# The impact of centralization on procurement outcomes and market structure: Evidence from Italy*

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**Abstract**

We examine the impact of centralization on procurement outcomes and market structure, leveraging data on medical-device orders from Italy and a legislative change mandating centralized purchases for a subset of devices. We find that prices for centralized devices fell by 14% relative to those of non-centralized purchases. We investigate whether this comes at the cost of increased concentration or longer delivery times. We find an increase in contracts per hospital and a greater number of suppliers such that concentration actually falls. These surprising results can be explained by the fact that authorities w split procurement contracts into lots to balance buyer power and competition. However, there may still be long-term ramifications since capacity constraints at smaller suppliers prevent their participation, such that the share of large firms increased by 7.4%. Lastly, we find no statistically significant effect on delivery times.

**JEL classification**: D44; H51; H57; I18

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# 1 Introduction

Centralization of procurement has been shown to benefit taxpayers by lowering prices because of bulk discounts or increased bargaining power (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 a cost, as centralization may also lead to a number of undesirable outcomes (see OECD, 2021). For instance, delivery time could increase because of suppliers' inability to quickly adjust capacity to satisfy the larger orders that result from centralization (see OECD, 2011), or because of increased distance between buyers and sellers. More importantly, centralization could affect market structure by generating barriers to entry for small and medium size companies that are unable to fulfill the resulting larger orders. As pointed out in Albano and Sparro (2010) there could be long-term ramifications for public procurement if smaller suppliers are locked-out of the market: *"raising the degree of competition today is likely to reduce the degree of competition tomorrow."* If prices fall, but delivery times become longer or barriers to entry increase, then the overall impact of centralization is ambiguous and may even be negative. Despite this, to our knowledge, the causal relationship between centralization and both delivery times and market structure has not been examined.

The contribution of this paper, is to investigate the impact of statutory centralized procurement for hospital medical devices not only on prices, but also on market structure and delivery times. To do so, we collected novel 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 sample are 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, to this we add balance-sheet information, allowing us to measure supplier size in order to make statements about market structure. Furthermore, our dataset also provides administrative information on both the order and delivery dates. allowing 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 fact that 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, market structure, 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 would have shared a parallel trend but for the implementation of centralization in 2016. We test and do not reject the existence of a common trend between treated and non-treated devices before 2016.

We find that centralizing procurement substantially reduced prices. To understand the mechanism driving this result, we investigate the impact of centralization on contract size. Centralization usually implies that contracts that otherwise would have been placed separately are pooled. 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 24% increase in the quantities purchased per contract in the treated group with respect to the control group of devices. These findings arise 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 that benefit hospitals (see Dubois et al., 2021).

Next we investigate whether the pooling of quantities resulting from centralization generates any disadvantages that should be considered against the benefits from lower prices. If contracts that would have been submitted separately by individual hospitals at multiple different suppliers are pooled and placed with a smaller number of sellers, there may be consequences for market structure. Similarly, the increase in contract size could result in longer delays if suppliers cannot quickly adjust capacity or if procured devices must travel longer distances. We investigate these possibilities using balance-sheet data and suppliers' addresses of incorporation.

Our findings suggest that centralization results in more contracts per hospital and a greater number of suppliers such that the level of concentration actually falls. These surprising results can be explained by the fact that the Italian authorities were aware of the potential danger for centralization to limit competition. The authorities actively worked to prevent this by splitting procurement contracts into lots, in order to strike a balance between increasing buyer bargaining power and the degree of competition. The approach is described in Albano and Sparro (2010) and Grimm et al. (2006), and corroborated by OECD (2015).

However, there may still be long-term ramifications for competition in public procurement if smaller suppliers are prevented from participating because of the size of contracts relative to their capacity. If centralization creates a barrier to entry for these sellers, in the long-run they may be locked out and competition could suffer. Our results suggest that this may indeed be a concern. We find that the increase in the number of suppliers is driven entirely by large firms (according to their balance sheets), suggesting that small and medium size players may have nonetheless ended up getting squeezed from the market.

We also find that there is no statistically significant effect on delivery times. This is related to our findings on market structure. Larger suppliers increase market share and they may be able to quickly scale up in order to meet delivery times.

To summarize, we find little evidence of a tradeoff from Italy's experience with centralization, at least in the short run. Prices fall and this does not appear to come at the expense of a more concentrated market or longer delivery times. Nonetheless, in the long-run smaller firms be excluded, affecting competition.

**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 et al., 2024). Bandiera et al. (2009) and Dubois et al. (2021) provide empirical evidence that centralized procurement reduces prices, while Lotti et al. (2024) 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 are the first to 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. Concurrently, Wang and Zahur (2021) have analyzed how the centralization of procurement of drugs in low and middle-income countries affects prices and delivery times. Like us, they find evidence that centralization has a negative impact on delivery times. Unlike us, they do not have access to a natural experiment, and instead employ an instrumental variables strategy to achieve identification. Moreover, we estimate the impact of a policy mandating centralization, whereas Bandiera et al. (2009) and Lotti et al. (2024) use a different type of identification coming from the fact that before 2016 public administrations could choose whether to buy from Consip (the first demand aggregator in Italy) or on the open market.

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.

The paper also contributes to the literature on set-aside contracts and preference-programs in procurement auctions. In a number of procurement settings, disadvantaged bidders are sometimes offered preferential treatment. These have been studies for instance by Krasnokutskaya and Seim (2011). Our findings suggest that small and medium firms may be disadvantaged by centralization.

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 are the first to focus on the delivery of standardized goods in the healthcare sector.

**Outline:** 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 following the mandatory centralization of procurement. Section 6 investigates whether the lower prices came at the cost of longer delivery time or a more concentrated market. Finally, Section 7 concludes.

## 2 Institutional background

In Italy more than 35,000 public administrations (e.g., hospitals, schools, ect.) regularly award procurement contracts to suppliers for goods, services, and works, and are strictly regulated by Italian procurement law. Contracts are adjudicated via public auctions. Procurement contracts specify the terms and conditions, including penalties for delivery delays, and at which hospitals orders can be placed for required medical devices.[1] 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*

[1]Penalties are usually a function of the contract value and are calculated on a daily basis with a cap at 10% on the total value of the procurement contract. Penalties might apply regardless on whether or not are directly specified in the call for tender.

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

*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 Italian Prime Minister on 24 December 2015, which went into force on February 9, 2016, indicated specific categories of goods and services for which, and contract-value thresholds above which, demand aggregators had to be used.[4] Table 1 presents a list of the goods that became subject to the use of demand aggregators following the 2015 decree. Due to our limited sample period reaching only the first half of 2018, we cannot consider sutures and gloves in the centralized set of devices, since they were centralized only in July 2018. These two categories are in our control group together with all other devices in the sample that are not listed in this table.[5]

Table 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. Contracts with values below the specified threshold can be awarded using discretionary procedures such as direct bargaining with one supplier or restricted procedures. *Contract Value Threshold* 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 EU threshold was €207,000 before January 2016 and increased to €209,000 after (EU Regulation 2015/2170).[6] 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 to the Italian Anticorruption Authority (ANAC).

Individual devices are precisely classified by the Ministry of Health, with an alphanumeric code called *CODICE CND*. These codes are used by hospitals when placing orders.

[3] We analyze medical devices ordered in Lazio region (i.e., the region including Rome). The municipality of Rome is not involved in the procurement of medical devices. The entire list of demand aggregators is available at: https://www.acquistinretepa.it/opencms/opencms/soggetti_aggregatori_new/chi_siamo/

[4] As discussed in Bandiera et al. (2009) and Lotti et al. (2024), before 2016 public administrations could choose whether to buy from Consip (the first demand aggregator in Italy) or on the open market.

[5] We also drop those devices in the sample that are subject to the policy of binding reference prices enforced by the Italian Anticorruption Authority in March 2016 for a specific subset of devices, namely some needles, syringes and dressings with given technical specifications.

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

Since we observe repeated orders (both within and across hospitals), we can use these codes as general device identifiers allowing comparability within devices. We provide an example in Table A.1 in Appendix A.1.

The contracts that we analyze are often executed using framework agreements. These agreements require the supplier to deliver (at a given price and over a defined period of time established in the "framework") the required quantities of devices that are ordered by a single buyer. This is a mechanism often employed by central procurement agencies, whereby the framework is established but the agencies do not commit to buy all units. Local buyers can then order the devices that are the object of the framework.[7]

Table 1: Goods subject to centralization and associated contract-value threshold

| Good | Contract Value Threshold ( €) | Year of decree |
|---|---|---|
| Drugs | 40,000 | 2016 |
| Vaccines | 40,000 | 2016 |
| Stent | EU threshold | 2016 |
| Incontinence aids | 40,000 | 2016 |
| Hip replacement | EU threshold | 2016 |
| General dressings | 40,000 | 2016 |
| Defibrillators | EU threshold | 2016 |
| Pacemaker | EU 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, *Contract Value Threshold (€)* indicates the contract value above which the use of centralized procurement is mandatory, and *Year of the decree* indicates the year of the regulation. The document is translated into English from Italian.

# 3 Data and descriptive statistics

In this section we describe our data. We combine two main 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

[7] The data do not allow us to fully disentangle which orders are under framework agreements. We assume that if there are multiple orders for a given contract, it should be the case that orders are under framework agreement.

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 176,062 orders between January 2015 and June 2018 from all 17 of the hospitals in the region for 1,980 different medical devices.[8] For each order, we observe detailed information on the type of medical device, including the brand and the exact model within the brand, manufacturer. 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 out (*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 one of the first papers that considers delivery times in the procurement of medical devices. Other papers on public 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. The value of the contract is based on an estimate made by the contracting authority. This value is released when the authority publishes the call for tender. Although unitary prices are decided at the contract-awarding stage, we do not observe them in the contract data, only in the order-level data. The Italian Procurement Law allows for price adjustments during the execution of the contract and so in theory there could be variation in the unitary price within each contract for a given brand of a device purchased by a hospital. In practice, this variation is low – the coefficient of variation is .05.

[8]A device corresponds to a unique identifier.

We 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.[9] We use this measure in Section 5 to investigate possible explanations for our findings.

Table 2: 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 (€) | 410.0 | 1,482 | 1.900 | 84.55 | 900 | 176,062 |
| Quantities ordered | 554.1 | 7,345 | 1 | 3 | 120 | 176,062 |
| Delivery time (days) | 17.79 | 27.26 | 3 | 9 | 40 | 176,062 |
| **Panel B: Contract-level** | | | | | | |
| Value contract | 329,735 | 1,412,448 | 50,000 | 122,321 | 548,475 | 2,680 |
| Total quantities used in the contract | 36,398 | 267,613 | 6 | 200 | 19,054 | 2,680 |
| Open auction (0/1) | 0.393 | 0.488 | 0 | 0 | 1 | 2,680 |
| Number of devices | 5.179 | 10.78 | 1 | 2 | 11 | 2,680 |

Notes. *Unitary price* is the per unit price provided in the purchase orders (in €). *Quantities ordered* are the quantities 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.

Our final sample contains data on 176,062 orders that can be associated with 2,680 contracts. Note that we exclude from the sample the orders issued after the reform came into force that were referring to contracts awarded before the reform.[10] Table 2 reports summary statistics. Panel A of Table 2 reports statistics for variables in our order-level data. The average (unitary) price is €410. Ordered quantities, on average, are 554 units, and the average time of delivery is almost 18 days. Panel B illustrates summary statistics at the contract-level for the 2,680 contracts associated with the orders. The average total value of the contracts is €329,735, and the average total quantities ordered in each contract are 36,398. Contracts in our sample are awarded 39% of the time using an open tender. We do not have data on individual bids and number of participants for all of

[9] Quantities in the contract can be equal to the number of devices the central procurement agency commits to purchase, or can be equal to the maximum number of devices the suppliers are required to deliver (at a given price and over a defined period of time) and this depends on the nature of the procurement contract (i.e., regular procurement or framework agreement).

[10] As a placebo test, we analyze orders associated with contracts published before February 9, 2016. As we expect, there is no effect of centralization if we focus on these "sticky" contracts. See Section A.3 in Appendix.

the 2,680 contract we observe. Finally, for each contract the median number of different devices, i.e., devices with a different identifier is 2. Thus, contract are often not related to a specific device.[11]

**Balance-sheet data:** We match these data with the firm-level balance-sheet database Centrale dei Bilanci (CB).[12] We use these data to investigate market-structure changes resulting from centralization in Section 6. The CB database contains the yearly financial statements of all public and privately-owned Italian firms that are required to file a balance sheet. In addition, CB records the firms' sector (e.g., construction), where the firm is incorporated, and the year of incorporation. CB does not report whether a construction firm operates specifically in the public procurement sector. Since we care about firms that operate in public procurement, we restrict attention to the 300 firms that we can match to winners in the procurement-market database described above, and that won at least one tender before 2016.

We also collected balance-sheet data for each hospital. Similar data have been used in Bucciol et al. (2020). Later we will use these data to classify hospitals on the basis of their spending on procurement of health-related goods and services before centralization took place (and also on the basis of the non-health related personnel costs). The data are available on the open data website of the Italian Ministry of Finance.[13]

# 4 Empirical strategy and results

To identify the effect of centralization on prices, we estimate the following difference-in-differences model:

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

where $P_{odcht}$ is the unitary price for order $o$ of device $d$ for contract $c$ in hospital $h$ in quarter $t$, $\theta_d$ are 1,980 device fixed effects, $\gamma_h$ are 17 hospital fixed effects, $\delta_t$ are 14 quarter fixed effects, which we include to control for spending cycles (see Liebman and Mahoney, 2017). *Centralized* is a dummy equal to one for those devices listed in Table 1 that are above the contract value and with year of decree 2016. These are the treatment devices, while all other devices are in the control group. The estimates also include controls such as the log of $Quantity_{odcht}$ and $ContractValue_c$, which are the ordered quantities and the

[11] We also observe a small and non-statistically significant negative correlation elasticity between delivery times and the total value of the order, and between the delivery times and the total value of the contracts. See Table A.11.

[12] These firm level micro data have been used in the past, for example by Guiso et al. (2005).

[13] https://bdap-opendata.rgs.mef.gov.it/content/2015-modello-di-rilevazione-del-conto-economico-degli-enti-del-ssn.

total value of the contract, respectively.[14] The parameter of interest is $\beta_1$, which can be interpreted as the difference between the change in $Ln(P_{odcht})$ in the treatment devices relative to the control devices from before to after February 9, 2016. We cluster standard errors at the device-hospital level (see Grennan and Swanson, 2020).[15]

Table 3: Difference-in-differences for unitary prices

| | (1) | (2) |
|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Price) |
| CentralizedXPost | -0.2463** | -0.1374** |
| | (0.113) | (0.068) |
| Post | -0.0557 | -0.1318** |
| | (0.079) | (0.066) |
| Ln(Quantity) | | -0.5409*** |
| | | (0.018) |
| Ln(ValueContract) | | -0.0717*** |
| | | (0.021) |
| Observations | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 593.4 | 593.4 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the unitary price of orders (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 3 reports results from the estimation of Equation (1), with and without controls for quantities and the value of the contract. 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. Specifically, considering the model with all the controls (column 2), centralization causes a reduction in prices of approximately 14% for treated devices. The average unitary price in the pre-centralization period is about €593 and so the decrease in prices amounts to a decrease of about €82.

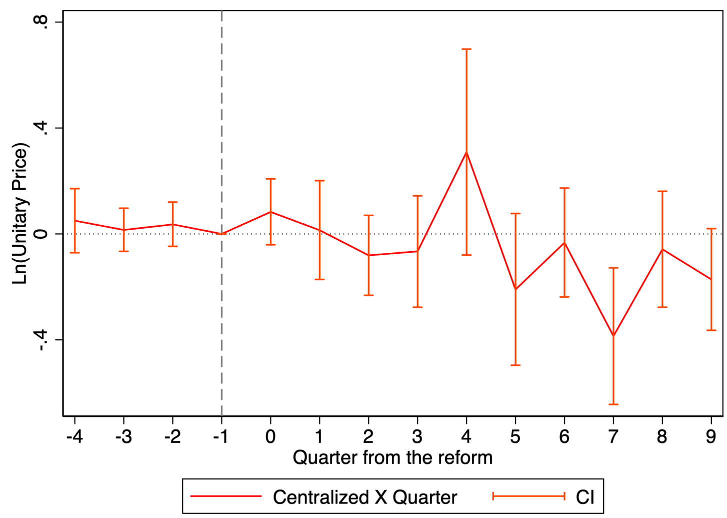
Figure 1 captures the dynamic effect of centralization on affected devices relative to controls. This figure is obtained estimating the following variant of Equation (1):

$$\begin{aligned} Ln(P_{odchj}) &= \sum_{j=-3}^{10} \theta_j Centralized_d \times Quarter_j + \beta_2 Ln(Quantity)_{odchj} \\ &\quad + \beta_3 Ln(ContractValue)_c + \theta_d + \gamma_h + \delta_j + \epsilon_{odchj}, \end{aligned} \tag{2}$$

[14] Bandiera et al. (2009) use quantities purchased as control in their unitary price regressions.

[15] Since the treatment is at the device level, Table A.5 reports the main results using standard errors clustered at the device level. Our main results are confirmed.

Figure 1: Dynamic effects of centralization on unitary prices




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 estimation includes device, hospital and quarter effects. SEs are clustered at the device-hospital level. *CI* are 95% confidence intervals.

where $j$ represents the number of quarters since the reform, *Centralized* is a dummy for devices centralized, $\theta_d$ are device fixed effects, $\gamma_h$ are hospital effects, and $\delta_j$ 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 1. As expected, after 2016, unitary prices drop more sharply for devices impacted by the centralization policy. These findings provide evidence that the effects of centralization are stronger few quarters after the reform.

## 4.1 Evidence in support of the identifying assumptions

For the identification strategy to work, we need to assume that the parallel trends for treated and untreated devices would have continued had it not been for the treatment. We cannot test this assumption directly, but we can implement other tests that provide evidence in support of our empirical strategy.

Figure 1 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. In Table A.2, 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.3. 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 February 9, 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 assignment to centralization of the medical devices, established by the decree from the Prime Minister issued on December 24, 2015 might not have been random. In this case, the 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.

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 is an indicator variable equal to 1 if the hospital is a healthcare facility where patients can be hospitalized or a hospital where clinical research is carried on, equal to 0 if the hospital is a unit providing healthcare services without possibility of hospitalization. These categories of hospitals are described in Section 3. Finally, we also include the expenses (in log) for every hospital for each device identifier in the year before the policy change.[16]

Our findings are reported in Table 4. The majority of these characteristics are balanced between treated and control devices prior to the implementation of the policy. In particular, the devices subject to centralization could have been chosen based on the rel-

[16] 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`

evance of their expense on the total expenses of a hospital for medical devices. Our test in column 7 shows that this is not the case.

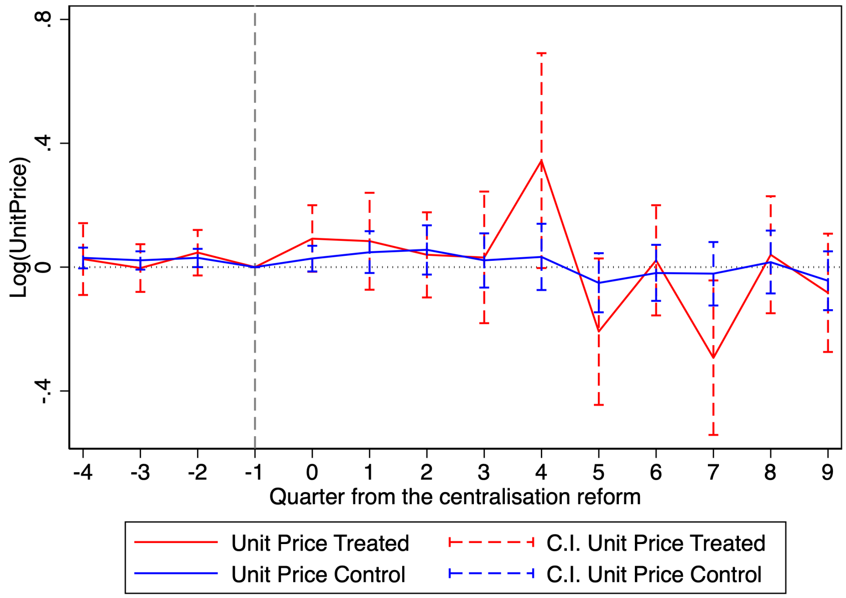
Table 4: Balance tests for hospital and contract characteristics

| | (1)<br>Rome(0/1) | (2)<br>OrderLastQuarter(0/1) | (3)<br>Bundle(0/1) | (4)<br>EUContract(0/1) | (5)<br>SmallContract(0/1) | (6)<br>Hosp.Category(0/1) | (7)<br>Log(ExpDeviceIDHospital) |
|---|---|---|---|---|---|---|---|
| Centralized | 0.0189 | 0.0279 | -0.1967*** | 0.1918*** | -0.0118* | -0.0484 | 0.0047 |
| | (0.049) | (0.017) | (0.041) | (0.062) | (0.007) | (0.075) | (0.119) |
| Observations | 114,181 | 114,181 | 108,019 | 114,181 | 114,181 | 114,181 | 2,440 |
| DeviceID Effects | No | No | No | No | No | No | No |
| Hospital Effects | No | Yes | Yes | Yes | Yes | No | Yes |
| Quarter Effects | Yes | No | Yes | 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 dummy variable equal to 1 if the hospital is a healthcare facility where patients can be hospitalized or a hospital where clinical research is carried on, 0 if the hospital is a unit providing healthcare services without possibility of hospitalization. *Log(ExpDeviceHospital)* indicates the total expenses (in logs) of an hospital in the year 2015 for a given device ID. *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% (***).

Another issue that might bias our identification strategy is the possibility of spillovers across different medical devices supplied by the same firms. Firms might charge more for devices not subject to the mandated centralization in response to a forced decrease in prices of the medical devices subject to the reform. As an example, a firm that supplies stent (treated) and respirators (control) may charge higher prices for respirators due to lower prices charged for stents. Figure 2 shows the dynamics of unit prices, for the treated and control groups of devices separately. We observe that unit prices in the control group seem to barely move from a straight line around 0. These results suggest that there are no spillovers from treated to control devices.

Figure 2: Dynamic effects of centralization on unitary prices for treated and control medical devices




Notes: Plot of the coefficients and the associated confidence intervals of the dummies indicating whether the order is issued x quarters from the reform, with x=-4,-3,-2,0,1...,9 for treated (in red) and control (in blue) medical devices. The base group is the quarter before the policy change. The estimation includes device, hospital and quarter effects. SEs are clustered at the device-hospital level. *CI* are 95% confidence intervals.

## 4.2 Additional results and robustness checks

In this subsection, we report a series of robustness checks. Table A.8 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. Results are similar to our main estimates or even stronger (see column 2).

Table A.9 shows that the results on unit prices are robust if we consider a more granular definition of fixed effects, based on the supplier-specific product number as registered in the Ministry of Health repository. The problem is that this variable has a lot of missing values. Thus, we prefer the less granular definition of device ID fixed effects.

# 5 What explains the price decrease?

The analysis so far has provided robust evidence that the introduction of centralized procurement reduced prices. 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).

To investigate these issues we start by estimating the causal effect of centralization on quantities per contract. As discussed in Section 3, the order-level data do not contain information on the total quantity specified in the contract; however, we 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 devices ordered per contract. Results are presented in column 1 of Table 5 and suggest that the introduction of centralized procurement generated a systematic increase in quantities purchased by about 25%.

Note that the quantities ordered are in fact a lower bound of the quantities specified in the contract, because hospitals may end up ordering fewer units than what was listed in the contract. We therefore also consider an alternative specification in which we compute a proxy for the contracted quantities using the unitary price of the device and the total price at which the contract was awarded. The ratio between the contract price and the unit price provides a rough computation of the contracted quantities. There are two drawbacks to this approach. First, although the data on the total price at which the contract is awarded can be recovered from the open data portal of the AntiCorruption authority, the database contains many missing values. Second, a single contract might include multiple devices and it is impossible to disentangle the quantities in the contract for a particular device ID. Using the computed quantities, we estimate a larger effect of centralization on quantities per contract. Results are presented in column 2 of Table 5. We find that quantities increase by 33% in the centralized group of devices relative to the control group of devices.[17]

Next we provide evidence to rule out the possibility that the increase in quantities for each contract of a device 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 quantities purchased per contract increase nonetheless. Using our order-level data, in columns 1 and 2 of Table 6, we show that the monthly quantities for a particular device ordered by hospitals do not change and that the number of orders also does not change. The results are robust to the inclusion of device identifier, hospital, and month effects. Table 6 confirms that total demand has not increased.[18]

[17] Note that in the control group contracted quantities fall by 45%. This may be because the sample contains all medical devices not subject to centralization so it might be that the centralization involved a more efficient spending for all other devices not subject to it.

[18] This finding is also reassuring against the presence of possible spillovers from treated into untreated devices.

Table 5: Difference-in-differences for contract-level quantities

| Dep.Variable | (1)<br>Ln(Tot.Q.PerContractDevice) | (2)<br>Ln(Tot.Q.PerContractDeviceComputed) |
|---|---|---|
| CentralizedXPost | 0.2446** | 0.3364*** |
| | (0.118) | (0.114) |
| Post | -0.1687*** | -0.4521*** |
| | (0.038) | (0.058) |
| Observations | 13,526 | 7,674 |
| DeviceID FE | Yes | Yes |
| Hospital FE | No | No |
| Time FE | No | No |
| Mean Y Centralized Pre | 18193 | 31,800,000 |

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.PerContractDevice* represents the total purchased quantities associated with the contract for a device. *Tot.Q.PerContractDeviceComputed* represents the total computed quantities associated with the contract for a device. The computation is made inferring total quantities from unit price and total value of the contract. *Post* is a dummy variable equal to 1 if the contract for a particular device is observed 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. Significance at 10% (*), 5% (**), and 1% (***).

Table 6: Difference-in-differences for hospital demand

| Dep.Variable | (1)<br>Ln(Tot.Q.HospDeviceQuarter) | (2)<br>N.OrdersHospDeviceQuarter |
|---|---|---|
| CentralizedXPost | 0.1463 | -0.2545 |
| | (0.117) | (1.368) |
| Observations | 25,180 | 25,180 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 2400 | 7.782 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on quarterly total quantities ordered per device and hospital in a quarter (in log) and number of orders per device-hospital-quarter. *Tot.Q.HospDeviceQuarter* represents the total quantities of device ordered in a quarter by an individual hospital. *N.OrdersHospDeviceQuarter* represents the number of orders per device-hospital-quarter. *Post* is a dummy variable equal to 1 if the outcomes are observed after the centralization policy. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. In columns 1 and 2, we cluster standard errors at device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

## 5.1 Heterogeneous effects across hospitals

Heterogeneity in public buyers' characteristics has been shown to either dampen or amplify the impact of public procurement policies (see for example Bucciol et al., 2020). In this section we study whether the impact of centralization was heterogeneous across hospitals. To explore this possibility, we take advantage of the balance-sheet data collected for each hospital, using them to classify hospitals on the basis of their spending on procurement of health-related goods and services before centralization took place (and also on the basis of the non-health related personnel costs).

With this information we have estimated the effects of the centralization reform on the prices of centralized devices versus non-centralized devices for hospitals with procurement costs above and below the median of the pre-centralizastion distribution of these costs. In Columns 1 and 2 of Table 7 we report evidence that low-spending hospitals benefited the most from centralization. In Columns 3 and 4 of Table 7 we use a classification of hospitals based on pre-centralization non-health related personnel costs. We find similar evidence that hospitals with lower non-health related personnel costs benefited the most from centralization.

These findings are consistent with the possibility that low-spending hospitals may not be capable of getting lower prices in the pre-reform period as they had lower bargaining power (i.e., demand) and therefore benefit most from the bulk purchasing opportunities offered by the centralization experiment.

Table 7: Difference-in-differences for unitary prices – heterogeneity analysis based on hospital size

| Dep.Variable | (1)<br>Ln(Price) | (2)<br>Ln(Price) | (3)<br>Ln(Price) | (4)<br>Ln(Price) |
|---|---|---|---|---|
| AbovemedianXCentralizedXPost | 0.4659* | 0.4210*** | 0.3608* | 0.3605*** |
| | (0.270) | (0.163) | (0.207) | (0.140) |
| AbovemedianXPost | -0.2003 | -0.1993* | -0.1202 | -0.0614 |
| | (0.183) | (0.109) | (0.153) | (0.111) |
| AbovemedianXCentralized | -0.2735 | -0.2218** | -0.2240 | -0.2229** |
| | (0.199) | (0.110) | (0.140) | (0.093) |
| CentralizedXPost | -0.6297*** | -0.4817*** | -0.5245*** | -0.4148*** |
| | (0.198) | (0.133) | (0.144) | (0.116) |
| Post | 0.1340 | 0.0566 | 0.0456 | -0.0796 |
| | (0.186) | (0.117) | (0.161) | (0.128) |
| Observations | 176,062 | 176,062 | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 593.4 | 593.4 | 593.4 | 593.4 |
| Pval AbovemedianXCentralizedXPost+CentralizedXPost | 0.256 | 0.446 | 0.253 | 0.490 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the unitary price of orders (in logs). In Cols. 1 and 2 (3 and 4) *Abovemedian* is a dummy equal to 1 if the hospital has non-health personnel costs ( procurement costs for goods and services) pre-reform that are above the median. *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% (***).

## 5.2 Other possible mechanisms

One might be concerned that our results are driven not by increased quantities, but rather by a move to framework agreements (see discussion in Section 2). To confirm that an increased use of framework agreements is not driving our results, in the Appendix we also consider the impact of centralization on the likelihood that a contract is executed using a framework agreements. We find that centralization did not change the likelihood of framework agreements (Table A.15).

These results confirm that contracts are awarded for larger quantities and this despite the fact that hospital-level demand did not change. Since quantities increase and prices decrease, it must be that either hospital bargaining power was enhanced or bulk discounts related to economies of scale were generated.

# 6 Potential costs from centralization

In this section we investigate whether the pooling of contracts resulting from centralization generates any disadvantages that should be considered against the benefits from lower prices. Since, contracts that would have been submitted separately by individual hospitals at multiple different suppliers are pooled and placed with a smaller number of sellers, there may be consequences for market structure. Similarly, the increase in contract size could result in longer delays if suppliers cannot quickly adjust capacity or if procured devices must travel longer distances. We investigate these possibilities using balance-sheet data and suppliers' addresses of incorporation.

## 6.1 Market structure

To investigate the impact of centralization on market structure, we focus on changes in the number of suppliers and the HHI. We restrict attention to the suppliers that we can match with balance-sheet data, as described in Section 3. We perform the same sort of difference-and-differences analysis as above and report results in Table 8. Panel A examines changes in the number of suppliers and the HHI at the hospital-deviceID-quarter level, the same level of aggregation used in the preceding analysis.[19] Panel B instead considers changes at the deviceID-quarter level to better capture the overall effect on market structure.

From Panel A we can see that the number of suppliers per hospital-device-quarter significantly increases, with a small decline in the HHI index indicating that concentration falls slightly. We also decompose this concentration effect looking at whether the decrease comes from large or small firms. Results suggest that the decrease in concentration stems from the entry of large firms, i.e., those that have revenues higher than the median in the year prior to the enactment of the policy.

To confirm that these hospital-level effects translate into broader market-level effects we turn our attention to Panel B. Our findings suggest that the results hold. The num-

[19] Please note that the reform entered into force on February 9, 2016. Thus, collapsing quantities, number of orders, number of suppliers and HHI index at the hospital-device-quarter level is tricky. For simplicity, we include the first quarter of 2016 in the post-reform period.

Table 8: Difference-in-differences for number of suppliers and HHI by quarter

| Dep.Variable | (1) N.Suppl | (2) HHI | (3) N.Small | (4) ShareSmall | (5) N.Large | (6) ShareLarge |
|---|---|---|---|---|---|---|
| | Panel A: Market defined by hospital-deviceID-quarter | | | | | |
| CentralizedXPost | 0.1423** | -0.0424*** | -0.0230 | -0.0409* | 0.1678*** | 0.0409* |
| | (0.060) | (0.012) | (0.030) | (0.023) | (0.058) | (0.023) |
| Observations | 20,751 | 20,751 | 20,185 | 20,185 | 20,185 | 20,185 |
| Mean Y Centralized Pre | 1.174 | 0.955 | 0.161 | 0.144 | 1.013 | 0.856 |
| DeviceID FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| | Panel B: Market defined by deviceID-quarter | | | | | |
| CentralizedXPost | 0.6553*** | -0.1000*** | 0.0950* | -0.0617** | 0.5781*** | 0.0617** |
| | (0.102) | (0.019) | (0.050) | (0.027) | (0.089) | (0.027) |
| Observations | 11,387 | 11,387 | 11,016 | 11,016 | 11,016 | 11,016 |
| Mean Y Centralized Pre | 1.776 | 0.839 | 0.315 | 0.165 | 1.461 | 0.835 |
| DeviceID FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Hospital FE | No | No | No | No | No | No |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on the number of firms (*N.Suppl*) per hospital-deviceID-quarter (in Panel A, and deviceID-quarter in Panel B); HHI is the Herfindahl index; *N.Small* (*N.Large*) is the number of small (large) suppliers per with revenues from sales pre-reform that are below (above) the median. *Post* is a dummy variable equal to 1 if the contract for a particular device is observed 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 hospital-deviceID (in Panel A, and deviceID in Panel B) level. Significance at 10% (*), 5% (**), and 1% (***).

ber of suppliers increases and the HHI falls, with large suppliers substituting for small suppliers.

These results can be explained by the fact that the Italian authorities were aware of the potential danger for centralization to limit competition. The authorities actively worked to prevent competition from being affected by splitting procurement contracts into lots, in order to strike a balance between increasing buyer bargaining power and the degree of competition. The approach is described in Albano and Sparro (2010) and Grimm et al. (2006), and corroborated by OECD (2015). As a result of these efforts, the number of contracts actually increased slightly following centralization.[20]

However, there may still be long-term ramifications for competition in public procurement if smaller suppliers are prevented from participating because of the size of contracts relative to their capacity. If centralization creates a barrier to entry for these sellers, in the long-run they may be locked out and competition could suffer. Our results suggest

[20] This is confirmed via regression. We regress the number of contracts per device-hospital-quarter on an indicator for centralized x post along with fixed effects for device, hospital and time, and we find that centralization increases the number of contracts by 0.1845, significant at the 1%.

that this may indeed be a concern. We find that the increase in the number of suppliers is driven entirely by large firms (according to their balance sheets), suggesting that small and medium size players may have nonetheless ended up getting squeezed from the market.

Table 9: Difference-in-differences for unitary prices – heterogeneity analysis based firm-level revenues

| Dep.Variable | (1) Ln(Price) | (2) Ln(Price) |
|---|---|---|
| LargeXCentralizedXPost | -0.9130*** | -1.2037*** |
| | (0.295) | (0.273) |
| LargeXCentralized | 0.2582 | 0.4735*** |
| | (0.211) | (0.155) |
| LargeXPost | -0.0458 | -0.0465 |
| | (0.128) | (0.113) |
| CentralizedXPost | 0.6288** | 1.0137*** |
| | (0.270) | (0.263) |
| Large | -0.3709*** | -0.3921*** |
| | (0.109) | (0.080) |
| Post | 0.0308 | -0.0449 |
| | (0.139) | (0.117) |
| Ln(Quantity) | | -0.5521*** |
| | | (0.019) |
| Ln(ValueContract) | | -0.0603** |
| | | (0.025) |
| Observations | 138,342 | 138,342 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 625.6 | 625.6 |
| Pval $LargeXCentralizedXPost + CentralizedXPost = 0$ | 0.0250 | 0.0170 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the unitary price of orders (in logs). *Large* is a dummy equal to 1 if the firm has revenues from sales pre-reform that are above the median. *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% (***).

At the same time, it turns out that the price effect estimated in Section 4 is stronger for larger firms. To investigate this we measure size using the firm balance sheet data and we define a firm as large if the firm has revenues from sales pre-reform that are above the median, and then we estimate the following difference-in-difference-in-difference model:

$$\begin{aligned} Ln(P_{odchst}) = {} & \beta_0 + \beta_1 Large_s \times Centralized_d \times Post_t + \beta_2 Large_s \times Post_t \\ & + \beta_3 Large_s \times Centralized_d + \beta_4 Centralized_d \times Post_t \\ & + \beta_5 Large_s + \beta_6 Post + \beta_7 Ln(Quantity)_{odchst} + \beta_8 Ln(ContractValue)_c \\ & + \theta_d + \gamma_h + \delta_t + \epsilon_{odchst}, \end{aligned} \quad (3)$$

where $P_{odcht}$ is the unitary price for order $o$, of device $d$, for contract $c$ in hospital $h$ by supplier $s$ in quarter $t$. *Large* is a dummy equal to 1 if the firm has sales above the median, $\theta_d$ are device fixed effects, $\gamma_h$ are hospital fixed effects and $\delta_t$ are quarter fixed effects. *Centralized* is a dummy equal to 1 for devices subject to centralization and a dummy *Post* equal to 1 if the order is issued after February 9, 2016. In all columns, we include hospital and device fixed effects together with time (quarter) fixed effects.

Our findings suggest that the decrease in prices observed in Table 3 is mostly coming from large firms. This could be because large firms are those operating at greater scale due to bulk purchasing, consistent with our findings in Section 5.

## 6.2 Delays

Next we investigate whether the lower prices resulting from centralization may have 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. The latter event could occur for instance because, as already shown, the centralized orders are filled by a smaller number of suppliers. If prices fall, but delivery times become longer, then the overall impact of centralization is ambiguous and may even be negative. Despite this, to our knowledge, the causal relationship between centralization and delivery times has not been examined.

Table 10: Difference-in-differences for delays

| | (1) | (2) |
|---|---|---|
| Dep.Variable | LogDays | LogDays |
| CentralizedXPost | 0.0369 | 0.0385 |
| | (0.133) | (0.134) |
| Post | -0.2658*** | -0.2663*** |
| | (0.081) | (0.083) |
| Ln(Quantity) | | -0.0186** |
| | | (0.008) |
| Ln(ValueContract) | | -0.0202 |
| | | (0.016) |
| Observations | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 15.26 | 15.26 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralized procurement on delivery delays of orders. *Post* is a dummy variable equal to 1 if the contract for a particular device is observed 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. Significance at 10% (*), 5% (**), and 1% (***).

Table 10 presents estimation results from a difference-in-differences regression similar to the one specified in equation (1) but replacing price with delay, measured in delivery days, as the dependent variable. Our findings suggest that centralization has no significant impact on delivery times, implying that there is no real tradeoff between lower prices and delayed delivery of products.[21]

This result is somewhat surprising. As mentioned, one might have expected that under centralization procured devices would have had to travel longer distances and/or that some suppliers might have found it difficult to quickly adjust capacity – especially smaller suppliers. To investigate these two possibilities we leverage balance-sheet data and suppliers' addresses of incorporation. We also consider the possibility that penalties for delay increased following centralization, incentivizing suppliers to deliver on time and helping to explain our finding that delays do not increase.

Table 11: Difference-in-differences for supplier distances (from hospitals)

| Dep.Variable | (1)<br>Distance (km) | (2)<br>Log(Distance) |
|---|---|---|
| Centralized×Post | -11.7846 | -0.1129 |
| | (21.321) | (0.180) |
| Post | 69.8857*** | 0.6464*** |
| | (20.745) | (0.188) |
| Observations | 141,502 | 141,492 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 241 | 241 |

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 outcome is observed 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 (in km) between the address of the supplier and the address of the health unit. Significance at 10% (*), 5% (**), and 1% (***).

We start by investigating the impact of centralization on shipping distance. With larger suppliers who might be located elsewhere in the country (or abroad), shipping times might increase, possibly leading to an 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 11. We find that the coefficient of the interaction term $Centralized \times Post$ is not significant suggesting that centralization did not lead shipping distances to increase. This result is robust to the use of the logarithm of the distance. 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 241km.

Another concern is that, as contract sizes increased, suppliers might not have been able to adjust capacity quickly enough and so would have trouble filling orders on time. Smaller, capacity-constrained suppliers might be especially affected. We investigate this possibility by estimating the same difference-in-difference-in-difference model as in equa-

[21] These results imply a small elasticity of delivery time with respect to prices of .28 (0.0385/0.1374) that is not statistically significant.

tion (3) but replacing price with delay, measured in delivery days, as the dependent variable. Results are reported in Table 12 and confirm that there is no effect on delays, and that there is no differential by size. In particular, smaller suppliers do not experience longer delays following centralization.

Table 12: Difference-in-differences for delays – heterogeneity analysis based firm-level revenues

| Dep.Variable | (1)<br>LogDays | (2)<br>LogDays |
|---|---|---|
| LargeXCentralizedXPost | 0.2212 | 0.2116 |
| | (0.281) | (0.280) |
| LargeXCentralized | -0.6401*** | -0.6339*** |
| | (0.217) | (0.215) |
| LargeXPost | 0.2402*** | 0.2395*** |
| | (0.088) | (0.087) |
| CentralizedXPost | -0.1160 | -0.1036 |
| | (0.228) | (0.227) |
| Large | -0.1750*** | -0.1741*** |
| | (0.065) | (0.064) |
| Post | -0.4429*** | -0.4449*** |
| | (0.118) | (0.119) |
| Ln(Quantity) | | -0.0201** |
| | | (0.008) |
| Ln(ValueContract) | | -0.0050 |
| | | (0.014) |
| Observations | 138,342 | 138,342 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 15.35 | 15.35 |
| Pval LargeXCentralizedXPost+CentralizedXPost | 0.536 | 0.527 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on delivery delays of orders (in logs). *Large* is a dummy equal to 1 if the firm has revenues from sales pre-reform that are above the median. *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% (***).

To investigate the possibility that penalties for delay increased following centralization, thereby motivating suppliers to deliver on time and helping to explain the fact that delays do not increase, we have collected data on the contractual penalties explicitly mentioned in a sub-sample of calls for tender that we are capable of matching with our order data. We then consider a difference-in-differences specification similar to the one in equation (1) but with penalties as the dependent variable to test whether centralized devices have different penalties following the centralization reform compared to control devices. Our findings are presented in Table 13 and show that the centralization reform had no significant impact on the penalties for treated devices, implying that it was not because of an increase in penalties that delays did not increase. In columns (3) and (4) we also explore the heterogenous effects of centralization by penalty size. Low penalties are defined as those for which the size of the fine is below the 25th percentile of the penalty distribution pre-reform. The evidence from Table 13 indicates that centralization increases delivery times when penalties are small.

Table 13: Difference-in-differences for penalties and days of delivery

| Dep.Variable | (1) PenaltiesEUR | (2) PenaltiesEUR | (3) LogDays | (4) LogDays |
|---|---|---|---|---|
| HighPenaltyXCentralizedXPost | | | -1.0755*** | -1.0089*** |
| | | | (0.144) | (0.217) |
| HighPenaltyXCentralized | | | 1.0837*** | 1.1054*** |
| | | | (0.059) | (0.177) |
| HighPenaltyXPost | | | 0.2180 | 0.1997 |
| | | | (0.146) | (0.136) |
| CentralizedXPost | -80.0404* | -37.9607 | 1.0663*** | 0.9956*** |
| | (41.639) | (80.707) | (0.144) | (0.211) |
| HighPenalty | | | -0.0432 | 0.0077 |
| | | | (0.049) | (0.050) |
| Ln(Quantity) | | 43.6197*** | | -0.0601** |
| | | (10.874) | | (0.024) |
| Ln(ValueContract) | | 183.7691** | | 0.0102 |
| | | (89.406) | | (0.062) |
| Observations | 6,991 | 6,991 | 6,991 | 6,991 |
| DeviceID FE | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 1291 | 1291 | 12.63 | 12.63 |
| Pval HighPenaltyXCentralizedXPost+CentralizedXPost | | | 0.898 | 0.851 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the penalties per day (€) and days of delivery (in logs). *HighPenalty* is a dummy variable equal to 1 if the penalty per day is above the 25th percentile of the penalties pre-reform, 0 otherwise. *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% (***).

Finally, we also consider the possibility that under centralization the order date is moving closer to the auction date (and hence earlier) because the system is more efficient at recording the process under centralization. We tested for this possibility and report results in Table A.10, which suggests that there are no effects of the centralization reform on the distance between order date and auction dates. For a small sub-set of our data we managed to locate information on planned delivery dates. With these data we compute a measure of days of delay relative to the planned delivery date and in Table A.12 we show that centralization has positive but not statistically significant effects on delays, and it has negative and not statistically significant effect on this outcome for treated devices compared to controls when we control for the quantities ordered (in log) and the value of the contract (in log). In the same sub-sample we confirm our main evidence that delivery days are not affected by centralization. As a sanity check we verified that in this sub-sample centralization has the same price effects as in the main sample, and we find that they are even stronger. With this data, in Table A.14 we repeated our analysis controlling for the timing of contract (cols 1-2) or order (cols 3-4), and find no effect of centralization on delivery times.

# 7 Conclusion

We study the effect of mandatory centralized procurement on prices, market structure, and delivery times of hospital medical devices. Our identification strategy takes advantage of the fact that starting in 2016, all hospitals were required to buy a sub-set of devices (stents, incontinence aids, hip replacements, general dressings, defibrillators, pacemakers, needles, syringes) using a central buyer while other devices could be directly purchased by hospitals. We use a unique administrative dataset on the purchases and deliveries of these medical devices, and leverage balance-sheet data and suppliers' addresses of incorporation.

Consistent with the literature, we document that unitary prices decreased following centralization. We also find that centralization resulted in more contracts per hospital and a greater number of suppliers such that the level of concentration fell. These findings reflect the fact that Italian authorities endeavored to prevent a decrease in competition by splitting procurement contracts into lots. However, we also that the increase in the number of suppliers is driven entirely by large firms suggesting that small and medium size players may have ended up getting squeezed from the market. Lastly, we find that there is no statistically significant effect on delivery times, which is related to our findings on market structure – larger suppliers increased market share and these firms may be able to quickly scale up in order to meet delivery times.

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# A Appendix

## A.1 Device identifiers

Table A.1: Example of device identifiers

| DeviceID | Description |
|---|---|
| A01010101 | hypodermic needlesm for syringes |
| A010102 | Butterfly needles |
| P09080401 | Femoral stems for primary implant |
| F0303 | Kit for emodialisis |
| T0304 | Protections for radiotherapy |

List of alphanumeric device identifiers and the related description. We use these identifiers as our *DeviceID* fixed effects.

## A.2 Test parallel trend

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

| | (1) | (2) |
|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Days) |
| Centralized$XQ1_{2015}$ | 0.0502 | 0.0512 |
| | (0.062) | (0.084) |
| Centralized$XQ2_{2015}$ | 0.0152 | 0.2802* |
| | (0.042) | (0.166) |
| Centralized$XQ3_{2015}$ | 0.0361 | 0.2898*** |
| | (0.043) | (0.103) |
| Centralized$XQ1_{2016}$ | 0.0833 | 0.1741 |
| | (0.063) | (0.117) |
| Centralized$XQ2_{2016}$ | 0.0143 | 0.1910 |
| | (0.095) | (0.161) |
| Centralized$XQ3_{2016}$ | -0.0810 | -0.1353 |
| | (0.077) | (0.266) |
| Centralized$XQ4_{2016}$ | -0.0661 | 0.3180** |
| | (0.107) | (0.132) |
| Centralized$XQ1_{2017}$ | 0.3091 | 0.2501 |
| | (0.199) | (0.180) |
| Centralized$XQ2_{2017}$ | -0.2096 | 0.1207 |
| | (0.146) | (0.145) |
| Centralized$XQ3_{2017}$ | -0.0327 | 0.0786 |
| | (0.105) | (0.148) |
| Centralized$XQ4_{2017}$ | -0.3858*** | 0.1183 |
| | (0.132) | (0.132) |
| Centralized$XQ1_{2018}$ | -0.0579 | 0.2909** |
| | (0.112) | (0.122) |
| Centralized$XQ2_{2018}$ | -0.1717* | 0.4969*** |
| | (0.098) | (0.152) |
| Ln(Quantity) | -0.5409*** | -0.0185** |
| | (0.018) | (0.008) |
| Ln(ValueContract) | -0.0717*** | -0.0206 |
| | (0.021) | (0.016) |
| Observations | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 593.4 | 15.26 |
| Pvalue Joint Test Pre 2016 Coefficients | 0.636 | 0.0446 |

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 $CentralizedXQ1_{2015} = CentralizedXQ2_{2015} = CentralizedXQ3_{2015}$. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.3: Test of a common linear trend for unitary prices and delivery times for the group of centralized and non-centralized devices before February 9, 2016.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Price) | Ln(Days) | Ln(Days) |
| TreatmentXQuarter | -0.0098 | -0.0083 | -0.0245 | -0.0245 |
| | (0.012) | (0.013) | (0.036) | (0.036) |
| Ln(Quantity) | | -0.5228*** | | -0.0002 |
| | | (0.019) | | (0.008) |
| Ln(ValueContract) | | -0.0669*** | | -0.0216 |
| | | (0.018) | | (0.016) |
| Observations | 114,107 | 114,107 | 114,107 | 114,107 |
| DeviceID FE | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 593.4 | 593.4 | 15.26 | 15.26 |

Notes: Coefficient (standard error in parentheses) of the interaction term between *Centralized* and a linear trend (*Quarter*) on the unitary price of orders (columns 1-2) and days of delivery (columns 3-4) 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 Old contracts

Table A.4: Difference-in-differences for unitary prices and delivery times. In the period post-reform, only orders associated to contracts published before the reform are considered.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Price) | Ln(Days) | Ln(Days) |
| CentralizedXPost | 0.0028 | -0.0361 | 0.0726 | 0.0701 |
| | (0.044) | (0.039) | (0.071) | (0.072) |
| Post | -0.0198 | -0.0199 | -0.0185 | -0.0179 |
| | (0.023) | (0.021) | (0.027) | (0.027) |
| Ln(Quantity) | | -0.5120*** | | -0.0168** |
| | | (0.018) | | (0.007) |
| Ln(ValueContract) | | -0.0625*** | | -0.0189 |
| | | (0.016) | | (0.012) |
| Observations | 257,273 | 257,273 | 257,273 | 257,273 |
| DeviceID FE | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 593.4 | 593.4 | 15.24 | 15.24 |

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% (***).

## A.4 Robustness

Table A.5: Difference-in-differences for unitary prices and delivery times. Standard errors are clustered at the device level.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Price) | Ln(Price) | Ln(Days) | Ln(Days) | Ln(Days) |
| CentralizedXPost | -0.2463** | -0.1374 | 0.0369 | 0.0385 | | |
| | (0.113) | (0.091) | (0.130) | (0.132) | | |
| Post | -0.0557 | -0.1318 | -0.2658*** | -0.2663*** | | |
| | (0.101) | (0.084) | (0.093) | (0.097) | | |
| Ln(Quantity) | | -0.5409*** | | -0.0186** | | |
| | | (0.025) | | (0.009) | | |
| Ln(ValueContract) | | -0.0717** | | -0.0202 | | |
| | | (0.030) | | (0.022) | | |
| Observations | 176,062 | 176,062 | 176,062 | 176,062 | | |
| DeviceID FE | Yes | Yes | Yes | Yes | | |
| Hospital FE | Yes | Yes | Yes | Yes | | |
| Time FE | Yes | Yes | Yes | Yes | | |
| Mean Y Centralized Pre | 593.4 | 593.4 | 15.26 | 15.26 | | |

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 level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.6: Quantile difference-in-differences estimation for unitary prices

| VARIABLES | (1)<br>LogPriceQ10 | (2)<br>LogPriceQ20 | (3)<br>LogPriceQ30 | (4)<br>LogPriceQ40 | (5)<br>LogPriceQ50 | (6)<br>LogPriceQ60 | (7)<br>LogPriceQ70 | (8)<br>LogPriceQ80 | (9)<br>LogPriceQ90 |
|---|---|---|---|---|---|---|---|---|---|
| CentralizedXPost | -0.1732* | -0.1617* | -0.1538** | -0.1465** | -0.1383** | -0.1304* | -0.1219* | -0.1133 | -0.1007 |
| | (0.102) | (0.087) | (0.078) | (0.072) | (0.068) | (0.068) | (0.072) | (0.079) | (0.094) |
| Post | -0.0774 | -0.0948 | -0.1068 | -0.1179* | -0.1304** | -0.1425** | -0.1553** | -0.1685** | -0.1875** |
| | (0.078) | (0.072) | (0.069) | (0.067) | (0.066) | (0.066) | (0.067) | (0.070) | (0.076) |
| Ln(Quantity) | -0.5254*** | -0.5303*** | -0.5338*** | -0.5370*** | -0.5405*** | -0.5440*** | -0.5477*** | -0.5514*** | -0.5569*** |
| | (0.021) | (0.019) | (0.018) | (0.018) | (0.018) | (0.018) | (0.018) | (0.019) | (0.022) |
| Ln(ValueContract) | -0.0787*** | -0.0765*** | -0.0749*** | -0.0735*** | -0.0719*** | -0.0704*** | -0.0687*** | -0.0671*** | -0.0646*** |
| | (0.025) | (0.023) | (0.022) | (0.021) | (0.021) | (0.020) | (0.020) | (0.020) | (0.020) |
| Observations | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 593.4 | 593.4 | 593.4 | 593.4 | 593.4 | 593.4 | 593.4 | 593.4 | 593.4 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization for centralized devices (*Centralized*×*Post*) at different quantiles for unitary prices (in logs). The estimation method used is the method of moments. *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.7: Quantile difference-in-differences estimation for delivery times

| VARIABLES | (1)<br>LogDeliveryQ10 | (2)<br>LogDeliveryQ20 | (3)<br>LogDeliveryQ30 | (4)<br>LogDeliveryQ40 | (5)<br>LogDeliveryQ50 | (6)<br>LogDeliveryQ60 | (7)<br>LogDeliveryQ70 | (8)<br>LogDeliveryQ80 | (9)<br>LogDeliveryQ90 |
|---|---|---|---|---|---|---|---|---|---|
| CentralizedXPost | 0.1077 | 0.0826 | 0.0669 | 0.0534 | 0.0408 | 0.0274 | 0.0122 | -0.0058 | -0.0311 |
| | (0.127) | (0.125) | (0.126) | (0.129) | (0.133) | (0.138) | (0.145) | (0.155) | (0.172) |
| Post | -0.1716 | -0.2060** | -0.2274*** | -0.2458*** | -0.2631*** | -0.2814*** | -0.3022*** | -0.3268*** | -0.3613*** |
| | (0.112) | (0.095) | (0.087) | (0.083) | (0.082) | (0.083) | (0.088) | (0.098) | (0.116) |
| Ln(Quantity) | 0.0020 | -0.0055 | -0.0101 | -0.0141* | -0.0179** | -0.0219*** | -0.0264*** | -0.0317*** | -0.0392*** |
| | (0.008) | (0.008) | (0.007) | (0.007) | (0.007) | (0.008) | (0.008) | (0.009) | (0.010) |
| Ln(ValueContract) | 0.0317* | 0.0129 | 0.0011 | -0.0090 | -0.0185 | -0.0285* | -0.0399** | -0.0534*** | -0.0723*** |
| | (0.017) | (0.016) | (0.015) | (0.015) | (0.016) | (0.016) | (0.016) | (0.017) | (0.019) |
| Observations | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 15.26 | 15.26 | 15.26 | 15.26 | 15.26 | 15.26 | 15.26 | 15.26 | 15.26 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization for centralized devices (*Centralized*×*Post*) at different quantiles for delivery times (in logs). The estimation method used is the method of moments. *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.8: Difference-in-differences for unitary prices: unitary prices collapsed by contract, device, hospital, and product code

| | (1) | (2) |
|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Price) |
| CentralizedXPost | -0.2642*** | -0.2183*** |
| | (0.087) | (0.071) |
| Post | 0.3708*** | 0.2561* |
| | (0.121) | (0.132) |
| Ln(Quantity) | | -0.3354*** |
| | | (0.014) |
| Ln(ValueContract) | | -0.0780*** |
| | | (0.022) |
| Observations | 17,709 | 17,709 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 722 | 722 |

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 the unitary price is observed after January 2016. *Centralized* is a dummy variable equal to 1 if the medical device is subject to centralization. SEs are clustered at the device-hospital level. *Ln(Quantity)* is the log of total quantities purchased for each contract-device-hospital-product. Significance at 10% (*), 5% (**), and 1% (***).

Table A.9: Difference-in-differences for unitary prices and delivery times. We use model numbers as our device identifiers fixed effects.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Price) | Ln(Days) | Ln(Days) |
| CentralizedXPost | -0.1427*** | -0.1137** | -0.0798 | -0.0626 |
| | (0.054) | (0.052) | (0.075) | (0.075) |
| Centralized | 0.2661 | 0.0885 | 0.4968** | 0.4423* |
| | (0.272) | (0.227) | (0.225) | (0.234) |
| Post | -0.0034 | -0.0741 | -0.2983*** | -0.2614** |
| | (0.074) | (0.063) | (0.115) | (0.111) |
| Ln(Quantity) | | -0.3082*** | | -0.0106 |
| | | (0.016) | | (0.008) |
| Ln(ValueContract) | | -0.0163 | | 0.0899*** |
| | | (0.016) | | (0.015) |
| Observations | 110,838 | 110,838 | 110,838 | 110,838 |
| Model Number Device FE | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 586.5 | 586.5 | 15.31 | 15.31 |

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 product code-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.10: Difference-in-differences for the difference between the order date and the date of publication of the tender (in log)

| | (1) | (2) |
|---|---|---|
| Dep.Variable | LogDaysDiffAuctionOrder | LogDaysDiffAuctionOrder |
| CentralizedXPost | 0.0369 | 0.0385 |
| | (0.133) | (0.134) |
| Post | -0.2658*** | -0.2663*** |
| | (0.081) | (0.083) |
| Ln(Quantity) | | -0.0186** |
| | | (0.008) |
| Ln(ValueContract) | | -0.0202 |
| | | (0.016) |
| Observations | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 873.3 | 873.3 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the difference between the order date and the publication date of the tender (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.11: Correlation between delivery times and contract value and between delivery times and order value (in log)

| Dep.Variable | (1) | (2) |
|---|---|---|
| Ln(ValueContract) | -0.0211 | |
| | (0.016) | |
| Ln(OrderValue) | | -0.0091 |
| | | (0.010) |
| Observations | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 15.26 | 15.26 |

Notes: Column 1 reports the correlation (standard error in parentheses) between the delivery days and the value of the contract (in logs). Column 2 reports the correlation (standard error in parentheses) between the delivery days and the value of the order (in logs). SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.12: Difference-in-differences for delivery days, days of delay and planned days for delivery

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Dep.Variable | DaysDelivery | DaysDelivery | DaysDelay | DaysDelay | DaysPlanned | DaysPlanned |
| CentralizedXPost | 2.6873** | 1.9887 | 9.5992*** | 7.7053 | -6.9119** | -5.7166 |
| | (1.176) | (1.289) | (3.659) | (5.088) | (3.384) | (4.612) |
| Ln(Quantity) | | -0.8044*** | | -1.6223*** | | 0.8179** |
| | | (0.298) | | (0.441) | | (0.365) |
| Ln(ValueContract) | | -0.5995 | | -6.1731 | | 5.5736 |
| | | (0.844) | | (4.394) | | (3.947) |
| Observations | 8,566 | 8,566 | 8,566 | 8,566 | 8,566 | 8,566 |
| DeviceID FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 40.46 | 40.46 | 37.04 | 37.04 | 3.418 | 3.418 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on days of delivery (*DaysDelivery*), days of delay (*DaysDelay*) and days of planned delivery (*DaysPlanned*). *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.13: Difference-in-differences for unitary prices and delivery times. Subsample of contracts for which we have data on planned delivery.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Dep.Variable | Ln(Price) | Ln(Price) | Ln(Days) | Ln(Days) |
| CentralizedXPost | -0.3085*** | -0.6103*** | 0.0582 | 0.0233 |
| | (0.063) | (0.094) | (0.098) | (0.094) |
| Ln(Quantity) | | -0.3605*** | | -0.0439** |
| | | (0.061) | | (0.019) |
| Ln(ValueContract) | | -0.1538 | | 0.0003 |
| | | (0.100) | | (0.061) |
| Observations | 8,566 | 8,566 | 8,566 | 8,566 |
| DeviceID FE | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Mean Y Centralized Pre | 347.7 | 347.7 | 40.46 | 40.46 |

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% (***).

Table A.14: Difference-in-differences for delivery times controlling for publication date of the contract and order date.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Dep.Variable | Ln(Days) | Ln(Days) | Ln(Days) | Ln(Days) |
| CentralizedXPost | 0.0390 | 0.0416 | 0.0364 | 0.0382 |
| | (0.128) | (0.129) | (0.131) | (0.132) |
| Post | -0.3290*** | -0.3273*** | -0.2103*** | -0.2103** |
| | (0.085) | (0.087) | (0.082) | (0.083) |
| Ln(Quantity) | | -0.0186** | | -0.0195*** |
| | | (0.007) | | (0.007) |
| Ln(ValueContract) | | -0.0110 | | -0.0198 |
| | | (0.016) | | (0.016) |
| DatePublicationContract | 0.0001*** | 0.0001*** | | |
| | (0.000) | (0.000) | | |
| DateOrder | | | -0.0012*** | -0.0012*** |
| | | | (0.000) | (0.000) |
| Observations | 176,062 | 176,062 | 176,062 | 176,062 |
| DeviceID FE | Yes | Yes | Yes | Yes |
| Hospital FE | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Mean Y Centralization Pre | 15.26 | 15.26 | 15.26 | 15.26 |

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. *DatePublicationContract* is the date of the publication of the tender. *DateOrder* is the date of the order. SEs are clustered at the device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

Table A.15: Probability that the group of orders for a device is associated to a contract

| | (1) | (2) |
|---|---|---|
| Dep.Variable | Framework (0/1)) | Framework (0/1) |
| CentralizedXPost | 0.0443 | 0.0455 |
| | (0.033) | (0.033) |
| Post | 0.4600*** | 0.4516*** |
| | (0.027) | (0.027) |
| Ln(Quantity) | | 0.0126*** |
| | | (0.003) |
| Ln(ValueContract) | | 0.0127*** |
| | | (0.003) |
| Observations | 13,525 | 13,525 |
| DeviceID FE | Yes | Yes |
| Hospital FE | Yes | Yes |
| Time FE | Yes | Yes |
| Mean Y Centralized Pre | 0.791 | 0.791 |

Notes: Coefficient (standard error in parentheses) of the effect of mandatory centralization on the probability that there are multiple orders for the same contract for the same device, 0 otherwise. *Post* is a dummy variable equal to 1 if the order is 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% (***).