GETTING THE PRICE RIGHT? THE IMPACT OF COMPETITIVE BIDDING IN THE MEDICARE PROGRAM

Hui Ding, Mark Duggan, and Amanda Starc*

Abstract—We study Medicare's competitive bidding program for durable medical equipment. We use Medicare claims data to examine the effect on prices and utilization, focusing on continuous positive airway pressure devices for sleep apnea. We find that spending falls by 47.2% after a highly imperfect bidding mechanism is introduced. This is almost entirely driven by a 44.8% price reduction, though quantities also fall by 4.3%. To disentangle supply and demand, we leverage differential cost sharing across Medicare recipients. We measure a demand elasticity of −0.272 and find that quantity reductions are concentrated among less clinically appropriate groups.

I. Introduction

PRICES convey information about consumer willingness to pay for a good or service and about its cost of production. Yet in many health care markets, the information aggregation properties of prices are distorted. Most insured consumers do not face market prices, and reimbursements are often set administratively. Prices may be substantially different from a competitive price and can be influenced by medical specialty societies, potentially leading to regulatory capture (Chan & Dickstein, 2019). Market price-setting mechanisms may also be imperfect. For example, in health care, one finds an implicit reliance on administered prices (Clemens & Gottlieb, 2017; Clemens et al., 2017), and firms can exert substantial market power (Cooper et al., 2019). Perhaps as a result, high prices are a key feature of relatively high health care costs in the United States (Anderson et al., 2003). In this paper, we examine how market institutions can control health care costs; specifically, we measure the impact of a shift from administered prices to a more market-based mechanism.

The Medicare program provided health insurance coverage to 62.8 million U.S. residents in 2020 at an annual cost of more than $800 billion (CMS, 2020a). For most Medicare recipients, the federal government directly reimburses hospitals, physicians, and other health care providers for the services delivered to patients. Prices for each service are determined by a complex set of regulations that vary by service type.[1] In part because of concerns about inefficiency in its price-setting process, Medicare has recently tried to inject market forces for certain health care services. One example of this is durable medical equipment (DME), which includes wheelchairs, oxygen concentrators, and dozens of other health care products.

In July of 2010, the Centers for Medicare and Medicaid Services (CMS) piloted a competitive bidding program (CBP) in nine areas around the country for a subset of DME products. Suppliers were asked to submit price bids for each product, and CMS selected the lowest bids, subject to the constraint that the winning suppliers could meet the total demand in these regions. In 2013, 100 regions were added, and the process was replicated for an expanded set of products. Before the CBP, Medicare set prices using a fee schedule based on supplier charges to Medicare during the 1980s and increased these amounts annually. These prices were adjusted by state, reflecting geographic price differences that were subject to national floor and ceiling price limits.[2] Evidence suggests that these prices paid by Medicare were often higher than market rates for various DME items and lowered to rates comparable to the prices paid by commercial insurers after the CBP (GAO, 2016; Newman et al., 2017).

CMS selected metropolitan areas with a large population and high DME costs to roll out CBP. In 2010, about 55% of Medicare recipients resided in an area where competitive bidding would apply by 2013. CMS selected high-cost and high-volume products to include in the competitive bidding process: the products included in competitive bidding in 2011 or 2013 accounted for more than half of DME expenditures in 2010. We leverage variation across geographic areas and across products in the use of competitive bidding. Medicare's competitive bidding process dramatically reduced spending, and most of the reduction was due to lower prices. Our findings reveal that spending on DME products included in competitive bidding fell by 47.2% and that this effect persisted over time.[3]

To better understand how the program affected consumers and suppliers, we next focus on a specific DME product: continuous positive airway pressure (CPAP) machines. The

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*Ding: Fudan University; Duggan: Stanford University and NBER; Starc: Northwestern University and NBER.

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[1]For example, prices for physician services are determined by the resource-based relative value scale (RBRVS). These prices are updated annually for more than 10,000 different procedures and vary with the estimated costs to provide each service.

[2]Price limits on a per claim basis were derived from the state-level fee-for-service payment. The price ceiling was set at the median of the state-level fee schedule amounts. The price floor was set as 85% of the median of the state-level fee schedule amounts. In 2016, CMS started to adjust these fee schedule to incorporate single-payment amounts from the CBP in noncompetitive bidding areas.

[3]We also find evidence for some substitution across DME products, with utilization actually increasing for those DME products not included in competitive bidding. When we account for this substitution, our estimated effects are slightly attenuated, with a 38.2% price reduction and a 7.8% decline in utilization.

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machine is the gold standard of treatment for obstructive sleep apnea (OSA).[4] Conditional on symptoms, a patient may decide to visit his or her doctor. The doctor may diagnose the patient as having one or more forms of sleep apnea.[5] Conditional on a sleep apnea diagnosis, the patient may be prescribed a CPAP machine. After the prescription, patients can rent a CPAP from suppliers.

CPAP machines are a particularly good market to study. First, sleep apnea diagnoses are linked to enrollees in the data. Second, a single product is included in the sample (E0601-RR), so a reduction in quantity demanded cannot be attributed to a rise in substitute products. Third, sleep apnea is a highly prevalent condition, especially among males and the elderly (Senaratna et al., 2017). Sleep apnea is associated with multiple health consequences such as cardiovascular disease and traffic accidents (Marin et al., 2005). In particular, evidence is increasing of a link between sleep apnea and higher risk for depression, anxiety, and suicidal ideation (Choi et al., 2015; Kaufmann et al., 2017; McCall et al., 2019). Given increasing suicide rates in the United States and the disparities by gender and age (Duggan & Scimeca, 2018), proper assessment and treatment for Medicare beneficiaries are increasingly important. Finally, CPAP is relatively large in terms of total Medicare spending (ranked sixth among DME products in 2010). Cost sharing is a substantial burden: 20% of the rental fee amounts to approximately $80 per month over our sample period.

Before competitive bidding, Medicare was spending nearly $200 million annually on CPAP machines, with rental payments making up most of this amount. Once CMS has made thirteen monthly rental payments for a CPAP machine, the Medicare recipient effectively owns it. Our results reveal that competitive bidding reduced the average rental price by 45% and utilization of this product by 4.3%. This effect was driven by a decline in both the extensive margin and the intensive margin.

Given the reduction in quantity, the overall impact of the policy change is unclear. We ask two key questions. First, to what extent are reductions in utilization due to reduced supply? Second, did the program ration care appropriately? To answer the first question, we explore whether the magnitude of the change in utilization differed for Medicare recipients who are dually eligible for the Medicaid program, as this group does not contribute to the cost of their medical care. Theoretically, one would expect a larger quantity reduction for this group because no offsetting demand response would be seen. Consistent with this prediction, we estimate a significantly larger reduction in utilization among "dual eligibles." Combining the differential change in duals' out-of-pocket costs with the differential change in their utilization, we estimate a demand elasticity of approximately −0.27. This is very similar to the oft-cited estimate from the RAND Health Insurance Experiment (Manning et al., 1987).

Overall quantity falls despite downward-sloping demand, implying supply-side changes. A supply reduction could lead to shortages. Patients may have unfilled prescriptions conditional on diagnosis or delays in treatment. The combination of lower prices and reduced utilization suggests a potential tradeoff between cost and access. To explore this trade-off, we first show that diagnosis rates were unchanged post-CBP. We next demonstrate that the quantity reductions were concentrated among consumers without a sleep apnea diagnosis. We then construct a measure of clinical appropriateness, similar in spirit to Chandra and Staiger (2007). Once again, our findings suggest that the quantity reductions mostly came from patients with clinical appropriateness below average, and marginal consumers affected by the CBP are those with lower CPAP propensity.

Although we focus on DME, our findings highlight the potential inefficiencies in the Medicare program's current methodology for setting prices. Public insurers often use regulated prices, reimbursing providers based on expected costs. Our results highlight that such an approach can lead to inefficiently high spending. Nevertheless, the CBP has some undesirable features, including nonbinding bids and the median pricing rule. Even with an imperfect bidding process, Medicare's prices for DME products fell by more than 40%. In our setting, the savings from introducing competitive bidding were substantial. However, simply setting lower prices is not without trade-offs: quantities also fell. The data indicate that the drop in quantities is due to supplier behavior and is partially offset by a demand response. Yet because the quantity reduction was concentrated in less clinically appropriate patients,[6] a cost-benefit analysis shows that the savings exceed the costs of reduced access. Future work should examine whether better auction mechanisms, such as a simultaneous descending clock auction, can improve outcomes.

In concurrent and independent work, Ji (2019) finds similar reductions in price and quantity following the introduction of the CBP. She models bidding and argues the observed prices are 6% too low. We estimate a demand elasticity that allows us to quantify the heterogeneous impact of changing prices. Our results indicate that the optimal, higher prices would dampen any negative distributional impact of the program. Higher prices would increase consumption among dual-eligible beneficiaries in particular. In combination with our results, this suggests that market forces could be a

[4] According to the American Academy of Sleep Medicine (AASM), positive airway pressure (PAP) is recommended or strongly recommended in nearly all cases for OSA (Patil et al., 2019). These include CPAP, auto-adjusting PAP (billed using the same product code as CPAP), and bilevel PAP (also included in the CBP but less commonly used;- quantity was a fourth of CPAP in 2010). Other treatment options for OSA include weight management, oral appliances, and surgery (reviewed in Morgenthaler et al., 2006).

[5] For example, in obstructive sleep apnea, the upper airways become blocked during sleep.

[6] This finding is consistent with the survey result from OIG (2017) that beneficiaries were unlikely to experience disruptions in access to CPAP supplies and their hypothesis that the CBP may have reduced provision of unnecessary supplies.

powerful instrument to reduce the high cost of health care in the general U.S. market and in the Medicare program specifically. Yet market reforms may have important distributional consequences. Our results add to a literature documenting the role of prices in driving health care spending (Anderson et al., 2003; Cooper et al., 2019). They also add to growing evidence on the important role of institutions and mechanisms for purchasing health care goods and services. Chandra et al. (2016) argue that the health care sector is similar to other industries and subject to standard market forces. Yet although a number of studies contrast public and private provision of insurance in Medicare (Town & Liu, 2003; Curto et al., 2019), less attention has been paid to the mechanisms used to procure health care services within public insurance. The price reductions we measure are more dramatic than those found in earlier studies examining markets for prescription drugs (Duggan & Morton, 2006, 2010; Dranove et al., 2021). In the meantime, competitive bidding was unsuccessfully implemented for physician-administered drugs (Martin & Sharp, 2018). More broadly, both Medicare and Medicaid use competitive bidding and market mechanisms to pay private drug and medical insurers, which have been more extensively studied in the previous literature (MACPAC, 2011; Decarolis, 2015; Curto et al., 2021; Dranove et al., 2021). Internationally, firms compete in competitive bidding systems in both drug and device markets (Decarolis & Giorgiantonio, 2015; Cao et al., 2021). Grennan and Swanson (2020) show that transparency can lead to saving in hospitals' purchases of medical devices, but the effect is limited in the business-to-business setting.

The paper is organized as follows. Section II describes the institutional setting and data. Section III measures the impact of the CBP on prices and quantities. Section IV measures demand elasticities and describes the marginal consumer. Section V presents a cost-benefit analysis, and section VI concludes and suggests avenues for future work.

II. Setting and Data

Medicare is a social insurance program that provides health insurance to 62 million elderly and disabled individuals in the United States (CMS, 2020a). Three primary categories of Medicare spending are in place for fee-for-service (FFS) recipients.[7] Part A covers inpatient care that is provided in hospitals or in skilled nursing facilities along with hospice care (typically provided in one's home). Part B covers outpatient care, physician services, home health care, and durable medical equipment (DME).[8] The majority of FFS recipients obtain private insurance coverage for prescription drug costs through Medicare Part D, which was created by the 2003 Medicare Prescription Drug, Improvement, and Modernization Act.

We utilize Medicare FFS claims data in each year for a random 20% sample of the Medicare FFS population. In our main analysis, we restrict attention in each quarter to Medicare beneficiaries who were enrolled in FFS Medicare Part B for all three months in the quarter.[9] Appendix table A1 describes Medicare spending for FFS recipients in both 2010 and 2015.[10] In 2010, Medicare DME spending was $11.3 billion, and more than 11 million Medicare recipients had one or more DME claims. Hundreds of DME products are available, including but not limited to diabetic testing supplies, CPAP devices, oxygen equipment, nebulizers, walkers, wheelchairs, and scooters. Appendix table A2 lists the top twenty (by 2010 spending) DME products.[11] CPAP machines, which are the focus of our study, accounted for $209.9 million in 2010 Medicare expenditures.

In addition to creating Medicare Part D, the 2003 Medicare Prescription Drug, Improvement, and Modernization Act established the framework for competitive bidding for certain DME products. The program officially started in January 2011 (with a bidding process in 2009) in nine round 1 competitive bidding areas (CBAs) and was then expanded to another 100 CBAs in round 2 in July 2013.[12] Each round lasted for three years, and so a "round 1 recompete" started

[7] In recent years approximately one-third of Medicare recipients have enrolled in private Medicare Advantage (MA) plans for their coverage. The remaining recipients are enrolled in traditional fee-for-service (FFS) Medicare, through which the government directly reimburses hospitals, physicians, and other health care providers for services delivered to or products obtained by Medicare recipients.

[8] Although the vast majority of FFS recipients have one or more Part B claims each year, only about one in five have a Part A claim.

[9] When predicting beneficiaries' propensity to use a CPAP device, we require people to be enrolled in FFS Medicare Part B for the full three months in current and previous three quarters so that we can observe all their claims related to sleep apnea.

[10] For each year, the first column displays the number of individuals with one or more claims for a service. The second and third columns list Medicare and patient spending for that service in the year. The fourth column lists total payment per capita, which is calculated as the sum of Medicare and patient spending, divided by the number of patients. For this table, we multiply both the number of patients and total spending in our data by 5 to estimate national totals. The top row shows that Medicare Part A and B spending (normalized to 2015 dollars using the Consumer Price Index) for those enrolled in FFS Medicare increased from $342.1 billion to $350.4 billion from 2010 to 2015; the number of Medicare recipients with one or more Part A and/or Part B FFS claims rose from 32.9 million to 34.5 million over this period. Part D was the fastest growing component of spending for Medicare FFS recipients during this period. Total Medicare spending was approximately one-third to one-half higher during this period than implied by our table because of Medicare Advantage, through which an increasing fraction of Medicare recipients obtained their coverage.

[11] As the table shows, oxygen concentrators accounted for more spending than any other DME product, with $1.98 billion in 2010 Medicare expenditures and reimbursement per claim of $189 in that same year (all 2010 prices and payments are adjusted to 2015 dollar value as in appendix table A1). The per-claim costs include coinsurance payments by Medicare recipients (or by their secondary insurer).

[12] Before the official start of the CBP in 2011, CMS implemented Competitive Bidding Demonstration for DME, prosthetics, orthotics, and supplies, during 1999–2002 in Polk County, Florida, and San Antonio, Texas. Three rounds of bidding in the two sites showed price reduction but little impact on utilization. More detailed evaluation has been reported (Hoerger et al., 2003). Then in 2007, CMS conducted the round 1 CBP and awarded contracts effective July 1, 2008. The Medicare Improvements for Patients and Providers Act (MIPPA) of 2008, however, terminated the round 1 contracts on July 15, 2008, and required CMS to repeat the competition in 2009 (GAO, 2016).

TABLE 1.—SUMMARY STATISTICS ACROSS GEOGRAPHIC AREAS

	Non-CBA ($N = 860$)	R1 CBA ($N = 9$)	R2 CBA ($N = 100$)
No. MCR FFS population	2,979	58,460	36,552
Age	70.7	71.1	71.1
Male	0.45	0.45	0.45
SSDI	0.20	0.18	0.18
Dual eligible	0.18	0.20	0.19
Average MCR payment	7,558	9,465	8,717
Average MCR DME payment	285.6	302.0	255.1
Has DME claim	0.29	0.28	0.26
Has CBP DME claim	0.18	0.18	0.16

Summary statistics from Medicare 20% FFS data in 2010. Geographic area is defined as core-based statistical areas (CBSAs), which are the basis for defining CBAs. For a few cases that are not perfectly matched, we keep CBSAs that consist of the majority of each CBA, and drop small areas that are left outside CBAs. Medicare FFS population counts beneficiaries that had no HMO coverage over the twelve months. Average Medicare payment per beneficiary includes only Medicare payment in Part A and B, but not deductible, coinsurance, etc. All summary statistics except average population are weighted by Medicare FFS population.

in January 2014 in the same nine round 1 CBAs. CBAs were selected by CMS mainly based on core based statistical areas (CBSAs) with larger populations, Medicare DME spending (per recipient), and suppliers per recipient.[13]

Table 1 provides summary statistics for round 1 CBAs, round 2 CBAs, and the remaining 860 CBSAs. The most notable difference is that the round 1 and round 2 CBAs on average had substantially more Medicare recipients than in other CBSAs. As a result, more than 60% of Medicare FFS recipients (based on 2010 enrollment and residence) lived in an area that had competitive bidding in effect by July 2013. Additionally, average spending per recipient was significantly higher in 2010 in the geographic areas that were selected for competitive bidding, yet average spending for DME products and the share of recipients with DME claims (included in the CBP) did not differ much between CBAs and other CBSAs.

Across different rounds of the CBP, CMS divided DME into fourteen categories. Within each product category, one lead item is assigned by CMS based on the highest total allowed charges nationwide together with its related accessories.[14] For example, rental payments for oxygen concentrators (HCPCS code E1390-RR) accounted for 83.2% of the payment in 2010 in the category of oxygen equipment, whereas other types of oxygen system equipment (i.e., portable, stationary, liquid, gaseous oxygen systems) and contents accounted for the remainder. As for the CPAP category, rental payments for the device (HCPCS code E0601-RR) accounted for 24.0% of category payments in 2010, and its accessories such as nasal interface, full face mask, and exhalation port accounted for 13.2% to less than 1%. For the other categories, the lead item accounted for between 27.6% and 91.5% of the total payment within the category in 2010.

The fourth column of appendix table A2 shows, for each of the top-selling DME products, whether it was included in round 1 (R1), round 2 (R2), round 1 recompete (R1RC), or national mail order (NMO). The next three columns list the average 2010 FFS price, the average 2015 FFS price, and the average 2015 price in CBAs. With just one exception (diabetic test strips, which experienced a significant price drop), the 2015 FFS price is only slightly lower than the 2010 FFS price.[15] For products included in competitive bidding, the 2015 FFS price represented the average price that prevailed outside of the 109 CBAs (an average across 53 state FFS prices published by CMS), and the next column lists the average price in competitive bidding areas in 2015. In almost every case, the average price in competitive bidding areas is substantially lower than the FFS price in that same year. For CPAP devices, the average price in competitive bidding areas was 54% lower ($47.0 vs. $102.4).[16] Our study will exploit variation over time and across space to explore the extent to which changes in prices and quantities were driven by the CBP.

In our empirical analysis, we initially consider the lead item in each of the twelve DME categories when estimating the effect of competitive bidding on the price and total quantity of each product along with the market structure (e.g., the number of suppliers or the HHI). We next focus on the effect of competitive bidding on just CPAP devices. These devices are used to treat obstructive sleep apnea, which is a potentially serious sleep disorder in which breathing repeatedly stops and starts during sleep. The American Academy of Sleep Medicine (AASM) recommends CPAP as both the first-line and the gold-standard treatment for obstructive sleep apnea (Ramar et al., 2015). Medicare beneficiaries rent CPAP devices for thirteen months, after which the patients own the device.[17]

A primary goal of the CBP was to induce market-based prices that would replace the current fee-for-service prices for home medical equipment. At the same time, Congress passed legislation creating the Medicare Part D program. That program successfully leveraged market mechanisms to reduce pharmaceutical prices (Duggan & Morton, 2010). A natural question is whether similar mechanisms can have a similar impact for other goods and services purchased by the

[13]Beyond CBAs we follow similar steps as CMS, grouping zip codes into core-based statistical areas (CBSAs).

[14]External infusion pumps will not be included in 2021 and therefore do not have a lead item selected. To be consistent with other categories, we also select the top item by 2010 Medicare payment, the external ambulatory infusion pump for insulin (HCPCS code E0784-RR), as the lead item of this product category.

[15]Most DME products were excluded from competitive bidding, though the products that CMS selected tended to have significantly higher spending and volume. CMS revised the fee schedule for non-mail order diabetic testing supplies to be equal to mail orders in 2012 (https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/DMEPOSFeeSched)

[16]The price reduction led to total spending in CBAs dropping from $102.2 million in 2010 to $63.9 million in 2015, while during the same period, total payment in non-CBAs increased from $107.7 to $138.3 million.

[17]CPAP is listed within CMS's "capped rental DME" category. In this setting, Medicare pays a monthly rental fee that is capped at thirteen consecutive months. Within the thirteen months, months 1–3 are paid at the published fee schedule rental rate, and months 4–13 are paid at 75% of the published rate.

Medicare program.[18] Yet important design issues exist even for DME products within the CBP.

Previous research has criticized two key features of the CBP: the median price auction and nonbinding bids. Under the approach used by CMS, a supplier does not have a financial incentive to truthfully bid its reservation price (Merlob et al., 2012; Cramton et al., 2015). If suppliers did bid their costs, the median price would then be set below some winning bidders' costs: the median-price auction is not ex post individually rational. Furthermore, "winning" the auction does not guarantee that a firm becomes a Medicare supplier. Although winning the auction earns a firm the option of signing a supply contract, bids are not binding. Cramton et al. (2015) point out that this feature generates the incentive for "suicide" (low) bids to preserve that option. In practice, this means that CMS could choose a price that is just high enough so that the market does not collapse.

Finally, the competitive bidding mechanism could affect market structure and prices in future periods. In the CPAP market we study, three major manufacturers (ResMed, Philips Respironics, and Fisher & Paykel) capture more than 80% of the total market share. Suppliers of the renting services are DME distributors, mostly regional and local providers together with a few national providers such as Lincare and Apria.[19]

Both the sign and the magnitude of the effect of Medicare's CBP on quantity are theoretically ambiguous. On the one hand, the lower price for DME products along with the termination of some supplier contracts could reduce the total quantity supplied. On the other hand, most Medicare recipients pay some share of their medical care cost out of pocket, and so the lower price could increase the total quantity demanded. Therefore, the equilibrium impact of competitive bidding on total quantity is ultimately an empirical question.

III. The Impact of Competitive Bidding on Prices and Quantities

A. *All Product Categories*

In this section, we evaluate the impact of Medicare's CBP on prices, quantities, and Medicare spending. We initially focus on the twelve lead items, excluding two categories of DME products, diabetic testing supplies and wheelchairs.[20] As denoted with an asterisk in appendix table A2, the lead items vary substantially in price and total payment. For example, the top product, oxygen concentrators, accounted for $1.98 billion in Medicare spending in 2010 with a monthly rental price that year of $189.0. TENS supplies, however, cost only $32.8 and had just $26.9 million in total spending that year.

We leverage variation with respect to time, product, and geographic area in the use of competitive bidding. We include R1 CBAs where the CBP started in 2011Q1, R2 CBAs where the CBP started in 2013Q3, and geographic areas that have never been included in the CBP as controls. We consider the period from the first quarter of 2009 through the fourth quarter of 2015, which gives us at least two full years before competitive bidding was launched in any CBA and at least two full years after launch in each area. To study the timing of the effect, we plot the estimated coefficients on indicators for the number of quarters since the CBP. More precisely, let E_{ps} be the quarter in which product p in geographic area s enters the CBP. Let $D^l_{pst} = 1(t - E_{ps} = l)$ be an indicator that is equal to one if and only if product p in geographic area s is l quarters from the start of the CBP at time t.[21] Then our event study specification is

$$Y_{pst} = \sum_{l=-20}^{9} \beta^l D^l_{pst} + \phi_{pt} + \sigma_{st} + \theta_{ps} + \epsilon_{pst}, \quad (1)$$

in which we include product by year-quarter fixed effects (ϕ_{pt}), CBSA by year-quarter fixed effects (σ_{st}), and product by CBSA fixed effects (θ_{ps}).[22] We plot the β^l coefficients for all time periods. We weight each observation by the number of claims in that geographic area for that product in 2010, and cluster standard errors by geographic area.

Figure 1 panel a plots the coefficients on the lag and lead indicators of competitive bidding for key outcome variables of interest: prices, quantities (total number of product/service counts per thousand Medicare FFS recipients), and spending (total Medicare allowed amount per thousand Medicare FFS recipients).[23] We estimate specifications in natural logs to account for the considerable differences in baseline prices, quantity, and spending across the twelve products.[24] The top row of figure 1 shows that prices fall

[18] For example, it may be difficult to auction off health care services such as medical procedures that may be of differing quality across providers.

[19] Lincare is owned by a multinational chemical company. Apria is privately held and managed by affiliates of the Blackstone Group.

[20] We exclude diabetic testing supplies from the analysis sample because only mail-ordered diabetic testing supplies were included in the CBP. This might cause substitution between mail- and non-mail-ordered items that confound the analysis. Moreover, mail-order diabetic testing bidding was first included in round 1 but then became nationwide in 2013. We exclude wheelchairs from the sample because CMS eliminated the purchasing option for the power wheelchair in 2011 (the same time as round 1 bidding) in non-CBAs, while keeping both purchasing and rental options in CBAs. See https://www.cms.gov/Regulations-and-Guidance/Guidance/Transmittals/Downloads/R848OTN.pdf for more details.

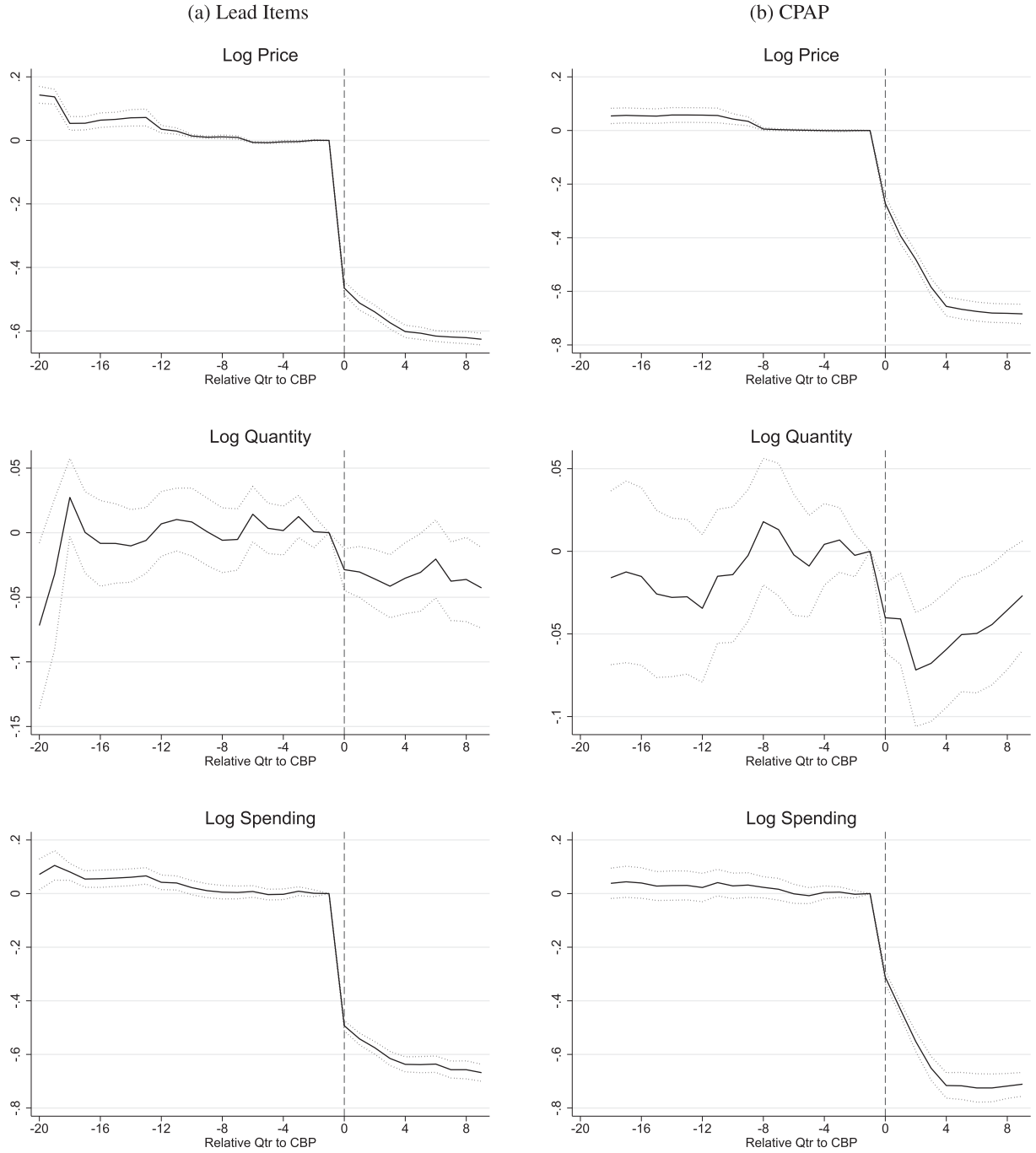
[21] We allow for twenty lags and nine leads, excluding periods that are nine quarters after the CBP (when there is only round 1 CBA in the sample that entered into round 1 recompete and experienced further changes in price and quantity). Furthermore, we set $\beta^{-1} = 0$.

[22] We can do this because different products are added in the CBP at different time.

[23] Since DME is covered by Medicare Part B, we restrict our sample to Medicare recipients who had full FFS Part B coverage in each quarter. We aggregate quantity and payment for DME among these beneficiaries and use this population as denominator.

[24] A minority of product by geographic area by quarter cells (21%) have zero claims and therefore are missing log price, log quantity, and log payment. This is mostly driven by small geographic areas not included in the CBP. Given that we weight by the number of claims in each area for each product in the pre-CBP period, this has a relatively small impact. In a series of robustness checks, we exclude areas that are not in the CBP from the analysis sample. The results are very similar.

FIGURE 1.—IMPACT OF COMPETITIVE BIDDING ON LEAD ITEM PRICES AND QUANTITIES



Plots of the effect of competitive bidding for twelve lead items (panel a) and specifically for CPAP (panel b). The observation is at product by CBSA by year-quarter level in (a) and CBSA by year-quarter level in (b). Outcome variables include price, quantity (total number of product counts per thousand Medicare FFS recipients), and spending (total Medicare allowed amount per thousand Medicare FFS recipients), all in natural log terms. The solid line is point estimates for the effect of quarter pre/post-CBP and the dotted lines are the 95% confidence interval for those coefficients, based upon standard errors that are clustered at the CBSA level. Regressions in (a) include product fixed effects, CBSA fixed effects, year-quarter fixed effects, and their double interaction, weighted by the number of claims in each CBSA for each product in 2010. Regressions in (b) include CBSA fixed effects and year-quarter fixed effects, weighted by Medicare FFS population in 2010.

dramatically in the postperiod. Appendix table A3 shows that post-CBP, prices fall by an average of 41.8%.[25] Similarly, the middle row shows that quantity is flat before competitive bidding, falls immediately when competitive bidding is introduced, declines slightly further over time, and on average dropped 9.3% after the CBP as shown in appendix table A3. Finally, the bottom row of figure 1 presents the net effect of competitive bidding on spending per enrollee. The fall in total spending is visually (and economically)

[25]The −0.46 coefficient in the initial quarter implies a 37% ($e^{-0.46} - 1 = -0.37$) decrease in price, which drops further to 45% four quarters after the CBP. The gradual decline in price could be due to a grandfather clause that enabled some patients to continue rental services from their old DME suppliers at the original price.

TABLE 2.—IMPACT OF COMPETITIVE BIDDING ON CPAP PRICES AND QUANTITIES

	(1) Log price	(2) Log quantity	(3) Log beneficiaries	(4) Log new beneficiaries	(5) Log spending
1(Competitive bidding)	−0.594***	−0.0442***	−0.0439***	−0.0437***	−0.638***
	(0.0150)	(0.0163)	(0.0151)	(0.0126)	(0.0193)
Mean	71.33	20.45	8.300	2.326	1.466
N	26,762	26,762	26,762	25,120	26,762
Year-quarter FE	Yes	Yes	Yes	Yes	Yes
CBSA FE	Yes	Yes	Yes	Yes	Yes

Results of regression analysis for the effect of the CBP on price and quantity of CPAP. Observation is at CBSA by year-quarter level. Outcome variables include price, quantity, number of (new) beneficiaries, and total spending, all denominated by thousand Medicare FFS beneficiaries except price, and all in natural log terms (the mean of dependant variable shown is in level terms). All regressions include CBSA fixed effects and year-quarter fixed effects. All regressions are weighted by Medicare FFS population in 2010. Standard errors are clustered at CBSA level. Significance levels: *0.1, **0.05, and ***0.01.

substantial. Appendix table A3 shows that spending falls by an average of 47.2% after the CBP. For both figure 1 panel a and appendix table A3, we use the number of claims in that geographic area for that product in 2010 to put more weight on larger geographic areas and products with more patients. As a robustness check, appendix table A4 weights observations by the number of Medicare FFS recipients in 2010 in each geographic area and presents almost identical results. In the subsequent analyses when we focus on CPAP or other specific products separately, we will use population weight for simplicity and consistency.

In appendix table A5, we present several robustness checks. Columns 1 and 2 restrict the sample to only the nine round 1 and one hundred round 2 competitive bidding areas; the results are similar. Columns 3 and 4 restrict the sample to large non-CBAs (>9,000 Medicare FFS population in 2010) along with round 1 and 2 competitive bidding areas. Again, the results are very similar. Columns 5 and 6 add a state-by-post-CBP indicator, which turns on when any area in the state has been included in the CBP to control for the effects of changes over time in state-level policies, including Medicaid. Again, the results are similar. Columns 7 and 8 restrict attention to Medicare FFS recipients who are enrolled in the program during our entire sample period; the results are once again quite consistent with our baseline results.

Appendix table A6 reports the results for different rounds. The sample used for columns 1 and 2 includes round 1 items in round 1 CBAs and non-CBAs. The sample used for columns 3 and 4 includes the same products and geographic regions, but restrict the time period to 2009Q1–2013Q4 (before round 1 CBAs were recompeted). The sample used for columns 5 and 6 includes round 2 items in round 2 CBAs and non-CBAs. The sample used for columns 7 and 8 includes round 1 recompete items in round 1 CBAs and non-CBAs. Whether or not we truncate the sample before the recompete, we get a slightly smaller price drop in round 1 than round 2. Within round 1 CBAs and round 1 items, excluding year-quarters after the recompete yields estimates of a smaller decrease in price, which indicates that there is a further price drop in the recompete. The quantity difference is largest among round 1 recompete items and smallest among round 2 items. This is consistent with results from separate specifications for each of the lead items within each category, as reported in appendix table A7. The range of the average price drop is 12% to 51%. Average quantity falls for all 12 items (and this is statistically significant among nine), and the reductions range from 2% to 90%. In the next section we look more closely at this results, focusing exclusively on CPAP machines.

Appendix table A3 panel B estimates the same specifications at the category (rather than product) level.[26] These specifications allow for substitution across products within a category. As expected, the impact is slightly attenuated: prices fall by 38.2%, and quantities fall by 7.8% once we allow for within-category substitution. The program, viewed from this level, still substantially lowers program expenditures: Medicare reimbursement falls by an average of 43.0%.

B. CPAP Machines

Figure 1 panel b restricts attention to CPAP machines.[27] Similar to the aggregate analysis, both the average price of CPAP machines and spending on these products fall significantly upon the introduction of competitive bidding. As this figure shows, average quantities also decline.

In table 2, we estimate the relative magnitudes of the impact of competitive bidding in a difference-in-difference specification. The estimating equation is given by

$$Y_{st} = \beta_1 \times CBP_{st} + \sigma_s + \theta_t + \epsilon_{st},$$

where the dependent variables are (the natural log of) price, quantity, the number of (new) beneficiaries with one or more CPAP claims, and Medicare reimbursement (all denominated by thousand Medicare FFS recipients except price) for CPAP in geographic area s during year-quarter t. The main variable of interest is the treatment indicator CBP_{st}, which is set equal to 1 when CPAP is included in the CBP in geographic area s during year-quarter t and otherwise equal to 0. In all regressions, we include geographic σ_S and

[26] We aggregate total payment and quantity (the number of items or services provided) within each category and calculate the average price per item.

[27] Price, quantity (per thousand Medicare FFS recipients) and spending (per thousand Medicare FFS recipients) are still in log terms to show changes in percentages. Only 1.4% of the geographic by quarter cells have zero claims for CPAP and thus have missing price, log quantity, and payments. We also weighted geographic area by it size, measured as Medicare FFS population in 2010 (based on FFS Part B months and counting people with six-month coverage as 0.5).

quarter-by-year θ_t fixed effects. We weight all regressions by the Medicare FFS population in each geographic area in 2010, and cluster standard errors by geographic area.

Table 2 presents the results. Because we are looking at a single product, we do not need to distinguish between the lead item and the rest-of-category demand. Again, the patterns in the results are striking. Competitive bidding leads to a 44.8% ($e^{-0.594} - 1 = -0.448$) reduction in the average price of the rental. Given a pre-competitive bidding mean of \$79/month in 2010, this represents a \$35/month price reduction (or \$7 in OOPC to consumers facing 20% cost sharing per claim). Again, quantities also fall by an average of about 4.3% ($e^{-0.0442} - 1 = 0.0432$), regardless of the measure of quantity; the quantity reductions are due to both new beneficiaries and existing consumers. On net, average Medicare spending for CPAP devices falls by 47.2% ($e^{-0.638} - 1 = -0.472$) following the introduction of competitive bidding.

Appendix figure A1 shows that market concentration grew post-CBP: the HHI increased by 0.05 (or 500) points in the average CBA. This is primarily because of two factors: small local firms exiting the market and large national players growing. A natural concern is that the CBP could lead to increased consolidation and higher prices in the future.[28]

Comparing across waves, appendix table A8 shows that CPAP also had a smaller price drop and larger quantity decrease in round 1 than round 2. This is consistent with suppliers learning how to adapt to competitive bidding over time. Within round 1 areas, excluding year-quarters after R1RC also shows smaller decreases in price and larger decreases in quantity, but the differences are not as big as the comparison between round 1 and 2. Appendix table A9 further shows that round 1 led to slightly smaller increase in HHI and larger reduction in the number of suppliers.[29] However, given the standard errors, we do not want to overinterpret this result. Furthermore, the slightly heterogeneous effects across waves may lead to the concern that our two-way fixed effect estimation is biased in the overall treatment effect. To address this concern, appendix figure A2 replicates our main results using alternative estimators that address potential issues with two-way fixed effects. The patterns are qualitatively similar across estimators. For example, our baseline estimate for the price reduction in the fourth quarter after CBP are −0.584, whereas the new estimates range from −0.416 to −0.615. For quantity, all estimators suggest an about −5.8% ($e^{-0.06} - 1 = -0.058$) decrease.

The supply-side changes in CBAs could have spillover effect to the neighboring non-CBAs; for example, the program could reduce the number of suppliers serving an untreated CBA adjacent to a treated CBA. From the demand side, the spillover effect could be limited since the reimbursement is based on the enrollee's address instead of the location of the providers. Appendix table A11 reports the results estimated using only nonadjacent non-CBAs (panel A) or only adjacent non-CBAs as controls (panel B), which produces qualitatively similar results to our preferred estimates. Panel C reports the placebo effect using adjacent non-CBAs as treated and nonadjacent non-CBAs as controls. Despite a slight decrease in price (0.3% of the main effect), we find no effects on quantity and market structure.[30]

Appendix table A13 documents other potential margins of adjustment. One potential concern is that the reduction in utilization is partly reflecting a deferral of necessary care among Medicare recipients. Column 1 shows that the incidence of obstructive sleep apnea (or OSA, as measured by number of patients newly diagnosed with OSA per thousand Medicare population) actually goes up slightly after the introduction of competitive bidding, suggesting that if anything more patients are receiving in-person care for this diagnosis. Appendix figure A3 shows similar result in event study format. The result is similar if we include all types of sleep apnea (SA) beyond OSA. Column 2 shows that total Medicare FFS spending (not including DME) for patients with an OSA diagnosis falls by 3.4% post-CBP along with a 29.5% ($e^{-0.349} - 1 = -0.295$) reduction in DME spending in column 3, suggesting no substitution to other types of care or deterioration of people's health.

One specific substitute for a CPAP machine that we observe in the data is the oral device/appliance used to reduce upper airway collapsibility (HCPCS code E0486). Appendix table A14 reports the impact of CBP on the price and quantity of this oral device. We find no effect on price, some evidence of an increase on the intensive margin (excluding the prevalent zeros), but no movement in overall quantity.[31] Under the same spirit, we also check the impact of CBP on the complements of CPAP. Although most of the accessories of CPAP are added together in the same round, one particular type of mask (combination oral/nasal mask, HCPCS code A7027) was not included in round 1. As shown in appendix table A15, the direct impacts of round 2 and the round 1 recompete on mask prices and quantities are similar to our main results. However, no effect on both price

[28] However, we note that the reduction in suppliers is a policy choice: only about one-third of the bidding suppliers were awarded CBP contracts (GAO, 2012). Despite rental services, suppliers also provide and get paid for the replacement of related supplies under frequency restrictions that are set by CMS. With the start of the CBP, new Medicare patients could only get CPAP from suppliers with a DME contract. Suppliers not awarded contracts could elect to become grandfather suppliers to continue providing CPAP for their existing patients (e.g., those who were four months into the thirteen months needed to own) but could not provide DME products to new patients.

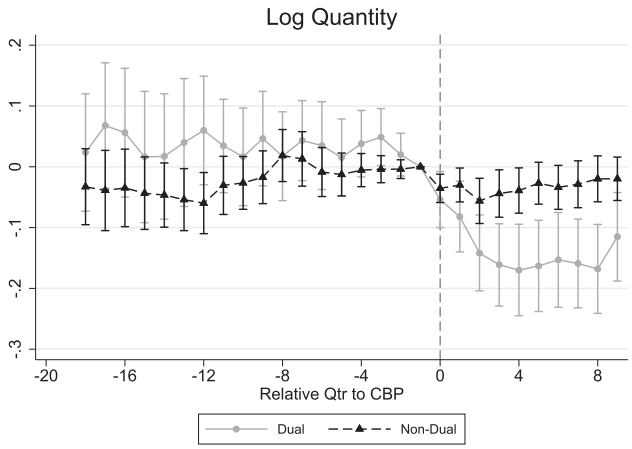
[29] Appendix table A10 replicates the impact of CBP on market structure by wave for lead items and categories. The increases in HHI and decreases in the number of suppliers are both largest in round 2.

[30] Appendix table A12 presents similar findings for lead items and categories.

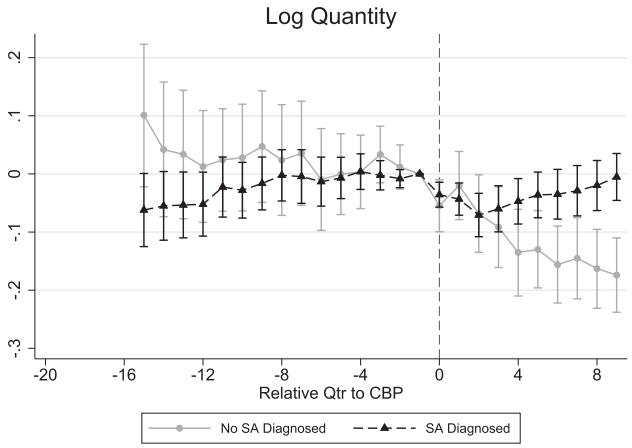
[31] Based on the imprecise estimation in column 3, the number of oral device per thousand Medicare population increased by 0.00669. Meantime, number of patients using CPAP is decreased by −0.484 per thousand Medicare population (in levels, not log, which is not included in the main table). That means only 1.38% of the decrease in CPAP patients switched to the oral device.

FIGURE 2.—IMPACT OF COMPETITIVE BIDDING ON CPAP QUANTITIES BY SUBGROUPS

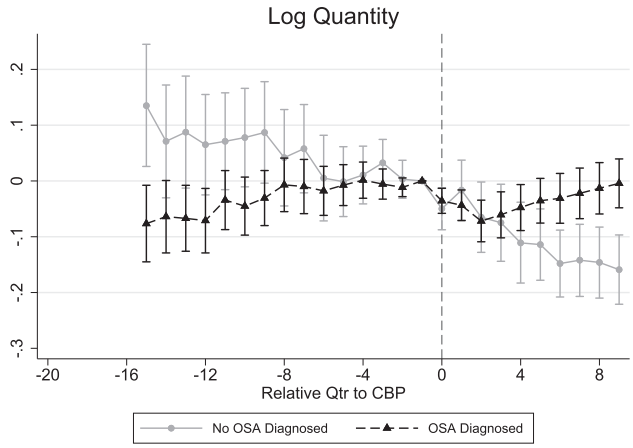
(a) By Dual Status



(b) By Sleep Apnea (SA)



(c) By Obstructive Sleep Apnea (OSA)



Plots of event study coefficients of relative years interacting with group dummies. The observation is at CBSA by year-quarter by subgroup level. Panel A groups sample to duals vs. nonduals. Panel B and C define subgroups as those diagnosed with either SA (primary diagnosis recorded as ICD-9 code 327.2 or ICD-10 code G47.3 in an inpatient, outpatient, or physician carrier table) or OSA (primary diagnosis recorded as ICD-9 code 327.23 or ICD-10 code G47.33) in the previous year, restricting to patients who remained enrolled in Medicare for the current and previous three quarters to get full information on their diagnosis (sample period starts from 2009Q4). Outcome variable is the total quantity of product per thousand Medicare FFS recipients, in natural log terms. The gray solid lines show point estimates for the effect of the CBP for duals/No SA/No OSA diagnosis, and the black dashed lines show point estimates for the effect of the CBP for nonduals/SA/OSA diagnosed. Vertical lines show the 95% confidence interval for those coefficients, based upon standard errors that are clustered at the CBSA level. All regressions include CBSA fixed effects, year-quarter fixed effects, and their interactions with a dummy variable for each group. All regressions are weighted by Medicare FFS population in 2010.

and quantity was seen in round 1. Note that this includes not only a complement effect but also a substitute effect, because other types of masks are included together with CPAP in round 1.

Taken together, the results in this section demonstrate that the introduction of competitive bidding led to a sharp reduction in the price of DME products and a reduction in the utilization of these products as well. The effects were similar when considering all lead items in the twelve DME categories or when focusing exclusively on CPAP devices. In both cases, we estimate that competitive bidding substantially lowered Medicare spending. In the next section, we investigate the mechanisms driving these changes and explore heterogeneity in both the price and utilization effects.

IV. Mechanisms and Heterogeneity

A. *Heterogeneity*

In this section, we focus on CPAP machines to (a) decompose the contribution of supply and demand to the changes summarized above and (b) measure allocative efficiency given the change in utilization. We do this by (a) focusing on heterogeneity by dual status and (b) clinical appropriateness. Figure 2 plots the differences in our event study framework between those Medicare recipients who are dually eligible for the Medicaid program and all other Medicaid recipients. The figure also shows the trajectory of prices and utilization before and after the introduction of the CBP for beneficiaries with and without a sleep apnea diagnosis.

TABLE 3.—IMPACT OF COMPETITIVE BIDDING ON CPAP QUANTITIES BY SUBGROUPS

	(1) Dual vs. nondual	(2) Female vs. Male	(3) No SA vs. SA	(4) No OSA vs. OSA	(5) Below vs. above median propensity
1(Competitive Bidding) × Group 1	−0.165***	−0.0625***	−0.123***	−0.132***	−0.125**
	(0.0308)	(0.0222)	(0.0350)	(0.0355)	(0.0516)
1(Competitive Bidding) × Group 2	−0.0182	−0.0293	−0.0242	−0.0164	−0.0197
	(0.0185)	(0.0210)	(0.0187)	(0.0180)	(0.0205)
Mean of dependent variable (Group 1)	19.34	16.75	4.253	5.504	3.103
Mean of dependent variable (Group 2)	20.86	25.32	162.2	157.1	39.05
Coefficient diff (Groups 1 and 2)	−0.147	−0.0332	−00983	−0.116	−0.106
p-value	[<0.0001]	[0.0148]	[0.00108]	[0.000287]	[0.0160]
N	50,477	52,486	45,270	45,949	32,456

Results of regression analysis for the effect of the CBP on quantity in different subgroups. The observation is at CBSA by year-quarter by subgroups level. Subgroups are defined as duals vs. nonduals, male vs. female, whether diagnosed with sleep apnea (or SA, primary diagnosis recorded as ICD-9 code 327.2 or ICD-10 code G47.3 in an inpatient, outpatient, or physician carrier table) or ubstructive sleep apnea (OSA, primary diagnosis recorded as ICD-9 code 327.23 or ICD-10 code G47.33) in the previous year, and CPAP propensity above vs. below median. OSA/SA diagnosis and CPAP propensity samples are restricted to patients who remained enrolled in Medicare for the current and previous three quarters to get full information on their diagnosis (sample period starts from 2009Q4). CPAP propensity is estimated using OSA/SA diagnosis and demographic variables in 2010 (details in section IVC). Main variables of interests are the CBP indicator interacting with group dummies (groups 1 and 2 corresponding to the order in column title). All regressions include CBSA fixed effects, year-quarter fixed effects, and their interactions with a dummy variable for each group. All regressions are weighted by Medicare FFS population in 2010. Standard errors are clustered at CBSA level. Significance levels: *0.1, **0.05, and ***0.01.

Theoretically, we expect a different quantity effect for dual eligibles. Duals were fully insulated from any price changes before and after the policy change because of their secondary coverage from Medicaid. In contrast, a reduction was seen in out-of-pocket price for nonduals as a result of the CBP, as the allowed amounts for Medicare declined. All else equal, this would lead to an increase in their utilization of CPAP machines.

Appendix figure A4 shows that the reduction in the total price is essentially identical for duals and nonduals. However, in figure 2 we observe a substantial reduction in utilization among duals (who had no offsetting effect of a lower out-of-pocket price) while the utilization remains relatively constant for nonduals. This strongly suggests that the differential changes in out-of-pocket prices were responsible for the relative decrease in quantity among those dually eligible for Medicaid. Perhaps not surprisingly, quantity declines more for those Medicare recipients without a sleep apnea diagnosis, suggesting that the patients with more severe sleep apnea continued to use CPAP devices.

Table 3 presents treatment effect estimates for different groups of consumers categorized by demographics and health status. The results in table 3 are quite consistent with the differences implied by figure 2. Quantities fell by significantly more among dual eligibles and among those without a sleep apnea diagnosis.[32] The point estimates also suggest a larger reduction among men than among women, though the difference is not statistically significant. We explore these differences further in the next section, along with the allocative efficiency of the changes in utilization.

B. Separating Supply and Demand

We observe very different utilization patterns between those Medicare recipients with and without Medicaid coverage (duals and nonduals, respectively). We will use this heterogeneity to separate the impact of the CBP into its supply-side and demand-side components.

How does a change in the administrative price affect equilibrium outcomes? First, because of the rules of the Medicare program, a price drop reduces out-of-pocket costs to consumers (by 20% of the change in price). The price reduction is passed on to nonduals in the form of lower cost sharing, which could increase in the quantity demanded. Second, a price reduction could also lead to a reduction in supply. This could occur along two margins: a reduction in the number of firms in the market and/or a reduction in the number of claims per firm. To answer the key policy questions of interest, we use variation driven by dual-eligible status to separate the effects of changes in supply from the effects of changes in demand.

The policy environment suggests a natural difference-in-differences specification: we can compare outcomes for dual eligibles and nondual eligibles before and after the introduction of the CBP. These two groups face the same suppliers in both periods in each geographic market. Although they may be demographically different, we can test for the existence of differential trends in the period leading up to the introduction of the CBP. Critically, because duals and nonduals face different changes in their out-of-pocket prices, we can separate supply from demand.

The left-hand panel in appendix figure A4 depicts the impact on the average price and how this varies over time, and appendix figure A5 shows the changes in the out-of-pocket cost (OOPC) faced by the two groups.[33] The total price falls for both groups, but the OOPC diverges. OOPC for duals (solid blue line) remains fixed and very close to zero, whereas the OOPC for nonduals (dashed red line) falls in line with total prices. Despite this, we again see in the right-hand panel of appendix figure A4 that the spending

[32] Appendix table A16 reports larger drop for people without sleep apnea diagnosis among only dual eligible as well.

[33] OOPC is calculated as 20% of the price for nondual eligibles and 0 for dual eligibles. This number can be different from the actual out-of-pocket payment if the beneficiary has Medigap coverage, which will bias us against finding any difference across the two groups. We explore this issue below.

TABLE 4.—IMPACT OF COMPETITIVE BIDDING ON CPAP DEMAND

	(1) OOPC	(2) Log quantity	(3) Log beneficiaries	(4) Log new beneficiaries
Panel A: OLS				
1(Competitive bidding)×Nondual	−7.183***	0.124***	0.115***	0.110***
	(0.174)	(0.0219)	(0.0207)	(0.0229)
1(Competitive bidding)	0	−0.149***	−0.139***	−0.139***
		(0.0258)	(0.0240)	(0.0221)
Panel B: IV				
OOPC		−0.0173***	−0.0160***	−0.0153***
		(0.00310)	(0.00292)	(0.00309)
1(Competitive Bidding)		−0.149***	−0.139***	−0.139***
		(0.0258)	(0.0240)	(0.0221)
Elasticity		−0.272	−0.251	−0.242
Mean of OOPC (Nondual)	15.76	15.76	15.76	15.77
F-statistic		1,707	1,707	1,671
N	50,477	50,477	50,477	41,656

Results of regression analysis for the effect of the CBP on price and quantity of CPAP separately among duals and nonduals. The observation is at CBSA by year-quarter by dual/nondual level. Outcome variables include out-of-pocket cost (OOPC, defined as 20% of price for nondual and 0 for dual), quantity and number of (new) beneficiaries, all denominated by thousand Medicare FFS beneficiaries, and all in natural log terms except OOPC. Panel A shows the OLS result, and panel B shows the IV result using 1(Competitive Bidding)*Nondual as the instrument for OOPC. All regressions include CBSA fixed effects, year-quarter fixed effects, and their interactions with a dummy variable for dual-eligible status. All regressions are weighted by Medicare FFS population in 2010. Standard errors are clustered at CBSA level. *F*-statistics is estimated using Kleibergen-Paap rk Wald *F*-test. Significance levels: *0.1, **0.05, and ***0.01.

reduction is more pronounced among the duals. As described above, quantities for duals fall, but quantities for nonduals actually rise slightly.

Both the direction and magnitude of these results are consistent with large supply-side changes. Absent OOPC changes, quantities supplied fall because of the reduction in price. A differential demand response among nonduals mitigates this quantity reduction because consumers actually face a lower price after the CBP. Given elasticity estimates, we can predict counterfactual quantities under alternative policies. To measure the demand elasticity, we leverage the differences in cost-sharing rules across "dual" and "nondual" beneficiaries directly. Formally, let G be a dummy variable that takes on a value of 1 for nonduals. We can calculate the total quantity D in market m at time t for group g in G or $1 - G$: D_{gmt}. We know that for nonduals ($G = 1$), $OOPC_{gmt} = 0.2 \times P_{gmt}$; for duals, $OOPC_{gmt} = 0$. The elasticity (which we can evaluate at the average $OOPC$) can be written as

$$\epsilon = \frac{\partial D}{\partial OOPC}\frac{OOPC}{D} = \frac{\partial \log(D)}{\partial OOPC}OOPC.$$

OLS estimates of $\partial \log(D)/\partial OOPC$ may be biased by omitted variables or reverse causality. For example, places with high demand of CPAP might generate higher price in the bidding while still having more claims than places with low demand. To address this, we estimate the elasticity using the interaction of competitive bidding and nondual status as the instrumental variable for OOPC. Intuitively, we are using exactly the variation depicted in appendix figure A5, comparing duals and nonduals before and after competitive bidding. The previous figures effectively plot the first-stage and reduced form using this variation, which we describe in table 4.

The first column in panel A describes the relationship between competitive bidding and OOPC. Columns 2–4 in panel B estimate the corresponding 2SLS regressions in which we include group fixed effects, time fixed effects, market fixed effects, and a "post" dummy in both stages of the regression. The excluded instrument is a "post" dummy interacted with G, the indicator for nonduals. This serves as the instrumental variable of OOPC because the competitive bidding decreases the OOPC only for nonduals, as confirmed in the first column of panel A. The exclusion restriction assumes no channel that the competitive bidding affects duals and nonduals differently other than through the change in OOPC. We scale the coefficient to obtain a demand elasticity. The coefficient in column 2 of panel B (−0.0173) corresponds to the coefficient in column 2 of panel A (0.124) divided by the coefficient in column 1 (−7.183). The coefficient represents the average treatment effect among compliers, who here are always nondual beneficiaries. This number allows us to calculate a demand elasticity for nonduals only.[34] The estimate suggests that a one dollar reduction in out-of-pocket cost, which represents a 6.34% reduction at the mean of 15.76 (among nonduals in 2010), leads to an increase of 1.73% in the quantity demanded. Taking the ratio of these two changes, we estimate a demand elasticity of −0.272. The estimate is very similar across specifications (using different dependent variables) and is close to the elasticity estimate of 0.2 for overall health care utilization in the well-known RAND health insurance experiment (Manning et al., 1987).

Our results indicate that demand is indeed downward sloping. Despite this, quantities fall post-competitive bidding, consistent with a large supply-side response to the

[34] It seems plausible that duals would be more price sensitive than nonduals given lower income and assets.

policy-induced reduction in price. A natural question is how much demand would have increased absent these supply-side changes. Given the supply-side changes, quantity falls. Quantity would have fallen by less than observed if not for the price drop leading to a countervailing increase in quantity demanded. If we applied the same demand elasticity to nonduals, we would expect only a 2.8% decrease in quantity ($0.149 - (-0.272) \times [0.2 \times (-35)/15.76]$). This indicates that a demand response insulated nonduals from much of the negative quantity impact of the policy change, which is consistent with the event study plots in figure 2 and OLS results for subgroups in table 3.

Our demand elasticity estimation leverages different OOPC changes among duals and nonduals assuming that nonduals pay 20% coinsurance and therefore faced a OOPC reduction after the CBP. This might be attenuated if nonduals have supplemental insurance insulating them from cost sharing. In fact, Medicare Supplement (Medigap) insurance would cover the 20% Part B copay associated with CPAP machines. We do not observe supplemental coverage at the individual level. However, we know how prevalent coverage is at the market level. To explore the impact of supplemental coverage on our elasticity estimates, we split the sample into above and below median Medigap coverage markets (average Medigap share is 37.6% and 25.5% respectively). Theoretically, one would expect a smaller quantity differential between duals and nonduals in high-Medigap states given that nonduals are more likely to be insulated from the effects of any price changes in high-Medigap states. Consistent with this, the results displayed in appendix table A17 show that quantity effect for nonduals is smaller in the below-median markets; the negative impact for duals is almost completely offset. The interaction term is smaller in markets where Medigap coverage is more prevalent; the quantity reduction for duals is more like nonduals. The "naive" elasticity estimates are also larger in magnitude: −0.341 in below-median markets versus −0.211 in above-median markets. Although the range of elasticity estimates is nontrivial, the elasticity estimate is below −0.5 in all subsamples.[35] Additional subsamples by terciles or isolating the top quartile show a consistent pattern: the "naive" elasticity estimate ranges from approximate −0.19 in markets where Medigap is especially prevalent to −0.41 in markets where Medigap coverage is rare. Our approach allows us to isolate the impact of consumer behavior and provide policy-relevant elasticities that account for market institutions.

Two potential concerns come up when comparing dual-eligible patients with nonduals, both related to Medicaid payment policy. First, Medicaid reimbursement could change at the same time that the CBP takes effect. We test this assumption using robustness checks with state-by-post-CBP indicators and state-by-dual-by-post-CBP indicators, which turn on when any place in the state has been included in the CBP and allow it to differ across dual and nondual population. For both main effects (table 2) and dual analysis (table 4), we find similar results as in appendix table A18 and A19 after controlling for changes in (dual or nondual specific) state-level policies that coincide with the CBP. Second, if Medicaid does not pay the full out-of-pocket cost after Medicare pays for the crossover claims, lowering the price in Medicare would cause different changes in the payment that suppliers receive for dual and nondual patients.[36] As a robustness check, we restrict the sample for dual analysis to be states that (1) set Medicaid price the same as Medicare price for DME items (AL, AK, DE, IN, IA, MN, MT, NV, NM, NC, WV, WY) or (2) have full crossover payment for Part B services (AR, HI, IA, ME, MS, MO, NE, OH, OK, SD, VT, WY).[37] Results are presented in appendix table A20 and yield a similar estimate for the demand elasticity. Finally, we also replicate the dual analysis using the pooled sample of twelve lead items in appendix table A21. The elasticities are similar to the CPAP estimates for new consumers but smaller for existing consumers. This is consistent with more within-category substitution in other DME product categories.

The quantity reduction among duals suggests a supply-side response to reduced reimbursement, consistent with provider responses in other health care markets (Clemens & Gottlieb, 2014). To use the data to construct a supply elasticity or measure firm costs, we would also need an assumption on firm conduct. This is an important direction for future work. From a normative perspective, it is not clear whether the reduction in quantity along with the fall in Medicare spending is "good" or "bad," because we have not specified the socially optimal level of CPAP consumption. Furthermore, it is difficult to determine whether the CBP led to a reduction in consumption among consumers for whom CPAP machines are clinically appropriate.

C. *Clinical Appropriateness*

To investigate the impact of the changes described above, we note that we observe very different utilization patterns for consumers with and without a sleep apnea diagnosis. We will use this heterogeneity to explore the allocative efficiency of the CBP. Following Chandra and Staiger (2007), we define the clinical appropriateness for treatment using preperiod

[35] We also estimate demand elasticity in different subgroups of Medigap share areas using the pooled sample of twelve lead items and see a similar pattern: −0.108 in below-median markets vs. −0.0444 in above-media markets.

[36] A crossover claim is a claim for a recipient dual eligible for Medicare and Medicaid, where Medicare pays its portion and Medicaid is billed for any remaining deductible and/or coinsurance.

[37] Information from MACPAC States' Medicaid Fee-for-Service Durable Medical Equipment Payment Policies, https://www.macpac.gov/publication/states-medicaid-fee-for-service-durable-medical-equipment-payment-policies/. Information from MACPAC State Medicaid Payment Policies for Medicare Cost Sharing, https://www.macpac.gov/wp-content/uploads/2015/01/State-Medicare-Cost-Sharing-2015.xlsx. Because no summary is available for DME payment policy, we refer to policy on physician services (also paid under Medicare Part B).

data on diagnoses and demographics. We then explore the extent to which the CBP reduced "appropriate" CPAP use given the clinical literature.

Given that only CPAP prices (and not for example physician reimbursement) are affected by the CBP, we do not expect a change in upstream diagnoses unless consumer and/or physician behavior changes. Previous results summarized above in appendix table A13 and appendix figure A3 demonstrated that overall diagnosis rates did not change much as a result of the CBP. Furthermore, there is no difference in trends between duals and nonduals in terms of the diagnosis rate of sleep apnea. The left-hand panel of appendix figure A6 shows the impact of the CBP on the probability of having any sleep apnea (SA) diagnosis in the past year (current quarter + previous three quarters, and the right-hand panel shows the probability of having obstructive sleep apnea (OSA) diagnosis in the past year (current quarter + previous three quarters). In both cases, the diagnosis rate increased by around 0.001 percentage points among each group (with nonduals slightly higher), which is relatively small compared to the mean of 2.9% for OSA and 3.3% for SA.

To model the utilization of CPAP devices conditional on demographic and clinical data, let ζ be a vector of consumer characteristics, including clinical appropriateness for CPAP treatment, Z. We define the population by a joint distribution $G(\zeta)$. We write a consumer i of type ζ's utility from CPAP consumption as $v(\zeta_i, OOPC)$, where $OOPC$ is the price faced by the consumer. We can then define the price at which a consumer is indifferent to owning a CPAP machine as $\sigma(\zeta_i) = \max(OOPC : v(\zeta_i, OOPC) > 0)$. We note that, given the inconvenience and treatment costs, this quantity could be negative. We can then write aggregate demand as

$$D(OOPC) = \int 1[\sigma(\zeta_i) \geq OOPC]\, dG(\zeta) = \Pr[\sigma(\zeta_i) \geq OOPC].$$

Now let the clinical appropriateness for treatment Z_i be one component of the vector ζ. The average clinical appropriateness in a market can be written as

$$\bar{Z}(OOPC) = \frac{1}{D(OOPC)} \int Z_i 1[\sigma(\zeta_i) \geq OOPC]\, dG(\zeta) = E[Z_i | \sigma(\zeta_i) \geq OOPC].$$

We are interested in $\frac{\partial \bar{Z}(OOPC)}{\partial OOPC}$, which also allows us to define the clinical appropriateness of the marginal consumer. We can estimate $\frac{\partial \bar{Z}(OOPC)}{\partial OOPC}$ using an exogenous change in $OOPC$.

To construct a measure of clinical appropriateness for treatment Z_i, we take a series of steps. First, we predict CPAP consumption in the preperiod. To do this, we estimate a logit regression using beneficiary-year data.[38] To avoid potential changes after the CBP, only the pre-CBP year of 2010 is used for estimation. We then predict the CPAP usage probability for all beneficiary years and aggregate to the geographic area by year level. We use a number of clinical and demographic predictors of CPAP usage: OSA diagnosis, SA diagnoses, age bins, gender, dual and SSDI (social security disability insurance) status.

The results from this analysis are summarized in appendix table A22. As the results there show, diagnosis is a very strong predictor of CPAP use. A beneficiary with a SA diagnosis is 76.7 ($e^{4.353} - 1$) times higher in odds ratio of having a CPAP claim than a beneficiary without such a diagnosis. The oldest beneficiaries are significantly less likely to have one or more CPAP claims, as are duals and women. Using these results, we can construct the empirical analog of Z_i above, the clinical appropriateness of treatment. We note that this variable measures clinical appropriateness conditional on the administrative price mechanism.

We next plot the impact of competitive bidding for consumers with above and below median CPAP propensities. The results are in figure 3. As noted above, prices fall similarly for those with above and below median clinical appropriateness.[39] However, the quantity series diverge. For consumers with above median clinical appropriateness for treatment, quantities are virtually unchanged. However, a large and persistent drop in CPAP use is seen for consumers with below median predicted CPAP propensity.[40] The differential effect is more precisely estimated in the difference-in-difference specification, as shown in table 3 column 5. The difference between the two coefficients, for below and above median propensity interacted with post indicator, is -0.106 (p-value $= 0.0160$). Taken together, these results suggest that utilization declined more for those who derive less benefit from CPAP use.

Our results suggest that some of the quantity reduction that we observe may be "efficient"; that is, the quantity reductions are concentrated among consumers for whom a CPAP machine is less likely to be clinically appropriate. To further explore this idea, we isolate the"marginal" consumers in an additional set of specifications. To do this, we follow the logic of Gruber et al. (1999). We estimate the following equation:

$$Y_{st} = \beta_1 \log(D_{st}/M_{st}) + \sigma_s + \theta_t + \epsilon_{pst},$$

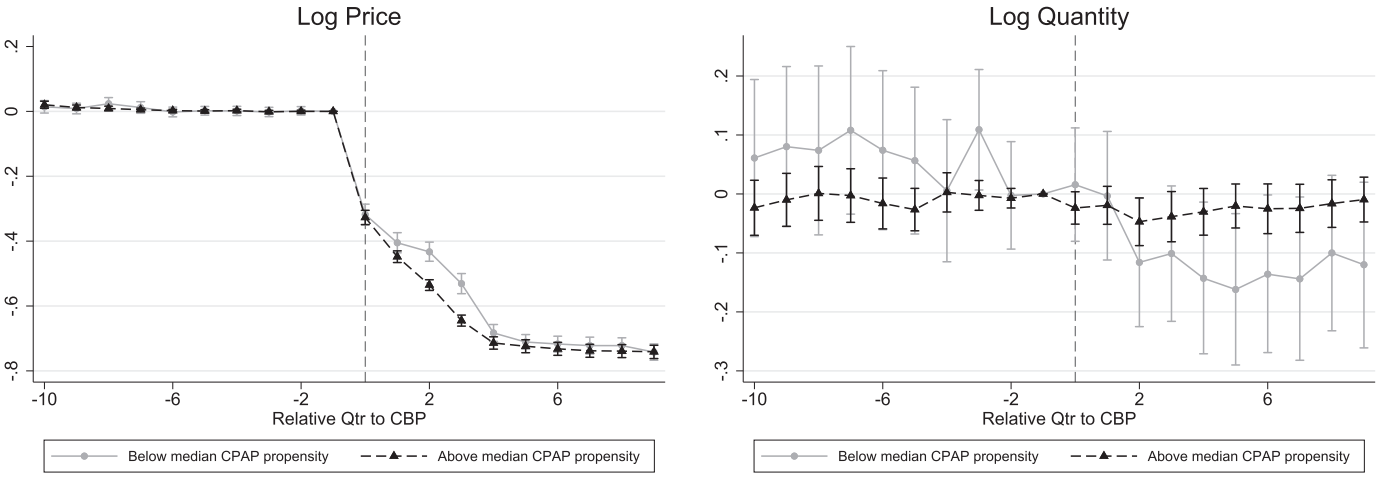
where Y_{st} is the average demographic characteristics of CPAP users (corresponding to variables we used to define

[38] We restrict attention to beneficiaries with full three-month Part B non-HMO Medicare enrollment in the current quarter and three previous quarters.

[39] The small differences are again due to the use of grandfathered suppliers.

[40] Appendix figure A7 plots coefficients separately by dual status and clinical appropriateness. The entire quantity effect is driven by dual enrollees. Within duals, the point estimate for quantity reduction is large in the below-median propensity group. However, we cannot reject that the impact is the same across subgroups of dual enrollees.

FIGURE 3.—IMPACT OF COMPETITIVE BIDDING ON CPAP PRICES AND QUANTITIES BY CPAP PROPENSITY



Plots of event study coefficients of relative years interacting with group dummies (estimated CPAP propensity below vs. above median). CPAP propensity is estimated using OSA/SA diagnosis and demographic variables in 2010, restricted to patients who remained enrolled in Medicare for the current and previous three quarters to get full information on their diagnosis. The observation is at CBSA by year-quarter by subgroup level. Outcome variables include price and quantity (total number of product/service counts per thousand Medicare FFS recipients), all in natural log terms. The gray solid lines show point estimates for the effect of the CBP for CPAP propensity below median, and the black dashed lines show point estimates for the effect of the CBP for CPAP propensity above median. Vertical lines show the 95% confidence interval for those coefficients, based upon standard errors that are clustered at the CBSA level. All regressions include CBSA fixed effects, year-quarter fixed effects, and their interactions with a dummy variable for each group. All regressions are weighted by Medicare FFS population in 2010.

TABLE 5.—MARGINAL CONSUMER OF CPAP

	(1) Dual	(2) Male	(3) SA diagnosed	(4) OSA diagnosed	(5) CPAP propensity
Log CPAP rate	0.459***	−0.160*	−0.398***	−0.576***	−0.0956**
	(0.155)	(0.0908)	(0.153)	(0.199)	(0.0456)
Mean	0.186	0.546	0.792	0.727	0.201
N	26,762	26,762	23,872	23,872	19,108
Year-quarter FE	Yes	Yes	Yes	Yes	Yes
CBSA FE	Yes	Yes	Yes	Yes	Yes

Results of regression analysis for the effect of the CBP on the average demographic characteristics of CPAP users. The observation is at CBSA by year-quarter level. For sleep apnea (SA) and obstructive sleep apnea (OSA) diagnosis, we restrict to patients who remained enrolled in Medicare for the current and previous three quarters to get full information on their diagnosis (sample period starts 2009Q4). For CPAP propensity which is estimated using 2010 data, we use observations only since 2011Q1 to estimate marginal consumer. Outcome variables include average CPAP propensity predicted as shown above, demographic characteristics and SA/OSA diagnosed. We instrument for the explanatory variable, Log CPAP rate, using the treatment indicator of the CBP. All regressions include CBSA fixed effects and year-quarter fixed effects. All regressions are weighted by Medicare FFS population in 2010. Standard errors are clustered at CBSA level. Significance levels: *0.1, **0.05, and ***0.01.

subgroups in table 3) and the endogenous independent variable of interest is the log of the CPAP rate, calculated as total demand D_{st} divided by Medicare beneficiaries M_{st}. The excluded instrument is the interaction from the difference in difference specification described above. The coefficients estimate the gap in demographics and outcomes between the marginal and the average consumer, where the marginal consumer is *less* likely to obtain a CPAP post-CBP.

Column 5 of table 5 shows that marginal consumers are 0.0956 pp lower in CPAP propensity than average consumers, as suggested by the graphical analyses. Columns 1–2 show that marginal consumers are more likely to be duals, consistent with our findings that duals reduce quantity more, and are less likely to be male. Columns 3 and 4 show that marginal consumers are also less likely to have an SA or OSA diagnosis in the past year, again consistent with our findings with subgroups. Appendix figure A8 shows event study results for the impact of CBP on the outcomes in table 5 and confirms that the average demographic characteristics of CPAP users do not have different pre-trends in treated and untreated areas.

V. Policy Analysis

To draw normative conclusions about the impact of the CBP, we must view our results in context. A full accounting of the welfare impacts of this significant change to the Medicare reimbursement policy is outside the scope of this paper. However, we develop a simple cost-benefit comparison from the government's perspective that also incorporates the effects on patient health. We ignore the impact of the program on firm profits. We begin with the approximation that the benefits of competitive bidding are the savings on inframarginal units: $dP \times D_2$. The costs of competitive bidding may fall on the government or on consumers. First, government expenditures may increase (decrease) if other covered services are substitutes (complements) for competitive bidding items; let E represent such average government

expenditure. Second, consumers value consumption of durable medical goods; let B represent (monetized) health benefits to consumers and let η represent the weight that the government places on consumer benefits.

The benefits of competitive bidding exceed the costs if and only if

$$dP \times D_2 > dE + \eta dB.$$

The first three objects in this equation are easy to calculate. According to table 2, the average price drop is $e^{-0.594} - 1 = 44.8\%$ from a baseline average price of \$71.33, which gives us $dP = 44.8\% \times \$71.33 = \$31.96$ per month, or \$415.43 over the thirteen-month rental period. We can multiply this by the number of inframarginal units; 8.30 beneficiaries per thousand Medicare beneficiaries have a CPAP claim. Therefore, the total savings are \$3448.07 per thousand Medicare beneficiaries. In appendix table A13, we show that (non-DME) Medicare expenditures actually fall post-competitive bidding; we (conservatively) ignore dE.

The last object—the loss of the health benefits to consumers no longer purchasing DME under competitive bidding—is harder to calculate. Although we can characterize marginal consumers, our empirical analysis makes it difficult to measure their willingness to pay.[41] To quantify the benefits of a CPAP machine, we turn to the clinical literature. We measure the health benefits of CPAP machines in terms of quality-adjusted life years (QALYs); 1 QALY is one year in perfect health. We then calculate the "cost-per-QALY," known as an incremental cost-effectiveness ratio (ICER). According to external estimates from the United Kingdom's National Institute for Health and Care Excellence (NICE, 2008), the cost for the average consumer is £20,585 per QALY for patients with mild OSA, assuming a CPAP price of £250–£550. Given the midpoint of that estimate, we calculate that a CPAP generates 0.0194 QALYs (400/20,585). For moderate and severe OSA, NICE estimated £9391 and £4413 per QALY respectively, which leads to CPAP values of 0.042 and 0.091 per QALY.

We can calculate the change in the number of consumers from our estimates: there are 0.37 ($e^{-0.0439} - 1) \times 8.30$) fewer CPAP consumers per thousand Medicare beneficiaries. The benefits of the CBP will exceed its costs if the value of a QALY is less than the savings divided by the number of new consumers multiplied by the benefits (in QALYs) per consumer. In our setting, this is given by $3448.07/(0.0194 \times 0.37) = \$480,366.40$. The QALY threshold is \$221,883.53 if the marginal CPAP user has moderate OSA, or \$102,407.78 if the marginal CPAP user has severe OSA. In our analyses above we find that the marginal consumer has a lower CPAP propensity than the average consumer, so they are less likely to have severe OSA. Estimates within the literature value a year of life in perfect health at \$75,000 to \$100,000 (Cutler & Meara, 2000). Therefore, we find that the saving from the reduction in Medicare spending substantially exceed the costs of reduced access to CPAP devices in our setting.

Taken together, our results suggest that the benefits of the lower health care expenditures outweigh any access loss from reduced quantity. However, we note several caveats. We do not account for supplier profits, nor is this meant to be a complete welfare analysis. We make several assumptions—about both social welfare weights and cash prices—that are not innocuous. However, our conservative estimates still highlight the potential for large government savings under the program. Future work should explore optimal reimbursement policy.

VI. Conclusion

We estimate the impact of Medicare's CBP, which was introduced a decade ago. We find that the roll-out of competitive bidding—staggered across product, space, and time—led to large reductions in the prices paid for DME. If the categories in the CBP were representative of all categories, we would expect a cost savings of 43.0%. The total non-CBP DME spending in 2015 was \$5 billion (appendix table A1), among which 2.6 billion are from CBAs. As a result, we would expect an additional \$1.1 billion in savings were CBP extended to all DME categories in the CBAs that used competitive bidding. However, reductions in quantities accompanied these price reductions. We explore the CPAP market in particular to show that the marginal consumer is more likely to be a dual-eligible who faces no cost sharing. The results suggest that changes in supply, rather than demand, are driving the overall reduction in quantity.

To separate supply and demand-side factors, we compare the impact of the CBP on dual-eligible and nondual-eligible enrollees. We show that reductions in out-of-pocket costs mitigate the impact of the program on utilization; there are no reductions in quantities for nondual eligibles (who see a reduction in their out-of-pocket price as a result of the CBP). Finally, we show that rates of diagnosis do not change. The quantity reduction is significantly higher among consumers without a formal sleep apnea diagnosis. Our model and empirical analysis indicates these consumers are less clinically appropriate for treatment. Given our results for price, utilization, and Medicare spending, we perform a cost benefit analysis. The calculations indicate that the benefits of the price reduction on inframarginal units more than offsets the costs of any loss in consumer surplus.

While highlighting the success of the CBP in reducing Medicare spending, our findings suggest that Medicare faces a serious challenge in setting prices for health care services within its fee-for-service program. Although most Medicare

[41] We know that (for nondual) consumers, willingness to pay is at least $0.2 \times P_1$. However, we are probably more interested in the upper bound; this requires considering the"worst case scenario" from the perspective of the consumer. We have two main concerns. The first, and potentially more damaging, is that changes in reimbursement could lead to underdiagnosis. Second, changes in reimbursement could lead to increases in spending elsewhere in the medical system. Medicare will still cover all of the services associated with a sleep apnea diagnosis.

recipients obtain coverage for prescription drugs through private Medicare Part D plans and nearly 40% obtain their health insurance through private Medicare Advantage plans, the majority of Medicare recipients have traditional Medicare fee-for-service coverage. Future work should consider whether market mechanisms such as competitive bidding could be effective in other areas of Medicare's fee-for-service program.

In both regulation and procurement, governments often face serious challenges. Governments may lack the information necessary to set prices at the efficient level (Chan & Dickstein, 2019). However, market mechanisms must be well designed. In our setting, the auction we study is unlikely to produce efficient outcomes, despite the price reductions we observe. Various features of the auction—such as a median-bid pricing rule and nonbinding bids—may lead prices to fall beyond the efficient level (Cramton et al., 2015). Auction rules should also be designed to prevent gaming by firms (Decarolis, 2015). The problems they face are often challenging and complex, especially in health care.

At the same time, looming challenges face Medicare financing, with expenditures for the program projected to more than double from 750 billion in 2018 to 1.559 trillion by 2028. This would represent a 7.6% annual growth rate in total spending (5.0% annual on a per-recipient basis) compared with an annual growth rate in total spending of just 4.9% during the preceding ten years (CMS, 2020b). Our results suggest that Medicare's future funding challenges could be reduced by targeted reforms of price setting in this program, which currently provides health insurance to one in five Americans.

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