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Increased consumption of cardiovascular drugs under volume-based procurement (VBP) policy: demand release or assessment inducing?

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Abstract

Background The phenomenon of growth in drug consumption within the framework of national volume-based procurement (VBP) policy raises speculations about demand release and policy inducing. This study aims to explore the reasons and mechanisms of drug consumption increases following VBP policy from two perspectives.

Methods We collected data from the China Drug Supply Information Platform, National Bureau of Statistics and the Joint Procurement Office. Twenty cardiovascular international non-proprietary names (INNs) in the first three VBP batches and 28 observation regions were included, constructing 418 valid INN-region combinations as the unit for analysis. The average monthly consumption volume of VBP cardiovascular drug was assigned as the explained variable. The generalized difference-in-difference method was conducted using the price reduction level and the size of policy assessment task as the policy intensity indicator. Moderating effect model was employed to examine the role of resident's income level.

Results Increased cardiovascular drug consumption was observed in 285 (68.18%) INN-region combinations after policy implementation. Under VBP policy, the price reduction level was significantly correlated with drug consumption in total ($\beta = 0.144$, $p < 0.001$), as well as in tertiary hospitals, secondary hospitals and primary healthcare centers (PHCs) (all p-values < 0.05). Resident's income level negatively moderated the impact of price reduction level on drug consumption in total ($\beta = -0.089$, $p < 0.001$) and in secondary hospitals ($\beta = 0.154$, $p < 0.001$) and PHCs ($\beta = -0.2.9$, $p < 0.001$), rather than in tertiary hospitals ($\beta = -0.079$, $p > 0.05$). The size of policy assessment task was positively associated with drug consumption in total ($\beta = 0.052$, $p < 0.001$), as well as in tertiary hospitals, secondary hospitals and PHCs (all p-values < 0.05).

Conclusions Two mechanisms codrive drug consumption increases under VBP policy: first is the improvement of cardiovascular medication access and consumption toward lower-income groups following price reduction, pointing to the fulfillment of unmet needs, and second is policy pressure from supporting assessment measures on hospital drug use, indicating potential overprescribing.

Keywords Volume-based procurement, Cardiovascular drug, Drug consumption

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What is known on this topic

- China's volume-based procurement (VBP) practice, which mainly focuses on drugs for chronic and common diseases, has gained great achievements in price reduction, cost saving and generic substitution among policy-covered drugs.
- The increased consumption of policy-covered drugs might relate to price changes and policy assessment measures on hospital drug use, but the specific reasons and mechanisms have not yet been empirically revealed.

What this study adds

- This study is the first to empirically explore the impact and mechanism of VBP policy on the consumption of drugs for chronic disease from the perspectives of demand release and policy assessment inducing.
- China's VBP practice has significantly increased cardiovascular drug utilization among lower-income groups, which is conducive to fulfilling the medication demand of disadvantaged patients with chronic diseases and promoting health equity.
- The size of policy assessment tasks under VBP policy is significantly correlated with greater drug consumption, indicating increased drug use induced by supporting policy assessment measures on hospital drug use that requires vigilance.

Background

Chronic non-communicable diseases are the greatest global health threat, the WHO reported that 74% of global deaths are attributed to non-communicable diseases, of which 17.9 million people die of cardiovascular diseases each year, accounting for 32% of all deaths [1]. In China, chronic diseases account for 86.6% of the total disease deaths and 70% of the total disease burden, which have become the largest disease burden and threat [2]. Among them, cardiovascular chronic diseases occupy the first place in the composition of disease deaths, accounting for 48.00% and 45.86% of rural and urban death causes in 2020 [3]. A total of 330 million Chinese patients are suffering from cardiovascular diseases, including 245 million patients with hypertension [3]. The rapid population aging in China has further advanced the morbidity and comorbidity, as well as polypharmacy of chronic diseases. It is reported that more than 78% of Chinese elderly suffer from one or more chronic diseases [4], with an average of 4.68 chronic diseases [5], and 75% of elderly patients with chronic diseases need to take five or more drugs simultaneously [6]. Patients with cardiovascular chronic disease usually need long-term medication, and the demand for combination and multiple medications increases as the patient ages and the disease progresses [7, 8], resulting in a heavy economic burden of medication.

Since 2018, the Chinese government has piloted and promoted the national volume-based procurement (VBP) policy of drugs nationwide, making China the current largest group purchasing organization in the world. VBP policy aims to restructure the pharmaceutical pricing system, purify the pharmaceutical circulation environment and, more importantly, reduce the medication burden of patients [9]. Through the policy measure of achieving volume-price linkage, ensuring drug quality and supply, guaranteeing hospital drug use and timely payment, etc. [10, 11], the implementation of VBP policy has played significant roles in reducing drug prices, saving drug costs and promoting the substitution of generic drugs [12–17]. As of October 2024, nine VBP batches have been carried out at the national level and successfully procured 374 drugs, most of which are treated for chronic diseases and common diseases.

In the context of national volume-based procurement (VBP) policy, a large number of studies have documented a pervasive increase in the consumption of policy-covered drugs [14, 18–22]. The same phenomenon occurs in cardiovascular drugs [23–28]. For example, Chen et al.'s [28] analysis of drug utilization within medical institutions city wide revealed a postpolicy surge of 41.96% in cardiovascular drug consumption, with the predominant increase occurring in primary healthcare settings (250.29% increment). The phenomenon of growth in cardiovascular drug consumption following VBP policy raises two possible explanations. One is the release of previously unmet medication demand brought about by VBP drug price reduction. Cardiovascular drugs have a significantly negative demand price elasticity (−1.100) in China [29], thus corresponding drug demand would increase after VBP's price reduction. Considering the prominent low demand elasticity of drug consumption, the increased drug use after the VBP policy should mainly stem from previously unmet medication needs due to affordability constraints. The second is the increase in drug use induced by supporting assessment measures for VBP policy. The National Health Commission (NHC) and National Healthcare Security Administration (NHSA) have issued supporting policies requiring the monitoring and assessment of VBP drugs' use in medical institutions [30–32] to urge the priority use of VBP bid-winning products as well as the completion of agreed procurement tasks. To ensure the timely completion of policy assessment tasks, the common practice of hospitals is to decompose the annual agreed procurement tasks by month and further decompose them to departments and even individual physicians [33, 34], which might restrict physicians' prescribing behaviour and easily develop the inertia behaviour of over prescribing. Previous studies

on the category of antibacterial drugs have indicated policy-induced consumption increment under VBP policy [35, 36].

The surge in VBP policy-covered cardiovascular drug consumption prompts the question of whether it satisfies the needs of broader chronic disease patients or is a consequence of policy-induced utilization. This directly relates to the public's sense of policy contentment and has implications for the sustainability and stability of system operation. Therefore, taking cardiovascular drugs (a class of chronic disease treatment drugs with the largest potential consumer) procured in the first three VBP batches as an example, this study attempts to explore the reasons for the increase in the use of policy-covered chronic disease drugs from two perspectives—drug demand release and policy assessment inducing, to provide decision-making reference for subsequent policy improvements.

Policy elements and hypotheses

VBP is a typical composite policy with multidimensional supporting measures [16, 19], in which two policy elements are closely related to drug consumption changes that this study concerned: (1) the prominent price reduction of policy-covered drugs under the VBP mechanism and (2) the supporting policy measure to ensure the prioritized use of bid-winning drugs, as shown in Box 1.

Box 1. Two policy elements related to drug consumption changes.

(1) Price reduction

- National consolidation of drug procurement demands. The NHSA centralizes the procurement demands for specific drugs, thereby enabling a purchasing alliance among numerous medical institutions across the nation
- Enhanced market competition. Eligibility for bidding is contingent upon meeting quality standards (generic consistency evaluation) and supply criteria. A select few bidders (less than 10[a]) who offer lower tender prices are awarded the contracts [9, 37].
- Diminished transactional costs. The aggregation of bulk drug procurement orders facilitates economies of scale in production, thereby reducing marginal manufacturing costs. Under the 'volume-price linkage' mechanism, pharmaceutical enterprises no longer need high sales and kickback costs, leading to substantial cost savings in the distribution process [38, 39].

(2) Policy assessment

- The NHC assesses the implementation progress of the VBP policy among medical institutions, with a focus on whether the annual agreed procurement task is completed and the use proportion of bid-winning drugs within the evaluation framework [31, 40]
- The NHSA has established a policy assessment mechanism that encompasses the procurement progress of VBP INNs into medical insurance agreement management and the medical insurance cost assessment for medical institutions [30]
- The surplus retention mechanism is established, stipulating that no less than 50% of the medical insurance funds saved through VBP policy implementation shall be returned to medical institutions for incentives [41]

[a] A 'single winner' method was applied in the early policy stage ('4 + 7' pilot), and then the government gradually increased the number of winners in the follow-up batches. According to the latest procurement documents, the maximum number of winners can reach 10 when the number of bidders is ≥ 13

In terms of drug price reduction. The pooled pharmaceutical procurement mechanism has been recognized to benefit the reduction of drug prices [42]. In China's VBP practice, the government has adeptly orchestrated the aforementioned strategies to prompt pharmaceutical enterprises to participate in VBP bidding and offer lower prices, either passively or proactively [10, 11, 17]. First, the substantial allure of the whole pharmaceutical market in the Chinese mainland toward pharmaceutical enterprises makes their eagerness to low prices in exchange for the national market. Second, the reduction of production and distribution costs, coupled with the government's mandate that medical institutions settle payments to pharmaceutical companies within a 30-day window, enabling the possibility of lower ex-factory and supply prices and, thereby, affording companies leeway for price concessions. Third, the intense competition ensuing from a finite number of bid winners necessitates that companies aggressively seek VBP bid winning to ensure their survival. Government statistics showed that the average price reduction exceeded 50% among 1–8 VBP batches between 2018 and 2023 [43]. Also, linkage price reduction effect on non-winning products was detected [15, 44, 45]. According to the consumer behaviour theory, changes in commodity prices affect the consumed quantity through the income effect and substitution effect, and the consumption of cut-price goods would increase [46]. Thus, we assume a significant correlation between price decline of policy-covered drugs and its consumption increase under the VBP policy with the following research hypotheses:

Hypothesis 1–1: the price reduction of VBP-covered cardiovascular drugs positively affects the consumption volume.

However, drugs, unlike general commodities, are necessities and usually have a low elasticity of demand, that is, people do not create drug needs simply because of price reduction [47]. It is worth noting that there is a large proportion of unmet medication needs among Chinese patients with chronic diseases [3, 8, 48]. Meanwhile, price reduction of policy-covered drugs refers to an improvement in drug affordability and availability, especially for vulnerable groups such as rural residents and the uninsured [11, 49]. Thus, theoretically, the implementation of the VBP policy could increase the use of policy-covered drugs, and the increase tends to occur in groups or regions that have more previous unmet drug needs.

Hypothesis 1–2: the positive effect of price reduction on policy-covered cardiovascular drug consumption is more prominent in low-income groups.

In terms of policy assessment, the original intention of the above VBP supporting policy measures is to ensure

the completion of agreed assessment tasks, and policies usually affect physician behaviour and, thus, affect drug consumption [50]. Relevant literature pointed out that there are behaviours such as physicians prescribing more drugs due to VBP policy assessment [36, 51]. Medical institutions generally complete the agreed procurement quantity of policy-covered drugs at a very high proportion [19], which, to some extent, indicates the possibility of policy-induced drug use increases. Therefore, we can indirectly measure the existence of VBP policy assessment-induced drug demand by estimating the relationship between the size of drug assessment tasks and their consumption changes under policy implementation.

Hypothesis 2: the size of the policy assessment task positively affects the consumption of policy-covered cardiovascular drugs.

Materials and methods

Data sources

We first obtained nationwide drug procurement data of public medical institutions from the China Drug Supply Information Platform (CDSIP), which is a comprehensive provincial drug centralized bidding procurement platform for national drug procurement data from 31 provinces (autonomous regions and municipalities). The data extracted from the CDSIP database include the name of the medical institution, procurement date, drug YPID (Yao Pin Identifier) code, drug name (international non-proprietary name, INN), dosage form, specification, package, manufacturer, unit price, purchasing unit, purchase quantity and purchase expenditures, etc. It was estimated that the CDSIP database covered more than 80% of drug purchasing data from national health facilities in mainland China. The CDSIP database has integrated large-scale real-world data covering 7782 drug active ingredients, 137,646 drug INNs and 146,993 products (calculated by YPID code) in basic drug attribute information and purchasing order information. Nationwide, 48,205 public medical institutions from 31 provinces were involved in the CDSIP, including 9176 public hospitals and 39,029 primary healthcare institutions [52].

In addition, the data on population, economy and income, medical service utilization in each observation region were obtained from the websites of national and local statistical bureaus. The data on the VBP INN list and the agreed procurement quantity of each policy batch were extracted from the official website of the Joint Procurement Office (JPO).

Sample selection

Using the CDSIP data from January 2018 to December 2020, we select study samples based on the following criteria:

(1) The drug scope was VBP policy-covered cardiovascular drugs, defined by the Anatomical Therapeutic and Chemical (ATC) classification C. The first three VBP batches were considered, among which the first VBP batch consisted of two rounds (i.e., '4+7' pilot and '4+7' expansion). The list of VBP policy-covered drug INN came from the procurement documents (GY-YD2018-1, GY-YD2019-1, GY-YD2019-2, GY-YD2020-1[1]) issued by the JPO. We included 20 cardiovascular drugs (by INN) covering seven therapeutic categories (Supplementary Table 1).

(2) The region scope was the provinces or cities that implemented the first three VBP batches, which was 11 cities for the '4+7' pilot, 25 alliance areas for the '4+7' expansion and 31 provinces for the second and third VBP batches. Several targeted areas with incomplete data were excluded from this study. A total of 28 regions were included (Supplementary Table 2).

(3) The facility scope was all public healthcare institutions in the included observation region, classified into tertiary hospitals, secondary hospitals and primary healthcare centers (PHCs).

Finally, 418 valid INN-region combinations were constructed as study samples based on the included INNs and regions.

Study variables

Explained variable

The average monthly consumption volume of VBP cardiovascular drug was assigned as the explained variable, including the total consumption of the whole region and the consumption in tertiary hospitals, secondary hospitals, PHCs, respectively. First, the ATC/DDD method developed by the WHO Collaborating Centre for Drug Statistics Methodology was applied to standardize drug procurement data and calculate the consumption volume—defined daily doses (DDDs)—of each INN in each observation region during each month. Second, considering that the implementation time and region are not completely consistent among different VBP batches, we calculated the monthly average consumption of pre- and post-VBP periods by INN-region combination based on the actual implementation time of each VBP batch in each observation region. The data of drug consumption volume was logarithmically transformed before model estimation.

[1] The procurement documents are released publicly on the JPO website: the '4+7' pilot (https://www.smpaa.cn/gjsdcg/2018/11/15/8511.shtml), '4+7' expansion (https://www.smpaa.cn/gjsdcg/2019/09/01/8974.shtml), the second VBP batch (https://www.smpaa.cn/gjsdcg/2019/12/29/9205.shtml) and the third VBP batch (https://www.smpaa.cn/gjsdcg/2020/07/29/9516.shtml).

Explanatory and moderating variable

For the testing of hypothesis 1–1, the explanatory variable is the interaction term of price reduction intensity (*D*_price) and policy intervention period (*T*). We calculated the decline range in the defined daily cost of each INN in each observation region before and after the VBP policy and divided it into six groups: no decline (1), 0–20% decline (2), 20–40% decline (3), 40–60% decline (4), 60–80% decline (5), > 80% decline (6).

For the testing of hypothesis 1–2, we used the residents' income level as the moderating variable. Regarding the correlation between the regional economic level and residents' medication use for chronic diseases [53, 54] and considering the per capita disposable income of residents could better reflect the living standards and purchasing power of local people compared with per capita GDP [55], we applied three indicators to measure the residents' income level: the per capita disposable income of residents, disposable income of urban residents and disposable income of rural residents. The residents' income data were logarithmically transformed.

For the testing of hypothesis 2, the explanatory variable is the interaction term of policy assessment task intensity (*D*_assessment) and policy intervention period (*T*). The size of the policy assessment task was measured by the ratio of first-year agreed procurement quantity to historical procurement quantity of each INN in each observation region, and the larger the ratio, the greater the policy assessment task of the INN in the region.

Control variable

According to relevant literature [19, 52, 53], this study considered factors that potentially impact regional drug consumption from three dimensions: population, economy and medical service volume. Specifically, the end-of-year population, the gross domestic product, the annual medical institution visits and the baseline drug consumption quantity were included and were logarithmically transformed before model estimation. Besides, fixed effects were applied to control the potential impact of invisible factors in the INN-level and regional level.

The definition of study variables are listed in Table 1.

Empirical approach

This study employed the generalized difference-in-difference (DID) model for empirical analysis [56, 57]. On the one hand, the generalized DID model can fully utilize the principles of the standard DID model to estimate the average treatment effect in the absence of a control group. On the other hand, it can effectively avoid estimation bias in the actual policy effect caused by the subjective selection of the treatment group. The primary equation of generalized DID is as follows:

$$Y_{ijt} = \alpha + \beta \cdot DT + \delta \cdot Control_{ij} + \mu_i + \lambda_j + \varepsilon_{ijt} \quad (1)$$

, where Y_{ijt} refers to the monthly average consumption volume of INN j in region i during period t. T refers to policy implementation periods, the pre- and post-VBP periods coded 0 and 1, respectively. D indicates policy intervention intensity, including the price reduction intensity (D_price) and the size of policy assessment task (D_assessment). $Control_{ij}$ refers to the above-mentioned control variables. μ_j and λ_j refer to the INN level fixed effect and region level fixed effect. ε_{ij} is the random error term.

A moderating effect model was constructed on the basis of Eq. (1), to estimate the effect of resident's income level, as follows:

$$Y_{ijt} = \alpha + \beta \cdot DT\_price \times income_j + \theta \cdot DT\_price + \gamma \cdot income_j + \delta \cdot Controls_{ij} + \mu_i + \lambda_j + \varepsilon_{ijt} \quad (2)$$

, where $income_j$ indicates the income level of residents in region j, including the per capita disposable income of residents, disposable income of urban residents and disposable income of rural residents.

In addition, two robustness test approaches were applied. First, a placebo test by generating a random grouping variable. Second, model estimating by replacing the explained variable.

Results

Descriptive statistics

Among the 418 included INN-region combinations, 285 (68.18%) presented an increasing trend in the consumption of VBP cardiovascular drugs after policy implementation, and 220 (52.63%) showed an increment of ≥ 20%. A total of 410, 406 and 396 samples reported drug consumption in tertiary hospitals, secondary hospitals and PHCs, among which 250 (60.98%), 277 (68.23%) and 292 (73.74%) reported increasing drug consumption under the VBP policy, as presented in Table 2. Among 20 included INNs and 28 observation regions, 17 INNs (35.00%) reported more than half of regions with increased drug consumption, and 24 regions (85.71%) reported more than half of INNs with increased consumption. The consumption change of VBP cardiovascular drugs showed significant differences among INNs and regions (Supplementary Table 3).

Generalized DID of price reduction

Table 3 reports the result of generalized DID using price reduction extent as the policy intensity indicator. The price reduction level showed a significant positive effect on total cardiovascular drug consumption under the VBP

Table 1 Definition of study variables

Variable	Description
Explained variable	
Drug consumption	The logarithm of monthly average consumption volume of VBP policy-covered cardiovascular drugs, including the total consumption of the whole region and the consumption in tertiary hospitals, secondary hospitals and PHCs, respectively
Explanatory variable	
T	Time period pointing VBP policy implementation, coded 0 for the pre-VBP period and 1 for the post-VBP period. The periods for the '4 + 7' pilot was April to December 2018 (pre-) and April to December 2019 (post-), for the '4 + 7' explanation was January to November 2019 (pre-) and January to November 2020 (post-), for the second VBP batch was May to December 2019 (pre-) and May to December 2020 (post-) and for the third VBP batch was November to December 2019 (pre-) and November to December 2020 (post-)
*D*_price	The decline range in defined daily cost of each INN in each observation region before and after VBP policy and divided it into six groups: (1) no decline, (2) 0–20% decline, (3) 20–40% decline, (4) 40–60% decline, (5) 60–80% decline and (6) > 80% decline
*D*_assessment	The size of the policy assessment task, measured by the ratio of first-year agreed procurement quantity to historical procurement quantity of each INN in each observation region (coded 1–11 from low to high)
Income	The logarithm of resident's income, including the per capita disposable income of residents (income), disposable income of urban residents (income_urban) and disposable income of rural residents (income-rural)
Control variable	
Population	The logarithm of the regional end-of-year population
GDP	The logarithm of the regional gross domestic product
Visits	The logarithm of the regional annual medical institution visits
Baseline consumption	The logarithm of the baseline (2018) drug consumption volume of each INN in each observation region

VBP, volume-based procurement; PHCs, primary healthcare centers; GDP, gross domestic product; INN, international non-proprietary names

Table 2 Interval distribution of drug consumption change among included samples

Category	*n*	Increased drug consumption	Consumption change interval		
			< −20%	−20 to 20%	≥ 20%
Total	418	285 (68.18)	88 (21.05)	110 (26.32)	220 (52.63)
Tertiary hospitals	410	250 (60.98)	90 (21.95)	137 (33.41)	183 (44.63)
Secondary hospitals	406	277 (68.23)	94 (23.15)	77 (18.97)	235 (57.88)
PHCs	396	292 (73.74)	71 (17.93)	73 (18.43)	252 (63.64)

n, the number of INN-region combinations; PHCs, primary healthcare centers

policy at the 1% statistical level, with an increment of 15.49% per increased price reduction level. The significant positive effect was also detected on drug consumption in tertiary hospitals, secondary hospitals and PHCs at the 1% statistical level, with the increment of 13.66%, 19.36%, 29.95%, respectively.

Moderating effect of resident's income

Table 4 reports the moderating effect of regional resident's income level. The overall resident's income level played a significant positive moderating effect between price reduction intensity and total drug consumption at the 5% statistical level. The income level of urban and rural residents played a positive moderating effect at the 10% and 5% statistical level, respectively.

Moderating effect analysis by the type of medical institution is presented in Table 5. Among secondary hospitals and PHCs, the moderating effects of overall resident's income level, as well as the income level of urban and rural residents, were significant at the statistical level of 1% and 5%. Among tertiary hospitals, no significant moderating effects of overall resident's income level, urban resident's income level, and rural resident's income level was observed at the 5% statistical level.

Generalized DID of policy assessment

Table 6 reports the result of generalized DID using the size of policy assessment task as the policy intensity indicator. The size of policy assessment task presented a significant positive effect on total cardiovascular drug consumption under VBP policy at the 1% statistical level,

Table 3 The generalized DID analysis on the effect of price reduction intensity on drug consumption

	(1) Total consumption	(2) Consumption in tertiary hospitals	(3) Consumption in secondary hospitals	(3) Consumption in PHCs
DT_price	0.144***	0.128***	0.177***	0.262***
	(0.022)	(0.026)	(0.029)	(0.039)
Population	−17.498**	−15.650*	−18.984**	−12.013
	(7.094)	(8.393)	(9.362)	(12.559)
GDP	−1.105	−0.246	−0.895	−0.727
	(1.708)	(2.022)	(2.289)	(3.017)
Visits	6.234***	5.747***	5.198***	5.145**
	(1.263)	(1.495)	(1.682)	(2.230)
Baseline consumption	0.186***	0.177***	0.205***	0.252***
	(0.015)	(0.018)	(0.020)	(0.028)
Constant	153.121***	129.503**	162.206**	103.785
	(48.496)	(57.405)	(64.753)	(85.911)
Region FE	Yes	Yes	Yes	Yes
Drug FE	Yes	Yes	Yes	Yes
Observations	836	834	826	826
R-squared	0.780	0.731	0.722	0.720

PHCs, primary healthcare centers; GDP, gross domestic product; FE, fixed effect

*, ** and *** indicate significance at 10%, 5% and 1% level, respectively

with an increment of 5.34% per increased policy assessment task level. The significant positive effect was also detected on drug consumption in tertiary hospitals, secondary hospitals and PHCs at the 1% statistical level, with the increment of 4.71%, 9.42% and 21.29%, respectively.

Robustness test

Two robustness tests were conducted: (1) placebo test (Supplementary Table 4). By replacing the policy intensity variable (*D*_price and *D*_assessment) using a randomly generated grouping variable (placebo), the placebo test could detect whether the observed influential effect on drug consumption might be caused by other policies or random factors. We found that the placebo effect was not significant at the 10% statistical level, indicating the observed effects were indeed caused by the VBP policy implementation. (2) Model estimation by replacing the explained variables (Supplementary Table 5). Considering the correlation between the consumption of bid-winning products and their corresponding INNs—the increased use of bid-winning products under VBP policy drives the total consumption increases of policy-covered INNs [58]. We constructed the indicator of 'monthly average consumption volume of bid-winning products' to replace the original explained variable and re-estimated the models. The estimated results were generally consistent, which confirmed the robustness of the above estimation results.

Table 4 The moderating effect analysis of resident's income level

	(1)	(2)	(3)
DT_price	1.067**	1.475**	1.115**
	(0.466)	(0.708)	(0.484)
DT_price × income	−0.089**		
	(0.045)		
DT_price × income_urban		−0.125*	
		(0.067)	
DT_price × income_rural			−0.100**
			(0.050)
Income	−413.317**		
	(186.159)		
Income_urban		2,593.309**	
		(1247.255)	
Income_rural			165.426**
			(70.225)
Constant	4,435.840**	−27,480.044**	−1,459.308**
	(1985.045)	(13,230.251)	(631.398)
Control	Yes	Yes	Yes
Region FE	Yes	Yes	Yes
Drug FE	Yes	Yes	Yes
Observations	836	836	836
R^2	0.781	0.781	0.781

FE, fixed effect

*, ** and *** indicate significance at 10%, 5% and 1% level, respectively

Table 5 The moderating effect analysis of resident's income level among different medical institution types

	Tertiary hospital			Secondary hospital			PHCs		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
DT_price	0.949*	1.211	1.096*	1.765***	2.574***	1.799***	2.422***	3.421***	2.350***
	(0.553)	(0.839)	(0.574)	(0.614)	(0.930)	(0.639)	(0.820)	(1.246)	(0.852)
DT_price × income	−0.079			−0.154***			−0.209***		
	(0.053)			(0.059)			(0.079)		
DT_price × income_urban		−0.102			−0.226**			−0.298**	
		(0.079)			(0.088)			(0.117)	
DT_price × income_rural			−0.100*			−0.167**			−0.215**
			(0.059)			(0.066)			(0.088)
income	−352.51			−426.300*			−173.965		
	(220.495)			(246.252)			(329.128)		
income_urban		2248.80			2,523.34			806.038	
		(1477.481)			(1649.584)			(2206.125)	
income_rural			139.689*			176.618*			88.712
			(83.148)			(92.973)			(124.205)
Constant	3,781.32	−23,831.81	−1233.982*	4,569.738*	−26,742.51	−1,564.927*	1,873.76	−8,531.56	−780.078
	(2351.180)	(15,672.364)	(747.590)	(2626.108)	(17,497.684)	(835.654)	(3509.576)	(23,401.429)	(1116.708)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Drug FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	834	834	834	826	826	826	826	826	826
R^2	0.731	0.731	0.732	0.724	0.724	0.724	0.722	0.722	0.722

*, ** and *** indicate significance at 10%, 5% and 1% level

Discussion

This study explored the effects of China's vigorous VBP reform on drug consumption employing the generalized DID and moderation effect models, taking the cardiovascular drug—a class of chronic disease treatment drugs with the largest potential consumer—as an example. Price reduction under VBP policy significantly increased the consumption of policy-covered drugs, and a lower resident's income level significantly correlated with greater drug consumption increment. In addition, the size of policy assessment tasks positively correlated with corresponding drug consumption after policy implementation. This study is the first to analyse the reasons for drug consumption changes as well as attempt to explore the behavioural mechanisms behind in the context of China's latest policy practice.

Price reduction has increased VBP cardiovascular drug consumption

This study detected increases in consumption of VBP policy-covered cardiovascular drugs after policy implementation, which is consistent with previous studies on multi-category drugs [20–22] as well as on chronic disease drugs [59]. We also confirmed a significant association between price reduction level and corresponding drug consumption increment through a generalized DID model, which can be explained by the negative price elasticity of cardiovascular drug demand among the Chinese population (−1.100) [29].

For a long time, the market failure of China's pharmaceutical market has hindered the effective regulation of the price and demand by the market adjustment mechanism, resulting in distorted market performance of greater consumption of high-price drugs and less consumption of low-priced drugs [60, 61]. Therefore, the currently observed correlation between price decline and consumption growth is also a positive signal that the regulatory role of the market is gradually coming into play under the VBP mechanism. Yang [62] found through Spearman correlation analysis that the relationship between drug prices and consumption volume was shifting from a positive correlation and no correlation to a negative correlation under VBP policy intervention, supporting the finding of this study.

Income level moderates cardiovascular drug consumption increment

This study confirmed a significant negative moderating effect of regional resident's income level on the increase of

Table 6 The generalized DID analysis on the effect of policy assessment task intensity on drug consumption

	(1) Total consumption	(2) Consumption in tertiary hospitals	(3) Consumption in secondary hospitals	(4) Consumption in PHCs
DT_assessment	0.052***	0.046**	0.090***	0.193***
	(0.017)	(0.020)	(0.022)	(0.029)
Population	−14.993**	−13.433	−16.363*	−11.163
	(7.239)	(8.489)	(9.461)	(12.568)
GDP	2.17	2.662	2.251	2.014
	(1.657)	(1.944)	(2.200)	(2.870)
Visits	3.454***	3.284**	2.759*	4.080*
	(1.243)	(1.458)	(1.625)	(2.160)
Baseline consumption	0.193***	0.184***	0.218***	0.286***
	(0.016)	(0.019)	(0.021)	(0.028)
Constant	103.776**	85.734	112.707*	70.641
	(48.969)	(57.446)	(64.572)	(84.993)
Region FE	Yes	Yes	Yes	Yes
Drug FE	Yes	Yes	Yes	Yes
Observations	836	836	834	826
R^2	0.771	0.771	0.725	0.715

PHCs, primary healthcare centers; GDP, gross domestic product; FE, fixed effect

*, ** and *** indicate significance at 10%, 5% and 1% level, respectively

cardiovascular drug consumption derived from the VBP policy, that is, the effect of VBP price reduction on the increase of cardiovascular drug consumption was more prominent in low-income groups. The finding is related to the release of consumer demand after the expansion of healthcare security. Relevant literature pointed out that patient's drug utilization was affected by medical security coverage and degree, and disadvantaged groups such as the low-income population had higher policy sensitivity, tending to produce more prominent demand release [63–66]. In this study, low-income groups are generally more sensitive to drug prices, and their drug consumption behaviour is easily affected by the price reduction of VBP policy. Therefore, the significant association between lower income level and greater drug consumption reflected that the increased use of cardiovascular drugs driven by VBP policy was more likely to occur in low-income patients with a potentially greater proportion of unmet drug needs in the past.

In addition, we detected the moderating effect of lower resident's income level on the increases of VBP drug consumption in the healthcare setting of PHCs and secondary hospitals, rather than tertiary hospitals. This might be related to the fact that low-income and other disadvantaged groups tend to seek medical treatment at PHCs and small-scale hospitals in China [67], where their unmet medication needs are released after VBP policy implementation. Another possible explanation was that PHCs previously had a limited number of equipped drugs, poor drug accessibility, as well a low online procurement rate [68, 69], while VBP policy implementation has greatly improved the accessibility of policy-covered drugs in these healthcare settings. In either case, this indicates that the VBP policy has promoted the release of cardiovascular drug demand, especially among low-income groups, presenting an increase in consumption volume. Chen et al. [28] and Liu et al. [70] have both found more prominent increases in drug consumption in PHCs than in higher-level hospitals after VBP policy, which supported the present finding.

In China, the medication rate of patients with chronic disease was significantly lower in rural and economically underdeveloped areas [8, 48], suggesting potential unmet chronic disease medication demands in these populations. Our finding indicates that the VBP policy provides a possibility to address these issues. Thus, to further target improve patient sense of gain and promote health equity, it is necessary to vigorously improve the availability of VBP bid-winning drugs among groups in need, such as primary healthcare settings, remote areas and low-income populations. For example, the initiative of 'VBP drugs entering the primary healthcare settings' [71] being piloted in several regions is worth encouraging. Meanwhile, in the post-VBP era, it might be urgent tasks to explore and promote the synergistic governance

between VBP policy and the national essential drug system, hierarchical medical system [72].

Policy assessment task is correlated with hospital drug consumption

We found through the generalized DID model that the size of policy assessment task (the ratio of first-year agreed procurement volume to historical consumption volume) was significantly associated with greater cardiovascular drug consumption, which should be closely related to the change in physician's prescribing behaviour under the influence of policy assessment measures. To ensure that the VBP bid-winning drug's assessment task is completed on schedule, hospital administrators generally decompose the annual assessment task by month, as well as the whole procurement task of the hospital into departments and even individual physicians [33, 34]. As mentioned by previous studies [36, 51], under the constraints of policy assessment measures, on the one hand, some physicians prescribe more drugs or prescribe drugs in advance under the pressure of policy assessment in some special time nodes; on the other hand, physicians might develop the inertia behaviour of using more bid-winning drugs, resulting in an overall increased consumption of the corresponding INN.

Although there is no support from research evidence at the individual behaviour level, the present findings based on an ecological perspective have suggested that there might be a certain degree of drug consumption increment induced by policy assessment measures. As the policy is implemented, hospital administrators and prescribers will improve their adaptability to the policy, thus, we speculate that this kind of induced drug consumption due to policy assessment would gradually decrease. However, this study only focused on the first three VBP batches, so whether the finding is also applicable to subsequent batches remains to be further investigated. Nevertheless, the present finding has reminded us to be wary of hospital drug utilization moves toward another extreme—shifting from 'economic (kickbacks) incentive' [29] to 'policy incentive'. Therefore, we recommended strengthening guidance on hospital administrators and prescribers and embedding the specific assessment requirements into the overall management of hospital drug use, avoiding 'one size fits all' policy assessment measures.

Limitations

This study has potential limitations. First, limited by data accessibility, the present study only used the data of 2018–2020 to investigate the first three VBP batches, among which the post-intervention observation period of '4+7' expansion, the second and the third VBP batch fell in 2020. Considering the decrease in medical service and drug consumption in hospitals caused by the control of the coronavirus disease 2019 (COVID-19) pandemic in 2020 [52], we believe that the drug consumption increment value of cardiovascular drugs calculated in this study might be underestimated. This factor should be taken into account when extending the present finding to other policy batches. Second, the data in this study only cover public medical institutions in 31 provinces, excluding private hospitals, retail pharmacies, etc.—they might also be within the implementation scope of VBP policy. Considering the prominent phenomenon of 'flowing out of the hospital' of some products (such as non-winning original drugs) after the VBP policy [73, 74], it is necessary to conduct a comprehensive analysis of VBP drug use based on all channels in the future to improve the completeness of research findings. Third, this study focuses on the macro-level and an ecological research perspective and is limited by the availability of individual prescription data, making it impossible to conduct an in-depth analysis of individual patients with different characteristics, which is a necessary direction for follow-up research.

Conclusions

In China, the implementation of VBP policy has significantly increased the use of policy-covered cardiovascular drugs, more prominently in lower-income level regions and primary healthcare settings, implying a possible release and fulfillment of previously unmet medication needs of disadvantaged groups after price reduction. Also, during the practice of the first three VBP batches, our findings indicate the existence of policy-covered drug consumption increases and potential overprescribing induced by supporting policy measures on hospital drug use assessment, necessitating vigilance, follow-up monitoring and scientific supervision.

Supplementary Information

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Supplementary material 1.

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Availability of data and materials
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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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