Supplementary

S1. TPV-VAR Model

The main goal of this study was to investigate the relationship between demographic changes and the effectiveness of hospitals' nurse staffing policy. To this end, we conducted the TV-IRA to obtain the responses of inpatient care quality to changes in nursing staffing within a 12-month timespan across our study period. The magnitude of these impulse responses served as a measure for the effectiveness of hospitals' nurse staffing policy. The methodology utilized in this study to assess policy effectiveness has been extensively employed in prior policy evaluation studies, spanning analyses of monetary and fiscal policies[33], copayment policies for outpatient care services[38], and emergency department visits.[39] To conduct the TV-IRA, we utilized the TVP-VAR model based on Nakajima's method as follows:[43]

Eq (1) $q_{it}^{s} = f(PNR_{it}, LOS_{it})$

where q_{it}^{s} denotes inpatient care quality (measured by the 14-day readmission rate) at time *t* in the hospital type *i* (*i*=*MC*, *RH*, and *DH*, corresponding to medical centers, regional hospitals, and district hospitals, respectively). *s* (*s*=1,2,3….,12) in superscript designates the temporal span of the impulse response analyses at time *t*. PNR_{it} and LOS_{it} represent the patient-to-nurse ratio (i.e., the average number of patients cared for by one nurse per shift) in acute care wards in hospital type *i* and the length of stay per admission in hospital type *i*, respectively. Let $f(\cdot)$ be the hospital production function. PNR_{it} is considered the labor input in the hospital production function, while LOS_{it} functions as a control variable, reflecting the severity of illnesses as introduced by Liang and his colleagues.[47] Given the variation in capital input across different types of hospitals within the hospital production function, we separately estimated Equation (1) for each type of hospital. Since hospital input is anticipated to yield positive patient outcomes, it is expected that there will be a positive correlation between PNR_{it} and q_{it}^{s}(i.e., $\partial q_{it}^{s}/\partial PNR_{it} > 0$). It is crucial to emphasize that the hospital nurse staffing policy aims to decrease PNR_{it}, thereby enhancing inpatient care quality, specifically manifesting as a reduction in the 14-day readmission rate. Consequently, the effectiveness of hospitals' nurse staffing policy in the long run was gauged by the cumulative

response of the 14-day readmission rate to a standard deviation change in the patient-to-nurse ratio in acute care wards within a 12-month timespan (namely, $\sum_{s=1}^{12} \partial q_{it}^{s} / \partial PNR_{it}$). This approach is commonly utilized in diverse policy evaluation studies, exemplified by the previous works.[33-34, 38-39]

In order to carry out the TV-IRA, we first tested our time series data for the unit root property through the break-point unit root test proposed by Perron.[52] If these time series data were stationary time series, we employed a time-varying vector autoregressive specification for Equation (1). The Bayesian Markov chain Monte Carlo method, with 10,000 repetitions, was then used to estimate Equation (1) and simulate responses of the 14-day readmission rate to a standard deviation change in the *PNR* in acute care wards over a 12-month period. Technical intricacies regarding the model specification and the estimation process for the TV-VAR model and TV-IRA can be found in previous research conducted by Nakajima[43], Lin and her colleagues[38], and Chen and his colleagues.[39]

S2. ARDL model

Given that previous studies, including those by Lin and her colleagues[38] and Chen and his colleagues[39], have delved into the impact of demographic change on healthcare policy effectiveness, we delineated the nonlinear relationship between age distribution and nurse staffing policy effectiveness as follows:

Eq (2) $R_t^i = \alpha_0^i + \sum_{j=1}^{J} \varphi_j^i h_{jt} + \alpha_1^i cv_t + \xi_t^i$

where R_t^i is the cumulative response of the 14-day readmission rate to a standard deviation change in *PNR* in acute care wards within a 12-month period in hospital type *i* at time *t*. Moreover, the share of the population in each specific age group *j* at time *t* (*t* = 1, 2, 3 ..., *T*) is denoted by h_{jt} (j =1, 2, 3, …, *J*), while cv_t represents control variables such as hospital competition, income and business cycles. The parameters α_0^i, φ_j^i, and α_1^i correspond to the constant term, the share of the population in age group *j*, and the control variables, respectively. The term ξ_t^i represents residuals. It is essential to highlight that the model specification in Equation (2) incorporates proportions of the population from all age groups h_{jt} (*j* = 1, 2, 3, …, *J*), leading to a perfect collinearity issue that prevented the estimation of our empirical model. To circumvent this challenge,

we introduced parametric restrictions on the φ_j^i parameters in Equation (2) using Fair and Dominquez's method for the coefficient estimation of h_{jt}.[49] Therefore, Equation (2) can be rewritten as follows:

Eq (3) $R_t^i = \alpha_0^i + \delta_1 z_{1t} + \delta_2 z_{2t} + \alpha_1^i cv_t + \xi_t^i$

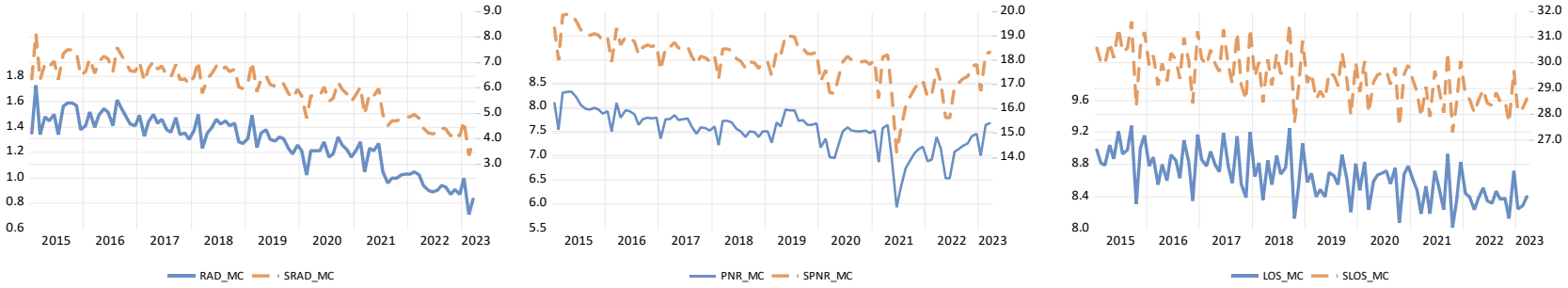
where $z_{1t} = \sum_{j=1}^{J} j h_{jt} - J^{-1} \sum_{j=1}^{J} j \sum_{j=1}^{J} h_{jt}$ and $z_{2t} = \sum_{j=1}^{J} j^2 h_{jt} - J^{-1} \sum_{j=1}^{J} j^2 \sum_{j=1}^{J} h_{jt}$, while $\phi_j^g = \delta_0 + \delta_1 j + \delta_2 j^2$ and $\sum_{j=1}^{J} \varphi_j^i = 0$. δ_1 and δ_2 are parameters corresponding to z_{1t} and z_{2t}, respectively. The definitions of R_t^i, cv_t, ξ_t^i, α_0^i and α_1^i are the same as those in Equation (2). The model specification of Equation (3) allowed us to utilize the delta method to compute the standard errors of h_{jt}, facilitating the establishment of 95% confidence intervals for the estimated coefficients of h_{jt}. These estimated coefficients, in turn, enabled us to illustrate the impact of demographic change on the effectiveness of hospitals' nurse staffing policy. The validation of statistical inferences derived from Equation (3) relies on the stationarity of time series data. In our study, certain variables in Equation (3) were identified as first-order stationary (i.e., I(1)) time series, while others were proven to be level stationary (i.e., I(0)) time series. Consequently, the traditional co-integration methodology became inadequate for identifying the long-term relationships among variables in Equation (3).[44] Instead, the ARDL model, proposed by Pesaran and his colleagues[44], is commonly recommended to discern co-integration relationships among time series data. Specifically, the ARDL model can be specified as follows:

Eq (4) $\Delta R_t = \mu + \rho R_{t-1} + \omega_1 z_{1t-1} + \delta \omega_2 z_{2t-1} + \theta cv_{t-1} + \sum_{j=1}^{p-1} \gamma_j \Delta R_{t-j} + \sum_{j=0}^{q-1} \pi_{1j} \Delta z_{1t-j} + \sum_{j=0}^{r-1} \pi_{2j} \Delta z_{2t-j} + \sum_{j=0}^{s-1} \phi_j \Delta cv_{t-j} + u_t$

Equation (4) represents the standard ARDL(*p*, *q*, *r*, *s*) cointegration model introduced by Pesaran and his colleagues.[44] The term u_t signifies an independent and identically distributed (*iid*) stochastic process, while Δ stands for the difference operator. The definitions of R_t, z_{1t}, z_{2t}, and cv_t remain consistent with those in Equation (3). The parameters to be estimated include $\mu, \rho, \omega_1, \omega_2, \theta, \gamma_j, \pi_{1j}, \pi_{2j}$ and ϕ_j. Specifically, the parameter ρ serves as the adjustment parameter, with a significantly negative value indicating stability in the dynamic healthcare system described in Equation (4). The long-term coefficients for z_{1t}, z_{2t}, and cv_t are derived as ω_1/ρ, ω_2/ρ, and θ/ρ,

respectively. In addition, *p, q, r,* and *s* denote the optimal lags chosen through the following lag selection procedures: initially, the Hannan–Quinn Criterion (HQC) was utilized to determine the lag lengths. This involved estimating the ARDL specification to identify the long-term relationships among R_t, z_{1t}, z_{2t}, and cv_t. Subsequently, the goodness of fit for the residuals (based on the lag lengths from the ARDL specification) in Equation (4) was evaluated through testing for residual auto-correlation, heteroskedasticity, and normality. Considering the limited sample size in this study, the maximum lag length was set to six. The lag selection procedures and diagnostic assessments of the goodness of fit for Equation (4) drew upon methodologies established in prior studies, such as those conducted by Chang and Chen[50] and Chen and Lin.[51]

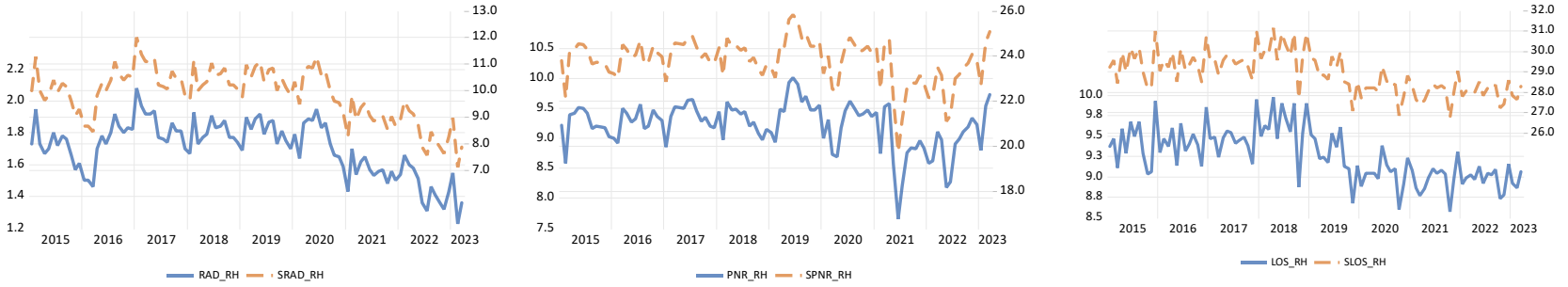
Following the determination of optimal lags, the existence of a stable long-term (namely, cointegrating) relationship was tested using the modified F-test, denoted as Fpss, for the joint null hypothesis of no cointegration (i.e., $H_0: \rho = \omega_1 = \omega_2 = \theta = 0$).[44,50-51] The recommended bound testing procedure involves two pivotal bounds: the upper and lower bounds.[44] If the Fpss statistic surpasses the upper critical bound, the null hypothesis is rejected. Conversely, if the Fpss statistic falls below the lower critical bound, the null hypothesis cannot be rejected. When the Fpss statistic lies between these critical bounds, the test result is deemed inconclusive. Upon establishing the long-run relationship among R_t, z_{1t}, z_{2t}, and cv_t, the parameters (i.e., α_0^i, δ_1^i, δ_2^i, and α_1^i) within the cointegration equation specified by Equation (3) could be derived from Equation (4). Subsequently, the parameters (φ_j^i) in Equation (2) representing the effects of various age groups could be further retrieved using Fair and Dominguez's methods.[49]



(a1) RAD^{MC}

(b1) PNR^{MC}

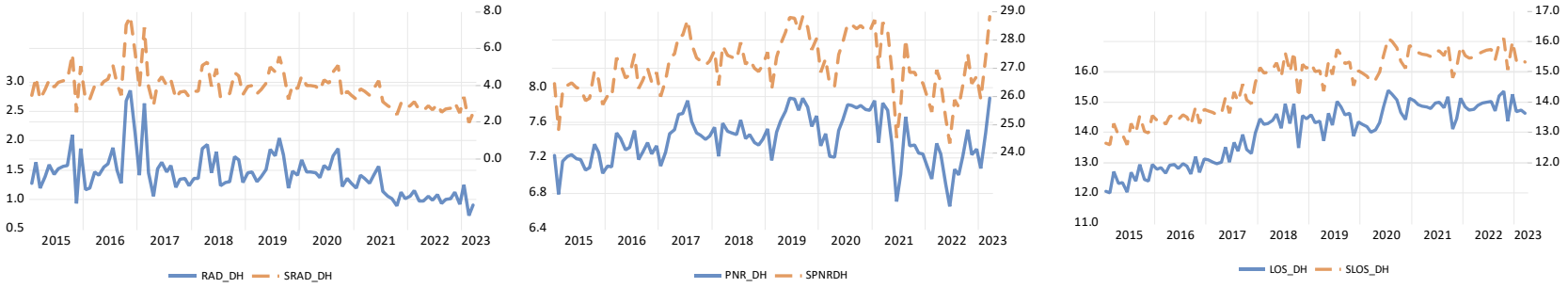
(c1) LOS^{MC}



(a2) RAD^{RH}

(b2) PNR^{RH}

(c2) LOS^{RH}



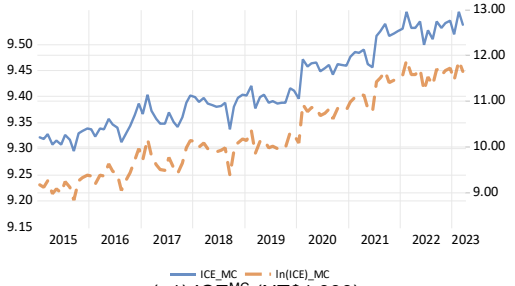
(a3) RAD^{DH}

(b3) PNR^{RH}

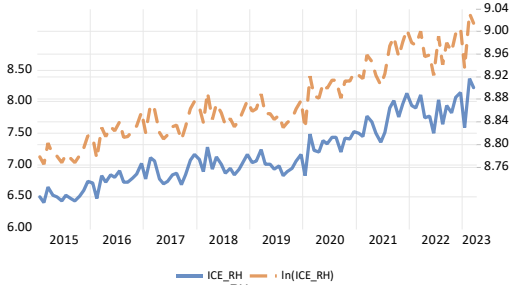
(c3) LOS^{DH}

Figure S1 Time Plots for Variables Used to Estimate the TVP-VAR model

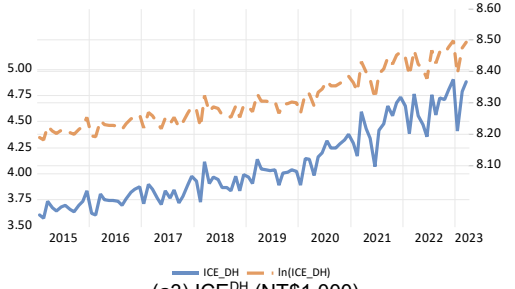
Note: RAD^{j} , PNR^{j}, LOS^{j} denote 14-day readmission rate, patient-to-nurse ratio, and length of stay at *j* type of hospitals, respectively. *j*=MC (medical centers), RH(regional hospitals), and DH(district hospitals).



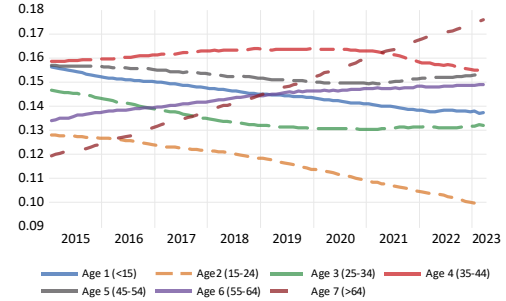
(a1) ICE^{MC} (NT$1,000)



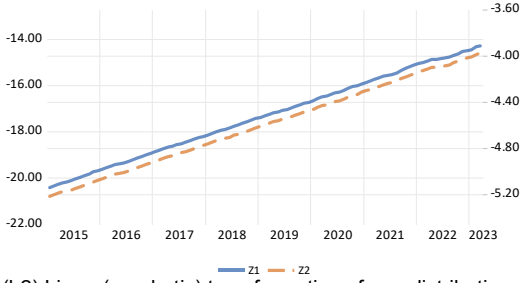
(a2) ICE^{RH} (NT$1,000)



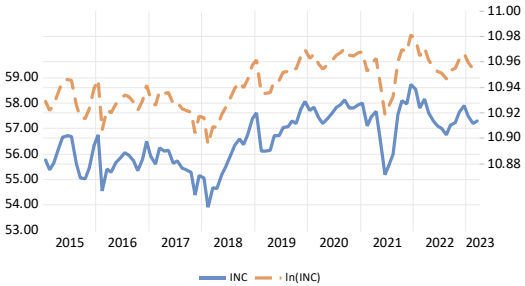
(a3) ICE^{DH} (NT$1,000)



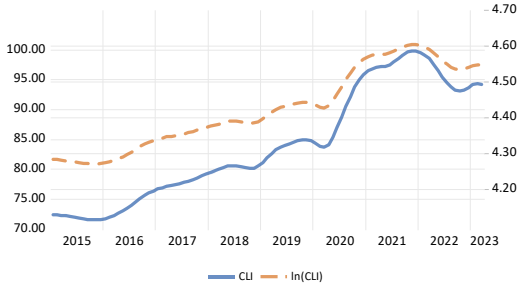
(b1) Age distribution



(b2) Linear(quadratic) transformation of age distribution



(c) INC



(d) CLI

Figure S2 Time Plots for Variables Used to Estimate the ARDL Model

Note: ICE^{j} denotes real reimbursement payment per diem for the *j* type of hospitals, where *j*=MC (medical centers), RH (regional hospitals), and DH (district hospitals). INC represents the real wage level in the healthcare industry. CLI is the leading indicator of business cycles. Age *i* is the share of total population at the specific age group *i*, where *i*=1(age <15), 2(15-24), 3(25-34), 4(35-44), 5(45-54), 6(55-64), and 7(aged 65+). Z1 and Z1 are the linear and quadratic transformation of age distribution.

Table S1 EQUATOR Checklist (STROBE Statement)

	Item	Recommendation	Information Addressed
TITLE & ABSTRACT	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	✓ (a) Please see the Title and the Method of Abstract. ✓ (b) Please see the Results and Conclusions of Abstract.
INTRODUCTION			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	✓ Please see the Background and Demographic Change in the Introduction section.
Objectives	3	State specific objectives, including any prespecified hypotheses	✓ Please see the Purposes of the Study in the Introduction section.
METHODS			
Study design	4	Present key elements of study design early in the paper	✓ Please see the Research Design in the Material and Methods section.
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	✓ Please see the Data Collection and Samples in the Material and Methods section.
Participants	6	(a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up. Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls/Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants;(b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed; Case-control study—For matched studies, give matching criteria and the number of controls per case	✓ This study belongs to time series analysis study rather than the cohort or case-control studies. ✓ This study uses secondary data, specifically monthly economic indicators, aggregate healthcare utilization, and demographic data for all residents in Taiwan. These data did not involve any human participants or tissue.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	✓ Please see the Data Collection and Samples in the Material and Methods section.
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	✓ Please see the Data Collection and Samples in the Material and Methods section.
Bias	9	Describe any efforts to address potential sources of bias	✓ We discuss potential sources of bias in the Further Reflection for Policy Implications and Limitations of Study in Discussion section.
Study size	10	Explain how the study size was arrived at	✓ Please see the Data Collection and Samples in the Material and Methods section.
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	✓ Please see the Data Collection and Samples in the Material and Methods section.
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding;(b) Describe any methods used to examine subgroups and interactions;(c) Explain how missing data were addressed;(d) Cohort study—If applicable, explain how loss to follow-up was addressed(Case-control study—If applicable, explain how matching of cases and controls was addressed；Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy);(e) Describe any sensitivity analyses	✓ (a) See Table 1 and Supplementary Materials of this study. ✓ (b) See Supplementary Materials of this study ✓ (c) No missing data were identified within the dataset. ✓ (d) Not applicable. ✓ (e) Not applicable.
RESULTS			
Participants	13	(a) Report the numbers of individuals at each stage of the study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed;(b) Give reasons for non-participation at each stage;(c) Consider use of a flow diagram	✓ This study uses secondary data, specifically monthly economic indicators, aggregate healthcare utilization, and demographic data for all residents in Taiwan. These data did not involve any human participants or tissue.
Descriptive data	14	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential confounders;(b) Indicate the number of participants with missing data for each variable of interest;(c) Cohort study—Summarize follow-up time (e.g., average and total amount)	✓ (a) See Tables 2-3. ✓ (b) Not applicable. ✓ (c) Not applicable.
Outcome data	15	Cohort study—Report numbers of outcome events or summary measures over time Case-control study—Report numbers in each exposure category, or summary measures of exposure Cross-sectional study—Report numbers of outcome events or summary measures	✓ Not applicable.
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included;(b) Report category boundaries when continuous variables were categorized;(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	✓ (a) See Table 4. ✓ (b) Not applicable. ✓ (c) Not applicable.
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	✓ See the Supplementary Materials of this study.
DISCUSSION			
Key results	18	Summarize key results with reference to study objectives	✓ Please see the Key Results & Policy Implications in the Discussion section.
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	✓ Please see the Further Reflection for Policy Implications and Limitations of Study in the Discussion section.
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	✓ Please see the Further Reflection for Policy Implications and Limitations of Study in the Discussion section.
Generalizability	21	Discuss the generalizability (external validity) of the study results	✓ Please see the Limitations of Study in the Discussion section.
OTHER INFORMATION			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	✓ Please see the Acknowledge section.