimation (15% versus 19%). 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 (columns 3 and 6).

We conclude that our main results are also valid in the sample of medical devices that are less comparable in their nature. This is reassuring as often estimates of the effects of centralization are obtained in datasets that allow to controls for less granular fixed effects as the one we add in our key estimates (see, for instance, Bandiera et al., 2009 and Dubois et al., 2021).

7 Conclusion

We study the effect of mandatory centralized procurement on prices and delivery times of hospital medical devices. Our identification strategy leverages the staggered implementation of centralized procurement for a sub-set of the medical devices regularly purchased by the Italian hospitals in our sample. We use a unique administrative dataset on the purchases and deliveries 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, the identity of suppliers, and their balance sheets 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 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. We use our balance sheet data to confirm that capacity did not increase in the two years after the centralization experiment.

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 fulfil 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.[12] Our results offer a re-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

[12] "*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 standardized – 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.*"

delivery times that should be considered in the evaluation of the effectiveness of centralized procurement policies.

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A Appendix

A.1 Test parallel trend

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

	(1)	(2)
Dep.Variable	Ln(Price)	Ln(Days)
$Q1_{2015}$×Centralized	0.0212	0.0156
	(0.058)	(0.175)
$Q2_{2015}$×Centralized	0.0460	0.0682
	(0.078)	(0.130)
$Q3_{2015}$×Centralized	-0.0111	0.2202**
	(0.038)	(0.100)
$Q1_{2016}$×Centralized	-0.1084	-0.0221
	(0.067)	(0.147)
$Q2_{2016}$×Centralized	-0.0777	-0.0524
	(0.057)	(0.137)
$Q3_{2016}$×Centralized	-0.2478***	0.1792
	(0.083)	(0.146)
$Q4_{2016}$×Centralized	-0.1087	0.3472***
	(0.076)	(0.130)
$Q1_{2017}$×Centralized	-0.1458*	0.2699*
	(0.083)	(0.142)
$Q2_{2017}$×Centralized	-0.0500	0.5104***
	(0.075)	(0.155)
$Q3_{2017}$×Centralized	-0.2304**	0.3552**
	(0.109)	(0.176)
$Q4_{2017}$×Centralized	-0.1292	0.6272***
	(0.107)	(0.230)
$Q1_{2018}$×Centralized	-0.1083	0.4549*
	(0.087)	(0.238)
$Q2_{2018}$×Centralized	-0.1617	0.1375
	(0.102)	(0.182)
Ln(Quantity)	-0.0138	-0.0177
	(0.010)	(0.022)
Ln(ContractValue)	-0.0463	-0.0383***
	(0.041)	(0.012)
Observations	3,703	3,703
Device FE	Yes	Yes
Hospital FE	Yes	Yes
Time FE	Yes	Yes
Mean Y Centralized Pre	1.009	11.60
P-value Joint Test Pre 2016 Coefficients	0.622	0.439

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 $Q1_{2015} \times Centralized = Q2_{2015} \times Centralized = Q3_{2015} \times Centralized$. 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	0.0184	0.0095	0.0244
	(0.039)	(0.021)	(0.022)	(0.054)	(0.055)	(0.061)
Centralized	-0.1713			-3.3911		
	(8.587)			(11.833)		
Quarter	-0.0027			-0.0072		
	(0.021)			(0.050)		
Ln(Quantity)			-0.0282*			-0.0031
			(0.017)			(0.030)
Ln(ContractValue)			-0.0259			-0.0828***
			(0.043)			(0.017)
Observations	1,397	1,397	1,397	1,397	1,397	1,397
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	11.59	11.59	11.59

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.2 Robustness

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

	(1)	(2)
Dep.Variable	Ln(Price)	Ln(Days)
q10	-0.122**	0.102*
	(0.0514)	(0.0573)
q20	-0.117**	0.160***
	(0.0460)	(0.0485)
q30	-0.123***	0.134***
	(0.0270)	(0.0503)
q40	-0.120***	0.163***
	(0.0264)	(0.0471)
q50	-0.128***	0.175***
	(0.0232)	(0.0455)
q60	-0.130***	0.167***
	(0.0232)	(0.0488)
q70	-0.138***	0.197***
	(0.0261)	(0.0481)
q80	-0.149***	0.187***
	(0.0338)	(0.0559)
q90	-0.257***	0.306***
	(0.0678)	(0.0664)
Observations	3719	3719
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	-0.2057	-0.1461**	-0.1530**	0.2187**	0.1860**	0.1797**
	(0.169)	(0.073)	(0.074)	(0.093)	(0.076)	(0.070)
Centralized	-1.1418***			0.6928***		
	(0.185)			(0.095)		
Post	0.1075			-0.1400*		
	(0.082)			(0.076)		
Ln(Quantity)			-0.0157			-0.0210
			(0.012)			(0.022)
Ln(ContractValue)			-0.0490			-0.0456***
			(0.043)			(0.013)
Observations	3,307	3,307	3,307	3,307	3,307	3,307
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	11.59	11.59	11.59

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**	0.2521***	0.1947**	0.1852**
	(0.273)	(0.091)	(0.119)	(0.095)	(0.081)	(0.076)
Centralized	-1.7058***			0.6928***		
	(0.210)			(0.095)		
Post	0.1564*			-0.1435*		
	(0.087)			(0.078)		
Ln(Quantity)			-0.0389*			-0.0192
			(0.020)			(0.022)
Ln(ContractValue)			-0.0233			-0.0455***
			(0.038)			(0.013)
Observations	484	473	473	3,719	3,719	3,719
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	11.59	11.59	11.59

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 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	-0.1438	-0.1437*	-0.1603*	0.1761*	0.1160	0.1037
	(0.159)	(0.083)	(0.086)	(0.098)	(0.086)	(0.078)
Centralized	-1.6459***			0.7931***		
	(0.209)			(0.093)		
Post	0.0974			-0.1435*		
	(0.085)			(0.079)		
Ln(Quantity)			-0.0181*			-0.0149
			(0.010)			(0.024)
Ln(ContractValue)			-0.0710			-0.0529***
			(0.050)			(0.015)
Observations	3,022	3,022	3,022	3,022	3,022	3,022
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	12.54	12.54	12.54

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

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Days)	Ln(Days)	Ln(Days)
Centralized×Post	-0.2110	-0.1857**	-0.2052**	0.3948***	0.3721***	0.3686***
	(0.303)	(0.080)	(0.086)	(0.119)	(0.093)	(0.092)
Centralized	-0.1639			0.4980***		
	(0.248)			(0.109)		
Post	0.0974			-0.1435*		
	(0.085)			(0.079)		
Ln(Quantity)			-0.0180			-0.0119
			(0.015)			(0.039)
Ln(ContractValue)			-0.1004**			-0.0193
			(0.046)			(0.012)
Observations	2,283	2,283	2,283	2,283	2,283	2,283
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	9.745	9.745	9.745

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. 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	-0.0779	-0.1881***	-0.1909***	0.1820**	0.1293**	0.1321**
	(0.151)	(0.064)	(0.066)	(0.084)	(0.060)	(0.060)
Centralized	-1.5066***			0.6645***		
	(0.189)			(0.087)		
Post	0.1316*			-0.1204		
	(0.070)			(0.075)		
Ln(Quantity)			-0.0407***			-0.0077
			(0.011)			(0.015)
Ln(ContractValue)			0.0088			-0.0024
			(0.020)			(0.008)
Observations	6,695	6,695	6,695	6,695	6,695	6,695
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	11.42	11.42	11.42

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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