HEALTH ECONOMICS
Health Econ. (2014)
Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/hec.3033

DO DIAGNOSIS-RELATED GROUP-BASED PAYMENTS INCENTIVISE HOSPITALS TO ADJUST OUTPUT MIX?

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ABSTRACT

This study investigates whether the diagnosis-related group (DRG)-based payment method motivates hospitals to adjust output mix in order to maximise profits. The hypothesis is that when there is an increase in profitability of a DRG, hospitals will increase the proportion of that DRG (own-price effects) and decrease those of other DRGs (cross-price effects), except in cases where there are scope economies in producing two different DRGs. This conjecture is tested in the context of the case payment scheme (CPS) under Taiwan's National Health Insurance programme over the period of July 1999 to December 2004. To tackle endogeneity of DRG profitability and treatment policy, a fixed-effects three-stage least squares method is applied. The results support the hypothesised own-price and cross-price effects, showing that DRGs which share similar resources appear to be complements rather substitutes. For-profit hospitals do not appear to be more responsive to DRG profitability, possibly because of their institutional characteristics and bonds with local communities. The key conclusion is that DRG-based payments will encourage a type of 'product-range' specialisation, which may improve hospital efficiency in the long run. However, further research is needed on how changes in output mix impact patient access and pay-outs of health insurance. Copyright © 2014 John Wiley & Sons, Ltd.

Received 3 July 2013; Revised 2 November 2013; Accepted 17 December 2013

KEY WORDS: DRGs; price effects; for-profit; hospital behaviour; prospective payment

1. INTRODUCTION

This study investigates whether the diagnosis-related group (DRG)-based payment method motivates hospitals to adjust output mix in order to maximise profits. Prior studies have acknowledged that disentangling hospitals' multiple reimbursement incentives is critical. Hodgkin and McGuire (1994) predict that independently of the shift from a fee-for-service (FFS) to DRG system, hospitals facing an average incentive will avoid earning negative net revenues by lowering treatment intensity to discourage admissions of unprofitable patients (a volume effect). On the contrary, marginal incentives will drive hospitals to reduce intensity to avoid supply-side cost sharing (a moral hazard effect), irrespective of the average reimbursement level. A large literature has focused on marginal incentives and investigated the impacts on resource use,[1] health care quality[2] and patient selection[3] of shifts from FFS to prospective payment systems (PPS). By comparison, only a few papers are devoted to hospital response to changes in DRG prices and profitability (e.g. Dranove, 1987; Newhouse, 1989; Hodgkin

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[1]See Newhouse and Byrne, 1988; Frank and Lave, 1989; Freiman *et al*., 1989; DesHarnais *et al*., 1990; Ellis and McGuire, 1988; Böcking *et al*., 2005.
[2]See DesHarnais *et al*., 1987; Davis and Rhodes, 1988; Rogers *et al*., 1990; Cutler, 1995.
[3]See Keeler *et al*., 1990; Friedman and Farley, 1995; Ellis and McGuire, 1996; Martinussen and Hagen, 2009.

and Mcguire, 1994; Gilman, 2000; Dafny, 2005; Lindrooth *et al*., 2007; Sood *et al*., 2008). Dafny emphasises that after a fixed-price regime is completely phased in, price levels constitute the sole lever to influence hospital behaviour. Yet, their impacts have not been fully explored. This limited array of research is almost exclusively derived from the USA and western European countries. This paper aims to fill a gap in the literature by looking at own-price and cross-price effects against the background of a DRG-based payment scheme in Taiwan. In particular, this study asks whether hospitals select more profitable DRGs and, if so, how profit-maximising hospitals alter the combination of different DRG caseloads (termed the output mix).

Similar to studies on marginal incentives, existing research on hospital response to average reimbursement mostly concerns intensity of care and patient selection. Gilman (2000), Sood *et al*. (2008) and Lindrooth *et al*. (2007) focus on the effects of changes in prospective payment levels on treatment intensity.[4] However, Dafny (2005) argues that some studies may suffer from endogeneity bias because bilateral causality between the intensity response and price changes is likely. Dafny exploits an exogenous change to Medicare DRG prices in 1988 and reports that hospitals up-coded patients to diagnoses subject to the largest price increases, a result consistent with findings reported elsewhere concerning up-coding behaviour under PPS (Silverman and Skinner, 2004; Brunt, 2011; Bowblis and Brunt, 2013). Newhouse (1989) reports that unprofitable DRGs are more prevalent in public hospitals of last resort, a result of nonpublic hospitals selecting patients.[5]

Building upon Hodgkin and McGuire's (1994) framework, this study evaluates substitution and complementarity between DRGs. This subject does not appear to have been empirically investigated.[6] The most closely related research is by Dranove (1987), who postulates that hospitals will expand supply in Medicare DRGs for which they enjoy the largest price–cost margins. For empirical estimation purposes, the present study measures profitability of DRGs as the ratio of price to costs, that is, one plus the excess of price over costs.

A study of changes in hospital output mix can potentially provide insights into hospital production decisions under PPS and more generally into resource allocation and balance in development of medical specialties. Understanding the causal relationship between output mix and DRG prices can benefit ongoing policymaking in the form of price adjustments and health services planning.

2. THE POLICY CONTEXT AND RESEARCH HYPOTHESES

Between 1995 and 2009, the Taiwan Bureau of National Health Insurance (BNHI) implemented a DRG-based hospital payment system termed the case payment scheme (CPS).[7] The CPS reimbursed 38 types of common operations on a per-discharge basis. These surgical procedures formed 54 DRGs across nine specialties, which were phased in from 1995 to 2004.[8] As of 2008, the CPS accounted for 13.6% of inpatient cases; the remaining cases continued to be reimbursed under the traditional FFS system (BNHI, 2009).

[4]Gilman (2000) decomposes the effect of the 1994 Medicaid DRG refinements on average length of stay and finds that the introduction of procedure-based DRGs triggers a strong average incentive of decreasing intensity for nonprocedure DRGs. Sood *et al*. (2008) estimate the change in the costs of care and average length of stay that are caused by a change in marginal and average reimbursement associated with the 2002 Inpatient Rehabilitation Facility Prospective Payment System. In addition, Lindrooth *et al*. (2007) examine hospital response to the 1998 US Balanced Budget Act. They show that hospitals cut treatment intensity for more severe cases and for disease categories that were more generously reimbursed.

[5]In addition, Zwanziger *et al*. (2000), Robinson (2011) and White (2013) evaluate whether hospitals raised prices for privately insured patients in response to decreases in Medicare/Medicaid payment rates. However, Taiwan runs a single-payer system; thus, the practice of cost shifting is not discussed here.

[6]There is a strand of literature looking at substitutes and complements from the physician's perspective, as discussed in Section 5.

[7]The goals of the CPS were to enhance hospital efficiency and rectify volume-driven practice caused by FFS payments. It was modelled after the US Medicare Prospective Payment System.

[8]The government stated that these surgical procedures, including total knee replacement and coronary artery bypass graft among others, had relatively high patient volume and low fee variation and for these reasons were selected into the CPS.

DOI: 10.1002/hec

The CPS DRGs were defined by groups of matching diagnoses and procedures using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes. The patient's primary diagnosis and principal procedure must together constitute one of the pairs specified to qualify for DRG payments[9]; otherwise, she or he would be reimbursed through the FFS system. Apart from the 'matching' restriction, the CPS stipulated two 'exclusion' criteria to improve clinical coherence within a DRG: (i) patients must not suffer from any of the comorbidities or complications (known as 'invalid c.c.') prespecified by the scheme and (ii) patients must meet any age limit set for a DRG.

Each DRG had a base price determined by the national historic average fee for the corresponding patient groups. DRG prices were adjusted for three hospital levels from high to low: academic, regional and local. Within each level, the DRG price was fixed nationally, irrespective of service volume, input cost or geographic area. In order for the government to monitor service delivery, hospitals were required to submit itemised bills (as under the FFS system), although they nonetheless received fixed payment per discharge.[10]

To prevent hospitals from under-supplying services, the CPS predefined a standard care package for each DRG, which bundled the primary surgical procedure with an array of auxiliary services. All services in the package were labelled 'compulsory' and 'noncompulsory'.[11] Hospitals would not receive any reimbursement if they did not deliver all of the compulsory items.[12] A patient's discharge status had to satisfy the standards laid down by the Scheme.

This study postulates that the care packages provided by hospitals resemble products in the market. Hospitals are seen as resembling profit-maximising, multi-product firms.[13] They differ in productive efficiency across DRGs; thus a DRG regarded as lucrative by one hospital could be seen as unprofitable by another.

In light of these assumptions, a change in DRG profitability is likely to have the following effects:

(1) When the profitability of a DRG increases, the proportion of the total caseload represented by that DRG will rise (i.e. the own-price effect or simply price effect), while when the profitability of another DRG rises, the share of the first DRG will fall (i.e. the negative cross-price effect).
(2) When there exist sufficiently strong economies of scope between two procedures, a relative increase in profitability for one DRG (holding constant the profitability of the other DRG) will lead to a rise in the share of the other DRG (the positive cross-price effect).

In addition, this study hypothesises that for-profit hospitals are more responsive to profitability than other hospital types and may adjust output mixes to a greater extent.

Hospitals' ability to adjust output mix was related to features of Taiwan's health care delivery system. There was no 'gatekeeper' under Taiwan's NHI. Hospitals ran regular outpatient hours to compete for patients. Patients, who had low outpatient co-payments and free choice of providers, tended to shop around. Moreover, doctors in Taiwan could predict costs for individual patients to some extent during outpatient consultations. Hospitals hence had the power if they so wished to screen patients in the first place.

[9]For example, DRG 0225A was for patients who had closed fractures of the tarsal/metatarsal bones or the phalanges of the foot and who received corresponding open reductions. Patients diagnosed with the same type of fracture but different treatments, such as arthrodesis of toes or closed reductions (nonsurgical) with applications of plaster of Paris casts, would have been automatically excluded from the CPS. Equally, patients with open fractures who had received open reductions would not have been grouped in a DRG because open fractures were not valid diagnoses under the CPS. In such cases, the government reimbursed hospitals through FFS.

[10]If the per-case payment was higher than the claimed fee, the hospital would retain the surplus; whereas if actual fees exceeded the fixed payments, hospitals would not receive extra reimbursement, unless the fees exceeded established stop-loss limits, that is, the case became a DRG 'outlier'. Stop-loss limits were set 10% to 30% higher than the fixed payment.

[11]Compulsory items included diagnoses, operations and wound care; whereas noncompulsory services comprised tests, examinations, medication and rehabilitation, among others. Hospitals may provide additional services not covered by the care package, but the bureau would not reimburse those services.

[12]When hospitals delivered 65–100% of total services (including compulsory items), they would be paid the full DRG price. A reduced payment was applied if a hospital delivered less than 65% of total services.

[13]The BNHI has put considerable financial pressure on medical institutions since 1998 because of ongoing financial crises due to greater growth of health expenditure than premium increases have covered. Hence, hospitals have strong incentives to pursue profits.

DOI: 10.1002/hec

3. EMPIRICAL SPECIFICATIONS

3.1. The system of output shares and instrumental variables

The empirical specification sets out to investigate within the CPS the relative change in DRG volume associated with a change in DRG profitability. Because cost data are not available at the national scale in Taiwan, this study uses inpatient fees as a proxy for costs. The BNHI has updated the FFS schedule regularly to adjust for inflation and for changes in costs of medical devices, materials and labour. Therefore, fees in the fee schedule are positively correlated with costs.

Accordingly, a system of M structural equations is proposed as follows:

$$\begin{aligned} q_{i,t,1}/Q_{i,t} &= \textstyle\sum_{m=1}^{M}\alpha_{1,m}P_{t-1,m}/F_{i,t-1,m} + \widetilde{x}_{i,t}'\widetilde{\beta}_1 + \widetilde{z}_{i,t,1}'\widetilde{\gamma}_1 + v_{i,t,1} \\ &\vdots \\ q_{i,t,M}/Q_{i,t} &= \textstyle\sum_{m=1}^{M}\alpha_{M,m}P_{t-1,m}/F_{i,t-1,m} + \widetilde{x}_{i,t}'\widetilde{\beta}_M + \widetilde{z}_{i,t,M}'\widetilde{\gamma}_M + v_{i,t,M} \end{aligned} \tag{1}$$

where

$$\textstyle\sum_{m=1}^{M} q_{i,t,m} = Q_{i,t} \forall i,t \quad \text{and} \quad v_{i,t,m} = h_i + k_t + \varepsilon_{i,t,m} \tag{2}$$

with cross-equation restrictions:

$$\textstyle\sum_{m=1}^{M}\alpha_{m,1} = 0; \cdots; \sum_{m=1}^{M}\alpha_{m,M} = 0 \tag{3}$$

$$\textstyle\sum_{m=1}^{M}\widetilde{\beta}_m = 0 \tag{4}$$

In Equation (1), in the left-hand side variable, $q_{i,t,m}$ refers to the caseload of DRG m (1, …, M) at hospital i (1, …, N) at time t (1,…,T). $Q_{i,t}$ is the total number of DRG patients, and $q_{i,t,m}/Q_{i,t}$ is the share for DRG m. It is assumed that hospitals cannot expand their output without limit. DRG profitability is measured by the profit ratio, that is, the ratio of DRG price ($P_{t,m}$) to claimed average fees for patients in DRG m ($F_{i,t,m}$). A ratio over one means that hospitals received more than $1.00 per dollar claimed, that is, the DRG is profitable. Because there exists a time lag for the BNHI to approve claim data and for hospitals to adjust output, the observed average profit ratio is lagged one period. For empirical estimation, lags of two and three periods are also used, because hospitals may require more time to reallocate resources and build new capacity.

$\widetilde{x}_{i,t}'$ includes variables for hospital characteristics, patient characteristics, the intensity of care, market concentration and time. The staff–patient ratio is used as a proxy for the average level of intensity within a hospital. Assuming that patients value intensity (e.g. more consultations or staff time), higher intensity will attract more patients.

$\widetilde{z}_{i,t,m}'$ contains equation-specific variables, that is, admission and treatment policies. Independently of DRG profitability, a hospital may traditionally have a higher or lower share of inpatients with CPS diagnoses. This aspect is defined by admission policy,[14] which will affect DRG patient volume. Treatment policy accounts for the hospital's propensity to choose CPS-paid over alternatively FFS-paid primary procedures for similarly diagnosed patients. As the CPS covered only the selected procedures, doctors could have chosen different procedures for a CPS diagnosis, affecting DRG caseloads. See Footnote 9 for an example.

The cross-equation restrictions are imposed on the coefficients of profit ratios, because the own-price ($\alpha_{m,n}$, $m = n$) and cross-price ($\alpha_{m,n}$, $m \neq n$) effects related to the same DRG sum to zero. Coefficients of all common explanatory variables $\widetilde{x}_{i,t}'$ are subject to the same cross-equation constraints.

With respect to disturbance terms ($v_{i,t,m}$), h_i denotes hospital fixed effects, which account for unobserved production technology and any time-invariant factors that are intrinsic to the hospital but

[14]Ellis and McGuire (1996) and Gilman (2000) relate an admission policy to a decision rule concerning what severity level of patients to admit. This study defines admission policy differently.

DOI: 10.1002/hec

not captured by measurable hospital characteristics. k_t is year dummies, which capture common shocks to hospital production. $\varepsilon_{i,t,m}$ are the idiosyncratic errors with mean zero. The within-group correlation for hospital i in equation m is assumed to be unstructured. In addition, $\varepsilon_{i,t,m}$ is assumed be contemporaneously correlated across equations.

Note that for a hospital's response to DRG profitability to be interpreted as a price effect, variation in DRG profitability needs to be exogenous, due only to price shocks or hospital cost variations that existed prior to the introduction of the CPS. Price changes under the CPS were likely to have been exogenous because they did not reflect changes in hospital resource use.[15] However, under NHI's mixed payment system, some hospitals could have differentiated treatment intensity between DRG and FFS patients (to increase DRG profitability) more than counterparts. This type of cost variation within a DRG creates the problem of using observed DRG profitability as the key independent variable. The reason is that a DRG-FFS mix payment system embodies both average and marginal incentives. It is essential to eliminate the impact of marginal incentives on DRG profitability to ensure that the causal effect of DRG profitability on output mix occurs only through average payment incentives.

Furthermore, if intensity affects both output and claimed fees and cannot be measured fully, observed DRG profitability would be endogenous because of an omitted variable problem. In the literature, various proxies (including the staff–patient ratio used in this study) have been proposed to measure resource use (Chalkley and Malcomson, 2003). However, intensity could comprise unquantifiable elements that vary across hospitals and change over time. Moreover, if treatment policy responded to DRG profitability, then treatment policy would also be endogenous. Hence, the estimation strategy is to tackle endogeneity and confounding effects of marginal incentives simultaneously by using instrumental variables (IV).

For the current model, a valid IV must be correlated with both observed DRG profitability and treatment policy and not related to unmeasured intensity. This study uses estimated average DRG profit ratios as the primary instrument (Appendix A[16]), in which claimed fees are replaced by their predicted values, $\hat{F}_{i,t,m}$. The predicted fees variable extracts the part of claimed fees attributable to measurable determinants of intensity and thus is clear of unmeasured intensity. Essentially, the goal is to capture profit variations derived from pre-existing exogenous differences in fees.

Another set of IVs is the share of patients with CPS diagnoses entitled to employment injury benefits (EIB) or natural disaster benefits in each DRG category.[17] EIB provides wage compensation to those incapacitated for work because of injury or sickness for which they are under medical treatment, and both benefit schemes cover patients' co-payments. This reduces the opportunity cost and financial burden of hospitalisation, thus altering the demand for various procedures and treatment policy.[18]

In terms of estimation of the output share model, the equation-by-equation Hausman test (1978) soundly rejects the null hypothesis of no correlation between the h_i and explanatory variables. Therefore, the whole system is first estimated by using the fixed-effects two-stage least squares (2SLS) method, followed by an application of the fixed-effects three-stage least squares (3SLS) technique.[19] 3SLS is preferable to 2SLS because of the need to impose cross-equation constraints.

[15]Under the CPS, all hospitals complied with standardised care packages; hence, the BNHI saw little need to link the national DRG rate with actual fees per discharge. Over the five-and-a-half-year study period, the BNHI altered DRG prices only twice when fees of compulsory items were adjusted under the FFS scheme.

[16]Appendix A describes a five-step procedure for predicting DRG profitability, including the derivation of the patient-level fee function from which predicted hospital claimed fees is obtained.

[17]Information on benefit schemes is recoded in hospital claim data. The data show that the share of patients covered by EIB/NDB monthly is between 0% and 15% across DRG categories.

[18]Each equation has six endogenous variables (five observed DRG profit ratios plus treatment policy) and six excluded exogenous variable, thus is just identified.

[19]The robust standard errors are used for both 2SLS and 3SLS regressions.

DOI: 10.1002/hec

Table I. Categorization of orthopaedics diagnosis-related groups

Category	DRG code	Description	Date of introduction	ICD-9 diagnosis[a]	ICD-9 procedure	No. (%) of cases
$m=1$	0224A	Open reduction of fracture with and without internal fixation, radius and ulna	July 1999	813.00-8, 813.20-3, 813.40-4, 813.80-3	79.22, 79.32	48 010 (21.34)
$m=2$	0209B	Total knee replacement, unilateral	November 1997	715.16, 715.26, 715.36, 715.96, 714.0	81.54	46 734 (20.77)
$m=3$	0211A	Open reduction of fracture with and without internal fixation, femur, age >17 years	July 1999	820.00-9, 820.20-2, 820.8, 821.00-1, 821.20-9	79.25, 79.35	42 039 (18.69)
$m=4$	0209A	Total hip replacement, unilateral	November 1997	715.15,715.25, 715.35,715.91, 733.42	81.51	23 881 (10.61)
	0471A	Total hip replacement, bilateral	July 1999			848 (0.38)
$m=5$	0219B	Open reduction of fracture with and without internal fixation, tibia and fibula, age >17 years	July 1999	823.00-2, 823.20-2, 823.80-2	79.26, 79.36	22 817 (10.14)
	0229A	Open reduction of fracture with and without internal fixation, carpals and metacarpals, phalanges of hand	July 1999	814.00-9, 815.00-9, 816.00-3, 817.0	79.23,79.24, 79.33, 79.34	18 582 (8.26)
	0225A	Open reduction of fracture with and without internal fixation, tarsals and metatarsals, phalanges of foot	July 1999	825.0, 825.20-9, 826.0	79.27, 79.28, 79.37, 79.38	11 823 (5.26)
	0219A	Open reduction of fracture with and without internal fixation, humerus, age >17 years	July 1999	812.00-9, 812.20-1, 812.40-9	79.21, 79.31	10 251 (4.56)
Total						224 985

DRG, diagnosis-related group; ICD, International Classification of Diseases.
[a]The case payment scheme guideline only specified the exclusion condition for total hip and knee replacement. The matching diagnoses for these procedures are identified retrospectively from DRG patient data.

3.2. Data and variables

This study chooses orthopaedics for empirical analysis. The primary reason for this choice is that there were nine orthopaedic DRGs, a large number, ranking second (after only the 10 DRGs in general surgery), allowing for a diverse output mix. To calculate the DRG shares, the nine orthopaedic DRGs are divided into five categories. The top four with the greatest number of nationwide cases are assigned to the first four equations, and the remainder are combined in the last equation. Table I shows that the four most frequently performed procedures are open reduction of fracture of the radius and ulna (forearm), unilateral total knee replacement (TKR), open reduction of fracture of the femur (thigh) and unilateral total hip replacement (THR). The last equation is composed of DRGs with relatively low caseloads, including open reduction of fracture of upper arm, lower leg and foot and hand bones.

The study period (for estimating the output share system) is from July 1999 to December 2004. Orthopaedic DRGs were not completely phased in until July 1999 (Table I, column 4). Data on all NHI orthopaedic inpatients were collected monthly over the study period. The other smaller data set for predicting post-CPS inpatient fees was collected at least 1 year prior to the introduction of a DRG. The source of data is the NHI Research Database. After exclusion of invalid patient records in the main data set (2.1% of initial sample), 224 985 orthopaedic DRG cases were identified. The end hospital panel data set comprises 268 hospitals and 14 637 hospital-month

DOI: 10.1002/hec

observations.[20] Note that only elective surgeries were included in the sample. Outpatients and emergency admissions were excluded because these were not covered by the CPS. DRG outliers were also excluded.

With respect to the covariates, the DRG profit ratio is first obtained at the patient level and then averaged per hospital per month. Admission policy is measured by diagnosis mix, which is defined as the fraction of patients whose primary diagnosis was one of the CPS matching diagnoses (Table I, column 5) among all admitted (FFS and DRG) patients.[21] Treatment policy is measured by procedure mix, calculated as the share of patients who underwent a CPS-paid primary procedure (Table I, column 6) among those who received a CPS-paid or an alternative FFS-paid primary procedure (Appendix A, Table A1, column 3) . The data show that the most popular alternative procedures for open reduction are closed reduction of fractures, for TKR are arthroscopy of knee and for THR are partial hip replacement.

Hospital characteristics are measured by dummies for three levels of accreditation (academic, regional and local) and for large general hospitals. Patient characteristics include percentages of females and shares of different age groups (age <17, 17–40, 41–60, 61–80 and >80 years), as well as a measure for severity of illness: the Charlson comorbidity index.[22] This study uses the average score of Charlson comorbidity index of all inpatients treated by the orthopaedic departments and not only for DRG patients, to avoid reverse causality stemming from the CPS exclusion criteria. The staff–patient ratio is calculated yearly per hospital by dividing the number of all types of medical staff (e.g. doctors, nurses, pharmacists and radiologists, among others) by the total number of admissions to a hospital.[23]

The Herfindahl–Hirschman index is used to measure degree of market concentration.[24] The data show that the market is moderately concentrated with a Herfindahl–Hirschman index of 1869.

Time variables include dummies for January and February and for the severe acute respiratory syndrome (SARS) pandemic during April to June 2003.[25]

Table II presents the descriptive statistics for model variables. The number 1, .., 5 following variable names denotes the corresponding DRG category. Overall, the observed DRG profit ratios range from 1 to 1.2, suggesting that DRG payments are generally profitable.

4. RESULTS

4.1. Own-price and cross-price effects

Tables III–V report the key results from the output share model, where the observed DRG profit ratios are lagged 1, 2 and 3 months, respectively. Own-price effects are estimated by the diagonal coefficients; cross-price effects correspond to the off-diagonal coefficients. Hence, each row sums to zero. Interactions between

[20]Hospitals observed for less than 1 year or which had fewer than 10% of the national average number of CPS admissions over the study period were excluded to ensure that the sample hospitals had sufficient patient volume to adjust DRG shares. This criterion reduced the number of hospitals from 423 to 268. The excluded hospitals treated only 1.76% of cases nationwide. Therefore, the patient sample is large and appropriate to the population.

[21]For example, diagnosis mix for Equation $m = 1$ is obtained by dividing the number of patients diagnosed with ICD-9 813.0/2/4/8 by the total number orthopaedic inpatients.

[22]The variable for CCI is calculated on the basis of the weighting system developed by Charlson *et al*. (1987), where cormobid diseases are given weighted indices of 0, 1, 2, 3 or 6, depending on their relative seriousness and their effects on the mortality rate. A patient can have more than one comorbid condition, in which case the respective scores are added.

[23]The staff–patient ratio is transformed into logarithms to improve normality and lagged 1 month to allow for a delay in demand response.

[24]This study uses the 17 medical areas proposed by the Taiwan Department of Health (2010) to define market areas and uses the number of admissions to a hospital (counting all departments) to define market share. Propper *et al*. (2004) propose different methods to measure market share and market area. However, Propper's methods are difficult to implement in Taiwan primarily because of a large number of patient flow crossovers in many directions.

[25]A dummy for January and February accounts for a decline in patient volume due to the Chinese New Year holiday. Dummies for summer months (July and August) and the implementation of hospital global budget policy (in July 2002) are not included because they are not statistically significant in any equations.

DOI: 10.1002/hec

Table II. Summary statistics

Variable	Mean (std.)	Variable[a,b]	Mean (std.) or %
Output share 1	0.22 (0.21)	Academic hospital (=1)	7.48%
Output share 2	0.16 (0.23)	Regional hospital (=1)	27.94%
Output share 3	0.21 (0.21)	Local hospital[b](=1)	64.58%
Output share 4	0.08 (0.13)	General hospital (=1)	56.04%
Output share 5	0.33 (0.26)	For-profit hospital (=1)	49.5%
Profit ratio 1	1.16 (0.21)	% Female	0.47 (0.24)
Profit ratio 2	1.05 (0.07)	% Age <17 years[b]	0.06 (0.11)
Profit ratio 3	1.15 (0.16)	% Age 17–40 years	0.25(0.22)
Profit ratio 4	1.04 (0.08)	% Age 41–60 years	0.25 (0.2)
Profit ratio 5	1.19 (0.22)	% Age 61–80 years	0.36 (0.25)
Procedure mix 1	0.57 (0.41)	% Age >80 years	0.09 (0.14)
Procedure mix 2	0.52 (0.47)	Comorbidity score	0.10 (0.19)
Procedure mix 3	0.50 (0.39)	Staff–patient ratio (in logs)	−0.31 (0.78)
Procedure mix 4	0.44 (0.49)	Herfindahl–Hirschman index	1869 (100)
Procedure mix 5	0.50 (0.31)	January or February (=1)	15.26%
Diagnosis mix 1	0.08 (0.08)	SARS pandemic (=1, April to June 2003)	4.58%
Diagnosis mix 2	0.07 (0.11)		
Diagnosis mix 3	0.10 (0.09)		
Diagnosis mix 4	0.16 (0.14)		
Diagnosis mix 5	0.13 (0.12)		

[a]For a dummy variable, the proportion of observations which take the value one is presented.
[b]A variable labelled with superscript refers to the base group omitted from the equations.

observed DRG profit ratios and a dummy variable for private for-profit hospitals (denoted by *FP*) are included in both Models IV and VI. Coefficient estimates of the remaining covariates are presented in Appendix B for Model V as an illustration. The *F*-test on excluded IVs in first-stage regressions shows that the excluded IVs are jointly significant at the 1% level[26] (Appendix C), implying that there exist strong correlations between endogenous variables and excluded IVs.

Overall, results from different lag windows are consistent. All estimates of own-price effects are positive and significant in 3SLS regressions (models II–VI). For example, Model II indicates that when the average profit ratio of DRG category 1 increases by 1, *ceteris paribus*, its output share increases by 28 percentage points. However, for 2SLS regressions (Model I), own-price effects are significant only for category 1, which may be due to the absence of cross-equation constraints.

In terms of cross-price effects, the results support the hypothesis of both substitution and complementary effects. For all 3SLS models, significant positive cross-price effects are found between joint replacements, that is, TKR (category 2) and THR (category 4).[27] Complementarity between THR and TKR could be explained by economies of scope, which are not fully measured by the price-fee profit ratios. Examples include bulk buying of artificial joints from the supplier and the diffusion of capital invested in postsurgery rehabilitation facilities. The BNHI stipulated rehabilitation therapy in the care package for TKR and THR as a noncompulsory item. Thus, hospitals must provide rehabilitation services to meet the 65% minimum

[26]To examine the validity of IVs, a series of tests was performed repeatedly for individual equations in the context of 2SLS regressions (Model I). The null hypothesis of the underidentification test that the matrix of reduced-form coefficients on excluded IVs is rank deficient is rejected for all equations at the 1% level (see last column of Table III). Hence, all equations are identified. In addition, the orthogonality conditions of the excluded IVs are tested by the C statistic, which is calculated as the difference of the Sargan–Hansen (1958) statistic of the equation with the full set of IVs and the equation with a smaller set of IVs that exclude instruments being tested. The null hypothesis that the predicted DRG profit ratios and EIB or NDB coverage are valid cannot be rejected at the 5% level for all equations. Therefore, the excluded IVs are considered exogenous.

[27]For example, in Model II, when the profit ratio of TKR (THR) is increased by 1, the output share of THR(TKR) increases by 9 (34) percentage points.

DOI: 10.1002/hec

Table III. Results from the output share model, with a lag of one period

	Model I: 2SLS, equation-by-equation[a,c]					Model II: 3SLS, a system of equations[b]				
	Output share 1	Output share 2	Output share 3	Output share 4	Output share 5	Output share 1	Output share 2	Output share 3	Output share 4	Output share 5
Profit ratio	0.09**	−0.07***	0.05*	−0.05**	0.02	0.28***	−0.20***	0	−0.17***	0.09***
1, t-1	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
Profit ratio	−0.09	0.1	−0.11**	0.03	−0.05	−0.22***	0.86***	−0.39***	0.09**	−0.34***
2, t-1	(0.05)	(0.06)	(0.04)	(0.04)	(0.05)	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)
Profit ratio	0.01	−0.02	0.01	−0.08***	0.08**	0.15***	−0.25***	0.25***	−0.19***	0.04
3, t-1	(0.03)	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
Profit ratio	−0.07	0.01	−0.01	0.04	−0.09*	−0.10**	0.34***	−0.03	0.07*	−0.28***
4, t-1	(0.04)	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)
Profit ratio	0.08	−0.11***	−0.09	−0.05	0.05	0.27***	−0.47***	0.03	−0.27***	0.44***
5, t-1	(0.05)	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)
Procedure	0.06					0.04***				
mix 1	(0.08)					(0.01)				
Diagnosis	0.98***					0.80***				
mix 1	(0.06)					(0.02)				
Procedure		−0.02					0			
mix 2		(0.08)					(0.01)			
Diagnosis		0.88***					0.57***			
mix 2		(0.11)					(0.01)			
Procedure			0.28***					0.07***		
mix 3			(0.01)					(0.01)		
Diagnosis			0.67***					0.69***		
mix 3			(0.02)					(0.02)		
Procedure				0.01					0.15***	
mix 4				(0.06)					(0.01)	
Diagnosis				0.10**					−0.09***	
mix 4				(0.03)					(0.01)	
Procedure					0.36*					0.29***
mix 5					(0.18)					(0.02)
Diagnosis					0.67***					0.29***
mix 5					(0.12)					(0.02)
Underidentification test, *p*-value:						R^2				
	0.0201	0.0134	0.0000	0.0035	0.0033	0.23	0.40	0.47	0.24	0.36

2SLS, two-stage least squares; 3SLS, three-stage least squares.
[a]The standard errors (in parentheses) are robust to heteroskedasticity and clustering on hospital panels.
[b]The standard errors are robust to arbitrary correlation within panels. The coefficients of the same row may not sum to zero because all figures are rounded to two significant digits.
[c]The instrumental variables for observed diagnosis-related group (DRG) profit ratios and procedure mix are estimated DRG profit ratios and the share of patients entitled to employment injury benefits or natural disaster benefits.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

DOI: 10.1002/hec

Table IV. Results from the output share model, with a lag of two periods

	Model III: 3SLS, no interaction[a]					Model IV: 3SLS, with interactions				
	Output share 1	Output share 2	Output share 3	Output share 4	Output share 5	Output share 1	Output share 2	Output share 3	Output share 4	Output share 5
Profit	0.24***	−0.21***	0.09***	−0.15***	0.04	0.25***	−0.29***	0.16***	−0.22***	0.10**
ratio 1, t-2	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)	(0.04)
Profit	−0.30***	0.87***	−0.35***	0.09***	−0.32***	−0.35***	0.91***	−0.43***	0.22***	−0.34***
ratio 2, t-2	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.05)	(0.06)	(0.05)	(0.04)	(0.06)
Profit	0.04	−0.26***	0.30***	−0.14***	0.06*	0.07	−0.31***	0.43***	−0.12***	−0.06
ratio 3, t-2	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.04)	(0.04)	(0.04)	(0.03)	(0.05)
Profit	−0.10**	0.37***	−0.13***	0.12***	−0.26***	−0.13*	0.44***	−0.15**	0.18***	−0.34***
ratio 4, t-2	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)	(0.05)	(0.06)	(0.05)	(0.04)	(0.06)
Profit	0.04	−0.38***	−0.04	−0.25***	0.63***	0.06	−0.43***	0	−0.30***	0.68***
ratio 5, t-2	(0.03)	(0.03)	(0.03)	(0.02)	(0.04)	(0.05)	(0.05)	(0.05)	(0.04)	(0.06)
FP × profit						−0.03	0.17***	−0.15***	0.12***	−0.11*
ratio 1, t-2						(0.01)	(0.01)	(0.01)	(0.00)	(0.01)
FP × profit						0.08	−0.25***	0.33***	−0.17***	0.01
ratio 2, t-2						(0.01)	(0.01)	(0.01)	(0.00)	(0.01)
FP × profit						−0.05	0.12*	−0.22***	0.01	0.14*
ratio 3, t-2						(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
FP × profit						0.05	−0.12	0.03	−0.08	0.13
ratio 4, t-2						(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
FP × profit						−0.03	0.05	0.03	0.09*	−0.15*
ratio 5, t-2						(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
R^2	0.42	0.48	0.43	0.30	0.25	0.41	0.46	0.40	0.31	0.28

3SLS, three-stage least squares; *FP*, for-profit hospitals.
[a]The standard errors (in parentheses) are robust to arbitrary correlation within panels. The coefficients of the same row may not sum to zero because all figures are rounded to two significant digits.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

Table V. Results from the output share model, with a lag of three periods

	Model V: 3SLS, no interaction[a]					Model VI: 3SLS, with interactions[a]				
	Output share 1	Output share 2	Output share 3	Output share 4	Output share 5	Output share 1	Output share 2	Output share 3	Output share 4	Output share 5
Profit ratio 1, t-3	0.17***	−0.13***	0.01	−0.15***	0.09***	0.15***	−0.17***	0.06	−0.20***	0.17***
	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)	(0.04)
Profit ratio 2, t-3	−0.26***	0.90***	−0.34***	0.09***	−0.38***	−0.29***	0.95***	−0.51***	0.22***	−0.38***
	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)	(0.05)	(0.06)	(0.05)	(0.04)	(0.06)
Profit ratio 3, t-3	0.04*	−0.23***	0.24***	−0.11***	0.06**	0.11**	−0.24***	0.32***	−0.13***	−0.05
	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.04)	(0.04)	(0.04)	(0.03)	(0.05)
Profit ratio 4, t-3	−0.17***	0.44***	−0.13***	0.08**	−0.22***	−0.22***	0.57***	−0.29***	0.18***	−0.24***
	(0.03)	(0.04)	(0.03)	(0.03)	(0.04)	(0.06)	(0.06)	(0.06)	(0.04)	(0.07)
Profit ratio 5, t-3	0.09**	−0.47***	0.08**	−0.23***	0.52***	0.07	−0.58***	0.26***	−0.28***	0.53***
	(0.03)	(0.03)	(0.03)	(0.02)	(0.04)	(0.05)	(0.05)	(0.05)	(0.03)	(0.06)
FP × profit ratio 1, t-3						0.01	0.11**	−0.12**	0.13***	−0.12**
						(0.04)	(0.04)	(0.04)	(0.03)	(0.05)
FP × profit ratio 2, t-3						0.03	−0.09	0.27***	−0.17***	−0.04
						(0.06)	(0.07)	(0.07)	(0.05)	(0.08)
FP × profit ratio 3, t-3						−0.10*	0.06	−0.17***	0.06	0.15**
						(0.04)	(0.05)	(0.05)	(0.03)	(0.05)
FP × profit ratio 4, t-3						0.11	−0.28**	0.29**	−0.16**	0.04
						(0.09)	(0.10)	(0.09)	(0.06)	(0.11)
FP × profit ratio 5, t-3						−0.02	0.15*	−0.21***	0.10**	−0.02
						(0.06)	(0.06)	(0.06)	(0.04)	(0.07)
R^2	0.45	0.42	0.44	0.36	0.31	0.46	0.40	0.37	0.36	0.31

3SLS, three-stage least squares; *FP*, for-profit hospitals.
[a]The standard errors (in parentheses) are robust to arbitrary correlation within panels. The coefficients of the same row may not sum to zero because all figures are rounded to two significant digits.
*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

DOI: 10.1002/hec

delivering rate. An increase in the number of patients attending rehabilitation sessions would reduce the marginal cost of rehabilitation services.

Furthermore, THR and TKR are specialised treatments. Patients tend to opt for reputable hospitals and experienced surgeons for an operation. The data show that a majority of THR procedures were performed in large hospitals located in cities with high population densities. It is possible that some network effects exist—an increase in demand for THR reinforcing the demand for TKR performed by the same hospital, and vice versa.

Most cross-price effects between open reductions of fractures (categories 1, 3 and 5) are positive. When a lag of three periods is used (Model V, Table V), five of six pairs of cross-price effects are statistically significant at the 5% level. This implies that hospitals may require a longer period to achieve economies of scope between different types of open reductions. During an open reduction, an internal fixation device is usually inserted to ensure the bones remain in an optimal position. Hence, when the consumption of various fixation devices increases simultaneously, hospitals could benefit from buying in quantity. However, rehabilitation therapy was not included in the care package of open reduction surgeries. Hospitals had no obligation to provide postsurgery rehabilitation care. This may partly explain why not all of the cross-price effects are significant for open reductions of fractures.

Finally, negative cross-price effects (many significant at the 0.1% level) are detected between DRGs that are distinct, that is, joint replacements and open reductions.[28] In general, TKR and THR are more responsive to own-price and cross-price effects than open reductions, probably because they are more expensive procedures.

4.2. Comparing for-profit and not-for-profit hospitals

The conjecture of differential price effects between for-profit and other hospital types is tested by models IV and VI.[29] The reference group consists of private not-for-profit hospitals and public hospitals.[30] Both models show that the diagonal interaction terms are negative (with some significant at the 0.1% level), implying that for-profit hospitals are less sensitive than other hospital types to own-price effects. For-profit hospitals also appear to be less responsive to positive/negative cross-price effects, as most coefficient estimates for the corresponding interaction terms are negative/positive.

A primary conclusion here is that for-profit hospitals are not necessarily more responsive to profitability. Several possible explanations exist for this. First, compared with not-for-profit and public hospitals, for-profit hospitals in Taiwan are smaller in size. Between 1999 and 2004, although 70% of hospitals in Taiwan were for-profit, they accounted for merely 30% of hospital beds[31] (Department of Health, 2011). Hence, they would have less scope to adjust output mix.

Furthermore, approximately 90% of for-profit hospitals are local hospitals, whose patients are mainly from local communities.[32] These hospitals may refrain from selecting DRGs to avoid jeopardising their long-term relationships with patients. In contrast, hospitals at higher levels see patients from all over the country, which is likely to have weakened their bonds with local residents. The Taiwan health law stipulates that for-profit hospitals can be owned only by individual doctors and not by partnerships or

[28]There are two types of joint replacements (DRG categories 2 and 4) and three types of open reductions of fractures (DRG categories 1, 3 and 5), so there are six pairs of distinct DRG categories.

[29]Interaction terms are treated as endogenous variables and instrumented by the products of predicted DRG profit ratios and *FP*. Cross-equation constraints are imposed on coefficients of interaction terms.

[30]Of 268 hospitals included in the sample, 54% are private for-profit, 24% are private not-for-profit and 22% are public hospitals.

[31]In contrast, public hospitals accounted for 15% of hospitals and 35% of beds, as did private not-for-profit hospitals; hence, together, they accounted for 30% of hospitals and 70% of beds.

[32]This study also ran a 3SLS regression without dummies for hospital levels, and the primary conclusion about for-profit hospitals did not change.

DOI: 10.1002/hec

corporations (Lin *et al*., 2004b). Consequently, the reputation of a for-profit hospital is linked to that of the practicing doctor, which may discourage selection behaviour.

5. DISCUSSION AND CONCLUSIONS

This study has demonstrated that hospitals increased the share of a DRG when the profitability of that DRG increased. In contrast with Dafny (2005), where no price effect is found in relation to changes in caseloads in 'levels', this study detects changes in case volume in 'shares'. This type of positive own-price effect bears out Hodgkin and McGuire's (1994) prediction of volume effects. Dranove (1987) highlights that productive efficiency prompted by DRG payments may stem from scale economies. In the present study, if the output share of a DRG is positively correlated with the volume of that DRG, the own-price effect would imply that hospitals pursue scale economics in a product line in which they already have lower costs, a finding supportive of Dranove's argument.

The finding of negative cross-price effects is analogous to that from the literature on physician response to fee change. Studies (Yip, 1998; Gruber *et al*., 1999; Nassiri and Rochaix, 2006; McGuire, 2008) have demonstrated that when there is a fee rise for a service, physicians will reduce the supply of other services, because of both income and substitution effects for other services working in the same direction. However, hospitals bear the costs of production whereas salaried physicians do not. In this regard, the positive cross-price effect is less likely to be found in physician behaviour. The negative cross-price effects are also in line with the findings of factor substitution in the production of health care (Okunade, 2003; Cawley *et al*., 2006).[33]

In contrast to 'product-line' specialisation relating to scale economies (Dranove, 1987), positive cross-price effects relating to scope economies found in this study may be seen as 'product-range' specialisation. This type of specialisation has been widely seen in business where companies exploit core technology or resources to produce a range of related products/services. To see whether hospitals specialise in a product range, this study compares the concentration in DRGs of joint replacements and open reduction. Between 2000 and 2004, the proportion of hospitals that did not admit any TK/HR patients increased from 19.4% to 22.4%, whereas the proportion of those that did not provide open reductions increased from 14.6% to 17.2%. These figures suggest that some hospitals abandoned the product range while others expanded it. These are changes in hospital practice styles (measured by a hospital's market share of discharges), as defined in Ellis and McGuire (1996).

Whether product-range specialisation is desirable is beyond the scope of this study. However, some implications of hospital specialisation can be drawn in the context of Taiwan's CPS. For policymakers, a key issue is whether alteration of output mix affects pay-outs of health insurance. Under a DRG-based payment system, hospitals' incentives to continuously reduce their costs such that they fall below the costs of other, competing hospitals can be explained by yardstick competition (Shleifer, 1985). However, it has been noted that after the CPS was introduced, claimed fees of DRG patients fell while their volume increased, so that aggregate NHI expenditure increased (Eggleston and Hsieh, 2004; Lang *et al*., 2004). Therefore, cost savings at the hospital level do not necessarily occur at the insurance level.[34]

For patients, concerns arise with respect to how specialisation affects patient outcomes. Little research on Taiwan has focused on the association between outcomes and specialisation. Yet there is evidence that Taiwanese hospitals adopted clinical pathways to improve productive efficiency in response to the CPS (Lin *et al*., 2004b). Using patient-level data, researchers have shown that after the introduction of Taiwan's DRG-based payment method, the surgical mortality rate fell (Lang *et al*., 2004), whereas emergency visits,

[33]This type of study considers the effect of changes in relative prices on the input mix in view of cost-minimization behaviour. For example, Cawley *et al*. (2006) show that when wages for direct care providers increase, nursing homes substitute materials for labour. Okunade (2003) estimates own-price and cross-price elasticities of factor demands in health maintenance organisation production, showing evidence of limited factor substitutions.

[34]A study by Moreno-Serra and Wagstaff (2010) shows that DRG-type payments in European and Central Asian countries increased national health expenditure (including out-of-pocket payments), but they are unable to separate hospital expenditure from national health expenditure.

DOI: 10.1002/hec

readmissions and post-discharge mortality remained unchanged (Cheng *et al*., 2012). The CPS did not reimburse hospitals further for DRG patients readmitted for the same condition within 14 days. Hence, hospitals have an incentive not to reduce costs at the expense of patient outcomes. If indeed outcomes do not worsen, specialisation potentially could result in improvements in efficiency.

Nevertheless, as Dranove (1987) argues, one unintended consequence of specialisation may be its adverse impact on access to care. When hospital production is geared towards a set of DRGs that have scope economies, the likelihood of a patient receiving treatment in her or his chosen hospital will largely depend on the DRG. This access problem is of less concern if various hospitals choose to deliver different product ranges. However, if some DRGs are systematically higher priced than other DRGs, patients in lower-priced DRGs may encounter difficulties in finding providers. Similarly, if there is large exogenous variation in hospital costs across geographic areas, such that all hospitals in area A find the DRG unprofitable and decide not to provide it, patients in area A may have to travel to area B to seek care. It may be essential for regulators to monitor the distribution of DRGs and to adopt sophisticated DRG pricing mechanisms that reflect cost variations which are beyond the control of hospitals.[35]

The finding that for-profit hospitals altered their output mixes less than not-for-profit hospitals did can in part be explained by phenomenon of 'for-profit in disguise'. Hirth (1999) points out that some profit-driven firms may disguise themselves as not-for-profits in order to exploit customers' trust in the nonprofit sector.[36] In Taiwan, doctors working in large not-for-profit hospitals are paid salaries calculated on the basis of their revenue productivity (Lin *et al*., 2004a; Lu and Chiang, 2011), that is, the number of patients seen and procedures performed. In this context, it is likely that there is no significant difference in financial incentives between for-profit and not-for-profit hospitals.[37]

Several limitations to this study must be noted. First, it would be preferable to use costs instead of fees to estimate the price effects, even if the direction of hospital responses could be the same as if cost data had been used. Second, this study does not use DRG prices as the key determinants because there was low variation. It may be possible to interact DRG prices with the share of DRG patients within a hospital (as the 'PPS bite' in the Medicare literature) to yield variation at the hospital level. Yet the exogeneity of 'CPS bite' would need verification. Finally, hospitals' up-coding behaviour has been well documented in the literature. For Taiwan's mixed payment system, hospitals may up-code diagnoses (by adding invalid c.c.) to shift expensive DRG patients to the FFS system, which will impact the output mix. To clarify this concern, this study undertakes a two-sample *t*-test and panel data model regressions (Appendix D) and finds that up-coding does not seem widespread.[38] However, further analysis may be needed to address this issue.

To conclude, this paper has disentangled own-price and cross-price effects on hospital output mix and addressed potential endogeneity of DRG profitability and treatment policy. The results suggest that a DRG-based payment system will incentivise hospitals to alter the combination of DRGs in such a way as to improve economies of scope between DRGs of similar type.

ACKNOWLEDGEMENTS

The author thanks Winnie Yip, A. Dale Tussing, Ching Fan Chung, Shou Hsia Cheng and two anonymous referees for providing helpful comments on an earlier draft of this paper. This study is based on data from Taiwan NHI Research Database. The interpretation and conclusions contained herein do not represent those of NHI administration, Ministry of Health and Welfare or National Health Research Institutes in Taiwan.

[35]See discussions by Pope, (1990) and Miraldo *et al*., (2011).
[36]This contention is built upon the presumption that nonprofit status serves as a signal of quality.
[37]In Lindrooth *et al*. (2007), not-for-profit hospitals are found to be more responsive than for-profit and public hospitals to changes in the average reimbursement per hospital admission.
[38]This may be explained by the generosity of DRG payments and the existence of DRG outliers.

DOI: 10.1002/hec

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DOI: 10.1002/hec