Development of a Risk-Adjusted Capitation Model Based on Principal Inpatient Diagnoses in Taiwan

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Background and Purpose: Taiwan's National Health Insurance (NHI) program has considered the use of capitation payments to health care providers as a method for control of the rising costs of the system. The establishment of capitation payments usually requires the performance of risk adjustment. The purposes of this study were to develop a diagnosis-based risk adjustment model for the NHI and to evaluate its predictability.

Methods: Using a 2% random sample of 371,620 NHI enrollees, the authors developed a Taiwan version of the Principal Inpatient Diagnosis Cost Groups (TPIPDCGs) from 1996 claim records to predict an individual's expenditure in 1997. Weighted least squares regression models were built in an estimation sample (two-thirds of the study sample), and were cross-validated in a validation sample (the remaining one-third of the study sample). Predictive R^2 and predictive ratios were used to evaluate the model's predictability.

Results: Only 7.88% of the study sample could be classified into 1 of the 16 TPIPDCGs. Combined with demographic variables, which alone could explain 3.7% of the variation in an individual's future expenditure, the risk adjustment model based on TPIPDCGs could explain 12.2% of expenditure variation. In addition, the finding that the predictive ratios of the TPIPDCG model approximated unity better than those of the demographic model in all subgroups indicates that the capitation payment as predicted by the TPIPDCG model for each subgroup would better correlate to the actual spending.

Conclusion: Taiwan's risk-adjusted capitation model based on principal inpatient diagnoses has higher predictability on individual's future expenditure than its counterpart in the USA. This finding provides insight into not only the development of Taiwan's diagnosis-based risk adjustment models but also the necessity of modification when applying foreign-developed risk adjustment models to the NHI.

Key words: Capitation fee; Health insurance; Health services; Risk adjustment; Taiwan

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Taiwan's National Health Insurance (NHI) program has gradually reformed its methods of paying health care providers. When the NHI program was first instituted, the payment basis was solely a fee-for-service system reimbursing services provided. Although a diagnostic-related-group–like prospective payment system (PPS) was introduced in the first year after introduction of the NHI and increasingly expanded to include more inpatient diagnoses, health care expenditure continuously escalated. Global budgeting has been introduced as a payment reform mechanism to curb the rapid rise of health care expenditure. In addition, capitation payment is under consideration to improve the health care provider's efficiency and responsiveness.[1] To reflect the variation of expected individual health expenditure (i.e., risk), some forms of risk adjustment are usually employed in capitation systems. In countries with limited information about individuals' health status, risk-adjusted capitation is usually based on demographic data such as age and gender.[2] Nevertheless, studies have shown that using only demographic information to adjust individual health expenditure would provide incentives for biased selection of healthy people into a health plan.[3]

Studies have employed different risk adjustment variables to improve the predictability of risk adjustment models in the last 2 decades.[4,5] Among these variables, diagnostic information is thought to be promising in terms of its high predictability for individual health expenditure and its relatively low

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vulnerability to manipulation.[6–9] After accumulating more than a decade of experience in the development of diagnosis-based risk adjustment models, the US Health Care Financing Administration (HCFA) implemented the Principal Inpatient Diagnostic Cost Group (PIPDCG) model to pay for Medicare's managed care plans in 2000.[10] The rationale behind the PIPDCG model is that inpatient diagnoses in the previous year can be used as a proxy of the individual's health status and are assumed to allow differentiation of enrollees with different levels of health expenditure in the subsequent year. Diagnoses are first classified into 172 clinically homogeneous diagnostic groups. The diagnostic groups are then ranked in descending order of the mean expenditure of the subsequent year, and grouped into 16 cost groups or PIPDCGs, based on the similarity of expenditure. Finally, each person with prior hospitalization is classified into a single PIPDCG.[11]

While models employing PIPDCGs have been validated in the United States[11] and the Netherlands,[12] in many countries such studies have not been performed, partly due to the lack of individual-level encounter data. Taiwan's NHI program has collected comprehensive claim data, but only a few studies have been reported in which demographic characteristics, prior utilization, and crude diagnostic information identifying catastrophic status were used as risk adjusters.[13,14] Therefore, comprehensive diagnostic information to construct a relevant classification system reflecting individual future consumption of health resources e.g., diagnosis codes, has not been well utilized in the development of risk adjustment models for Taiwan. The purposes of this study were to develop an inpatient diagnosis-based risk adjustment model using Taiwan's NHI data, and to evaluate its performance in terms of various aspects of predictability.

Methods

Sample and expenditure data

Our analyses used a 2% random sample of enrollees eligible for the NHI in 1996 and 1997. The sample included those enrollees with a full 12 months of eligibility in 1996 who were still enrolled on January 1, 1997. Forty four enrollees with unidentifiable gender, age, or identification number were excluded from the sample, resulting in a sample size of 371,620.

Data were obtained from NHI enrollment and medical expense claim files. The enrollment file contains detailed individual subscription information, and the individual-based claim file contains comprehensive inpatient and ambulatory care records, including unique patient identification numbers, and patients' gender, birth date, ICD-9-CM (International Classification of Diseases, 9th Revision, Clinical Modification) codes for inpatient diagnoses, and claimed medical expenses for each encounter. The medical expense claim files include both claimed reimbursement and co-payment information.

Expenditures were aggregated from all inpatient and outpatient claimed expenses for each enrollee in 1996 and 1997, respectively. Dental care and Chinese medical care, however, were excluded from the aggregation since their budgets are treated separately in the NHI payment system. Expenditures for subjects who ended their NHI enrollment or died during 1997 were annualized, i.e., divided by the fraction of the year for which they were included in the NHI. Each enrollee's expenditure was weighted by this fraction in all analyses, thus avoiding underestimation of their expected expenditures.[8]

Risk adjusters

Age and gender are the basic risk adjusters employed by most capitation payment models.[2] Our study stratified subjects into 17 age groups by 5-year intervals, and further divided them by gender, thus yielding 34 age-gender groups.

Diagnosis-based risk adjusters were developed using the source code published by HCFA to classify each enrollee into PIPDCGs based on his/her diagnoses in 1996.[15] Moreover, since the practice patterns of providers and the fee schedule could be considerably different between Taiwan and USA, a Taiwan version of PIPDCGs (TPIPDCGs) was developed using the diagnostic cost group sorting algorithm developed by Ash et al.[6,8,9,11]

Development of TPIPDCGs involved classification of enrollees' principal inpatient diagnoses in 1996 into 172 diagnostic groups, called principal inpatient diagnostic groups (PIPDxGs), using the same mapping scheme as the original PIPDCGs. Each enrollee's 1997 expenditure was then assigned to his (or her) PIPDxGs. If an enrollee had multiple PIPDxGs, the same 1997 expenditure was assigned for each PIPDxG nonetheless. PIPDxGs were then ranked in descending order of their mean 1997 expenditure, and the highest ranked PIPDxGs were grouped into the highest TPIPDCG. After the highest ranked TPIPDCG was formed, enrollees in this group were removed from the sample, the mean 1997 expenditure by PIPDxG was recalculated, and the PIPDxGs were re-ranked. This process was repeated until 16 TPIPDCGs were formed, thus yielding a comparison between PIPDCGs and TPIPDCGs that was compatible in terms of the number of groups.

Table 1. Predictive R^2 statistics of various risk adjustment models.

Model name	Risk adjusters	Mean predictive R^2 (SD)† [%]
Demographic	33 (2 x 17 – 1) age/gender*	3.7 (0.24)
PIPDCG	33 age/gender* + 15 PIPDCGs*	10.4 (0.97)
TPIPDCG	33 age/gender* + 15 TPIPDCGs*	12.2 (1.18)
Prior inpatient	33 age/gender* + prior inpatient expenditure	9.6 (1.29)
Prior utilization	33 age/gender* + prior inpatient expenditure + prior outpatient expenditure	35.9 (2.32)
TPIPDCG + prior outpatient	33 age/gender* + 15 TPIPDCGs*+ prior outpatient expenditure	36.5 (2.33)
TPIPDCG (if any) + prior outpatient expenditure (if no TPIPDCG)	33 age/gender* + 15 TPIPDCGs* + No. inpatient* x outpatient expenditure	29.5 (2.33)

* Categorical variables. Reference groups: male and age of 0 to 4 for age/gender; PIPDCG 4 or no admission for PIPDCGs; TPIPDCG 1 or no admission for TPIPDCGs; 15 TPIPDCGs' admissions for no. inpatient, i.e., no. inpatient = 1 when no 15 TPIPDCGs' admissions.
† The mean predictive R^2 is the mean of the predictive R^2 values of 100 estimations by bootstrapping technique. The mean predictive R^2 values of these 5 models are significantly different from each other ($p < 0.001$).
PIPDCG = principal inpatient diagnostic cost groups; TPIPDCG = Taiwan version of PIPDCG.

In order to minimize the incentive for admitting patients unnecessarily, some PIPDxGs with minor, transitory, or non-specific characteristics, such as sprain, influenza, and fever, or diagnoses with length of stay less than 2 days, were classified into the lowest PIPDCGs, which are considered to have no recurrent condition in the subsequent year. Moreover, when developing the TPIPDCGs, at least 1 of 2 criteria was applied. First, each TPIPDCG had to contain at least 300 enrollees in order to assure stability of the estimated payment in the model. If the number of enrollees was smaller than 300, the PIPDCG was expanded to include PIPDxGs in the next lower range until a sufficient number of enrollees was reached. Second, the mean expenditure of the lowest PIPDxG in a (higher-ranked) TPIPDCG was required to be NT$10,000 (US$1 = NT$28.7 in 1997) greater than the highest PIPDxG in the next ranked PIPDCG.

Inpatient expenditure and outpatient expenditure in 1996 were used as risk adjusters in prior utilization models. Expenditure in the prior year was found to be the best predictor of the subsequent year's expenditure.[16] Therefore, the risk adjustment models based on prior expenditure served as a gauge to evaluate the performance of the diagnosis-based models. Table 1 summarizes the risk adjusters used by each of the risk adjustment models.

Analytical procedures

Risk adjusters obtained from 1996 information were used as independent variables, and the 1997 total expenditure, i.e., the sum of inpatient and outpatient expenditures, was the dependent variable. A weighted least squares regression was employed to build risk adjustment models, weighting each enrollee's total expenditure by the fraction of the year enrolled during 1997. Although a skewed distribution in the total expenditure may violate the assumption of a normal distribution, studies have shown that the estimate for group mean expenditures is more robust and unbiased if sample sizes are large enough.[17]

To assess the predictive performance, a split-sample method was applied,[6] whereby a randomly selected estimation sample of 247,994 subjects (approximately two-thirds of the study sample) and a validation sample of 123,626 subjects (the remaining one-third of the sample) was constructed. The model was fitted using the estimation sample and the estimated parameters were then used to predict expenditure in the validation sample. A predictive R^2 was then calculated to indicate the proportion of variation of actual expenditure in the validation sample predicted by the estimated parameters. Moreover, to demonstrate the stability of the model's predictability, a bootstrapping technique was applied by creating 100 new samples through random sampling with replacement in the validation sample, and predictive R^2 values were calculated for the new samples. Models were then compared in terms of the distributions of predictive R^2 values through 1-way analysis of variance (ANOVA) and Tukey's post hoc comparison.[12]

Finally, apart from predictive R^2, predictive ratios (PRs) for 10 subgroups of enrollees, grouped according to their 1996 expenditure, were used to evaluate how closely each model predicted the average 1997 expenditure for different subgroups. A PR greater than 1 indicates too high a level of reimbursement, and vice versa.[6] Therefore, PRs indicate the model's fairness for subgroups with different risk.

Results

Similar to the NHI population, the study sample had a mean age of 32.76 years, and 49.66% were male.[18] The means of total expenditure in 1996 and 1997 were NT$9792 and NT$11,005, respectively. As shown in Table 2, only 7.88% of the sample had been hospitalized in 1996 and could be classified into 1 of the 16 PIPDCGs, leaving 92.12% of the sample without

Table 2. Descriptive statistics for TPIPDCGs and PIPDCGs by group.

Group	PIPDCG			TPIPDCG		
	Percent of those hospitalized in 1996	Mean 1997 annualized expenditure ($NT)	Standard deviation	Percent of those hospitalized in 1996	Mean 1997 annualized expenditure ($NT)	Standard deviation
Entire sample (n = 371,620)		12,195	62,599		12,195	62,599
No. of admissions in 1996		9411	43,327		9411	43,327
Sum of PIPDCGs or TPIPDCGs	100.00			100.00		
PIPDCG 4 or TPIPDCG 1	61.82	22,589	81,170	56.62	20,223	75,816
PIPDCG 5 or TPIPDCG 2	6.77	13,239	37,013	12.34	16,923	47,807
PIPDCG 6 or TPIPDCG 3	0.08	110,226	154,427	5.04	35,391	84,177
PIPDCG 7 or TPIPDCG 4	0.13	31,775	85,856	5.96	46,915	120,129
PIPDCG 8 or TPIPDCG 5	6.39	47,841	103,689	1.70	55,699	137,551
PIPDCG 9 or TPIPDCG 6	2.69	42,865	112,762	1.64	65,339	155,927
PIPDCG 10 or TPIPDCG 7	2.90	80,177	139,377	1.77	72,078	218,720
PIPDCG 11 or TPIPDCG 8	5.27	43,951	144,280	2.75	86,794	200,788
PIPDCG 12 or TPIPDCG 9	5.52	90,698	218,653	3.02	98,512	230,944
PIPDCG 14 or TPIPDCG 10	0.64	114,031	351,610	2.05	110,758	252,531
PIPDCG 16 or TPIPDCG 11	4.10	125,230	278,794	1.80	122,625	270,870
PIPDCG 18 or TPIPDCG 12	0.58	121,999	292,826	1.84	137,473	196,389
PIPDCG 20 or TPIPDCG 13	1.68	317,320	422,605	0.52	180,894	383,255
PIPDCG 23 or TPIPDCG 14	1.00	206,666	417,597	1.57	224,808	361,070
PIPDCG 26 or TPIPDCG 15	0.28	337,002	562,852	0.43	397,278	683,322
PIPDCG 29 or TPIPDCG 16	0.14	652,512	1,660,072	0.97	481,426	760,188

PIPDCG = principal inpatient diagnostic cost groups; TPIPDCG = Taiwan version of the PIPDCG.

PIPDCGs. For those enrollees with admissions in 1996, 61.82% were classified into PIPDCG 4. In the original version of PIPDCGs, the number assigned to a PIPDCG represents the mean expenditure in the next year. Therefore, the lowest PIPDCG (PIPDCG 4) has the lowest mean expenditure in the next year (about US$4000), and the highest PIPDCG (PIPDCG 29) has the highest mean expenditure (about US$29,000). Using data from Taiwan, however, the original classification system did not perform well in terms of the hierarchical structure of expenditure among the PIPDCGs. For example, PIPDCG 6 had higher mean 1997 annualized expenditure than PIPDCGs 7 to 12.

In contrast, in the Taiwan version, the number of the PIPDCG only represents the ranking in mean 1997 annualized expenditure. Given that the formation of TPIPDCGs was based on the ranking of their 1997 expenditure, it is not unexpected that most TPIPDCGs followed the hierarchical structure of expenditure, i.e., the higher the number of the TPIPDCG, the higher the 1997 annualized expenditure. Nevertheless, TPIPDCG 1 accounted for 56.62% of those hospitalized in 1996 and had a higher mean 1997 annualized expenditure than TPIPDCG 2, mostly due to the inclusion of discretionary hospitalization in this group. Table 3 gives some example diagnoses in each TPIPDCG. These groups were slightly different to those in the original US version.[11]

Table 1 shows the predictive R^2 statistics of various capitation models. As anticipated, the demographic model performed relatively poorly, with a predictive R^2 of 0.037. The values of R^2 for the PIPDCG and TPIPDCG models were 0.104 and 0.122, respectively, indicating that the TPIPDCG model performed better than the original PIPDCG model. With an R^2 of 0.096, the prior inpatient model had an inferior performance to the diagnostic models in terms of predictability. Nevertheless, when the inpatient-based models incorporated prior outpatient expenditure, R^2 reached 0.359 and 0.365 for the prior utilization model and the TPIPDCGs plus prior outpatient expenditure model, respectively. When the model was based on either TPIPDCGs or prior outpatient expenditure separately, the improvement in R^2 was somewhat limited (R^2 = 0.295).

The difference of predictability among the various models is also revealed in Table 4. If capitation payment is based on the demographic model, health plans with enrollees who have expenditures below the average in the previous year will obtain more profit, and vice versa. The profit and loss differences can be huge for insurers with low-risk and high-risk enrollees, i.e., the risk-adjusted payment can be 3.44 times the actual expenditure for those with no expenditure in 1996 and only 3% of actual expenditure for those with expenditure of more than NT$500,000 (US$1 = NT$27.5 in 1996) in 1996. However, the problems of over-paying or under-paying can be alleviated by using diagnostic risk adjusters, especially TPIPDCGs. On the other hand, the prior utilization model outperformed the other models evaluated in this study in terms

Table 3. Example diagnoses in each of the Taiwan version of the Principal Inpatient Diagnostic Cost Groups (TPIPDCGs).

TPIPDCG*	Example diagnoses
TPIPDCG 2	Bacterial pneumonia; kidney infection; brain injury; alcohol/drug dependence; pelvic fracture; fractures of skull and face; ongoing pregnancy with complications; abdominal hernia, complicated
TPIPDCG 3	Aortic and other arterial aneurysm; transient cerebral ischemia; asthma; central nervous system infections; peptic ulcer; anxiety disorders; inflammatory bowel disease
TPIPDCG 4	Cellulitis and bullous skin disorders; other cancers†; coma and encephalopathy; atrial arrhythmia; fracture of femur
TPIPDCG 5	Hypertension, complicated; cancer of placenta/ovary/uterine adnexa†; precerebral arterial occlusion; gastrointestinal hemorrhage
TPIPDCG 6	Peripheral vascular disease; angina pectoris; bone/joint infections/necrosis; spinal cord injury
TPIPDCG 7	Tuberculosis; dementia; epilepsy and other seizure disorders; cerebral hemorrhage; valvular and rheumatic heart disease
TPIPDCG 8	Pulmonary fibrosis and bronchiectasis; post-myocardial infarction; pancreatitis/other pancreatic disorder; stroke
TPIPDCG 9	Chronic obstructive pulmonary disease; acute myocardial infarction; coronary atherosclerosis; malignant neoplasm of colon
TPIPDCG 10	Cirrhosis, other liver disorders; breast cancer†; major depression; unstable angina
TPIPDCG 11	Cancer of bladder, kidney, urinary organs†; depressive disorder; congestive heart failure; septicemia/shock
TPIPDCG 12	Cancer of female genital organs†; blood/immune disorders; rectal cancer†; cancer of male genital organs†; thromboembolic vascular disease; schizophrenic disorders
TPIPDCG 13	Atherosclerosis of major vessel; adrenal gland, metabolic disorders; polyneuropathy; benign brain/nervous system neoplasm
TPIPDCG 14	Aspiration pneumonia; metastatic cancer†; liver/pancreas/esophagus cancer†; diabetes with chronic complications
TPIPDCG 15	Brain/nervous system cancers†; cardiorespiratory failure and shock; lung cancer†
TPIPDCG 16	Blood, lymphatic cancers/neoplasms†; renal failure/nephritis

* Diagnoses not included in TPIPDCG 2 to TPIPDCG 16 are classified into TPIPDCG 1 and are not shown.
† Includes principal diagnoses, and secondary diagnoses when the principal diagnosis is chemotherapy or radiotherapy.

Table 4. Predictive ratios* in various risk adjustment models.

Expenditure range in 1996 ($NT)	Percentage	Mean expenditure in 1997	Predictive ratios				
			Demographic	PIPDCG	TPIPDCG	Prior inpatient	Prior utilization
0	12.7	2867	3.44	3.01	2.98	2.96	0.96
0–1000	16.5	3188	2.63	2.33	2.32	2.27	0.86
1000–5000	36.2	5760	1.58	1.41	1.40	1.37	0.88
5000–10,000	14.7	10,702	1.07	0.96	0.95	0.94	0.98
10,000–20,000	9.7	16,829	0.86	0.82	0.80	0.80	1.08
20,000–50,000	7.1	28,319	0.65	0.74	0.74	0.73	1.13
50,000–100,000	1.9	53,350	0.43	0.69	0.69	0.64	1.08
100,000–200,000	0.7	80,293	0.29	0.68	0.76	0.78	1.08
200,000–500,000	0.3	142,717	0.14	0.50	0.61	0.87	0.96
Above 500,000	0.1	528,694	0.03	0.17	0.19	0.28	1.03

* Predictive ratios were obtained from dividing the total predicted expenditure by the total expenditure in 1997 for each subgroup.
PIPDCG = principal inpatient diagnostic group; TPIPDCG = Taiwan version of the PIPDCG.

of paying for enrollees more fairly with PRs in all subgroups close to 1.

Discussion

This study demonstrated that risk-adjusted capitation models based on principal inpatient diagnoses can significantly improve the predictability of a risk adjustment model compared to a demographic model. These results are consistent with those found in other countries, but the improvement was somewhat better in this study from Taiwan than in previous studies from the USA, in which the R^2 of diagnoses-based risk adjustment models ranged from 0.062 to 0.106 for the Medicare population and the non-elderly population, respectively.[11,19]

Nevertheless, when prior outpatient expenditure was incorporated into inpatient-based models, the predictive R^2 improved dramatically, indicating that the use of outpatient information contributed to a higher predictability. However, this increase in predictability was restricted to 6% (35.9% *vs* 29.5%) if either inpatient or outpatient information alone was utilized in the risk assessment.

The high predictability in terms of R^2 obtained in this study is well beyond the maximal predictability of 0.20 to 0.25 suggested in previous reports.[5,15,20,21] Our previous study suggested that the predictability of a risk adjustment model in Taiwan might outperform those in other countries.[13] There are several reasons to explain a higher predictability of risk adjustment models in Taiwan. First, estimates of maximal predictability in previous reports from other countries might have been based on partial information about health care services, e.g., a Dutch study excluded primary physician fees and drugs,[20] and Medicare data was mainly obtained from the elderly

population in a study from the US.[5] Thus, the higher predictability in this study may be attributable to the comprehensive nature of the information used. In addition, given the uniqueness of high outpatient service utilization in Taiwan, which consumes two-thirds of NHI's total health expenditure,[18] and the high correlation between 2 consecutive years of outpatient expenditures,[5,13,20] it is not unexpected that adding outpatient expenditure could raise predictability dramatically. Further studies to investigate the predictability of a risk adjustment model incorporating diagnostic information from outpatient encounters are needed. Such studies have been reported in the United States as well as the Netherlands and indicated that more diagnostic information can improve the predictability of a risk adjustment model.[22,23]

The higher a model's overall predictability, the more fairly it will pay for different risk groups. This study has demonstrated that a diagnoses-based model had higher overall predictability than a demographic model. However, as with the demographic model, the diagnoses-based model would pay quite fairly for most enrollees, but would still seriously under-pay for enrollees with very high expenditure. While underpayment does not seem to be a problem in the prior utilization model, given its inherent propensity for inappropriate provision of health service in the previous year, prior utilization as a risk adjuster still receives severe criticism.[16] Therefore, if diagnosis-based risk adjustment models are to be adopted, some risk-sharing mechanisms that have been proposed in other countries may require further investigation to understand their impacts on health providers with more enrollees who have extremely high expenditures.[24]

In spite of the relatively good performance of our TPIPDCG risk adjustment model, some limitations in applying this type of risk adjustment model should be taken into consideration. First, while a risk adjustment model based only on principal diagnoses has the advantage of avoiding coding proliferation of secondary diagnoses, it may lose some information about individuals' health status that can be found in secondary diagnoses. Although secondary diagnoses may not be as accurate or important as principal diagnosis, the former usually record the comorbidities that may increase the risk of incurring higher future expenditure. Besides, it is sometimes unclear which diagnosis should be principal; thus, health providers may have the incentive to reorder the diagnoses to maximize payment. Therefore, further investigation of the contribution of incorporating secondary diagnoses into the model may be necessary.

Second, in line with the above problem, models based on diagnoses always raise concern about up-coding behaviors, or even inappropriate increase in admissions, as occurred in the implementation of diagnosis-related groups/prospective payment system in the USA.[25] Several methods were adopted in our study to mitigate this concern, such as putting transitory or potentially high-discretion diagnoses into the lowest TPIPDCG, or not rewarding re-admissions or multiple admissions by using a single TPIPDCG to classify enrollees. Nevertheless, careful monitoring of the coding behavior and admission rate for certain diagnoses will still be necessary if inpatient diagnoses-based risk-adjusted capitation is to be implemented.

Thirdly, this study treated the effect of risk adjusters on the future expenditure as additive; therefore, the possible interaction effect of risk adjusters may have been underestimated. In addition, the cost of coexisting diagnoses across multiple body systems or disease types was not captured in our model. For example, the cost of a person with both diabetes and hypertension could be different from the sum of the cost of diabetes only and the cost of hypertension only. Whether the relationship between risk adjusters or diseases is additive or multiplicative also warrants further investigation.

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