O'Reilly Gerard (Orcid ID: 0000-0001-5763-917X)

McAllan Fern (Orcid ID: 0000-0002-3677-5786)

Planning for the future

Title of Manuscript

Planning for the future: Modelling daily emergency department presentations in an Australian capital city

Author List:

Fern J McAllan[1], MBBS, BMedSci(Hons)

Diana Egerton-Warburton[2,3], MBBS, MClinEpi

Gerard O'Reilly[4,5] MBBS, MPH

Tracey J. Weiland[6] BBSc(Hons), MPsych/PhD

George A. Jelinek[6] – MD, MBBS,

Author Affiliations:

1. Emergency Department, Critical Care Services, Royal Adelaide Hospital, Adelaide, South Australia, Australia
2. School of Clinical Sciences, Monash University, Melbourne, Victoria, Australia
3. Emergency Department, Monash Medical Centre, Clayton, Victoria, Australia
4. Emergency and Trauma Centre, The Alfred Hospital, Melbourne, Victoria, Australia
5. School of Public Health and Preventative Medicine, Monash University, Melbourne, Victoria, Australia

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6. Neuroepidemiology Unit, School of Population and Global Health, University of Melbourne, Melbourne, Victoria, Australia

Corresponding Author: Fern McAllan fern.mcallan@sa.gov.au

Postal address: Emergency Department, Royal Adelaide Hospital, Port Rd, Adelaide, SA 5000

Planning for the future: Modelling daily emergency department presentations in an Australian capital city

Abstract

Objective

(1) To describe and model a decade of emergency department (ED) presentations in metropolitan Melbourne, Australia, from July 2000 to June 2010; (2) To validate the model of ED presentations by testing the model's performance in forecasting the subsequent two-year period of daily presentations, from July 2010 to June 2012.

Methods

Retrospective analyses of prospectively collected data sourced from the Victorian Emergency Minimum Dataset were performed and included 13 public hospitals. Time series modelling involved unobserved components modelling and forward selection of variables using incidence rate ratios (IRR). Forecasting with the model and validation were performed using the two-year period to June 2012. Model performance was calculated using the mean average percentage error (MAPE).

Results

A total of 7,031,242 patient presentations occurred to the sample metropolitan EDs in the 12-year study period. An absolute increase in mean daily ED presentations of 81.3% was observed. Presentations increased on Sunday and Monday IRR 1.10 (95%CI 1.08–1.11, p<0.05). No monthly or seasonal pattern was evident. Public holidays were associated with increased presentations, IRR 1.11 (95%CI 1.08–1.15, p<0.05).

The model with the best goodness-of-fit and Wald Ç^{2} value included Sunday-Monday (versus Tuesday-Saturday), public holidays, the trend of gradual increase over time and a stochastic (random white noise) cycle. The MAPE for the two-year forecast period was 3.6%.

Conclusion

We have produced and validated a model for predicting daily ED presentations across a major city. Even though ED presentations are multifactorial, city-wide daily presentations are predictable and explained by a small number of variables. The model will have implications for future health planning.

Introduction

The globally ageing and expanding population renders future planning a crucial step for health systems as they plan and budget within time and resource-limited environments. These pressures are felt acutely in the emergency department (ED) where there is little control over workload and case-mix at any given time.

Health services must plan for future infrastructure and workforce requirements. In doing so, it is essential to consider the demand that the service is likely to experience into the future, as informed by past demand. ED demand and workload is not simply a concern of the ED, but of the whole health system.

The modelling of ED presentations can be used to facilitate workforce and infrastructure planning.(1-4) Constructed rigorously, these models provide an accurate baseline representation of ED presentations. They can also be used to forecast presentations,(4-7) and testing the model using a distinct and independent period of ED presentations is an appropriate method to validate the model.(8) Once validated as a forecasting tool, this modelling can be used to predict presentations into the future.

Description and modelling of emergency department demand at a city level can assist with baseline workforce and infrastructure planning. Additional capacity will be required for surges in presentations, for example from disease outbreaks or natural disasters, however these are by nature very difficult to predict and the scope to manage them should be planned based on the locally anticipated disaster situations.

We aimed to use a decade of ED presentation data across one Australian capital city to develop and validate a model that could predict total daily ED presentations. Specifically, our aims were:
(1) To describe and model a decade of emergency department (ED) presentations in metropolitan Melbourne, Australia, from July 2000 to June 2010; (2) To validate the model of ED presentations by testing the model's performance in forecasting the subsequent two-year period of daily presentations, from July 2010 to June 2012.

It is envisaged that such modelling data will be of interest for policymakers, health workforce planning and the broader emergency medicine community.

Methods

Study design

The study was performed in two stages. Initially, a retrospective analysis of prospectively collected data was performed to describe and model daily ED presentations from July 2000 to June 2010. Following this, validation of the modelling for the forecast period from July 2010 to June 2012 was undertaken before the presentation data for this period was available to the researchers. Ethics approval was granted by Monash Health (Project 11408L). Stata v12.1 (StataCorp LP, TX, USA) was used for all statistical analyses. Means and standard deviations

(SD) are presented for normally distributed data, medians and interquartile ranges for skewed data and frequency for categorical variables. A p value of <0.05 was considered statistically significant.

Setting and participants

Population data were sourced from the Australian Bureau of Statistics. ED presentation data were sourced from the Victorian Emergency Minimum Dataset (VEMD), a detailed state-wide database maintained by the Victorian Department of Health and Ageing regarding public EDs. The accuracy of this data is assessed at the time of collection for completeness and the presence of unlikely data combinations, then returned to the health service to correct or confirm the original data submission.(9)

The study sought data from 13 public hospitals reporting for the entire decade to June 2010. Excluded were three smaller mixed EDs (one of which opened part-way through the sample period), seven private hospitals with 24-hour EDs, two women's specific hospitals, a children's hospital, and a specialist eye and ear hospital.

For the entire period, data on every ED presentation included the patient's date of presentation, age, sex and Australasian Triage Scale score. Inter-hospital transfers and re-presentations were not identifiable within the data. Presenting complaint, length of stay, disposition and which specific ED the patient attended were not assessed.

The Australasian Triage Scale can be summarised as(10); Category One presentations are immediately life-threatening; Category Two presentations are imminently life-threatening, require important time-critical treatment, or are patients in very severe pain; Category Three presentations are potentially life-threatening or have situational urgency; Category Four presentations are potentially serious, have significant complexity or severity, or situational urgency; Category Five presentations are less urgent or clinico-administrative problems.

Data analysis and modelling

The incidence rate ratio (IRR) is a measure of the relative number of presentations occurring under the conditions specified, calculated using negative binomial regression to account for over-dispersion of the presentation data.

Time series modelling of daily presentation data, using unobserved components modelling (UCM) and forward selection of variables was undertaken. To model presentations, a random walk with drift model was used. This type of model can describe data with an increasing mean over time, while including the white-noise term which accounts for many of the factors which influence presentations but are not explicitly included in the model. Variables were initially assessed for inclusion graphically and using negative binomial regression. Assessed variables were day of the week, individual month of the year, season (summer December-February, warm months November-March, winter June-August, combined summer and winter months), public holidays, exact date and year. Initial modelling described the presentations from July 2000 to June 2010.

Forecasting and validation

Forward selection of variables for inclusion in the model introduces inherent bias. The intended use of the model in Melbourne precludes assessment against an independent dataset and lends itself to assessment against the same population at a different time. After derivation of the model, the VEMD data for the period from July 2010 to June 2012 was obtained to allow local validation of the model.

Validation was assessed with the calculation of the mean average percentage error (MAPE). The MAPE is calculated using the difference between the number of presentations expected based on the model (modelled presentations) compared to the actual number of presentations (observed presentations), with this difference labelled the residual presentations. The modelled presentations can be either higher or lower than the observed numbers therefore the MAPE uses the absolute value of the residual presentations.

Results

Population data

The population of the Greater Melbourne area increased from 3,338,704 at the 2001 census to 3,999,982 at the 2011 census, an absolute population increase of 19.8%.(11) VEMD population characteristics for the initial ten years and for the validation period revealed an increase in overall presentations with changing patterns of presentations (Table 1). Over 12 months, there was an average of 1077.8 (SD 92.4) presentations per day in the 2000/01 year and 1931.8 (SD 117.8) for the 2010/11 year, representing a 79.2% increase in daily presentations over a similar period to the census data. The increase was 81.3% from the 2000/01 year to 2011/12 year.

Patients aged over 64 years had 600.3 presentations per day in the initial ten years and 452.7 in the validation period. ATS Category one and two patients increased from 175.6 to 254.0 patients per day. Ambulance (fixed wing, helicopter, private and public road ambulances) represented 28.1% and 30.2% of the derivation and validation datasets, respectively. Males represented 52.0% and 51.5% of the two datasets, respectively.

Month and season were not associated with a pattern in presentations across the decade. The incidence rate ratio (IRR) for presentations in winter (June to August) was 0.99 (95% CI 0.98 – 1.01), as compared to the other months of the year. For the warmer months (November to March) the IRR did not meet statistical significance at 1.01 (95% CI 1.00 – 1.02).

Presentations were increased by 9.7% on Sunday and Monday compared to the rest of the week, IRR 1.097 (95% CI 1.083–1.111), $p < 0.05$). Presentations were increased by 11.4% on public holidays, IRR 1.114 (95% CI 1.077–1.153, $p < 0.05$), an effect independent of the Sunday-Monday increase.

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Table 1 - Comparison of mean presentations per day for the derivation and validation periods of the study

Patient presentations			**Derivation period – mean per day (SD)**	**Validation period – mean per day (SD)**
Total presentations			1536.4 (272.9)	1942.8 (113.8)
Age (years)	Under 5		93.8 (20.2)	162.8 (23.8)
	5 to 14		11.7 (4.1)	132.5 (23.5)
	14 to 64		830.5 (158.2)	1194.7 (85.7)
	65 and over		600.3 (118.9)	452.7 (39.5)
		65 to 74	144.0 (33.6)	168.1 (18.5)
		75 and over	456.3 (88.6)	284.6 (26.7)
Sex	Male		798.9 (146.0)	1001.1 (70.3)
	Female		737.6 (131.7)	942.3 (55.4)
Triage category	1 Resuscitation		15.7 (4.9)	13.7 (4.3)
	2 Emergency		159.9 (44.3)	240.3 (23.7)
	Category one and two combined		175.6 (46.3)	254.0 (24.5)
	3 Urgent		526.6 (108.4)	745.3 (48.8)
	4 Semi-urgent		698.3 (120.1)	812.7 (65.1)
	5 Non-urgent		135.9 (31.6)	130.8 (25.7)
Mode of arrival	Ambulance			
		Air ambulance	0.7 (1.6)	2.0 (2.6)
		Road ambulance	404.8 (84.6)	558.0 (32.9)
	Non-ambulance			
		Private car	814.1 (518.8)	1309.3 (100.8)
		Other	314.9 (374.8)	71.6 (20.2)
Other transport:	Community transport, police, undertaker, private ambulance, unspecified.			

Modelling of presentations

To model presentations, a random walk with drift model was used. The model incorporated the trend (gradual increase in the number of presentations per day), Sunday-Monday (model coefficient 123.52 (95% CI 117.74-129.29)), public holidays (model coefficient 89.92 (95% CI 76.52 – 103.33)), the cycle (11.01 days (95% CI 5.88 – 16.13 days) and the random white-noise component. The Wald Ç^{2} value was used to assess the fit of the model as variables were progressively included.

$$y_t = \mu_{t-1} + \beta + 11.01(C_t) + 123.52(D) + 89.92(H) + \eta_t, \qquad t = 1, \ldots, T,$$

Equation 1- Random walk with drift unobserved components model of total daily emergency department presentations

y_t – dependent variable (presentations). μ_t – trend component. ^{2} – drift component. C_t – cyclical component. $\cdot_t$ – white noise term. D – Sunday-Monday effect. H – public holiday.

Forecasting of presentations

Once the model was created, validation for July 2010 to June 2012 was performed. The mean average percentage error (MAPE) was 3.6% for the forecast period, as seen in Figure 1. At 1942.8 presentations per day, this corresponds to a 69.9 presentation per day error across 13 EDs.

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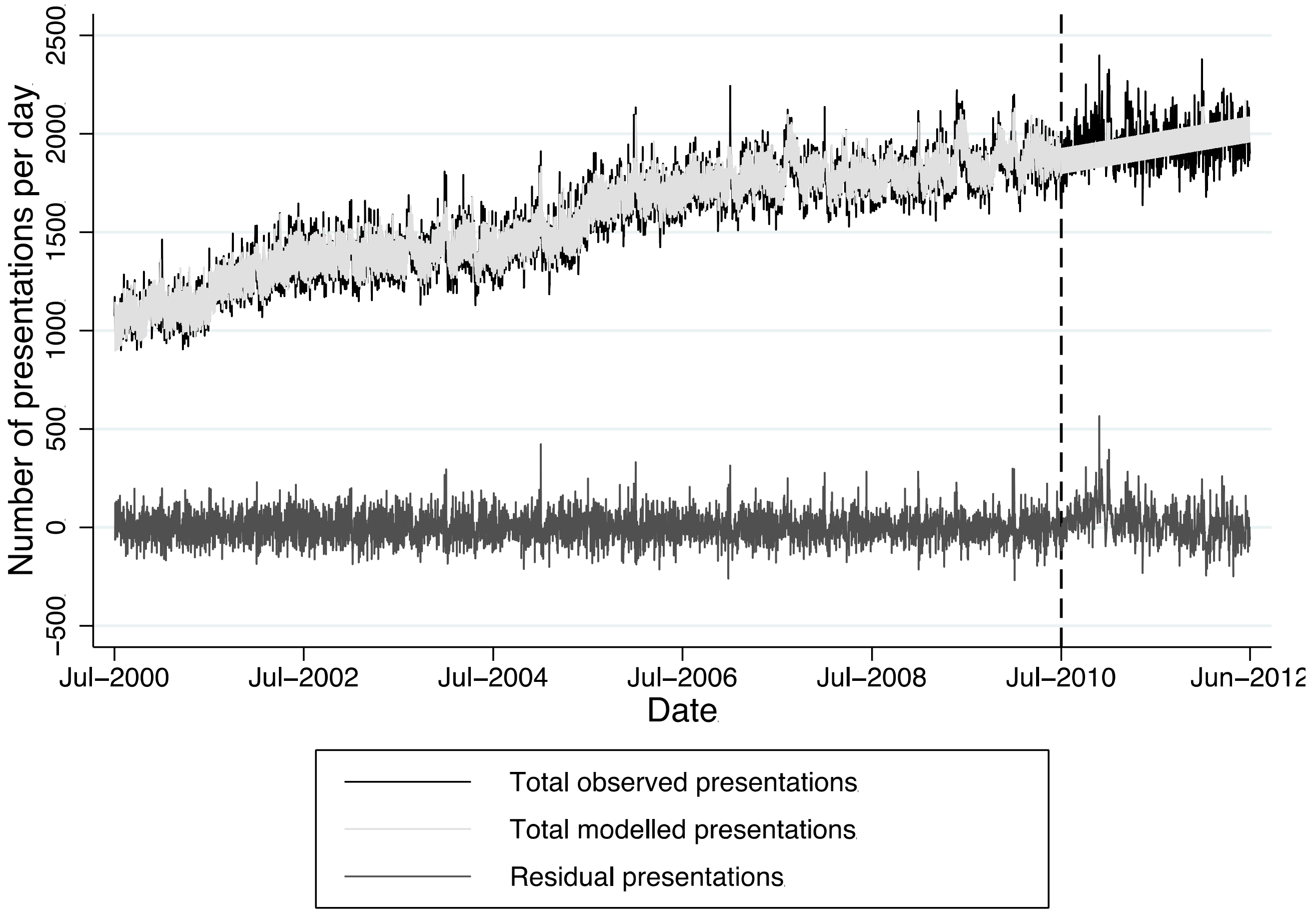

Figure 1 - Number of Presentations Per Day

Modelled ED presentation numbers overlaid on observed ED presentations. Residual presentations show the difference between the observed and modelled number of presentations. Dashed line at July 2010 demarcates the beginning of the validation period.

Discussion

We have modelled the number of daily ED presentations and validated this model. This is the first time total daily presentations have been modelled in this Australian capital city and only the second instance of the use of unobserved components modelling (UCM) in the ED literature(12) . The low mean average percentage error gave a difference between the predicted and observed number of presentations of 3.6% on any given day. A MAPE of 5% is generally considered an excellent model and 20% a good model, although no standardisation exists.(12)

Several time-series methods have been used internationally for the modelling of daily ED presentations, including unobserved components modelling,(13) autoregressive integrated moving average (ARIMA)(5, 12, 14), and generalised linear modelling.(7) Although ARIMA models are one of the time series methods(15) and have been used for daily data in previous studies, they are not recommended for high frequency (i.e. daily or weekly) data.(16) Generalised linear modelling is another approach however this requires outcomes to be independent and ED presentations cannot be presumed to be independent of the day before.

The strength of unobserved components modelling (UCM) is in handling high frequency time series data with a mean that changes over time (i.e. increasing numbers of ED presentations). UCM, as implemented by Stata, is based on state-space modelling which aims to describe the 'state' (i.e., number of presentations) with the minimum number of explanatory variables(17). It has only once previously been implemented for modelling of daily ED presentations.(13)

Planning for the future

From the first to the last year of the 12-year study period the number of presentations increased by 81.3%. The population increase over that same period was just under 20% for Greater Melbourne. The increase we have demonstrated is larger than previously published(18), likely due to the robustness of the dataset across the same group of hospitals. These data do not allow speculation regarding the cause of this increase but a steady rise in ED presentations four times that of the population increase has significant implications for health planning and policy.

Presentations were not observed to have a monthly nor seasonal pattern. Despite previous evidence suggesting ED overcrowding in winter(19, 20) , and the increased mortality associated with overcrowding(21, 22), we have demonstrated that there is not an increase in total ED presentations in winter for Melbourne. Therefore, other avenues of investigation should be pursued such as case mix, ED length of stay, diagnosis and perhaps most importantly, inpatient length of stay, over that period.

The increase in presentations of nearly 10% observed on Sundays and Mondays, as compared to other days of the week, has consistently been observed globally, although our dataset is one of the largest.(6, 14, 23) A comparable increase was observed on public holidays. This pattern has important local implications for human resource management, rostering and bed planning. Many EDs have lesser numbers of senior clinicians rostered on for weekends and public holidays. Similarly, many hospital and community support services that may facilitate discharge from the ED are typically not accessible on Sundays or public holidays. Health services should consider developing and staffing more responsive support facilities in line with demand if patient needs are to be optimally met.

Future directions include the expansion of the study to include increasingly longer data periods. In addition, the new hospitals joining the network could be included in the modelling. For individual hospitals with large numbers of presentations, this modelling may be useful for the analysis of specific patterns in presentations and hospital-level planning. The replication of similar study methods in other locations would add strength to the technique but require investigation of local patterns in presentation to implement.

The applications of this forecasting of ED presentations are largely at a broad health planning level. Health workforce planning both in EDs and in the associated support facilities can be informed by data around ED presentations and demand. Infrastructure planning can also be informed by data-driven information around ED utilisation.

Limitations

Limitations of this study include the use of population data collected across multiple facilities and collated at a state level. Despite thorough internal checks by the Department of Health and Ageing, a dataset of this size is likely to contain errors. We have included the largest hospitals in the area, although are missing some smaller facilities that commenced reporting during the study period, all private hospitals and some specialty hospitals. We were unable to compare the city-wide modelling to the number of presentations at individual facilities due to restrictions in our access to potentially identifiable data. Transfers between facilities, many of whom will again present to an ED, were not identified separately. Without additional work, this study is not directly applicable to individual EDs. The impact of after-hours general practices was not assessed in this study but may have affected the workload on EDs. The relationship between hospital capacity, ED crowding, boarding and presentations were not assessed. The decision to utilise only one modelling method may limit comparison with other studies.

Conclusion

This study has for the first time, produced and validated a model for predicting daily ED presentations across an Australian capital city. Despite winter overcrowding noted in the emergency medicine literature, there was no seasonal variation in the number of total ED presentations; however, there were predictable and substantial increases in throughput on Sundays, Mondays and public holidays.

A four-fold increase in ED presentations compared to population growth was demonstrated. This trend has important implications for ongoing sustainable care delivery. Although ED presentations are multifactorial, daily presentations are predictable and explained by a small number of variables. The model will have important implications for policy makers involved in future health planning.

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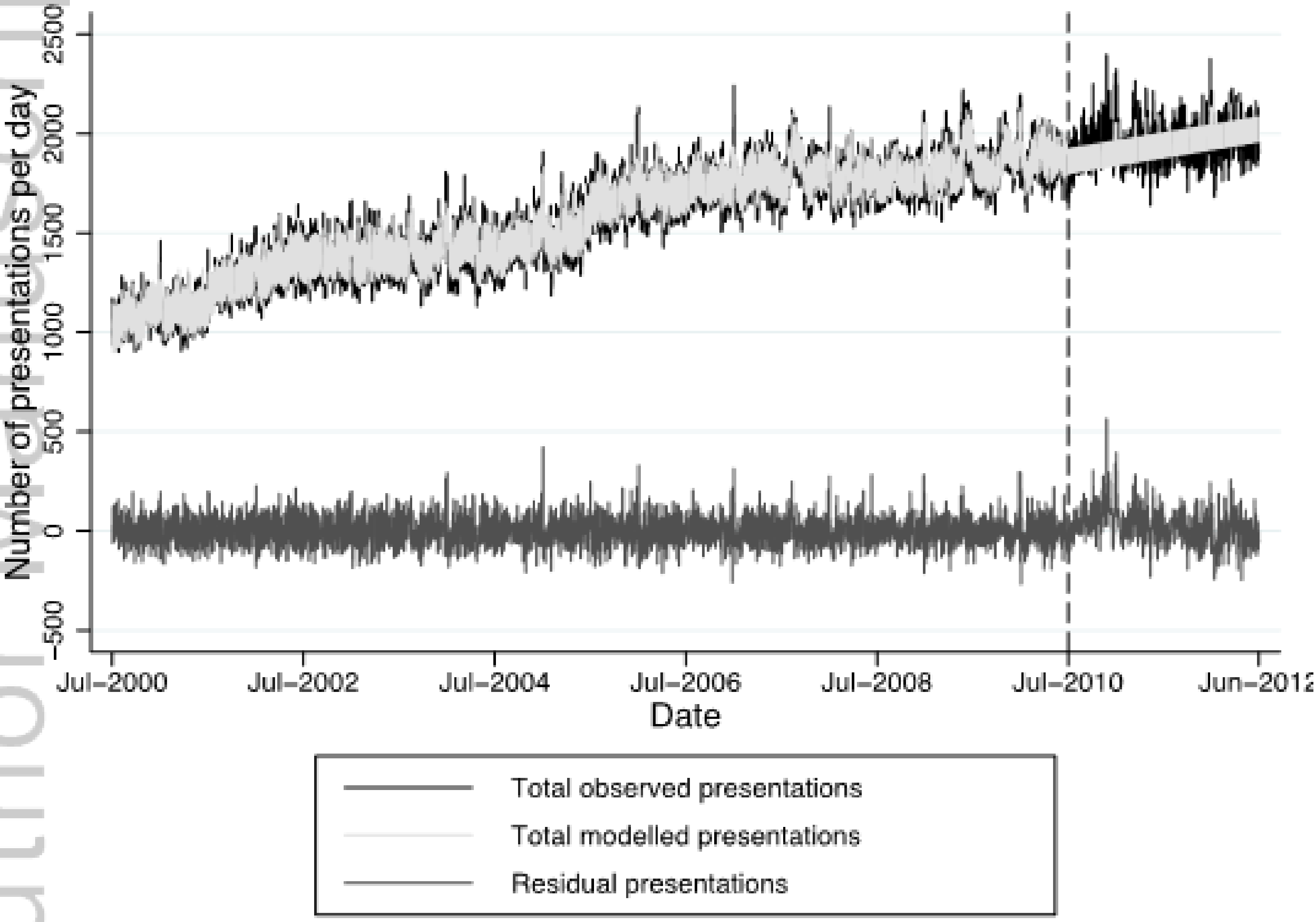

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