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Accounting for Quality in the Measurement of New Zealand Hospital Output

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Abstract: Measuring patent safety as an indicator for quality in the health sector has been widely recommended, but empirical research on an overall measure of this in the New Zealand health care context is limited. In this paper we explore the construction of hospital quality indices based on a set of 20 patient safety indicators and apply these to New Zealand hospital admissions data from 2001 to 2009. Variation in the indices is explained using panel econometric analysis.

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Note: This paper is currently under revision and presents preliminary analysis. Please contact the first author for an up to date version of the paper. Contact: Nick.Bowden@vuw.ac.nz

Section 1 – Introduction

Issues of patient safety and quality of health care are becoming increasingly important in the provision of modern health care (Kohn, J. M.Corrigan et al. 2000; McDonald, Romano et al. 2002). In New Zealand the Ministry of Health has recognised quality as an integral part of a high performing health system and it is an objective of the New Zealand Disability Strategy. The Ministry of Health has identified safety as one of the key dimensions of quality in the health care sector (Ministry of Health 2003).

In this paper we construct four hospital quality indices based on a set of 20 patient safety indicators developed by the Agency for Healthcare Research and Quality (ARHQ) applied to readily available New Zealand hospital data. The patient safety indicators developed by ARHQ are based on algorithms that screen administrative hospital output data to determine the occurrence of a variety of adverse events reflecting amongst other things the quality of services provided by a facility. While the indicators are useful for (operationally) monitoring different dimensions of the quality of hospital services, their analytical value is limited by the infrequency and diversity of the adverse events. A single index which captures the quality of a range of hospital services is preferable as it can summarise quality across multiple indicators and be more easily independently analysed.

We explore different ways to develop a quality index based on adjusting and weighting a selection of the 20 safety indicators. The simplest approach is to treat each adverse event as being equally reflective of patient safety and develop an index using an equal weight system based solely on provider level observed rates. This simple approach ignores two significant issues when dealing with PSIs: risk adjustment and reliability. Risk adjustment is a process which attempts to control for the fact that providers treat patients with dissimilar case-mix. In this way valid comparisons can be made between different providers and over time. Reliability is a concern because PSIs indicate adverse events which are extremely infrequent and as a result provider level observed rates can vary significantly. Reliability adjustment addresses this issue by placing less weight on those indicators which at the provider level have greater variability.

We examine three patient safety composite indices which incorporate adjustment for both risk and reliability. Each index incorporates the same risk and reliability adjustment process but their final weighting systems differ. The first uses an equal weighting system so that each indicator is treated as reflecting patient safety in the same way. The second exploits the covariation in the indicators and develops weights based on factor analysis of the 20 indicators. The third develops a set of weights based on the "expert opinion" of clinicians, who are, justifiably, the most knowledgeable about hospital services. We develop these indices, discuss their underlying rationale, and apply them to New Zealand hospital data at the District Health Board (DHB) level from 2001 to 2009.

The following section briefly reviews the relevant literature. Section 3 describes the data used in the study and summarises some of the key variables. Section 4 explains the Patient Safety Indicators, their origin, development, and application to New Zealand data. Section 5 describes the methodology employed in creating our composite indices in a six step process. Section 6 provides a panel econometric analysis of one of the composite indices while Section 7 concludes.

Section 2 – Literature Review

Patient safety, and quality of healthcare are receiving increasing attention (Kohn, J. M.Corrigan et al. 2000; McDonald, Romano et al. 2002). In New Zealand the Ministry of Health has identified quality as a cornerstone of a high performing system with one of the key dimensions of quality being patient safety (Ministry of Health 2003). In one of the few studies on patient safety and quality of care in New Zealand public hospitals it was found that 12.9 percent of admissions were associated with adverse events, of these events approximately 35 percent were found to be highly preventable and for each adverse event, on average, length of stay increased by nine additional days (Davis P, Lay-Yee R et al. 2001).

There has been a range of metrics of quality of care and patient safety reported in New Zealand. The Health Benchmarking Information (HBI) reports, published quarterly by the Ministry of Health but discontinued in 2010, provide 15 performance metrics based on hospital services data supplied by DHBs. Of these several were considered measures of hospital quality: Emergency triage rates, Acute readmissions rate, Patient Satisfaction, and

Healthcare Associated *S. aureus* Bloodstream Infections (HABSI). DHBs are now responsible for reporting such measures independently. A 2007 paper by the Ministry of Health on productivity and efficiency in the delivery of public hospital services in New Zealand reported four indicators of quality: In-hospital mortality, Hospital acquired infections, Readmission to hospital within 30 days, and Patient satisfaction (Ministry of Health 2007). A further report conducted by the Ministry of Health considered health sector amenable mortality as a proxy for health sector performance (Ministry of Health 2010). Information for New Zealand hospitals on risk adjusted mortality rates and readmission indices has also been published (Ministry of Health 1995).

To the best of our knowledge this study is the first of its kind in New Zealand to construct a composite Patient Safety Index from the AHRQ PSIs. AHRQ's PSIs are inexpensive, easy to use, less subject to bias than some other sources of patient safety data, and provide reliable estimates of rates of preventable adverse events (Rivard P, Rosen A et al. 2006). They have been increasingly used by hospitals, health systems, and those monitoring hospital patient safety performance (Miller M, Elixhauser A et al. 2001; Romano P, Chan B et al. 2002). Two of the more extensive studies which have used the AHRQ PSIs are from (Romano P, Geppert J et al. 2003) who examined safety events in more than 36 million discharges from U.S. hospitals in 2000 and (Zhan C and Miller M 2003), whose study investigated the relationship between PSIs and length of stay, charges, and mortality rates in 28 U.S states in 2000 .

Section 3 – Data

The primary source of data for this study is taken from nine years of the National Minimum Dataset (NMDS) from 2001 to 2009. NMDS is a national collection of all inpatient and day patient discharges. This covers all discharges from publicly funded hospitals (from 1988) and publicly funded events at private hospitals (from 1997) in New Zealand. An observation in NMDS corresponds to a single hospital discharge and is uniquely identified by an event ID variable. Each observation contains a variety of clinical and patient related information including: event start and finish date, length of stay, facility code, DHB code, Major

Diagnostic Category (MDC), Diagnostic Related Group (DRG)[1], age, sex, ethnicity, rurality[2], and deprivation level[3]. This unfiltered data set contains roughly 6.5 million discharge level observations.

Two filtering processes have been applied to the original NMDS data set. The first is advised by the Ministry of Health (MoH) and is particularly relevant if providers are being compared against each other to ensure consistent data across providers and over time (Ministry of Health 2005). This filter employs a 20 step process which drops observations such as non-treated patients, those with error DRGs, and renal dialysis patients.[4] The second filter relates to facility size and selection. Many of the 91 facilities in NMDS are specialist facilities and/or extremely small facilities which have limited treatment capabilities and care for a relatively small number of patients. Facilities with less than 500 discharges per year or with a proxy number for beds per year of less than 35 are dropped using this filter thus reducing the total number of facilities to 37. This comprises the final data set of 5 503 942 observations used in this study is henceforth referred to as the reference population.

Table 1 in Appendix A describes some overall characteristics of NMDS and hospital discharges in New Zealand from 2001 to 2009. The table demonstrates increases in total discharges and clear variation in key demographics over time. Total discharges increase over the nine year period. This should be expected due to population growth in New Zealand however from 2001 to 2009 total discharges have increased on average by 2.98% p.a. whereas the New Zealand population has increased at only 1.33% p.a.[5]

Table 1 also illustrates clear changes in patient demographics over time. Gender distribution is relatively unchanged. Average patient age has increased from 44.58 in 2001 to 45.70 in 2009. Most of this increase can be explained by the proportion of elderly

[1] The DRG variable used for this study is AN-DRG v3.1 using version 4.2 of the grouper software. Technical information can found at http://www.nzhis.govt.nz/moh.nsf/pagesns/318.
[2] Rurality of areas is defined by the urban-rural profile classification developed by Statistics New Zealand on a 4 point scale from 0 to 3, 3 being the most rural.
[3] For this study deprivation level is indicated using NZDep06 where 1 represents the least deprived areas and 10 the most deprived. More information can be found at: http://www.moh.govt.nz/moh.nsf/Files/NZDepfiles/$file/nzdep2006-users-manual.pdf
[4] Details of this can be found at http://www.moh.govt.nz/moh.nsf/pagesmh/5934/$File/hospital-throuhout-0304-appendix.pdf. Note: This analysis did not filter with respect to transfers, step 18.
[5] Source: World Bank, World Development Indicators.

patients (age ≥ 65) which has risen from 29.8% in 2001 to 30.7% in 2009. The ethnic breakdown of discharges also shows some interesting changes over time. The proportion of New Zealand Europeans has decreased from 63.6% in 2001 to 58.9% in 2009. This is in contrast to increases in proportions of Maori from 15.1 to 16.3%, Pacific 5.5 to 7.8%, and Asian 2.7 to 5.4% patients from 2001 to 2009 respectively. As would be expected by definition deprivation level has generally remained unchanged while mean rurality has fallen slightly, possibly reflecting the urbanisation of New Zealand's population.

Table 2(a) in Appendix A lists total discharges and DHB[6] means for the variables in Table 1. Table 2(b) describes these same variables as differences from the reference population means. Both tables show clear variation across DHBs in all listed variables. Total discharges as expected vary across DHBs with DHB 10 having the highest number of discharges at 563438 more than ten times greater than DHB 21, the lowest at 51495. Gender has the least variation gender distribution with the DHB 20 proportion of female discharges 4.0 percentage points above the reference population mean while DHB 21 is 3.8 percentage points below the mean. Variation in age can be illustrated by DHBs 10 and 12. DHB 10 has an average patient age of 40.17 (4.79 years below the mean), with a higher than average proportion of patients with age ≤ 5 (3.0 percentage points above mean), and a lower than average proportion of elderly patients (7.5 percentage points below mean). On the other hand DHB 12 has an average patient age of 50.74 (5.8 years above the mean), with a lower than average proportion of patients aged ≤ 5 (3.6 percentage points below mean), and a higher than average proportion of elderly patients (8.6 percentage points above mean). Ethnicity is the variable that varies the most across DHBs. DHB 10 and 12 have the lowest (26.0 percentage points below mean) and highest (24.7 percentage points above mean) proportion of New Zealand European patients respectively. The proportion of Maori patients varies from DHB 12 at 4.3% (11.3 percentage points below mean) to DHB 15 at 33.4% (31.3 percentage points above mean). Pacific patient proportions vary from 0.03% (6.5 percentage points below mean) for DHB 21 to 26% for DHB 10 (19.2 percentage points above mean), while the proportion of Asian patients varies from 0.5% (3.9 percentage points below mean) to 13.2% (8.9 percentage points above mean) for DHBs 21 and 9 respectively. As expected by definition deprivation level varies considerably across DHBs.

[6] For the purpose of this study DHBs have been kept anonymous.

DHB 15 has the highest mean deprivation level at 8.40 while DHB 13 has the lowest at 5.31. Rurality also varies across DHBs with DHB 9 the lowest with mean rurality equal to 0.058 (most urban) and DHB 21 the highest at 1.637 (most rural).

This study incorporates the use of Ministry of Health collated DHB input cost data. This data is used in explaining variation of our indices over time. The Input data set contains monthly input and costing information at the DHB level from 2001 to 2009. The data set is related to all DHB level expenditures hence it is not possible to identify the proportion of provider arm inputs/expenditures. The dataset contains FTE numbers for medical, nursing, Allied Health, support, and management/administration. It also contains total personnel cost for the staffing groups listed above, outsourced services, clinical supplies, and infrastructure and non-clinical supplies.

Section 4 - Patient Safety Indicators

The Agency for Healthcare Research and Quality (AHRQ) Patient Safety Indicators (PSIs) comprise one of four modules of Quality Indicators (QIs) developed by AHRQ. The development of these QIs began in the early 1990s in response to the growing need for accessible and reliable health care quality indicators and they were named the Healthcare Cost and Utilization Project (HCUP) QIs (AHRQ 2007). Their development was furthered by AHRQ who in 1999 commissioned the UCSF-Stanford Evidence-based Practice Center to refine, modify and extend the original QIs which were then released as the AHRQ QIs from 2000.

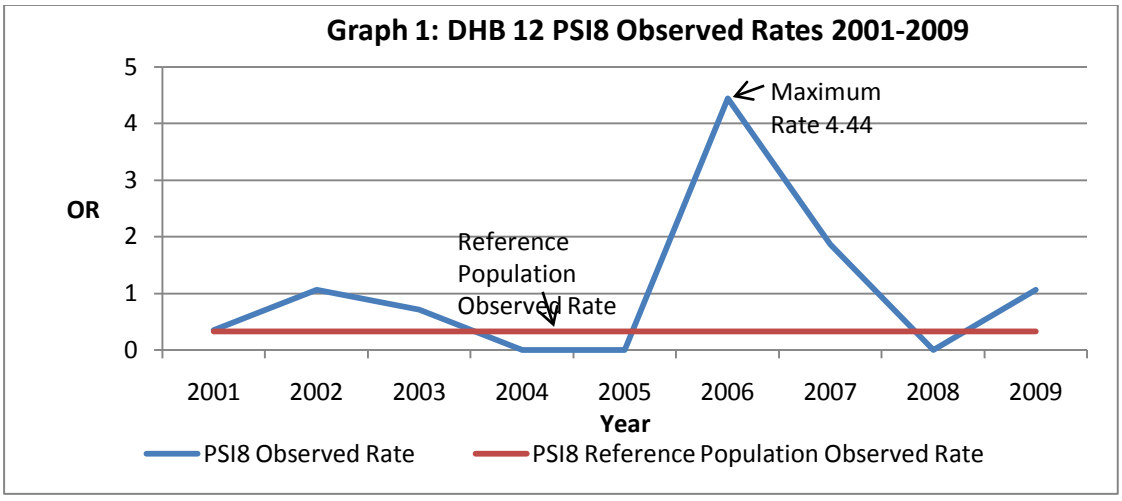
Module Three of AHRQ's QIs is the Patient Safety Indicators (PSIs) which consist of 20 provider level and seven area level PSIs and were initially released in 2003. Their purpose is to help identify potentially preventable complications and iatrogenic events for patients treated at hospitals and become a starting point for analysis to help reduce such errors through system or process changes (AHRQ 2007). In their development the PSIs were subjected to a rigorous evaluation procedure including face validity, precision, minimum bias, and construct validity[7] (McDonald KM, Romano PS et al. 2002). Independent studies

[7] Face validity reflects how well the indicator captures an aspect of quality that is widely regarded as important and subject to provider or public health system control. Precision requires there be a substantial amount of

have shown the PSIs to have good face and construct validity (Zhan C and Miller MR 2003; Rosen AK, Rivard P et al. 2005). Table 3 in Appendix B lists the 20 PSIs and a brief definition of each.

The AHRQ provider level PSI algorithms refined for New Zealand data were applied to NMDS to create 20 PSI indicator variables at the patient discharge level. Each PSI is effectively a 0/1 dummy variable; `1' indicates the occurrence of a particular adverse event, `0' indicates that the adverse event did not occur but that the patient was at risk of such an event occurring, and `.' indicates the patient was not at risk. The PSIs can then be used to generate observed PSI rates per 1000 discharges at whatever level of aggregation is desired.

Table 4 in Appendix B lists each PSI, its numerator (the total number of adverse events), denominator (total number of patients at risk), observed PSI rate (numerator/ denominator*1000), and its standard deviation for the reference population. Table 4 illustrates that each PSI indicates adverse events which are very infrequent. The least frequent is PSI1: Complications with Anaesthesia with an observed rate of 0.015 per 1000 discharges. Even the most frequent, PSI4: Failure to Rescue occurs at a rate of only 106 per 1000 discharges. As a result when PSIs are aggregated at the provider level, the infrequent nature of these adverse events can result in considerable observed rate variation over time. Graph 1 below demonstrates this using DHB 12 an example.



provider- or community-level variation that is not attributable to random variation. Minimum bias requires there is either little effect on the indicator of variations in patient disease severity and comorbidities, or it is possible to apply risk adjustment and statistical methods to remove most or all bias. Construct validity requires the indicator to perform well in identifying true (or actual) quality of care problems.

As shown in Graph 1, DHB 12's observed PSI rate varies considerably over time and deviates markedly from the reference population rate of 0.334. For three years out of nine the DHB's observed rate is zero, however in 2006 the observed rate is 4.44 (over ten times the reference population average). This variation is an issue that is particularly problematic for smaller providers and also when the adverse events are more infrequent. This must be addressed when considering how to develop a PSI composite index and is revisited later in this paper.

Section 5 - Methodology

The purpose of our study is to create a single composite index of patient safety based on a series of event-specific patient safety indicators. We are in the early stages of this work, but once completed the methodology can be used to include other hospital quality indicators and construct indices that permit examination of quality variation across DHBs (or facilities) and over time.

We explore different ways to develop a quality index based on weighting the 20 safety indicators. The first and simplest approach is to treat each adverse event as being equally reflective of patient safety and hence develop an index using an equal weight system based solely on provider level observed rates. We also investigate three further patient safety composite indices which incorporate adjustment for both risk and reliability. These three indices differ by their final weighting system. The first uses an equal weighting system so that each indicator is treated as reflecting patient safety in the same way. The second exploits the covariation in the indicators and develops weights based on factor analysis of the 20 indicators. The third develops a set of weights based on the "expert opinion" of clinicians, who are the most knowledgeable about hospital services. These three indices are created using a six step methodology based on that developed by (AHRQ 2008).

This section describes the six step process involved in creating the PSI composite indices. Step 1 describes the component (PSI) selection for use in the composite indices. Step 2 shows how the reference population rates as well as DHB observed rates are calculated. The simple index is also generated here. Step 3 describes risk adjustment, its significance and how this is applied using New Zealand data to create risk adjusted rates. Step 4 adjusts the

risk adjusted rates for reliability and explains why this is important. Step 5 describes how the component weights are derived and is the step which distinguishes the later three indices from each other. In step 6 the final composite index is formed.

The following steps make frequent reference to the reference population and the population of interest. The reference population refers to all observations from the full nine years of filtered NMDS data from 2001 to 2009 described in Section 2. Population of interest refers to observations relating to a particular DHB j for a particular year t.

Step 1: Component Selection

From the 20 provider level AHRQ PSIs we have chosen to follow (AHRQ 2008) in choosing 11 of these as components for the composite PSI indices. This selection criteria omits all obstetric related PSIs (PSI17 – 20). In addition to PSI1: Complications of Anaesthesia is omitted due to reliance on E-codes, PSI4: Failure to Rescue because it is already a composite, and PSI2: Death in Low Mortality DRGs, PSI5: Foreign Body Left During Procedure and PSI16: Transfusion Reaction as they are low frequency "never" events which are reported as counts.

Step 2: Calculating the Reference Population PSI rates (α_k) and DHB Level Annual Observed PSI Rates (OR_j)

Each PSI is represented by its 0/1 outcome of interest variable Y_{ijt}^k, where k indexes the PSI, i indexes the patient, j indexes the provider (DHB) and t indexes time (year). Therefore $Y_{ijt}^k = 1$ indicates the occurrence of the adverse event indicated by PSI k for patient i treated at DHB j at time t. PSI rates are defined as the incidence of adverse events per 1000 discharges at risk.

The reference population PSI rates (α_k) are calculated as follows:

$$\alpha_k = \frac{\sum_i \sum_j \sum_t Y_{ijt}^k}{N_k} * 1000$$

Where N_k represents the total number of patients from the reference population at risk of experiencing the adverse event indicated by PSI_k.

For ease of notation from this point forward the time subscript *t* and the PSI superscript *k* have been dropped. Hence the following calculations apply to each of the k PSIs at each of the t time periods.

The observed PSI rate per 1000 discharges at DHB j (OR_j) is calculated as:

$$OR_j = \frac{\sum_i Y_{ij}}{n_j} * 1000$$

Where $Y_{ij} = 0 \; or \; 1$, and represents the PSI outcome for patient i in DHB j. n_j = the number of patients in DHB j at risk of the given adverse event indicated by the corresponding PSI. OR_j is the observed PSI rate at DHB j, or the realised proportion of adverse events to the total number of patients at risk of experiencing such an event at DHB j per 1000 discharges.

The simple index uses as its components the ratio of the observed rates to the reference population rate:

$$OR_j / \alpha_k$$

The completed simple PSI composite index for DHB *j* at time *t* is the weighted average of the *k* PSI components, where *k*=11:

$$Simple\ PSI\ Composite\ Index_{jt} = \frac{1}{11} * \sum_k OR_{jt}^k / \alpha_k$$

Step 3: Risk Adjustment and calculating the Risk Adjusted PSI Rates (RAR_j)

As discussed earlier the above index does not make any case-mix adjustment. Step three discusses risk adjustment and describes how the AHRQ risk adjustment process was applied to New Zealand data.

Why Risk Adjustment?

"Valid conclusions regarding the differences in quality among providers require the removal of the confounding effect of different institutions providing care to patients with dissimilar severity of illness and case complexity." (Wray N, Hollingsworth J et al. 1997). Risk adjustment is a process which addresses this concern.

The relevance of risk adjustment in the patient safety context can be illustrated using a simple example. Consider two hospitals, A and B. Each hospital treats an equal number of patients and provides the same treatment to each patient. If a given PSI indicates the occurrence of an equal number of adverse events for each hospital then we might conclude that both hospitals have the same level of patient safety. However if the "case-mix" (the characteristics–age, gender and health status–of the population served by the health provider) of each hospital were different, for example if the patients who attended hospital A were all young adults with no comorbidities and low severity of illness, while those who attended Hospital B were all elderly patients, with multiple comorbidities and extreme severity of illness then this conclusion is probably inaccurate. This is because the set of patients treated by hospital B would be more likely to experience adverse events than those treated by hospital A. A valid comparison of patient safety should therefore take this increased risk into consideration. Risk adjustment attempts to control for the differences in hospital case-mix so that fairer and more valid comparisons between DHBs and over time can be made.

The AHRQ Risk Adjustment Process

Our PSI composite indices incorporate a risk adjustment methodology based on that developed by AHRQ. The AHRQ risk adjustment process uses a reference population which includes 38 US States and approximately 90 million discharges from the State Inpatient Databases (SID) from 2001-2003 to estimate risk adjustment coefficients (β^{US}) for each PSI. These coefficients are estimated by logistic regressions of Y_{ij}^{US}, the 0/1 PSI outcome of interest, on X_{ij}^{US} an explanatory vector of covariates containing information such as age, sex, DRG, and comorbidities, where the i subscript represents the patient.

We follow the above methodology but instead use our reference population, 9 years of filtered NMDS data covering all 21 DHBs and including approximately 5.5 million observations. Therefore we estimate New Zealand specific risk adjustment coefficients, β^{NZ} for each of the 11 PSIs. Our regressions also include additional New Zealand specific covariates for ethnicity, rurality, and deprivation level[8].

[8] Risk adjustment regression coefficients provided on request.

The estimated β^{NZ} coefficients are then utilised to produce predicted probabilities of positive PSI outcomes (P_{ij}) for each patient at risk of experiencing these adverse events.

$$P_{ij} = \exp\left(X_{ij}\beta^{NZ}\right)/(1 + \exp\left(X_{ij}\beta^{NZ}\right)$$

P_{ij} should be interpreted as the estimated probability of patient i at DHB j experiencing the adverse event indicated by the corresponding PSI.

The predicted probabilities are used to derive expected PSI rates (ER_j). The expected PSI rate at DHB j (ER_j) per 1000 discharges is calculated as:

$$ER_j = \frac{\sum_i P_{ij}}{n_j} * 1000$$

ER_j is therefore the proportion of total expected adverse events to the total realised number of patients at risk of experiencing such an event at DHB j per 1000 discharges. The expected rate is calculated based on the actual case-mix of patients which present at DHB j, and the estimated probability of each patient experiencing an adverse event as determined by the β^{NZ} coefficients estimated from the logistic regression on the reference population. Intuitively ER_j can be seen as the PSI rate that would be expected at DHB j if its performance was the same as the reference population.

The Risk Adjusted PSI Rate at DHB j (RAR_j) is calculated as:

$$RAR_j = \left(OR_j \Big/ ER_j\right) * \alpha_k$$

Where α_k is the reference population PSI_k rate. The risk adjusted rate can be interpreted as the PSI rate a DHB would have if it had an average case-mix, or expressed in another way, it holds the DHB's performance on the PSI constant and calculates the expected rate if the provider performed at the average level.

The Risk Adjusted Ratio ($RAratio_j$) is:

$$RAratio_j = \left(OR_j \Big/ ER_j\right)$$

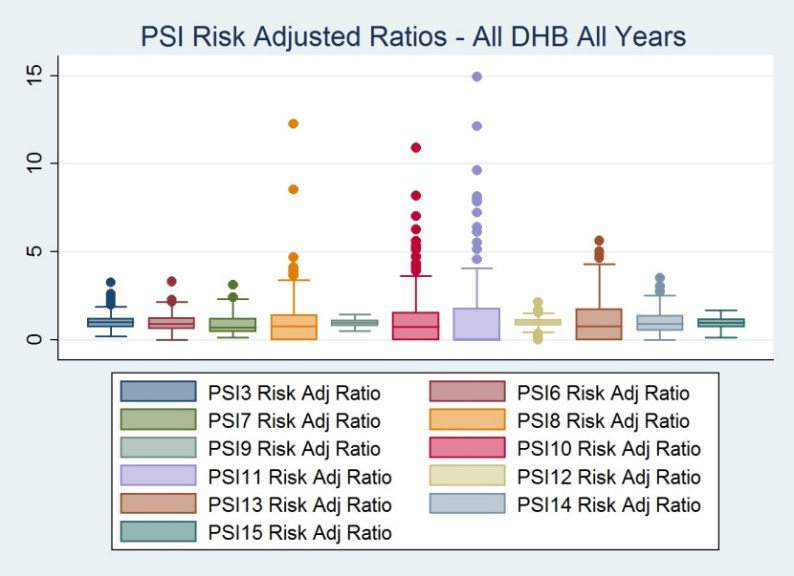
The risk adjusted ratio can be interpreted in one sense as a performance indicator with respect to the reference population. For example if the OR_j/ER_j ratio is greater than 1 this can

be considered as below average performance relative to the reference population since the observed rate at DHB j is greater than the expected rate. If the $^{OR_j}/_{ER_j}$ ratio is less than 1 this can be viewed as "above average" relative to the reference population. The risk adjusted ratio has the advantage that it has the same scale across all PSIs and can therefore be more successfully aggregated to form the composite PSI index.

Step 4: Calculating the Reliability Weights (RW) and the reliability adjusted ratio

The following step adjusts the risk adjusted ratio based on the "reliability" of the PSI rate. The premise is that when dealing with events which occur at a very low frequency, the risk adjusted ratio for any given DHB can be extremely volatile. Graph 2 below illustrates the variation in the PSIs risk adjusted ratios across all DHBs over the nine year period.

Graph 2: PSI Risk Adjusted Ratios



As shown PSI8, PSI10, and PSI11 have the most volatile risk adjusted ratios. Recall from Table 4 that these PSIs are also those with the lowest adverse even occurrence in the reference population. The volatility in the PSI risk adjusted ratios is also exaggerated the smaller the provider. The purpose of the reliability weight is to reduce the impact of this volatility. The reliability adjusted ratio is calculated as:

$$Reliability\ Adjusted\ Ratio_j = RAratio_j * RW + Reference\ Population\ Ratio * (1 - RW)$$

Where the Reference Population Ratio = 1 as the observed rate and expected rate must be equal. The reliability weight (RW) is determined by the ratio of the signal variance to the sum of the signal variance SV and noise variance NV:

$$RW = {SV}/{(SV + NV)}$$

Where the noise variance is the variance of the risk adjusted ratio, $Var(RAratio_j)$ and the signal variance for this study is approximated by using the signal variance from the US reference population. Therefore the greater is $Var(RAratio_j)$ the less reliable the PSI is deemed to be and the reliability adjusted ratio is weighted more towards one. The Noise Variance (NV) is calculated as:

$$\begin{aligned} NV = Var(RAratio_j) &= Var[(OR_j/ER_j)] \\ &= (1/ER_j)^2 Var[OR_j] \text{ since } var(aX) = a^2 var(x) \\ &= (1/ER_j)^2 Var[(1000/n_j)\textstyle\sum_i Y_{ij}] \text{ by definition of } OR_j \\ &= (1/ER_j)^2 (1000/n_j)^2 Var[\sum_i Y_{ij}] \\ &= (1/ER_j)^2 (1000/n_j)^2 \textstyle\sum_i Var[Y_{ij}] \text{ since } var(\sum X_i) = \\ &\textstyle\sum var(X_i) \text{ if } X_i \text{ is independent} \\ &= (1/ER_j)^2 (1000/n_j)^2 \textstyle\sum_i [P_{ij}(1 - P_{ij})] \text{ since Y is binary and the} \\ &\text{variance of a binary number is P(1-P)} \end{aligned}$$

Step 5: Calculating the Component Weights

Three separate PSI component indices are constructed based on three different sets of weights. Composite 1 is based on an equal weighting system, Composite 2 is based on weights derived from factor analysis, and Composite 3 is based on a weighting system derived from data collected on the expert clinical opinions of a sample of New Zealand Senior Medical Officers (SMOs).

Equal Weights

As the composite index is generated using 11 individual PSI components each weight for the equal weighting system is $Weight_k = \frac{1}{11} = 0.909\ (3dp)$

Factor Analysis Based Weights

Factor analysis is a statistical method which describes the latent structure of a set of variables in terms of a potentially lower number of latent factors that are correlated with the original set of variables by examining the correlation between the underlying variables themselves.[9] The factor analysis procedure extracts succeeding factors (each explaining less and less variance) until the variance explained by an additional extracted factor is less than the explanation of any one of the individual variables. Because the first factor contains the most information that is common with the largest number of variables, (Ram 1982) argues that it is a natural choice for an index to measure the common characteristics of the variables. [10] (Srinivasan 1994) suggests that although subsequent factors do contain relevant information, there are problems with combining them into a single index.

Conceptually the case can be made for a principal components based weighting system if there is strong covariation between the PSIs, i.e. if for any given year a DHB has poor performance in relation to one PSI there is a greater chance it will also have poor performance with respect to the other PSIs. If this is the case the first principal component will explain the majority of the variation of the PSIs and hence be the basis for constructing the composite index. To explore this possibility we examined the correlation matrix between the 11 reliability adjusted PSI rates. Table 5 in Appendix C displays the results. Correlation between the PSIs was found to be small adding little support to a factor analysis based index. The maximum correlation coefficient was 0.341 and the average correlation coefficient was only 0.044 with several showing negative correlation. To further confirm the case against a factor analysis based index a preliminary principal component factor analysis was run. Table 6 in Appendix C shows the first principal component accounts for only 17.4 percent of the overall variation of the PSIs. As a result this weighting system was abandoned.

[9]For a review of factor analysis, see (Kline 1994). In addition, (Adelman and Morris 1967), and (Ram 1982) each gives descriptions of this procedure.

[10] Principal components have been used to construct indices in (Ram 1982) and (Mazumdar 1996).

Expert Opinion Based Weights

For this set of weights we surveyed clinicians and asked them to rate each PSI in terms of its relative importance in measuring the quality of hospital care as reflected by patient safety.[11] Respondents were asked to rate each PSI on a seven point Likert scale. The weightings we derived from these ratings were calculated as follows:

$$Weight_k = \frac{Average\ Clinician\ based\ rating\ for\ PSI_k}{\sum_k Average\ clinician\ based\ rating\ for\ PSI_k}$$

In this sense heavier weightings are associated with those PSIs deemed to better represent the quality of hospital care and patient safety. The Table 5 below lists the opinion based weights:

Table 5: Opinion Based Weights

Patient Safety Indicator	Opinion Based Weight
PSI3: Decubitus Ulcers	0.1007
PSI6: Iatrogenic Pneumothorax	0.0576
PSI7: In-hospital Fracture	0.1199
PSI8: Postoperative Respiratory Failure	0.1055
PSI9: Postoperative Haemorrhage or Haematoma	0.0815
PSI10:Postoperative Abdominal Wall wound Dehiscence	0.1007
PSI 11: Postoperative Respiratory Failure	0.0600
PSI12: Postoperative Pulmonary Embolism or DVT	0.1199
PSI13: Postoperative Sepsis	0.1127
PSI14: Postoperative Wound Dehiscence	0.0815
PSI15: Accidental Puncture Or Laceration	0.0600

Step 6: Calculating the PSI Composite

The final composite measure is the weighted average of the reliability adjusted ratios for each PSI.

$$Composite_j = \text{Weight}_3 * RRAratio_{3j} + \text{Weight}_6 * RRAratio_{6j} + \ldots\ldots\ldots + \text{Weight}_{15} * RRAratio_{15j}$$

The index should be interpreted such that a rise in the value of the index from one year to the next reflects a worsening level of patient safety. Roughly speaking levels of the index

[11] At the time of writing the opinion based weighting system is based on pilot study results only. The full national survey results will be available at a later date.

above one suggest patient safety performance below average while the levels below one suggest above average performance. The index is derived such that conceptually comparisons across DHBs can also be made but we recognise that this requires research

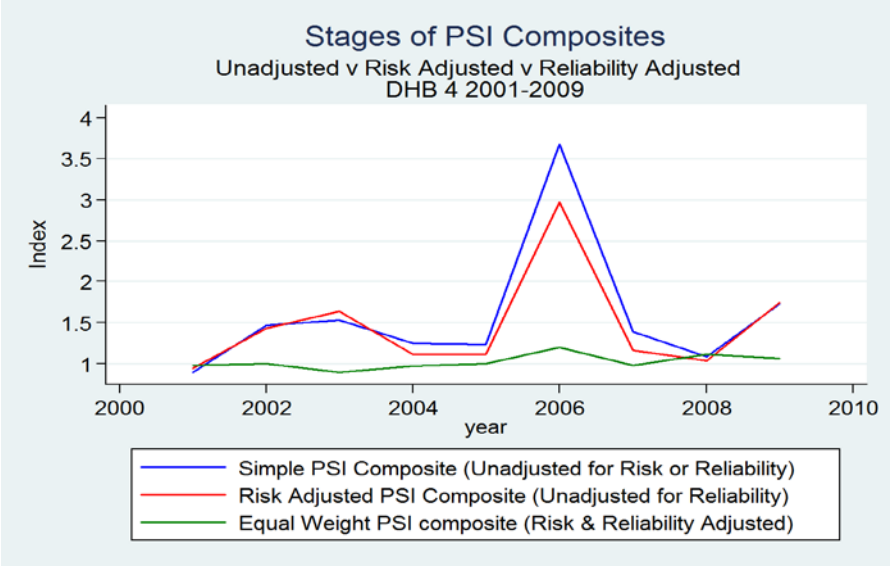
Section 6 – Results and Discussion

The first part of this section uses one DHB as an example to illustrate and discuss two of the key stages of the indices development. Following this we use panel econometric techniques to attempt to explain variation in the composite index.[12]

Risk and Reliability Adjustment

Two key stages of the indices' development: risk adjustment and reliability adjustment, are illustrated in Graph 3 below. The blue line represents the Simple PSI Composite Index (unadjusted for risk or reliability), the red is the weighted average of the risk adjusted (but reliability unadjusted) ratios, and the green line is the final Equal Weight Composite Index.

Graph 3: Risk and Reliability Adjustment – an Example, DHB 4



As can be seen risk adjustment can either increase or decrease the Simple PSI Composite Index value. In 2003 for example DHB 4's Risk Adjusted PSI index is greater that its Simple

[12] Because at the time of writing pilot survey results for the opinion based weighting system only were available only just the equal weight composite index has been considered for this part of the analysis.

PSI Composite Index Value counterpart. The opposite is the case for 2006 where the red line lies below the blue one. It is the DHB's expected PSI rates relative to the reference population rates that determine this shift. If the DHB's expected rates are less that the reference population rates the index will shift up. Alternatively it will shift down when expected rates are greater than reference population rates.

The shift from the red to green line illustrates the reliability adjustment. For DHB 4 this generally entails a reduction in the index in each year as its components with high risk adjusted ratios are pulled towards one. In 2006 this adjustment is most noticeable. The spike in the red line for this particular year is primarily driven by extreme levels of risk adjusted ratios for PSI8, PSI11, and PSI13. These PSIs combined give rise to around 78% of overall risk adjusted index for that year. PSI8 alone accounts for 38% of this value. Reliability adjustment significantly reduces the impact on the final Equal Weight PSI index of such one off high risk adjusted ratios of individual components. In this case the index is reduced from 2.97 to 1.20 and the contribution of the three PSIs reduced to what can be argued as a more reasonable level of 42.7% of the overall index. Conversely, 2008 illustrates that the reliability adjustment does not necessarily pull the risk adjusted index towards one. In 2008 DHB 4 experienced several observed PSI rates of zero. As a result the contribution of these components to the risk adjusted index is also zero. In this case the reliability adjustment pushes these individual components upwards towards one resulting in an increase in the overall Equal Weight PSI Composite.

A Panel Econometric Analysis of the Equal Weight Composite Index

To construct the data set for this analysis we apply the methodology described in the previous section to NMDS data and create the Equal Weight PSI Composite Index annually for each DHB. We also use NMDS data to generate annual clinical and demographic variables for each DHB. We merged these variables with the DHB input cost data described in section 3, which we aggregate from monthly to annual level observations. The resulting dataset is a balanced panel with 189 observations (21 individual DHBs, each with nine annual observations).

Using this data set we estimate and report preliminary regressions to explain variation in the Equal Weight PSI Composite Index. In order to avoid problems pertaining to degrees of freedom we choose to estimate three separate models. Model 1 seeks to explain variation using DHB input expenditures. The covariates in this model are per discharge expenditure on medical staff, nursing staff, Allied Health staff, outsourced services, clinical supplies, and infrastructure and nonclinical supplies. Model 2 focuses on patient characteristics, the covariates for this model are proportion female, young (≤5), elderly (≥65), New Zealand European, Maori, Pacific, and Asian, mean deprivation level, and mean rurality. The covariates in Model 3 utilise two clinical categorical variables: Major Diagnostic Category (MDC)[13] and Complexity Class Level (CCL)[14] using the proportions of each category as the covariates.[15]

We believe the assumption that unobserved DHB characteristics are constant over time is reasonable. The advantage of this assumption is that a fixed-effects specification would control for all time-invariant differences between the DHBs, so the estimated coefficients of the fixed-effects models would not biased because of omitted time-invariant characteristics. We do however appreciate that the choice of fixed versus random effects is complicated so given the preliminary nature of this analysis we have decided to estimate and report both DHB fixed-effects and random-effects specifications. We test for fixed-effects and random-effects separately and also apply the Hausman test for model choice. Results for these tests are reported in the tables for each model.

Model 1 estimates the effects of DHB expenditure on the PSI index. The regression results from both random-effects and fixed-effects are displayed in Table 6. In general this model does not appear to offer any valuable insight explaining the variation of our index. The only statistically significant coefficient at the five percent level from either specification (random-effect or fixed-effects) is for expenditure on outsourced services per discharge. While it is

[13] MDC is a category based on a medical classification that is associated with a particular medical specialty. These include 23 broad categories of diagnosis. E.g. MDC1 = Disease and disorders of the nervous system.
[14] CCL indicates the clinical severity within a DRG code on a 4 point scale: CCL1 minor, CCL2 moderate, CCL3 major, and CCL4 extreme.
[15] Proportion MDC4 and proportion CCL1 have not been included as regressors to avoid issues of perfect co-linearity

statistically significant its sign is positive which counter intuitively suggests an increases in outsourced services expenditure worsens the level of patient safety and is likely spurious.

Table 6: Model 1 Regression Results

	Random Effects			Fixed Effects		
	Wald chi2(6) =		27.9400	F(6,162) =		5.1300
	Prob>chi2 =		0.0001	Prob>F =		0.0001
PSI Comp Index	Coef.	Std. Err.	Prob.>z	Coef.	Std. Err.	Prob.>z
Exp Med Staff / Dsch	0.0515	0.0559	0.3560	0.0298	0.0623	0.6330
Exp Nurs Staff / Dsch	-0.0074	0.0416	0.8580	-0.0129	0.0496	0.7950
Exp A.H Staff / Dsch	-0.0336	0.0655	0.6080	-0.0669	0.0945	0.4800
Exp Outsrc Srvc / Dsch	0.0947	0.0384	0.0140	0.0758	0.0431	0.0810
Exp Clin Supp / Dsch	0.0396	0.0525	0.4510	0.1166	0.0648	0.0740
Exp Non-Clin Supp / Dsch	-0.0313	0.0233	0.1790	-0.0253	0.0249	0.3110
constant	0.9143	0.0256	0.0000	0.8881	0.0240	36.9600
sigma u	0.0676			0.0831		
sigma e	0.0768			0.0768		
rho	0.4369			0.5395		
	BP LM test for Random Effects			F Test for Fixed Effects		
	chi2(1) =		76.69	F(20,162) =		6.38
	Prob>chi2 =		0.00	Prob>F =		0.00
Hausman Test	chi2(6) =					6.6300
FE v RE	Prob>chi2 =					0.3568

Model 2 estimates the effects of gender, age, ethnicity, deprivation level and rurality on the PSI index. Regression results for both the random-effects and fixed-effects specifications are reported in Table 7. Both specifications have statistically significant coefficients for proportion female, proportion New Zealand European and proportion Pacific. The coefficient for proportion of female patients is positive indicating higher proportions of female patients leads to lower patient safety performance. Conversely the coefficients for proportion New Zealand European and proportion Pacific are negative suggesting increases in their respective proportions are estimated to have positive effects on patient safety performance. In the fixed-effects model specification the coefficient for the proportion of Maori is also significant. Its positive sign indicates increases in the proportion of Maori patients worsens patient safety performance. The Hausman test for fixed-effects versus

random-effects has a p-value of 0.0537 and suggests the random-effects specification is the preferred choice for the model.

Table 7: Model 2 Regression Results

	Random Effects			Fixed Effects		
	Wald chi2(6) =		46.82	F(9,159) =		5.59
	Prob>chi2 =		0.00	Prob>F =		0.00
PSI Comp Index	Coef.	Std. Err.	Prob.>z	Coef.	Std. Err.	Prob.>z
%female	1.7399	0.6628	0.0090	1.8136	0.7881	0.0230
%young	1.7943	1.0985	0.1020	0.3851	1.2651	0.7610
%elderly	-1.0672	1.1905	0.3700	0.6304	1.6435	0.7020
%NZEuro	-1.0132	0.2875	0.0000	-1.1891	0.3187	0.0000
%Maori	-0.4470	0.3994	0.2630	2.5577	0.9280	0.0070
%Pacific	-1.5910	0.5809	0.0060	-3.9677	1.9855	0.0470
%Asian	1.1056	0.8311	0.1830	1.6380	1.5690	0.2980
Ave NZdep06	0.0141	0.0333	0.6730	-0.0414	0.0671	0.5380
Ave Rural	0.0778	0.0564	0.1680	-0.3124	0.2001	0.1200
constant	-1.0618	0.9650	0.2710	0.4153	1.2969	0.7490
sigma u	0.0600			0.3606		
sigma e	0.0729			0.0729		
rho	0.4041			0.9607		
	BP LM test for Random Effects			F Test for Fixed Effects		
	chi2(1) =		39.42	F(20,159) =		5.25
	Prob>chi2 =		0.00	Prob>F =		0.00
Hausman Test	chi2(9) =					18.07
FE v RE	Prob>chi2 =					0.0537

Model 3 estimates the effects of the proportion of patients in each MDC group and the proportion of patients at each CCL-level and regression results are reported in Table 8. The Hausman test for this model (p-value 0.00) clearly indicates the fixed-effects specification is the correct choice for the model. The fixed-effects specification output shows all three CCL categorical variables to be significant. The signs of their coefficients suggests patient safety performance worsens for the higher the proportions of CCL3(major) and CLL4 (extreme) patients treated, while higher proportions of CCL2(moderate) patients treated results in patient safely improvement. Of the MDC categories only MDC9: Diseases and disorders of the skin, subcutaneous tissue and breast, is significant. Its coefficient suggests improvements in patient safety for higher the proportion of MDC9. It is not clear why this is the case.

Table 8: Model 3 Regression Results

	Random Effects			Fixed Effects		
	Wald chi2(6) =		46.82	F(25,143) =		5.13
	Prob>chi2 =		0.00	Prob>F =		0.00
PSI Comp Index	Coef.	Std. Err.	Prob.>z	Coef.	Std. Err.	Prob.>z
%MDC1	-7.6805	1.8090	0.0000	-2.4376	2.3476	0.3010
%MDC2	-2.0040	1.4749	0.1740	-0.0300	2.0085	0.9880
%MDC3	-3.8499	1.6862	0.0220	-3.8000	1.9886	0.0580
%MDC5	-3.8243	1.3959	0.0060	-1.7220	1.7477	0.3260
%MDC6	-3.2368	1.3393	0.0160	-3.0888	1.6270	0.0600
%MDC7	-3.0169	3.3803	0.3720	1.0056	3.3054	0.7610
%MDC8	-4.7122	1.4440	0.0010	-1.0449	1.7600	0.5540
%MDC9	-4.6517	1.3400	0.0010	-3.2274	1.5411	0.0380
%MDC10	-3.1989	3.8121	0.4010	-5.3651	4.0477	0.1870
%MDC11	-6.1889	2.3809	0.0090	-2.4526	2.5367	0.3350
%MDC12	-9.8182	3.1314	0.0020	-2.1598	3.7896	0.5700
%MDC13	-4.3518	1.6247	0.0070	-0.8914	2.0616	0.6660
%MDC14	-4.7450	1.3294	0.0000	-0.2734	1.6362	0.8680
%MDC15	-0.1972	1.6778	0.9060	0.6199	1.7740	0.7270
%MDC16	-6.0378	3.5985	0.0930	-3.2180	3.5684	0.3690
%MDC17	-2.1068	3.1047	0.4970	3.6691	3.2580	0.2620
%MDC18	-15.8940	4.0780	0.0000	-3.9408	3.9745	0.3230
%MDC19	-4.4050	7.7929	0.5720	8.9256	10.7414	0.4070
%MDC20	11.6709	12.0107	0.3310	-10.8313	11.7886	0.3600
%MDC21	0.5544	2.2722	0.8070	1.2679	2.7341	0.6440
%MDC22	-6.3570	15.6002	0.6840	7.9355	14.7174	0.5910
%MDC23	-3.2386	1.5115	0.0320	-0.8684	1.8408	0.6380
%CCL2	-1.2980	0.4915	0.0080	-2.0442	0.5704	0.0000
%CCL3	1.2522	1.5110	0.4070	4.0993	1.6092	0.0120
%CCL4	14.9406	5.0303	0.0030	20.1785	5.1260	0.0000
constant	4.5254	1.1975	0.0000	2.6218	1.4146	0.0660
sigma u	0.0000			0.1152		
sigma e	0.0642			0.0642		
rho	0.0000			0.7629		
	BP LM test for Random Effects			F Test for Fixed Effects		
	chi2(1) =		15.49	F(20,143) =		6.70
	Prob>chi2 =		0.0001	Prob>F =		0.00
Hausman Test	chi2(20) =					78.76
FE v RE	Prob>chi2 =					0.00

Section 7 - Conclusion

This paper reports preliminary results of our work in developing a methodology for constructing a composite hospital quality index that can be used for benchmarking, adjusting hospital output and productivity indicators for quality changes and differences, and independently assessing variation in hospital quality service variation across time and space. Our initial efforts have centred around a series of patient safety indicators, but the methodology being developed is general enough to incorporate other dimensions of hospital quality.

We have explored three indices, one that consists of equally weighting a series of patient safety indicators, another that attempts to base component weights on the basis of covariation in the patient safety indicators, and a third that develops weights using expert opinion (those most closely involved in delivering clinical services in hospitals). Since observed measures of quality are likely to be influenced by the case-mix of inpatients in a hospital, and also have considerable variation in measurement, we have developed risk and reliability-adjusted indices on the lines of AHRQ guidelines.

Our preliminary results with hospital admission data in New Zealand indicate that the covariation approach to developing weights is not feasible because patient safety indicators do not covary enough to yield reasonable results in a factor analysis. Equal weighting is simple and straightforward, and with risk and reliability adjustment can be one basis for developing a quality indicator. However it is conceptually unappealing because of its assumption that each PSI is of equal importance in measuring patient safety that most certainly reflect differentially on the quality of hospital services; it can be used as a benchmark for assessing other indices. The expert opinion approach, roughly modelled on the lines along which DALY weights were developed at the World Health Organisation, is the most promising one, but at this point we do not have sufficient data from our pilot survey to assess its value.

Key findings from our preliminary panel econometric regressions indicate DHB input expenditures do not appear to have any explanatory power in explaining variation in our PSI index. However we find patient safety is estimated to worsen with higher the proportions of Maori and female patients treated while higher proportions of New Zealand European and Pacific patients suggests patient safety improves. In addition as the complexity and comorbidity of patients becomes more extreme DHB patient safety performance is estimated to worsen. We leave a more thorough econometric analysis of the PSI index with particular emphasis on model specification to further research.

Appendix A

Table 1: NMDS 2001-2009

Year	Total Discharges	Prop. Female	Mean Age	Prop. ≤ 5	Prop. ≥ 65	Prop. NZ European	Prop. Maori	Prop. Pacific	Prop. Asian	Prop. Other	Mean Deprivation Level	Mean Rurality
2001	543997	0.563	44.576	0.105	0.298	0.636	0.151	0.055	0.027	0.107	6.264	0.687
2002	549146	0.561	45.197	0.101	0.304	0.627	0.152	0.058	0.030	0.111	6.275	0.679
2003	577382	0.566	44.506	0.109	0.296	0.618	0.154	0.065	0.039	0.109	6.284	0.654
2004	605466	0.570	44.384	0.109	0.294	0.610	0.153	0.068	0.044	0.110	6.361	0.627
2005	608260	0.568	44.571	0.105	0.294	0.608	0.154	0.067	0.045	0.109	6.332	0.627
2006	628790	0.567	44.981	0.104	0.299	0.599	0.157	0.070	0.047	0.111	6.315	0.614
2007	641562	0.570	45.137	0.101	0.301	0.593	0.158	0.073	0.050	0.111	6.314	0.611
2008	661119	0.568	45.387	0.101	0.303	0.589	0.159	0.076	0.052	0.110	6.315	0.619
2009	688220	0.568	45.701	0.101	0.307	0.589	0.163	0.078	0.054	0.104	6.239	0.633

Table 2a: DHB Descriptive Statistics

DHB	Total Discharges	Prop. Female	Mean Age	Prop. Age ≤ 5	Prop. Age≥ 65	Prop. NZ European	Prop. Maori	Prop. Pacific	Prop. Asian	Prop. Other	Mean Deprivation Level	Mean Rurality
1	188580	0.548	48.090	0.080	0.337	0.802	0.068	0.009	0.011	0.101	5.712	0.687
2	237917	0.566	45.351	0.104	0.314	0.629	0.243	0.031	0.013	0.067	6.976	0.826
3	608440	0.575	46.703	0.075	0.305	0.547	0.092	0.081	0.072	0.178	5.048	0.286
4	140169	0.556	44.450	0.111	0.299	0.761	0.095	0.014	0.010	0.108	5.570	0.956
5	165551	0.564	42.377	0.125	0.264	0.507	0.358	0.021	0.015	0.091	7.360	0.878
6	208659	0.565	42.731	0.132	0.273	0.601	0.163	0.079	0.044	0.099	6.270	0.324
7	198873	0.567	45.109	0.101	0.316	0.720	0.139	0.019	0.019	0.086	6.921	1.125
8	114046	0.548	46.050	0.103	0.327	0.658	0.232	0.013	0.008	0.084	7.419	0.759
9	464643	0.568	45.429	0.088	0.283	0.471	0.092	0.166	0.132	0.124	6.009	0.058
10	563438	0.565	40.166	0.134	0.225	0.347	0.189	0.260	0.088	0.102	7.442	0.245
11	322863	0.551	46.235	0.112	0.336	0.611	0.247	0.010	0.016	0.094	6.778	0.802
12	93976	0.566	50.736	0.068	0.386	0.853	0.043	0.006	0.008	0.068	5.751	0.939
13	605843	0.580	44.851	0.114	0.307	0.737	0.061	0.021	0.024	0.132	5.305	0.524
14	70910	0.548	48.103	0.082	0.343	0.749	0.157	0.015	0.007	0.058	6.758	0.851
15	89784	0.558	42.187	0.126	0.262	0.459	0.469	0.013	0.007	0.043	8.399	0.495
16	245582	0.542	45.831	0.099	0.313	0.549	0.343	0.010	0.007	0.076	7.835	1.482
17	240221	0.559	49.028	0.079	0.366	0.830	0.048	0.015	0.015	0.085	5.540	0.953
18	163424	0.561	47.918	0.092	0.358	0.729	0.140	0.006	0.009	0.094	6.646	1.083
19	437303	0.570	44.417	0.108	0.298	0.641	0.204	0.018	0.025	0.095	6.721	1.071
20	292225	0.607	43.065	0.108	0.270	0.572	0.114	0.100	0.059	0.138	5.224	0.319
21	51495	0.529	47.180	0.086	0.307	0.838	0.073	0.003	0.005	0.070	6.873	1.637

Table 2b: DHB Descriptive Statistics – differences from reference population means

DHB	Total Discharges	Prop. Female	Mean Age	Prop. Age ≤ 5	Prop. Age≥ 65	Prop. NZ European	Prop. Maori	Prop. Pacific	Prop. Asian	Prop. Other	Mean Deprivation Level	Mean Rurality
1	188580	-0.0190	3.1315	-0.0239	0.0375	0.1955	-0.0879	-0.0593	-0.0325	-0.0080	-0.5879	0.0496
2	237917	-0.0010	0.3925	0.0001	0.0145	0.0225	0.0871	-0.0373	-0.0305	-0.0420	0.6761	0.1886
3	608440	0.0080	1.7445	-0.0289	0.0055	-0.0595	-0.0639	0.0127	0.0285	0.0690	-1.2519	-0.3514
4	140169	-0.0110	-0.5085	0.0071	-0.0005	0.1545	-0.0609	-0.0543	-0.0335	-0.0010	-0.7299	0.3186
5	165551	-0.0030	-2.5815	0.0211	-0.0355	-0.0995	0.2021	-0.0473	-0.0285	-0.0180	1.0601	0.2406
6	208659	-0.0020	-2.2275	0.0281	-0.0265	-0.0055	0.0071	0.0107	0.0005	-0.0100	-0.0299	-0.3134
7	198873	0.0000	0.1505	-0.0029	0.0165	0.1135	-0.0169	-0.0493	-0.0245	-0.0230	0.6211	0.4876
8	114046	-0.0190	1.0915	-0.0009	0.0275	0.0515	0.0761	-0.0553	-0.0355	-0.0250	1.1191	0.1216
9	464643	0.0010	0.4705	-0.0159	-0.0165	-0.1355	-0.0639	0.0977	0.0885	0.0150	-0.2909	-0.5794
10	563438	-0.0020	-4.7925	0.0301	-0.0745	-0.2595	0.0331	0.1917	0.0445	-0.0070	1.1421	-0.3924
11	322863	-0.0160	1.2765	0.0081	0.0365	0.0045	0.0911	-0.0583	-0.0275	-0.0150	0.4781	0.1646
12	93976	-0.0010	5.7775	-0.0359	0.0865	0.2465	-0.1129	-0.0623	-0.0355	-0.0410	-0.5489	0.3016
13	605843	0.0130	-0.1075	0.0101	0.0075	0.1305	-0.0949	-0.0473	-0.0195	0.0230	-0.9949	-0.1134
14	70910	-0.0190	3.1445	-0.0219	0.0435	0.1425	0.0011	-0.0533	-0.0365	-0.0510	0.4581	0.2136
15	89784	-0.0090	-2.7715	0.0221	-0.0375	-0.1475	0.3131	-0.0553	-0.0365	-0.0660	2.0991	-0.1424
16	245582	-0.0250	0.8725	-0.0049	0.0135	-0.0575	0.1871	-0.0583	-0.0365	-0.0330	1.5351	0.8446
17	240221	-0.0080	4.0695	-0.0249	0.0665	0.2235	-0.1079	-0.0533	-0.0285	-0.0240	-0.7599	0.3156
18	163424	-0.0060	2.9595	-0.0119	0.0585	0.1225	-0.0159	-0.0623	-0.0345	-0.0150	0.3461	0.4456
19	437303	0.0030	-0.5415	0.0041	-0.0015	0.0345	0.0481	-0.0503	-0.0185	-0.0140	0.4211	0.4336
20	292225	0.0400	-1.8935	0.0041	-0.0295	-0.0345	-0.0419	0.0317	0.0155	0.0290	-1.0759	-0.3184
21	51495	-0.0380	2.2215	-0.0179	0.0075	0.2315	-0.0829	-0.0653	-0.0385	-0.0390	0.5731	0.9996

Appendix B

Table 3: Patient Safety Indicators

PSI	PSI Description
PSI1	Complications of anaesthesia - Cases of anaesthetic overdose, reaction, or endotrachial tube misplacement for surgery discharges. Excludes codes for drug use and self-inflicted injury.
PSI2	Death in low mortality DRGs - In-hospital patient death in DRGs with less than 0.5% mortality. Excludes trauma, immuno-compromised, and cancer patients.
PSI3	Decubitus ulcers - Cases of decubitus ulcer for discharges with a length of stay of 5 or more days. Excludes patients with paralysis or in MDC 9 (Skin, subcutaneous tissue and breast), MDC 14 (Pregnancy, childbirth and puerperium), and patients admitted from a long-term care facility.
PSI4	Failure to rescue - Death of patient having developed specified complications of care during hospitalization. Excludes patients age 75 and older, neonates in MDC 15 (Newborns and other neonates), patients admitted from long-term care facility and patients transferred to or from other acute care facility.
PSI5	Foreign body left during procedure - Discharges with foreign body accidentally left in during procedure.
PSI6	Iatrogenic pneumothorax - Cases of iatrogenic pneumothorax. Excludes trauma, thoracic surgery, lung or pleural biopsy, or cardiac surgery patients, and MDC 14.
PSI7	Selected Infections Due To Medical Care - Episodes with ICD-10-AM diagnosis code of: Infections following infusion transfusion & therapeutic injection, Infection and inflammatory reaction due to other cardiac and vascular devices, implants and grafts and infection following immunisation. Excludes patients with immunocompromised state or cancer.
PSI8	Postoperative Hip Fracture - Cases of in-hospital hip fracture for surgical discharge. Excludes patients in MDC 8 (Musculoskeletal system and connective tissue), with conditions suggesting fracture present on admission and MDC 14.
PSI9	Postoperative haemorrhage or haematoma- Cases of hematoma or haemorrhage requiring a procedure. Excludes MDC 14.
PSI10	Postoperative Physiologic And Metabolic Derangement - Cases of specified physiological or metabolic derangement for surgical discharges. Excludes patients with principal diagnosis of diabetes, with diagnoses suggesting increased susceptibility to derangement and obstetric admissions.
PSI11	Postoperative Respiratory Failure - Cases of acute respiratory failure. Excludes MDC 4 (Respiratory system) and MDC 5 (Circulatory system) and obstetric admissions.
PSI12	Postoperative pulmonary embolism or DVT - Cases of deep vein thrombosis or pulmonary embolism for surgical discharges. Excludes obstetric patients.
PSI13	Postoperative sepsis - Cases of sepsis for elective surgery patients, with length of stay more than 3 days. Excludes principal diagnosis of infection, or any diagnosis of immunocompromised state or cancer, and obstetric admissions.
PSI14	Postoperative wound dehiscence - Cases of reclosure of postoperative disruption of abdominal wall during abdominopelvic surgery. Excludes obstetric admissions.
PSI15	Accidental Puncture or Laceration - Cases of technical difficulty (e.g., accidental cut or laceration during procedure). Excludes obstetric admissions.
PSI16	Transfusion reaction - Cases of transfusion reaction
PSI17	Birth trauma, injury to neonate - Cases of birth trauma, injury to neonate. Excludes some preterm infants and infants with osteogenic imperfecta.
PSI18	Obstetric trauma, vaginal delivery with instrument - Cases of obstetric trauma (3rd or 4th degree lacerations) during instrument-assisted vaginal deliveries.
PSI19	Obstetric trauma, vaginal delivery without instrument - Cases of obstetric trauma (3rd or 4th degree lacerations) during vaginal deliveries without instrument assistance.
PSI20	Obstetric trauma, caesarean delivery - Cases of obstetric trauma (3rd or 4th degree lacerations) during caesarean deliveries.

Table 4 – Reference population PSI descriptive Stats

PSI	Numerator	Denominator	Rate per 1000 discharges	SD
PSI1: Complications of Anaesthesia	24	1559414	0.015	0.004
PSI2: Death in Low Mortality DRGs	1915	1563946	1.225	0.035
PSI3: Decubitus Ulcers	11362	802180	14.164	0.118
PSI4: Failure to Rescue	9531	89356	106.663	0.309
PSI5: Foreign Body Left During Procedure	328	3790410	0.087	0.009
PSI6: Iatrogenic Pneumothorax	1448	3644396	0.397	0.020
PSI7: In-hospital Fracture	8098	1521920	5.321	0.073
PSI8: Postoperative Respiratory Failure	324	971012	0.334	0.018
PSI9: Postoperative Haemorrhage or Haematoma	25476	1340105	19.011	0.137
PSI10:Postoperative Abdominal Wall wound Dehiscence	212	114682	1.849	0.043
PSI 11: Postoperative Respiratory Failure	130	84999	1.529	0.039
PSI12: Postoperative Pulmonary Embolism or DVT	4387	1344090	3.264	0.057
PSI13: Postoperative Sepsis	235	18865	12.457	0.111
PSI14: Postoperative Wound Dehiscence	573	120148	4.769	0.069
PSI15: Accidental Puncture Or Laceration	9704	3789862	2.561	0.051
PSI16: Transfusion Reaction	24	226427	0.106	0.010
PSI17: Birth Trauma – Injury to Neonate	2133	70455	30.275	0.171
PSI18: Obstetric Trauma – Vaginal Delivery With Instrument	2624	41416	63.357	0.244
PSI19: Obstetric Trauma – Vaginal Delivery Without Instrument	4206	280204	15.011	0.122
PSI20: Obstetric Trauma – Caesarean Delivery	466	110450	4.219	0.065

Appendix C

Table 5: Correlation Matrix of the Reliability Adjusted Ratios

	PSI3	PSI6	PSI7	PSI8	PSI9	PSI10	PSI11	PSI12	PSI13	PSI14	PSI15
PSI3	1.000										
PSI6	0.036	1.000									
PSI7	0.341	-0.107	1.000								
PSI8	-0.079	0.026	-0.064	1.000							
PSI9	0.050	0.045	0.380	0.059	1.000						
PSI10	0.053	-0.147	0.059	0.016	-0.066	1.000					
PSI11	0.029	-0.114	-0.089	0.241	-0.003	0.320	1.000				
PSI12	0.004	-0.053	0.110	-0.016	0.168	0.047	0.018	1.000			
PSI13	-0.066	0.040	-0.121	0.230	0.005	0.027	0.205	0.020	1.000		
PSI14	0.022	0.068	0.163	-0.115	0.063	-0.099	-0.144	0.001	-0.159	1.000	
PSI15	0.229	-0.060	0.354	-0.004	0.305	0.009	0.163	0.038	0.056	-0.067	1.000

Table 6: Principal Component Factor Analysis Results

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	1.917	0.206	0.174	0.174
Factor2	1.711	0.459	0.156	0.330
Factor3	1.251	0.178	0.114	0.444
Factor4	1.073	0.137	0.098	0.541
Factor5	0.936	0.029	0.085	0.626
Factor6	0.907	0.123	0.083	0.709
Factor7	0.784	0.016	0.071	0.780
Factor8	0.768	0.081	0.070	0.850
Factor9	0.687	0.147	0.063	0.912
Factor10	0.541	0.117	0.049	0.962
Factor11	0.424	.	0.039	1.000

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