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RESEARCH ARTICLE

Future demand for primary hip and knee arthroplasty in Scotland

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Abstract

Introduction: The rising prevalence of osteoarthritis, associated with an ageing population, is expected to deliver increasing demand for arthroplasty services in the future. Understanding the scale of potential change is essential to ensure adequate provision of services and prevent prolonged waiting times that can cause patient harm.

Methods: We set out to provide projections of future primary knee and hip arthroplasty out to 2038 utilising historical trend data (2008–2018) from the Scottish Arthroplasty Project. All analyses were performed using the Holt's exponential smoothing projection method with the forecast package in R statistics. Results were adjusted for projected future population estimates provided by National Records of Scotland. Independent age group predictions were also performed.

Results: The predicted rise of primary hip arthroplasty for all ages is from 120/100k/year in 2018 to 152/100k/year in 2038, a 28% increase. The predicted rise of primary knee arthroplasty for all ages is from 164/100k/year in 2018 to 220/100k/year in 2038, a 34% increase. Based on a static 3-day length of stay average this would see 4280 and 7392 additional patient bed days required for primary hip and knee arthroplasty patients respectively per annum. The associated additional cost is anticipated to be approximately £26 million.

Conclusions: Anticipated future demand for arthroplasty will require significant additional resource and funding to prevent deterioration in quality of care and an increase in patient wait times, additional to that already required to clear the COVID-19 backlog. Understanding presented projections of changes to arthroplasty demand is key to future service delivery.

KEYWORDS
arthroplasty, demand, future, hip, knee, primary

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1 | INTRODUCTION

Total Hip Arthroplasty (THA) and Total Knee Arthroplasty (TKA) are two of the most frequently performed and successful operations performed in the UK, resulting in excellent long-term outcomes for the vast majority of those with end-stage OA (Evans et al., 2019; Learmonth et al., 2007). At an average cost of £6000 per joint replacement, the National Health Service (NHS) spends nearly a billion pounds per annum on THA and TKA provision (Clarke et al., 2015). Despite these figures, it is still considered an extremely economical procedure, costing approximately £1372 and £2101 per QALY respectively. This figure is well below the £20,000 per QALY considered cost-effective (Jenkins et al., 2013).

As a result of the ongoing proven success of THA and TKA, the number of primary hip and knee replacements has more than doubled in Scotland between 2001 and 2019 (Public Health Scotland, 2020). The escalating demand for the arthroplasty service has been leading to an inevitable strain on service provision, with an associated deterioration in waiting times for surgery. Such delay has been shown to have a significant detrimental impact on patient's quality of life and mental health in both the short and longer term (Nikolova et al., 2016; Ostendorf et al., 2004; Scott et al., 2019). Previous estimates of future demand for THA and TKA have been performed for the U.K., with suggestion of a rising incidence (Culliford et al., 2015; Dixon et al., 2004; Yapp et al., 2021), but these are largely now outdated and were not performed using best-practice techniques for forecasting.

Prolonged waiting lists and the correlated negative consequences for patients will be significantly compounded if the NHS fails to adapt to future demand for the service. This is particularly true with the additional significant surgical backlog now created secondary to the Coronavirus (COVID-19) pandemic (Yapp et al., 2021).

We have therefore set out to aid future service delivery planning through:

I. Prediction of impending demand for primary hip and knee arthroplasty in Scotland out to 2038
II. Assessment of the health economic implications of predicted future hip and knee arthroplasty demand

This information is integral to providing adequate service provision to avoid further deterioration in surgical waiting lists that is associated with patient harm.

2 | MATERIALS AND METHODS

2.1 | Data source and participants

Calculated predictions of future elective primary hip and knee arthroplasty incidence are based on data provided by the Scottish Arthroplasty Project (SAP). The SAP comprises a national audit of elective primary and revision arthroplasty surgery carried out within Scotland, with a purpose of encouraging continual improvement in the quality of care provided to these patients. The data collected by SAP consists of routinely collected Scottish Morbidity Record information (SMR01). This data is extracted from clinical sources by experienced clinical coders, with routine assessment of data quality performed by the Data Quality Assurance (DQA) team governed by the National Services Scotland Information and Intelligence division. The latest DQA report (National Services Scotland, 2016) has suggested an accuracy of 94% for the main procedure within this dataset.

Following approval of an SAP information request Scottish national level data was provided regarding all patients that had undergone primary TKA and THA from 1998 to 2018. For each year of data volume was categorised by procedure (TKA vs. THA), and age (≤49, 50–59, 60–69, 70–79, 80+, all ages). Information was provided by SAP as raw volume data, therefore historic age specific Scotland mid-year population estimates from the National Records of Scotland (NRS) National Records of Scotland (2019) were used to calculate incidence for the general population at risk (age ≥18 years), as well as specific age subcategories, per 100,000 population. Age specific population projections for Scotland provided by the NRS were also utilised to provide appropriate denominators for calculation of adjusted future arthroplasty incidence based on predicted population demographics. There was no missing data identified in any field utilised for the main analysis.

2.2 | Projection analyses

Utilising the HoltWinters package in R statistics (*R Foundation for Statistical Computing, Vienna, Austria*) Holt's Exponential Smoothing method was used to forecast predicted arthroplasty numbers for each sub-category (age/sex/operation type) from 2019 to 2038 using raw yearly data. This technique was chosen due to its previously demonstrated performance regarding model performance in time series data that displays trend and no seasonality. It provides benefit over other regression type modelling (e.g. linear or logistic regression) in that it weights historical data by recency and provides estimates that include prior prediction when making forward analyses (Chatfield, 1978). Details of the equation used and model parameters for each calculation are included in Appendix 1. Following the analyses raw data output including 95% Confidence intervals for projection values were then converted into at risk population estimates per 100,000. Where age specific incidence rates were calculated weighted rates (age specific population at risk for each year vs. overall population at risk for each year) were produced which allowed for analyses to account for changes in population demographics at a national level. Figures presented were created using the package ggplot in R statistics.

2.3 | Health economics

Utilising data obtained from the forecasting process we also performed a basic health economic analysis for both the potential number of additional hospital bed days required per annum and the potential cost implications associated with a future change in primary hip and knee arthroplasty incidence. With regards to the number of additional hospital bed days per annum this was calculated based on a current 3-day median length of stay for primary hip and knee arthroplasty as per the 2020 SAP report (Public Health Scotland, 2020), and an estimated average hospital cost of £5500 per procedure (Summers).

2.4 | Ethics and reproducibility

The code used to produce the analysis is available on request to the corresponding author. Given the anonymised national level data that was utilised ethical approval was not required for this study.

3 | RESULTS

3.1 | Data source and participants

Data from the Scottish Arthroplasty Project (SMR01) revealed a total of 256,933 primary and revision hip and knee arthroplasty procedures performed in Scotland within the time frame 1998–2018. There were in total 112,567 and 119,560 primary THA and TKA procedures included respectively.

3.2 | Projection analyses

Demographic data was used to determine the denominator for calculating the number of procedures per 100,000 (100k) population. Also, the age specific projected population figures in the future were used as denominator for calculating the number of procedures per adjusted 100k population.

There was an overall 11% increase in primary hip arthroplasty numbers from 1998 to 2018 (107 per 100k to 119 per 100k) for the whole population. From 2018 to 2038, an overall increase of 28% was predicted (119 per 100k to 152 per 100k) [Figure 1]. The age wise data is shown in Table 1.

For primary knee arthroplasty, the numbers showed an increase of 123% from 1998 to 2018 (73.4 per 100k to 164 per 100k), with an increase of 34% predicted from 2018 to 2038 (164 per 100k to 220 per 100k; Figure 2). The age wise data is shown in Table 2.

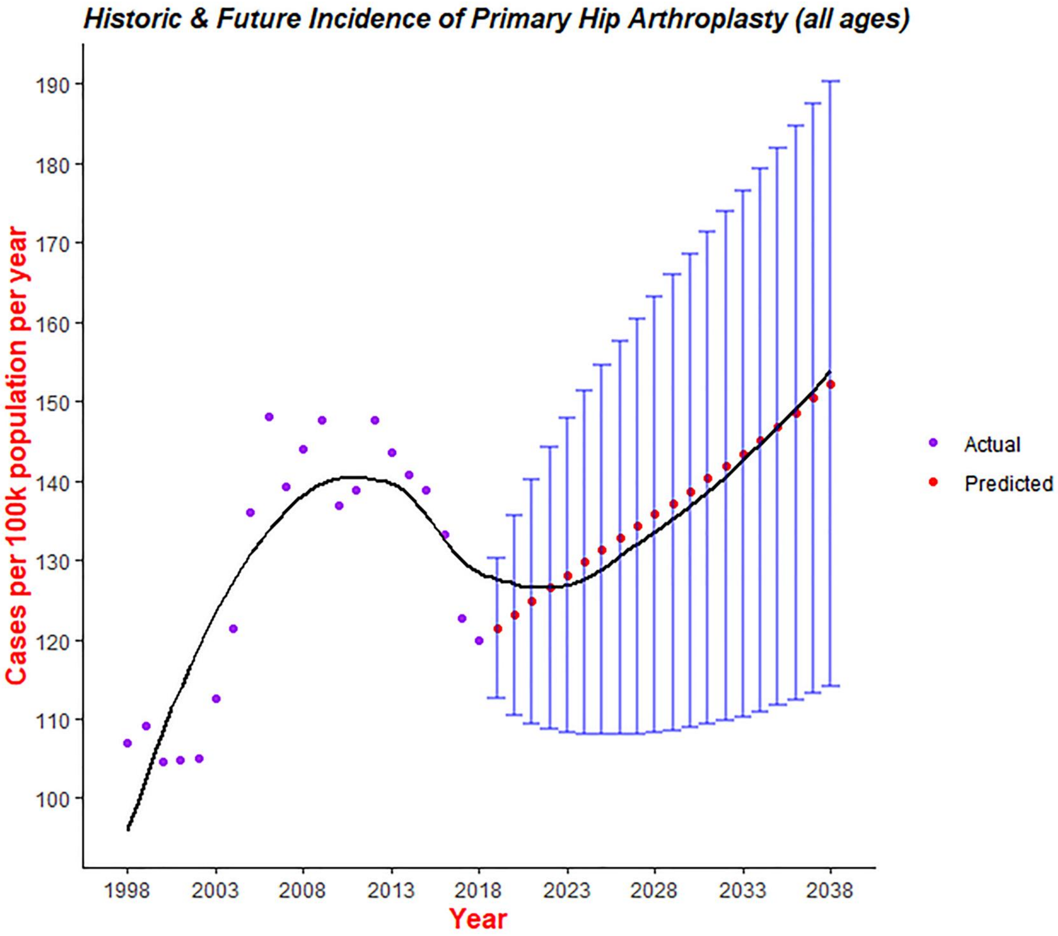

FIGURE 1 Historic and future incidence of primary hip arthroplasty (all ages)

TABLE 1 Projections for primary hip arthroplasty incidence according to Holt's exponential smoothing method

Age	1998–2018 (unadjusted)	1998–2018 (adjusted)	2018–2038 (unadjusted)	2018–2038 (adjusted)
80+				
a*	14.3–19.4	0.66–1.16	19.4–14.4	1.16–1.27
b*	36% ↑	76% ↑	26% ↓	9% ↑
70–79				
a*	34.8–43.7	3.27–4.58	43.7–43.4	4.58–6.00
b*	26% ↑	40% ↑	1% ↓	31% ↑
60–69				
a*	36.4–34.3	4.62–4.95	34.3–37.7	4.95–5.28
b*	6% ↓	7% ↑	10% ↑	7% ↑
50–59				
a*	15.3–16.8	2.35–3.02	16.8–19.4	3.02–2.96
b*	10% ↑	28% ↑	15% ↑	2% ↓
18–49				
a*	6.23–5.65	3.61–2.89	5.65–5.37	2.89–2.58
b*	9% ↓	20% ↓	5% ↓	11% ↓

*a = change in number of procedures per 100k population, b = percentage change.

3.3 | Health economics

Gross additional bed days were calculated based on the 5284 and 7247 primary THA and TKA's performed in 2018 and the projected 7064 and 10,227 primary THA and TKA's in 2038. An additional 1780 and 2980 primary THA and TKA per annum translates into 5340 and 8940 additional bed days for THA and TKA respectively (considering median length of stay of 3 days). With improved surgical and anaesthetic techniques, evolving pain management protocols, median length of stay could potentially reduce in 2038. Considering the median length of stay to become 2 days, required bed days would correspondingly decrease by 1724 for THA [(7064 × 2) – (5284 × 3)], and 1287 for TKA [(10,227 × 2) – (7247 × 3)]. With a static length of stay the predicted additional cost incurred would amount to £26 million per annum, based on a £5500 current total inpatient stay. Based on a £1000 reduction in cost for one additional bed day saved, a reduction in median length of stay to 2 days would save approximately £17 million per annum.

4 | DISCUSSION

This study used historic information from national, representative Scottish databases (SAP and NRS) to create a model for predicting the future demand for hip and knee arthroplasty up to 2038, adjusted

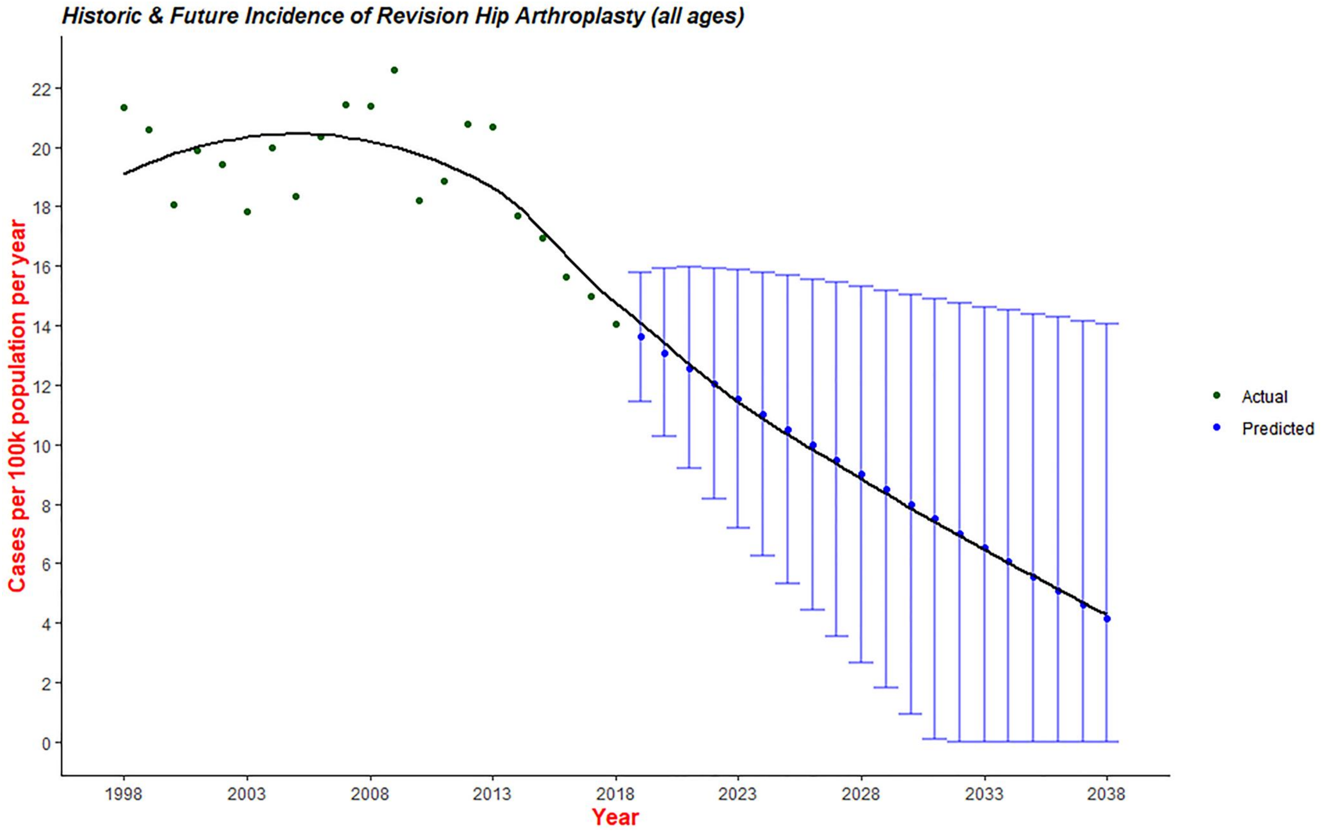

FIGURE 2 Historic and future incidence of primary knee arthroplasty (all ages). Blue lines represent 95% confidence intervals for predicted values

TABLE 2 Projections for revision hip arthroplasty incidence according to Holt's exponential smoothing method

Age	1998–2018 (unadjusted)	1998–2018 (adjusted)	2018–2038 (unadjusted)	2018–2038 (adjusted)
80+				
a*	4.61–3.88	0.21–0.23	3.88–2.59	0.23–0.23
b*	16% ↓	9.5% ↑	33% ↓	No change
70–79				
a*	7.30–4.79	0.68–0.50	4.79–2.59	0.50–0.36
b*	34% ↓	26% ↓	45.9% ↓	28% ↓
60–69				
a*	5.60–2.82	0.71–0.41	2.81–0.13	0.41–0.02
b*	50% ↓	42% ↓	95% ↓	95% ↓
50–59				
a*	2.33–1.72	0.36–0.31	1.72–1.79	0.31–0.27
b*	26% ↓	14% ↓	4% ↑	12% ↓
18–49				
a*	1.52–0.86	0.88–0.44	0.86–0.84	0.44–0.41
b*	43% ↓	50% ↓	2% ↓	7% ↓

*a = change in number of procedures per 100k population, b = percentage change.

for population demographics. Rates of THA overall have increased by 11% between the period 1998–2018 and this trend is set to continue with a projected 28% increase in the total number of primary hip replacements by 2038. This trend is particularly pronounced in the older age groups with a predicted 31% increase in those patients aged 70–79. Similarly, primary knee procedures have seen a 123% increase between 1998 and 2018 with a further predicted increase of 34% by 2038. Again, this is largely driven by increases in the older age groups, with a predicted 64% increase in the 70–79 age group, and 31% in the 80+ age group. An extra £26 million per annum of investment would be required to get the service to these numbers with a static length of stay, a figure which is unadjusted for inflation.

4.1 | Relevant literature

There have been relatively few similar prediction studies using population level data conducted in the UK.

Yapp et al. have provided the only other suggested projection for Scotland as part of their analysis into the backlog caused by the COVID-19 pandemic (Yapp et al., 2021), but their results did not provide population adjusted incidence rates or detailed age-group analyses, both of which are crucial to understanding the future impact on healthcare services. Their predictions (10.7% increase for THA and 11.4% for TKR by 2030) therefore likely represent an underestimate, particularly when compared to our projections and those from other similar studies.

Three other similar studies have been conducted in the UK. The most notable of these is a study by Culliford et al. (2015). They used two prediction models, a 'static' model using a fixed incidence of THA/TKA based on 2010 figures and a model predicting THA/TKA if incidence were to increase 'log-linearly' (Poisson regression). They predicted a 32.4% and 39.6% in THA and TKA respectively using the fixed model, and up to 358% and 816% using the log-linear method between 2015 and 2035. Whilst the fixed model appears to agree with our projections, the log-linear method appears to vastly overestimate risk, likely due to the inflexible nature of the model used. Dixon et al. (2004) which predicted a 22% and 63% rise for THA and TKA respectively from 2001 to 2010 using hospital statistics for England only. Finally, Birrell et al. (1999) who projected a 40% increase in THA by 2026 using Swedish THR data and applying it to UK population demographics.

There have also been a number of international papers providing national projections for THA, the biggest of which by Kurtz et al. (2007) which used a similar model to Culliford and colleagues (log-linear). They projected a 174% increase in the demand for THA, and 673% increase in demand for TKA, in the USA by 2030. Again, the use of the exponential log-linear method has likely significantly overestimated risk within this population, as these contrast significantly with our more conservative estimates. There have also been studies from Nordic countries (Nemes et al., 2014; Pedersen et al., 2005), Germany (Pilz et al., 2018), Australia (Ackerman et al., 2019), New Zealand (Hooper et al., 2014) and Canada (Sharif et al., 2015). Predictions in these studies vary widely, which is most likely attributable to differing methods of analyses, access and accuracy of national data and differences in healthcare systems with some private hospital data not being made available for research purposes.

4.2 | Study strengths

This study is the first to utilise best practice forecasting techniques such as Holt's exponential smoothing methods that likely provides a more accurate representation of true change due to the ability to account for recency in the data trends. This provides a more flexible modelling approach than other methods such as log-linear which can only project exponential growth.

Our study also offers a focus specifically on Scottish population demographics and arthroplasty numbers, although these are likely similar to other western healthcare settings.

This study also provides estimates based on data prior to the impact of the COVID-19 pandemic, which has significantly impacted outpatient clinic and arthroplasty activity making current estimates unreliable. This data therefore provides the most accurate representation of the true projected future incidence to determine the mismatch between supplied and required TKA/THA provision during assessment of the surgical backlog associated with the pandemic. Assessment of the surgical activity required to manage this backlog must consider these projected increases in the future volume of TKA and THA, largely driven by an ageing population.

4.3 | Study weaknesses

Some limitations of our study are that the SAP data does not discriminate between operations performed in an 'elective' setting and those carried out on an urgent basis, for example, proximal femoral fractures. These non-elective cases accounted for 8.4% of THA in 2019 (Public Health Scotland, 2020). As with all projection studies future demand for the arthroplasty service is difficult to predict as healthcare policy changes direction. It may become the case that a nationalised service will become unsustainable if numbers were to increase as predicted. In addition to this, supply constraints may have a significant impact in our projections. For example, more investment into trained surgical staff, hospital beds and operating theatres will be required to cope with the increasing burden of disease, which could lead to a plateau in arthroplasty incidence in the short term.

Other studies, such as Culliford et al. (2015), were able to include BMI data within their projections that were not available to include in our model. They identified that future predicted BMI category distributions did not influence THA projections, but had a 7% influence on future TKR incidence, indicating a potential underestimate in our own TKA projection. Obesity rates between the two populations are however broadly similar, with 66% of adults classed as overweight (including obesity) versus 64% in England in 2019 (Office of National Statistics, 2020; Population Health Directorate, 2020).

It is also feasible that other population drivers of THA/TKA that have not been assessed in this study have an unforeseen significant influence on future demand. For example, the extended current waiting times for arthroplasty may increase the number of these procedures undertaken in the private setting, diminishing those patients requiring THA and TKA delivered through the NHS.

5 | CONCLUSION

Considering an ageing population, a trend of increasing rates of THA/TKA, and the impact of the COVID pandemic, NHS Scotland faces a significant burden on arthroplasty services over the next 2 decades. From our economic calculations we have identified that a significant increase in investment and capacity will be required if our health service is to cope with this level of demand, but that these can potentially be at least partially offset by reductions in average length of stay.

Our study provides a novel analysis of historic numbers to quantify potential incidence and provide a true reflection of future service demand, which also provides a core blueprint for COVID recovery targets. This will provide healthcare policy makers with a strong guide to plan for the future, as well as an incentive to be innovative with strategies that decrease the number of hospital bed days per inpatient stay.

AUTHOR CONTRIBUTIONS

Luke Farrow: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing – original draft; Writing – review and editing. He is the Guarantor. **J. McLoughlin**: Formal analysis; Investigation; Validation; Writing – original draft; Writing – review and editing. **Sahil Gaba**: Formal analysis; Investigation; Validation; Writing – original draft; Writing – review and editing. **George Patrick Ashcroft**: Conceptualization; Formal analysis; Methodology; Supervision; Writing – original draft; Writing – review and editing.

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CONFLICT OF INTEREST

Luke Farrow is supported by a CSO Clinical Academic Fellowship. J. McLoughlin, Sahil Gaba, and George Patrick Ashcroft declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

INFORMED CONSENT

Informed consent was not required due to the use of anonymised aggregated data.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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APPENDIX 1

Holt's exponential smoothing method:

$$\begin{aligned}&\text{Forecast equation : } \hat{}y_{t+h|t} = \ell t + hb_t\\&\text{Level equation : } \ell_t = \alpha y_t + (1-\alpha)(\ell_t - 1 + b_t - 1)\\&\text{Trend equation : } b_t = \beta^*(\ell_t - \ell_t - 1) + (1-\beta^*)b_t - 1\end{aligned}$$

where ℓ_t denotes an estimate of the level of the series at time t, b_t denotes an estimate of the trend (slope) of the series at time t, α is the smoothing parameter for the level, $0 \leq \alpha \leq 1$, and $\beta*$ is the smoothing parameter for the trend, $0 \leq \beta{*}\leq 1$.