8. ESTIMATING A HOSPITAL PRODUCTION FUNCTION TO EVALUATE THE EFFECT OF NURSE STAFFING ON PATIENT MORTALITY IN TAIWAN: THE LONGITUDINAL COUNT DATA APPROACH[1]

Yia-Wun LIANG[2]

Wen-Yi CHEN[3]

Yu-Hui LIN[4]

Abstract

This study employed the Random Effect Zero-Inflated Poisson model incorporating a first-order autoregressive structure to estimate the hospital production function. We specifically investigated the effect of nurse staffing on patient mortality in acute-care hospitals under Taiwan universal health insurance system. Our results showed that the probability of being mortality free in the high patient-to-nurse ratio group is 0.019 lower than that in its counterparts and those patients who were in the high patient-to-nurse ratio nursing unit generates 3.419 more deaths than its counterparts. These findings suggested that nurse staffing below target levels in acute-care hospitals is associated with increased mortality. The policymakers should consider healthcare policy that matches staffing with patients' need for nursing care through setting a shift-based, minimum patient-to-nurse ratio from the perspective of maintaining quality of patient care.

Keywords: health production; hospital production; nurse staffing; patient mortality; Random Effect Zero-Inflated Poisson

JEL Classification: C23, C35, I12, I18

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2 Department of Senior Citizen Service Management, National Taichung University of Science and Technology, Taichung, Taiwan. E-mail: ywliang@nutc.edu.tw

3 Corresponding author: Wen-Yi CHEN, Department of Senior Citizen Service Management, National Taichung University of Science and Technology, Taichung, Taiwan. E-mail: chenwen@nutc.edu.tw

4 Department of Business Administration, Nan Kai University of Technology, Nan-Tou, Taiwan. E-mail: lin2138@nkut.edu.tw

I. Introduction

Health economists have long been considered about the production of health because how to maintain and improve the health of human populations in an efficient and sustainable way is always a central concern to the health policies. Over the past few decades, there were substantive literature investigating on the relationship between health inputs and health outcomes. For example, in their seminal work (Auster, Leveson, Sarachek, 1969), Auster and his colleagues were the first to evaluate the effectiveness of healthcare through the concept of a conventional production function. The main result of their study is that the environmental variables (such as education, income, occupation, health behavior, etc.) are more important in determining the health outcome (measured by age-adjusted mortality). In addition, Grossman (1972) established a theoretical health production that treats healthcare, socioeconomic, lifestyle and environmental factors as inputs and health status as an output of the health production function. Following this line of research, some studies investigated the socioeconomic determinants of health (Lopez-Casasnovas, Soley-Bori, 2014; Bayati, Akbarian, Kavosi, 2013; Baltagi, Moscone, Tosetti, 2012; Lordan, Soto, Brown, Correa-valez; 2012; Halicioglu, 2011), and other studies concentrated on the effect of healthcare expenditure on health status (Brown, Martinez-Guiterrez, Navab, 2014; Jaba, Balan, Robu, 2014; Heijink, Koolman, Westert, 2013; Schoder, Zweifel, 2011; Akkoyunlu, Lichtenberg, Siliverstovs, Zweifel, 2010).

It is important to address that the hospital sector represents the most important element in a healthcare system because it is the main provider for various healthcare services and the medical spending on the hospital sector contributes the largest proportion of healthcare expenditure (Gaynor, Town, 2012). There are two strands of literature in the hospital production. The first focused on the measurement of inefficiency (or productivity) of hospitals through the data envelopment analysis or the stochastic frontier analysis (Castelli, Street, Verzulli, Ward,2015; Mateus, Joaquim, Nunes, 2015), and the second estimated either the hospital production function or hospital cost function in order to better understand the relationship between hospital inputs and hospital outputs (Carey, Burgess, Young, 2015; Pourmohammadi, Hatam, Bastani, Lotif, 2014; Lee, McCullough, Town,2013; Liang, Chen, Lee, Huang, 2012; Liang, Tsai, Chen, 2012). This second strand of literature is highly related to the literature of the health production in terms of model specifications. The econometric methods used to estimate health or hospital production function included the cross sectional data analysis (Carey, Burgess, Young, 2015; Auster, Leveson, Sarachek, 1969;), panel data analysis (Brown, Martinez-Guiterrez, Navab, 2014; Jaba, Balan, Robu, 2014; Lopez-Casasnovas, Soley-Bori, 2014; Pourmohammadi, Hatam, Bastani, Lotif, 2014; Bayati, Akbarian, Kavosi, 2013; Heijink, Koolman, Westert, 2013; Lee, McCullough, Town,2013; Baltagi, Moscone, Tosetti, 2012; Lordan, Soto, Brown, Correa-valez; 2012; Schoder, Zweifel, 2011) and time series analysis (Halicioglu, 2011; Akkoyunlu, Lichtenberg,Siliverstovs, Zweifel, 2010).

In this study, we followed the second strand of the literature in the hospital production, and the purpose of this study is to estimate the hospital production function in order to understand the relationship between inputs and outputs of the hospital production. We specifically concentrated on the effect of an important hospital input (namely, nurse staffing) on an output of hospital production (measured by death counts) in acute-care hospitals under Taiwan universal health insurance system. Our focus on the relationship between nurse staffing and patient mortality has a threefold significance. First, nursing is practiced in virtually all settings where health care is delivered. Nurses are vital to providing patients with quality care. However, findings from previous studies indicated that there are not enough hospital nurses to provide quality care (Liang, Chen, Lee, Huang, 2012; Liang, Tsai, Chen, 2012; Aiken, Clarke, Sloane, Sochalski, Busse, Clarke, Giovannetti, Hunt, Rafferty, Shamian, 2001; Aiken, Sochalski, Anderson, 1996). The nurse shortage increases the workload for incumbents. Many research also found that an additional patient per registered nurse per shift is associated with increased relative risk of mortality by 6-7% in surgical patients (Aiken, Clarke, Sloane, Sochalski, Silber, 2002; Aiken, Clarke, Cheung, Sloane, Silber, 2003), and an increase from 1.06 to 2.66 registered nurse full time equivalent per patient day is associated with a relative reduction in hospital-related mortality by 9% (Person, Allison, Kiefe, Weaver, Williams, Centor, Weissman, 2004). Second, Taiwan is a country with the rapidest rate of population aging in the world. In 2014, the elderly population (aged 65 and higher) accounted for approximately 12% of total population (Ministry of Interior, 2015), and the elderly population is expected to occupy more than 21% of total population (complying with the United Nation definition of the hyper-aged society) in 2025 (National Development Council, 2014). Given this rapid rate of population aging, the excess demand for nurses is expected and it would further result in an even larger nurse shortage that definitely deteriorates the quality of care in Taiwan. Third, similar to other publicly financing health care systems, Taiwan's National Health Insurance system (characterized by the single payment system with a universal coverage program for all residents) has suffered from serious financial difficulties; therefore, the hospital sector is undergoing widespread reorganization, mostly focusing on the increase of patient turnover (in terms of shortening the average length of stay) in order to increase hospitals' efficiency and financial performance (Mark, Harless, McCue, 2005). Nevertheless, increased patient turnover, meaning increased workload, not only placed new stresses on nurses (Heinz, 2004; Institute of Medicine, 2004) but also possibly led to nurse shortages resulting from reduced nurses' trust for nurse administrators, lack of autonomy and decreased job dissatisfaction (Institute of Medicine, 2004 ; Buerhaus, Staiger, Auerbach, 2000).

Since the death counts were assigned to be the output of hospital production, we adopted the Random Effect Zero-Inflated Poisson (RE-ZIP) model incorporating a first-order autoregressive structure to estimate the hospital production function. There are three appealing features in the RE-ZIP model incorporating a first-order autoregressive structure. First, the RE-ZIP model allows us to simultaneously deal with the discrete nature of death counts and the excess zero death counts so that the risk of mortality resulting from different nurse staffing levels can be fully evaluated. Second, the RE-ZIP model provides more information to evaluate the effect of nurse staffing on patient mortality through the estimates of the probability of being mortality free and adjusted mean death cases. Therefore, the results generated from the present study not only demonstrated that better hospital nurse staffing is associated with more favorable patient outcomes but also serve an important reference to implement legislative and administrative actions to increase nurse staffing levels, and in turn, improve quality of care in Taiwan acute-care hospitals.

II. Empirical Model and Data

II.1 Empirical Model

This study explored the relationship between hospital nurse staffing and patient outcomes at the nursing unit level through estimating a hospital production function. Death cases were used as an output of the hospital production. The same as the conventional production function used by Auster, Leveson, Sarachek(1969), the inputs of the hospital production in this study included labor and capital inputs. There are two special features in modeling such relationships: the discrete nature of death counts and the excess zero death counts during the study period. The former feature makes the estimation from linear regression models inconsistent and inefficient (Cameron, Trivedi, 2005), and the latter feature may result from a possible endogenous selection effect based on unobservable heterogeneities such as unobserved severity of illness in the observed hospital nursing units (Winkelmann, 2000). Since the data were collected in a form of panel data with many hospital nursing unit characteristics being time invariant during the observed period, the Random Effect Zero-Inflated Poisson (RE-ZIP) model, proposed by Hall, was used to analyze the data (Hall, 2000). The RE-ZIP model employs two components that correspond to two zero generating processes. The first process governed by a binary distribution generates structural zeros, and the second process governed by the Poisson distribution generates count data that may also include zero counts. Note that Hall incorporated a random intercept into Poisson component of the RE-ZIP model (Hall, 2000). Following Greene (2012), this study also allows a first-order autoregressive structure in the random effect to avoid the possible bias from the time dependence of errors at different observed time periods. Therefore, the RE-ZIP model can be specified as follows:

$$\varphi_{it} \sim logistic(\xi_{it}) \text{ , } \xi_{it} = \gamma_0 + \sum_{j=1}^{k} \gamma_j x_{it} \quad (1)$$

$$\Pr(y_{it} \mid x_{it}) = \begin{cases} \varphi_{it} + (1-\varphi_{it}) \dfrac{e^{-\mu_{it}} \mu^{y_{it}}}{y_{it}!} & \text{for } y_{it} = 0 \\ \Pr(y_{it} \mid x_{it}) = (1-\varphi_{it}) \dfrac{e^{-\mu_{it}} \mu^{y_{it}}}{y_{it}!} & \text{for } y_{it} > 0 \end{cases} \quad (2)$$

$$\mu_{it} = \exp((\beta_0 + \varepsilon_{it}) + \sum_{j=1}^{k} \beta_j x_{it}) \quad (3)$$

$$\varepsilon_{it} = \rho \varepsilon_{it-1} + \nu_{it} \text{ , } \nu_{it} \sim N(0, \sigma_{\nu}^2) \quad (4)$$

where: y_{it} denotes the death cases observed in the ward *i* at time *t*. x_{it} represents the inputs of the hospital production and $\beta_j(\gamma_j)$ are the coefficients associated with x_{it}.

Equation (1) represents the data generating process for the extra zero stage. φ_{it}, following the logistic cumulative density function ($\text{logistic}[\xi_{it}]$), is the probability of being an extra zero. Equations (2)-(4) model the data generating process for the frequency stage. μ_{it} is the mean death cases conditional of the random effect (ε_{it}). Note that the random effect does not affect slope parameters but the intercept only from equation (3). In addition, we incorporate auto-correlated parameter (ρ) in equation (4) in order to prevent the time dependence bias from our longitudinal data. The model specifications of equations (1)-(4) refer to as the "Generalized, Linear, and Mixed Model (GLMM)" in the statistics literature (Diggle, Heagerty, Liang, Zeger, 2002; Molenbergh, Verbeke, 2007); accordingly, the maximum simulated likelihood estimation (MSLE) method was suggested to estimate the RE-ZIP model in this study (Greene, 2012).

II.2 Data Sources

Data for our analyses were retrieved from the 2008 Hospital Nursing Staffing and Patient Outcomes survey sponsored by the Department of Health (DOH). Through a stratified random sampling, a total of 108 hospital nursing units within 32 hospitals, including 11 district hospitals, 18 regional hospitals, and 3 medical centers, were sampled from 421 accredited Western-medicine hospitals at the end of 2007. Data were collected monthly by the head nurses of the nursing units from July 1st 2008 to January 31st 2009 for seven consecutive months. Therefore, the unit of analysis is "nursing unit" in this study. The effective sample size is 756 nursing units. The output of the hospital production is the number of death cases observed during the study period. "In-hospital mortality," "30-day mortality," and "failure-to-rescue" account for the death cases in this study. Out-of hospital mortality information was obtained from death records by linking unique patient identifiers. Failure-to-rescue is defined as patient deaths resulting from complications, identified by ICD-9-CM codes in the secondary diagnosis (Van den Heede, Diya, Lesaffre, Vleugels, Sermeus, 2008; Van den Heede, Sermeus, Diya, Lesaffre, Vleugels, 2006).

The inputs of the hospital production include labor and capital inputs. Two dummy variables, PTND and PSBD, were created for labor inputs to dichotomize different levels of skill labor inputs (including nurses and physicians). The former dummy variable (PTND) was coded as "1" if the patient-to-nurse ratio (defined as number of patients divided by number of nurses staffing in the observed nursing unit) is higher than 8 during the survey period and coded as "0" if the ratio is 8 or less. The 8 of the patient-to-nurse ratio was chosen because the requirement of nurses deployed to a hospital nursing unit set by Taiwan hospital accreditation association. Number of nurse staffing is obtained by calculating the number of full time equivalent nurses. The latter dummy variable (PSBD) was coded as "1" if professional-staff-to-bed ratio (measured by number of nurses and physicians divided by number of beds in the observed hospital) is higher than its sample mean during the survey period and coded as "0" if the ratio is less than or equal to its sample mean during the survey. The capital inputs included three dummy variables specific to district hospitals (reference group), regional hospitals, and academic medical centers. Generally, the district hospitals (referring to a small sized hospital) are responsible for secondary care, regional hospitals (referring to a middle sized hospital) deal with tertiary care, and academic medical centers (referring to a large sized hospital) are oriented to deal with the most complex diseases.

As suggested by the Grossman (1972), several control (environmental) variables were included in the specification of the hospital production function. Control variables consisted of different professional nursing units, and the average patient's age in the observed nursing unit. A dummy variable for average patient's age (AGED) (coded as "1" if the age is higher than 50 in the observed nursing unit and "0" is 50 years of age or less), and four types of hospital nursing units (internal medicine nursing unit, surgical nursing unit, comprehensive nursing unit, and intensive care unit (ICU), were used to control different severity of illness. The 50 of average patient's age is determined by grid searches that maximize the likelihood function and result in model convergence. Age has been proved to be a good proxy for the severity of illness (Warwick, Frank, 1998). In general, the older a person is the more severe an illness one would expect. Additionally, a patient's illness is considered more complicated than his counterparts, if he is hospitalized in the ICU. Therefore, this study adopted ICU as a reference group to indicate different complexity of illness in the observed nursing units.

III. Results

As Table 1 indicates, there were approximately 9% of observed nursing units whose patients' average age were less than 50. The mean of the patient-to-nurse ratio was 9.23, meaning that a nurse is responsible for caring for approximately 10 patients on average per shift. Approximately 64% of observed nursing units belonged to higher patient-to-nurse ratio groups (PTND＞8). The samples distributed to internal medicine nursing units, surgical nursing units, comprehensive nursing units, and ICUs were 34%, 25%, 12%, and 29%, respectively. The samples distributed to academic medical centers, regional hospitals, and district hospitals were 11%, 58%, and 31%, respectively. The mean of professional-staff-to-bed ratio was 0.84, meaning that 84 professional staff (nurses and physicians) were allocated to one hundred beds. The high professional-staff-to-bed ratio group (PSBD>0.84) accounts for approximately 47% of total observations during the survey period. Approximately 32% of the observed nursing units were not found to have death cases during the study period, and the mean of monthly death cases was 4.36; far less than its variance of 37.21. These two results indicated that the equal-dispersion assumption (variance=mean) imposed in the cross-sectional Poisson model is not appropriate, and this study will have to specify an empirical model that could accommodate excess zero counts for this analysis.

This study estimated four count data models including RE-ZIP, ZIP (Zero Inflated Poisson), RE-Poisson (Random Effect Poisson), and Poisson model. Note that the random effects come into both RE-ZIP and RE-Poisson model, sharing the same rationale how the cross-sectional Negative Binomial (NB) regression model incorporates with over-dispersion (variance>mean) in data (Greene, 2012). Figure 1 displayed the several model specification tests for the RE-ZIP model. The space limitation prevents us from explaining these testing results in details (the detailed report is available upon request to the authors). All testing results, however, indicated that the RE-ZIP model fit data better than other count data models. In fact, Greene pointed out that the Random Effect Negative Binomial (RE-NB) model may be over-parameterized in contrast to RE-Poisson model for adjusting over-dispersion property from data

(Greene, 2012). As such, it may be common that an attempt to fit the RE-NB model is less likely to obtain convergence results than RE-Poisson model (Greene, 2012). Therefore, our analyses proceed with the RE-ZIP Model.

Table 1

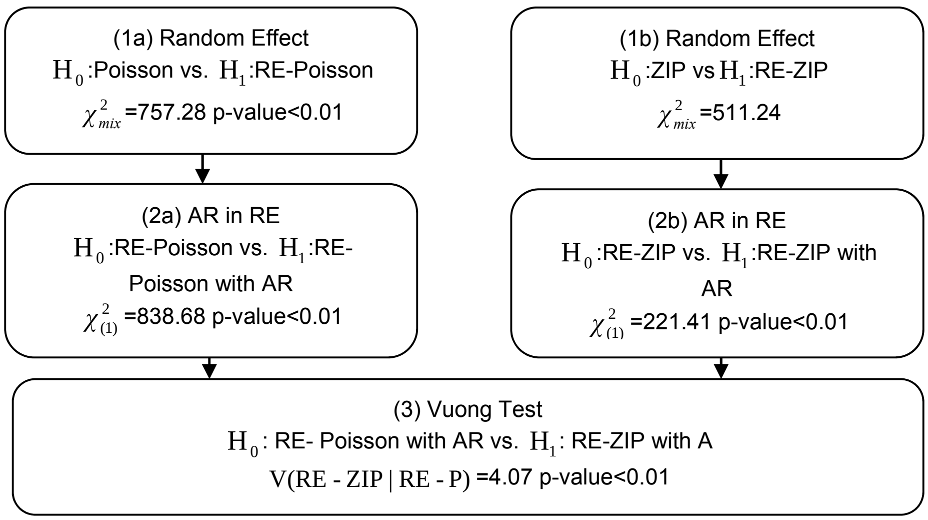
Characteristic of the Study Nursing Units

Variables	Description	Mean	Std.Dev
AGE Dummy	AGED=1 if AGE＜50; AGE=0 if others.	0.09	0.29
Patient-to-nurse Ratio	# of patients divided by # of nurses staffing to the observed nursing unit during the observed month.	9.23	5.17
Patient-to-nurse Ratio Dummy	PTND=1 if Patients to Nurses Ratio＞8; PTND=0 if others.	0.64	0.48
Internal Medicine Nursing Unit	WD1=1 if the observed nursing unit is an internal medicine nursing unit. WD1=0 if others.	0.34	0.47
Surgical Nursing Unit	WD2=1 if the observed nursing unit is a surgical nursing unit. WD2=0 if others.	0.25	0.43
Comprehensive Nursing Unit	WD3=1 if the observed nursing unit is a comprehensive nursing unit. WD3=0 if Otherwise.	0.12	0.33
Intensive Care Unit (Reference Group)	WD4=1 if the observed nursing unit is an ICU. WD4=0 if others.	0.29	0.45
Academic Medical Center	HD1=1 if the hospital is an academic medical center. HD1=0 if others.	0.11	0.31
Regional Hospital	HD2=1 if the hospital is a regional hospital. HD2=0 if otherwise.	0.58	0.49
District Hospital (Reference Group)	HD3=1 if the hospital is a district hospital. HD3=0 if otherwise.	0.31	0.46
Professional Staff to Bed Ratio	Total number of nurses and physicians divided by total number of beds in the observed hospital during the observed month.	0.84	0.29
Professional-staff-to-bed Ratio Dummy	PSBD=1 if Professional Staff to Bed Ratio>Mean	0.47	0.50
Death Cases	Monthly death cases in the observed nursing unit.	4.36	6.10
Cases	Number of Counts	%	Accumulation (%)
0	239	31.61	31.61
1-3	240	31.75	63.36
4-6	89	11.77	75.13
7-9	60	7.94	83.07
10-12	51	6.75	89.81
13-16	39	5.16	94.97
17+	38	5.03	100.00

The estimated results for the RE-ZIP model in Table 2 were separated into two stages: extra zero stage and frequency stage. They are related to the modeling of extra zeros (in the logit scale), and the Poisson data generating process adjusted by extra zeros, respectively. This study found that both the random effect and its estimated auto-correlated parameter in the RE-ZIP Model are significantly different from zero at 1%. These findings echoed the results from the model specification tests in Figure 1.

Figure 1

Model Specification Tests



RE-ZIP and RE-Poisson model are estimated by Maximum Simulated Likelihood Estimation method based on 100 Halton draws which produces lower simulation error than 1,000 random draw (Bhat, 2001). ZIP and Poisson model were estimated in the same way but restricting random effects to be zero. p values for the model specification tests (1a)-(1b) were generated from a mixture of two chi-square distributions with both weight equal to 0.5 (Verbeke, Molenbergh, 2000). p values for the model specification tests (2a)-(2b) were generated from a chi- square distributions with one degree of freedom. p value for the model specification test (3) was generated from standard normal distribution (Vuong,1989).

Table 2 shows that the estimated coefficients of the patient-to-nurse ratio dummy (PTND) have a significantly negative impact on extra zero stage but a significantly positive impact on the frequency stage. The former result indicated that a high patient-to-nurse ratio nursing unit is less likely to produce a mortality free (extra zeros) outcome than its counterparts. The latter result suggested that a high patient-to-nurse ratio nursing unit is more likely to be associated with high mortality. The probabilities of being extra zero (mortality free) are 0.039 (=anti-logit(-2.278-0.415)) and 0.058 (=anti-logit(-2.278)) in the high patient-to-nurse ratio and the low patient-to-nurse ratio nursing units, respectively. The difference in probability of being extra zero (mortality free) between high and low patient-to-nurse ratio nursing units is -0.019, indicating that the probability of being mortality free in the high patient-to-nurse ratio nursing units is 0.019 lower than that in its counterparts. The adjusted mean death cases are 10.237 (=(1-0.039)×exp(1.979+0.387)) and 6.817 (=(1-0.058)×exp (1.979)) in the high patient-to-nurse ratio and the low patient-to-nurse ratio nursing unit, respectively. The difference in adjusted mean death cases is 3.419, indicating that being in the high patient-to-nurse ratio nursing unit generates 3.419 more death cases than its counterparts.

The estimated coefficients of the professional-staff-to-bed ratio dummy (PSBD) have a positive impact on the extra zero stage but a negative impact on the frequency stage. However, only the estimated coefficient for the frequency stage is statistically significant. These results imply that the increase of professional staff (physicians and nurses) will reduce the frequency of death. The adjusted mean death cases are 4.994 (=(1-0.058)×exp(1.979-0.311)) and 6.817 (=(1-0.058)×exp(1.979)) in the high professional-staff-to-bed ratio and the low professional-staff-to-bed ratio nursing unit, respectively. The difference in adjusted mean death cases is -1.823, indicating that being in the high professional-staff-to-bed ratio nursing unit would generate a 1.823 death cases less than its counterparts. Moreover, the signs of the estimated coefficients for age dummy (AGED) are positive in the extra zero stage but a negative impact on the frequency stage. However, only the estimated coefficient for the frequency stage is statistically significant. These results implied that the young patients are likely to reduce the frequency of death. The adjusted death cases are 5.967 (=(1-0.058)×exp(1.979-0.133)) and 6.817 (=(1-0.058)×exp(1.979)) in the young patient group and the old patient group, respectively. The difference in adjusted mean death cases is -0.850, showing that being in the old patient group is associated with 0.850 death cases more than its counterparts.

This study found that the estimated coefficients for three types of hospital nursing units (internal nursing unit, surgical nursing unit, and comprehensive nursing unit) are all statistically positive at 1% significance level for the extra-zero stage but all statistically negative at 1% significance level for the frequency stage. These results indicated that the intensive care unit has a lower probability of being mortality free but a higher frequency of death than its counterparts. The probabilities of being extra zero (mortality free) for internal medicine nursing unit, surgical nursing unit, comprehensive nursing unit, and intensive care unit are 0.291 (=anti-logit(-2.278+1.895)), 0.803 (=anti-logit(-2.278+4.190)), 0.247 (=anti-logit (-2.278+1.673)), and 0.058 (=anti-logit(-2.278)), respectively. The probability of being extra zero (mortality free) in the intensive care unit is 0.233, 0.745, and 0.189 lower than that in the internal medicine nursing unit, surgical nursing unit, and comprehensive nursing unit, respectively. The adjusted number of mean death cases for internal medicine nursing units, surgical nursing units, comprehensive nursing units, and intensive care units were 2.003 (=(1-0.291)×exp(1.797-0.941)),0.347 (=(1-0.803)×exp(1.797-1.416)),1.451 (=(1-0.247)× exp(1.797-1.323)), and 6.817 (=(1-0.058)×exp(1.979)), respectively. These results showed that the adjusted mean death cases in the intensive care unit are 4.814, 6.471, and 5.367; higher than those in the internal medicine nursing unit, surgical nursing unit, and comprehensive nursing unit, respectively, a result indicating that patients hospitalized in the intensive care unit are more likely to generate a higher mortality compared to the other types of nursing units.

Table 2

Empirical Results for Random Effect ZIP Model[5]

	1st stage: extra zero stage (logit scale)			2nd stage: frequency stage (Poisson Process)		
	Coeff (T value)	φ=Pr(Being Extra Zero)	Difference	Coeff (T value)	Adjusted Mean (1-φ)exp(μ)	Difference
Patient-to-nurse ratio＞8	-0.415 (-1.89)*	0.039	-0.019	0.387 (8.71)‡	10.237	3.419
Prof-staff-to-bed ratio＞mean	0.280 (1.30)	0.058	0.017	-0.311 (-7.99)‡	4.994	-1.823
AGE＜50	0.598 (1.56)	0.058	0.043	-0.133 (-2.49)†	5.967	-0.850
Internal Medicine Nursing Unit	1.895 (3.98)‡	0.291	0.233	-0.941 (-21.47)‡	2.003	-4.814
Surgical Nursing Unit	4.190 (9.22)‡	0.803	0.745	-1.416 (-20.68)‡	0.347	-6.471
Comprehensive Nursing Unit	1.673 (3.36)‡	0.247	0.189	-1.323 (-14.11)‡	1.451	-5.367
Academic Medical Center	-0.0640 (-0.22)	0.055	-0.003	0.012 (0.14)	6.927	0.109
Regional Hospital	-0.916 (-3.30)‡	0.024	-0.034	0.458 (10.48)‡	11.168	4.351
Constant	-2.787 (-5.83)‡	0.058	------	1.979 (39.50)‡	6.817	------
Random effect				0.402 (12.49)‡		
AR Parameter(ρ)				0.601 (14.88)‡		

The estimated coefficients for the academic medical center did not generate any significant results. The signs of the estimated coefficients for regional hospitals were statistically negative for the extra zero stage but statistically positive for the frequency stage. The probabilities of being extra zero (mortality free) for regional hospitals and district hospitals are 0.024 (=anti-logit(-2.278-0.916)), and 0.058 (=anti-logit(-2.278)), respectively. The probability of being extra zero (mortality free) in the regional hospitals is 0.034 lower than that in the district hospitals. The adjusted mean death cases for regional hospitals and district hospitals are 11.168 (=(1-0.024)×exp(1.979+ 0.458)) and 6.817 (=(1-0.058)×exp(1.979)), respectively. These results showed that the adjusted mean death cases in regional hospitals are 4.351 higher than those in the district hospitals, indicating that patients hospitalized in regional hospitals are associated with a higher mortality than those in district hospitals.

[5] *RE-ZIP model was estimated by Maximum Simulated Likelihood Estimation method based on 100 Halton draws which produces lower simulation error than 1,000 random draw (Bhat, 2001). "‡", "†" and "*" represent 1%, 5% and 10% significance level, respectively. Asymptotic t values are reported in the parentheses.*

IV. Discussion

The Department of Health (DOH) in Taiwan proceeded with a research project entitled Hospital Nursing Staffing and Patient Outcomes in 2008 in order to investigate the effect of hospital nursing staffing on patient outcomes. The first study generated from the DOH's research project was completed in 2010, and then published in 2012 (Liang, Chen, Lee, Huang, 2012). The study aimed to explore the direct link between nurse staffing and patient mortality in acute-care hospitals in Taiwan. Specifically, the nurse staffing was defined by the direct nursing care hours, and the results showed that the more the direct nursing care hours, the better the patient outcomes. Although the study had raised a lot attention in Taiwanese nursing workforce community, the concept of the direct nursing care hours is somehow difficult to be taken as a managerial instrument to allocate appropriate nurse staffing that could maintain quality of patient care. Accordingly, the impact of the nurse staffing (measured by the patient-to-nurse ratio) on patient mortality was reexamined in the second study (derived from the DOH's research project), and the negative impact of low nurse staffing on patient care is also confirmed (Liang, Tsai, Chen, 2012). In this line of research, we extended these two previous studies by analyzing the accurate death count data (not available until recently) from the DOH's research project through the RE-ZIP model. Several interesting findings obtained from this study have their own merits to be addressed:

First, we found that a Taiwanese nurse is responsible for approximately 10 patients averagely per shift. This number may be underestimated, because Sun, Lin, Kao, Chang, Shaw (2005) found that the mean patient load across all staff nurses is approximately 10, 16, and 22 patients per nurse for daytime, midnight, and early morning shifts, respectively. Actually, Taiwan has legislation mandating minimum patient-to-nurse ratio for hospitals. However, the hospitals are only mandated to employ a minimum patient-to-nurse ratio for the daytime shift, formalizing a grey area within the incomplete mandating ratios, leading hospital administrators not to provide adequate nurse staffing for the other two shifts. Furthermore, cost plays an important role in administrators' decision-making. Many hospital administrators oppose the mandatory ratios because of the perceived increase in operating expenses. Under the current ratios, Taiwanese nurses are responsible for more patients during a shift and, therefore, cannot dedicate adequate time to the patients.

Second, the probability of being mortality free in the high patient-to-nurse ratio group (PTND>8) is 0.019 lower than that in its counterparts and those patients who were in the high patient-to-nurse ratio nursing unit generates 3.419 more death cases than its counterparts. These findings echo other studies showing that mortality reduction are associated with increased nurse staffing. In Taiwan, there is no nursing shortage problem like other countries such as the US because the nurse practice rate is less than 60% based on the most current data published by the National Union of Nurses Associations (Sun, Lin, Kao, Chang, Shaw, 2005). This means that there are more nurses leaving the nursing profession leading to an average vacancy rate of 28% in Taiwan (Sun, Lin, Kao, Chang, Shaw, 2005). Though Taiwan does not have a nursing shortage, high turnover for nurses is of great concern. Prior studies on nurses' high turnover indicated that staffing is a major concern of many nurses. Nurses are dissatisfied with many other aspects of their professional life, including hospital workplace climate, compensation, feelings of being overworked, and feelings that they are burdened by duties that distract them from performing the activity that gives them the most satisfaction: providing patient care (Buerhaus, Needleman, Mattke, Stewart, 2002; Coffman, Seago, Spetz, 2002). All the above reasons result in loss of nurses to other professions that offer better wages with less workload.

This research makes contributions in comparison to previous research on the hospital production in several ways: First, nurses constituted 54% of all health care workers in Taiwan, and 68% of all Taiwanese nurses, work in hospitals (Department of Health, 2010). Nevertheless, little is known about the nurses' contribution to the provision of care that is safe, beneficial, efficient, patient-centered, timely, and equitable, even as nurses represent the single largest providers of patient care. This study addressed the importance of nurse staffing on the quality of care in Taiwan's hospitals, contributing to literature on the hospital production function. Second, Taiwan has differently organized healthcare system compared to other countries, and it can be questioned that North-American evidence (such as Mark, Harless, Spetz, 2009) is applicable to Taiwan setting when concerning about mandating minimum nurse staffing rations by shifts to improve patient safety and the nursing work environment. Therefore, the findings obtained from our empirical model can be used to compare with those in other types of healthcare systems. This information will serve as an important reference for mandating minimum nurse staffing rations by shifts in Taiwan. Third, nurse staffing varies from units to units, depending on the acuity of the patients and types of illnesses being treated. Therefore, nursing unit staffing levels provide accurate information about the patients in the units. In this study, all analyses were conducted at the nursing unit level rather than at the hospital level, making this study a unique contribution to the international body of knowledge (Van den Heede, Diya, Lesaffre, Vleugels, Sermeus, 2008). Fourth, we adopted the most sophisticated panel data methodology, the RE-ZIP model incorporating a first-order autoregressive structure to estimate the hospital production function. This novel methodology can simultaneously deal with the discrete nature of death counts and the excess zero death counts. In addition, the first-order autoregressive structure imposed in the RE-ZIP model is able to avoid the possible bias from the time dependence of errors at different observed time periods. Our model delivered more reliable evidence for the effect of nurse staffing on patient mortality.

Several limitations and methodologically controversial aspects of this study are noteworthy. First, this study was not able to obtain the hospital-specific case-mix index for each hospital in each month to compute severity of illness for each patient. In this present study, patients' age was used to adjust for differences in severity of illness or risk of mortality, however, inpatients' adverse outcomes result from a complex mix of factors. Controlling for inpatients' risks may enable this study to adjust for a recognizable source of outcome variation and to identify more accurately actual quality difference (Van den Heede, Sermeus, Diya, Lesaffre, Vleugels, 2006). Second, the number of patients a nurse cares for is not a true measure of the workload of the nurses. The patient flow (admissions, discharges, and transfers to/from other units) can result in nurses providing care for many more patients in a day than what is reflected in the nurse-to-patient ratio.

V. Conclusions

For years, nurses have reported that there are not enough nurses in hospitals to provide quality care in Taiwan. In response to this concern, this study employed the RE-ZIP model incorporating a first-order autoregressive structure to estimate the hospital production function. We specifically investigated the relationship between nurse staffing and patient mortality in acute-care hospitals under Taiwan National Health Insurance system. Our results showed that the probability of being mortality free in the high patient-to-nurse ratio group is 0.019 lower than that in its counterparts and those patients who were in the high patient-to-nurse ratio nursing unit generates 3.419 more deaths than its counterparts. These findings suggested that nurse staffing below target levels in acute-care hospitals is associated with increased mortality. The policymakers should consider healthcare policy that matches staffing with patients' need for nursing care through setting a shift-based, minimum patient-to-nurse ratio from the perspective of maintaining quality of patient care.

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