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Impact of regulatory body actions and subsequent media coverage on use of services in a fee-for-service system: A longitudinal cohort study of computed tomography scanning in Australia

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Complete List of Authors:	Youens, David; Curtin University, School of Population Health Doust, Jenny; The University of Queensland Faculty of Medicine and Biomedical Sciences Ha, Ninh ; Curtin University, School of Population health O'Leary, Peter; Curtin University Faculty of Health Sciences, School of Population Health; The University of Western Australia, Medical School, Faculty of Health and Medical Sciences Slavotinek, John; SA Health, SA Medical Imaging; Flinders University, College of Medicine and Public Health Wright, Cameron; Curtin University, School of Population Health; Fiona Stanley Hospital Moorin, Rachael; Curtin University, School of Population Health; The University of Western Australia, School of Population and Global Health
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Title page

Title: Impact of regulatory body actions and subsequent media coverage on use of services in a fee-for-service system: A longitudinal cohort study of computed tomography scanning in Australia

Author names and affiliations:

David Youens* [a], Jenny Doust [b], Thi Ninh Ha [a], Peter O'Leary [a, c, d], John Slavotinek [e, f], Cameron Wright [a, g, h, i], Rachael Moorin [a, j]

* Corresponding author. David.youens@curtin.edu.au. GPO Box U1987, Perth, Western Australia, 6845

a Health Economics and Data Analytics, School of Population Health, Curtin University, Perth, Australia

b Centre for Longitudinal and Life Course Research, Faculty of Medicine, University of Queensland

c Obstetrics and Gynaecology, Medical School, Faculty of Health and Medical Sciences, The University of Western Australia, Perth, Western Australia, Australia

d PathWest Laboratory Medicine, QE2 Medical Centre, Nedlands, Western Australia, Australia

e SA Medical Imaging, SA Health

f College of Medicine and Public Health, Flinders University, Adelaide, South Australia

g Fiona Stanley Fremantle Hospitals Group, Western Australia, Australia

h Medical School, Faculty of Health and Medical Sciences, The University of Western Australia, Western Australia, Australia

i School of Medicine, College of Health & Medicine, University of Tasmania, Tasmania, Australia

j School of Population and Global Health, The University of Western Australia, Western Australia, Australia

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Abstract

Objective: The Professional Service Review (PSR) is an Australian Government agency aiming to reduce inappropriate practices funded via Medicare, Australia's public insurer. Our objective was to examine changes in Computed Tomography (CT) use following the 2008-09 PSR annual report, which noted excessive CT use.

Design: Interrupted Time Series Analysis examined trends in CT use following the 2008-09 PSR report, estimating both change in the immediate rate of CT and the slope of the trend in usage post-intervention.

Setting: Medicare-funded imaging (most out-of-hospital imaging) in Australia.

Participants: Patients receiving Medicare-funded CT and other imaging

Intervention: The 2008-09 PSR report highlighted concerns regarding excessive CT use. Two providers were financially penalised for CT overuse with these cases detailed in the PSR report and highlighted in an associated *Report to the Professions*, distributed to 50,000 providers. Media articles on radiation risks followed.

Outcomes: Quarterly rates of out-of-hospital CT, magnetic resonance imaging (MRI, as a comparator), and all other Medicare-funded diagnostic imaging examinations 2001-2019.

Results: CT scanning increased from 4,663.5 per 100,000 person-years in 2001 to 14,506 in 2019 (211% increase), with substantial variation by type and anatomical region. The 2008-09 PSR report was followed by an immediate reduction in CT scanning of 237.7 CTs per 100,000 people per quarter (95% CI -333.4 to -141.9) though growth in use soon continued at the pre-intervention rate. The degree of change in utilisation following the report differed between states/territories and by scan type, both in terms of the immediate change and the slope. For other diagnostic imaging modalities there was an increase in the slope, while for MRI there was no change in either parameter.

Conclusion: Actions consisting of financial disincentives for service overtesting and provider / public education components may be effective in the short-term to limit excessive use of diagnostic imaging in fee-for-service systems.

Keywords: Diagnostic Imaging, Fee-for-Service, Computed Tomography, Medical Overuse,

Strengths and limitations of this study

- This study made use of whole of population administrative data, improving generalisability and preventing loss to follow-up or non response
- Multiple imaging modalities were examined, allowing for an assessment of CT (the target of the PSR actions) and potential substitution by other modes
- Only data on publicly-funded services accessed in the out-of-hospital setting were available; trends in in-hospital CT use were not examined
- The PSR actions involved multiple components and it was not possible to examine specific components in isolation from each other

Introduction

Overtesting is defined as the use of non-recommended screening tests in asymptomatic patients or more testing than necessary to diagnose patients.[1] Overtesting is problematic due to the wasted resources it incurs and the potential for patient harm. Harms of overtesting may fall under six domains:[2] physical, psychological, treatment burden, social, financial, and dissatisfaction with health care. Overtesting with CT may manifest in many of these areas, for example physical harms resulting from radiation exposure [3, 4] or psychological harms resulting from incidental findings.[5] Overtesting also consumes healthcare expenditure without improving outcomes,[1] imposing an opportunity cost. Overtesting may result from intrapersonal (e.g. fear of litigation, risk aversion, intolerance of uncertainty), interpersonal (e.g. pressure from patients and colleagues) or contextual (e.g. guidelines, financial incentives, time constraints, test availability) factors.[6] Studies in different countries have shown that over 10% of CT scans reflect overtesting,[7, 8] indicating substantial room for improvement in this area.

CT scanning in Australia is delivered in public and private hospitals, or in the out-of-hospital setting on referral from a general practitioner (GP) or specialist. Most out-of-hospital CT is performed by private clinics[9] which are reimbursed on a fee-for-service (FFS) basis by the Federal Government via Medicare, Australia's public insurer, which covers almost all Australian citizens and permanent residents[10] (with prisoners an exception). Similarly, GPs operate in private practices which are reimbursed by Medicare on a FFS basis hence are incentivised to maximise service volumes.[11] Patients do not register with practices and are free to change providers at any time, so multiple providers compete for services in the out-of-hospital environment, potentially driving overtesting where patients expect certain medical interventions (such as diagnostic CT) and providers feel compelled to meet patient expectations so as to prevent the patient from being 'lost' to another GP who provides or refers for the expected service.[12, 13] Note that decisions regarding out-of-hospital CT scanning are primarily made by referrers (GPs and specialists); radiologists at private clinics generally do not know the setting or patient and are not well positioned to deny scans requested. Although Medicare provides reimbursement for CT scans referred by a GP, MRI scans are generally only reimbursed when referred by a specialist (with some exceptions since 2011).[14] Furthermore, MRI machines must be licensed by the Federal Government in order for scans using that machine to attract reimbursement, with license availability restricted.[14] This may limit substitution of CT scans by MRI. No such restrictions exist for other modalities.

One of the bodies regulating healthcare in Australia is the Professional Services Review (PSR), which has responsibility for preventing inappropriate practice, both to protect patients from risk and to reduce Government funding of inappropriate care.[15] The PSR reviews the activities of practitioners where unusual service volumes or prescribing patterns suggest inappropriate care. Upon investigation by the PSR, a practitioner found to have engaged in inappropriate practice (as determined by a peer panel of practitioners) may be partially or fully disqualified from claiming Medicare reimbursements for some time, may be required to repay reimbursements claimed for delivery of inappropriate care, or may face suspension from practice.[16] In the 2008-09 PSR annual report published in October 2009, two providers were penalised for CT overtesting. In addition, the Director's report within the annual report commented on CT overtesting, noting concerns about use of CT screening for lower back pain.[17] Alongside this annual report was the dissemination by the PSR of a *Report to the Professions* to 50,000 health providers detailing these cases (and others), and the PSR director also spoke at medical conferences and to the media.[17] This was followed by a period of media interest concerning CT risks, including the publication of articles highlighting the risks of CT, targeted at both clinical audiences[18, 19] and the general public.[20-23] These articles, published through 2010 and 2011 in national[21, 23] and state-specific media,[22] outlined the PSR director's concerns, cancer risks associated with CT, the role of patient expectations as a factor and alternative imaging modalities. These events are collectively referred to as "the PSR actions" throughout this paper for simplicity. Any change in CT scanning resulting from the PSR actions may reflect either a change in imaging levels overall, or shifts to other modalities.

The aim of this project was to examine the impact of the PSR actions on the rate of CT scanning in Australia, to determine if regulatory body action influences overtesting in the FFS context.

Methods

This was a retrospective whole-of-population longitudinal cohort study using aggregate-level administrative data. Reporting follows the Reporting of studies Conducted using Observational Routinely-collected health Data (RECORD) guidelines.[24]

Data source

Quarterly utilisation data for Australia and for each Australian state/territory from Jan-March 2001 to Oct-Dec 2019 inclusive were sourced from publicly available Medicare Benefits Schedule (MBS) records.[25] Data pertaining to CT were extracted using MBS item reports. Data for other Medical Imaging modalities (Ultrasound, Nuclear Medicine and MRI) were extracted

using the Group report for Category 5 Diagnostic Imaging Services. Data included only those services performed by a registered provider for services that qualify for Medicare Benefits and for which Services Australia had processed a claim. Data excluded services provided by hospital doctors to public patients in public hospitals and services that qualified for a benefit under the Department of Veterans' Affairs National Treatment Account. The location services were provided (state/territory) was based on patient address. Calendar quarter was determined by the date of processing by Services Australia, not the date the service was provided to the patient. Note that date of processing is typically within days of the service date. For the denominator the Medicare eligible population for each state/territory was sourced from Medicare enrolment data quarterly standard reports.[26]

CT scanning data were aggregated into fourteen groups reflecting either anatomical area of the scan (e.g. head, chest etc.) or, due to lack of anatomical location on the MBS coding, grouped according to technique (cone beam CT, pelvimetry, spiral angiography and interventional CT) using the MBS item codes in Appendix 1. Since MBS items are for re-imbursement rather than clinical purposes, several items covered multiple CT examinations (Chest, Abdomen/Pelvis and Brain, Chest/Upper Abdomen). For analysis, all CT scanning records pertaining to these items were counted as a single CT scanning event. In the analysis by type of CT these items were grouped separately (see Appendix 2) and were not included in the analysis of their relevant sub-groups (i.e. brain, chest or abdomen/pelvis).

Quarterly rate of imaging

The quarterly rate of MBS funded imaging per 100,000 eligible persons was calculated for all Australia and by state/territory by dividing the number of services processed in that quarter by the eligible Medicare population for that quarter multiplied by 100,000.

Statistical analysis

Interrupted time series analysis (ITSA) was used to evaluate the impact of the PSR actions on the quarterly rate of medical imaging excluding CT, MRI, all CT scanning and type of CT scanning for all Australia and by state/territory.

The analysis was conducted using the '*itsa*' package[27] in Stata version 15.[28] Since the PSR actions affected the whole of Australia a control group was not available for comparison, therefore the model was a single-group ITSA (i.e. the preintervention trend was projected into the postintervention period to serve as the counterfactual) with a dummy indicator variable set

to quarter 4 2009 representing the PSR action. Coefficients were estimated using ordinary least squares regression with Newey-West standard errors to handle autocorrelation and heteroskedasticity.

Each model was first fitted with lag 0 specified (i.e. no autocorrelation), following which autocorrelation in the error distribution was tested for using the program '*actest'*[29] and the appropriate lag used in the final model. The model was implemented after adjustment for seasonality using Fourier terms (pairs of sine and cosine functions)[30] using the program '*circular*'.[31] Following Imbens and Lemieux[32] the median timepoint (quarter 4 2004) of the preintervention period was used as a robustness test to determine if the underlying assumption of stability in time-varying unmeasured confounders should be challenged. Where the post-intervention trend was non-linear, multiple dummy variables were used to adequately capture the shape of the post-intervention trend so that a more accurate estimation of the immediate change in the trend and change in level resulting from the PSR action could be estimated.

Classification of response to the 2009-10 Professional Services Review

For each model the direction and statistical significance of the estimates of the level (initial change in the quarterly rate of CT use) and slope (gradient of the trend in quarterly CT use) parameters in the post-intervention period (or for the slope the immediate post-intervention segment where a non-linear trend was observed) were used to classify the response to the PSR action. The primary typology was based on the direction and significance of the level parameter as follows: Type 1: significant reduction in the level; Type 2: no significant change in the level and Type 3: significant increase in the level. Each type was further classified into sub-types based on the change in the slope parameter: a) significant reduction; b) no significant change and c) significant increase.

Calculation of net change in CT imaging procedures following the PSR action

The net change in the CT procedures performed was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of imaging procedures. To reduce over-estimation of the net change where no significant difference was observed between the pre and post-intervention slopes (i.e. sub type b) the pre-intervention slope parameter was used to define the post-intervention slope rather than the point estimate provided in the ITSA model. Similarly, where no significant difference in level was observed (i.e. type 2), the post-intervention curve was defined with the

level change set to zero. When the post-intervention trend was non-linear the net change was only calculated until the beginning of the subsequent change in trend. The net change could be negative (i.e. net reduction in the rate of imaging examinations through the post-intervention period) or positive.

Patient and public involvement

As this is an analysis of secondary data, there was no patient or public involvement.

Results

Over the 19-year study period 369.5 million Medicare funded medical imaging examinations were undertaken in Australia (6.2% of all Medicare funded activity) of which CT scanning comprised 11.4% (42.2 million) (Appendix 2). The most frequently performed type of CT scan was abdomen/pelvis comprising 18.8% [~8 million] of all CT examinations, closely followed by head CT (17.6% [7.5 million]) and spinal CT (17.6% [7.4 million]).

As shown in Table 1 the rate of CT scanning increased from 4,663.5 per 100,000 Medicare eligible persons in 2001 to 14,506.1 per 100,000 in 2019. The increase of 211% was much larger than the increases observed for Ultrasound (+150%) and Nuclear Medicine (+96%), or for diagnostic imaging overall (75%). While the largest increase in the rate of imaging (by modality) was observed for MRI (increasing by ~400% over the study period), the absolute rate was still 64% lower than the rate of CT scanning in 2019. Table 1 also shows the rate of CT scanning according to type across the study period. In 2001 the top three types of CT scanning, ranked according to the rate performed per 100,000 persons, were head CT (1,529.8), followed by abdomen/pelvis CT (1,018.9) and CT of the facial bones (629.9). However, by 2019 this ranking had changed such that abdomen/pelvis CT had the highest rate per 100,000 (2,565.0); spinal CT was now ranked second (2,237.1) and head CT third (1,884.4). The largest relative change in the rate of CT scanning by type from 2001 to 2019 was observed in interventional CT which increased by 1,089% (from 95.4 per 100,000 in 2001 to 1,134.0 in 2019. Similarly, the rate of spiral angiographic CT scanning also rose by 1,054% (from 85.5 per 100,000 in 2001 to 987.0 in 2019). Other notably very large relative increases (i.e. more than tripling of the 2001 rate) were observed for chest/abdomen/pelvis CT (+451%), CT of the extremities (+407%) and pelvis CT (+358%). Rate increases of over 100% were observed for chest CT (+199%), abdomen/pelvis CT (+152%) and soft tissue neck CT (+147%). The only type of CT scan to reduce in rate was cone beam CT which was first funded under Medicare in 2011 (quarter 3).

Table 1 Quarterly rate of MBS funded diagnostic imaging by modality and type of CT scanning services in Australia for selected years across the study period

Time period (Year and quarter)	Rate per 100,000 eligible population				Rate of CT per 100,000 eligible population				
	All diagnostic imaging	MRI	US	Nuc Med	All CT	Head	Face	Soft tissue Neck	Chest
2001Q1	15,422.0	235.7	4,385.1	363.3	1,092.9	376.7	146.2	29.3	125.4
2001Q2	15,771.5	263.5	4,438.3	372.2	1,127.8	392.8	157.1	29.6	127.1
2001Q3	16,139.3	281.0	4,476.9	390.7	1,154.8	386.6	169.5	29.8	133.1
2001Q4	15,482.3	275.9	4,453.5	368.7	1,286.7	373.7	157.1	30.7	133.5
Total 2001	**62,816.4**	**1,056.3**	**17,754.3**	**1,494.9**	**4,663.5**	**1,529.8**	**629.9**	**119.4**	**519.1**
2007Q1	18,596.9	465.5	6,071.7	406.1	2,093.7	438.0	176.3	41.8	187.1
2007Q2	18,794.5	488.8	6,100.9	414.4	2,115.3	449.0	190.0	39.1	183.5
2007Q3	19,686.1	514.3	6,293.4	426.6	2,144.5	443.8	203.1	41.2	194.9
2007Q4	19,101.8	489.8	6,251.9	437.1	2,162.9	448.3	194.7	41.7	200.0
Total 2007	**76,183.2**	**1,958.5**	**24,719.1**	**1,684.3**	**8,516.9**	**1,779.2**	**764.2**	**163.8**	**765.6**
2013Q1	22,335.4	650.6	8,332.2	633.1	2,699.7	454.3	191.2	49.6	230.3
2013Q2	23,799.2	738.5	8,934.5	678.4	2,842.7	474.9	212.4	51.8	246.0
2013Q3	24,502.0	773.4	9,166.0	692.5	2,891.2	473.9	221.0	51.1	255.9
2013Q4	23,586.7	840.5	8,935.3	673.8	2,813.0	434.7	202.6	51.4	254.5
Total 2013	**94,233.9**	**3,004.0**	**35,372.4**	**2,678.0**	**11,247.5**	**1,837.8**	**827.3**	**203.9**	**986.8**
2019Q1	26,965.0	1,186.6	10,977.7	709.2	3,524.9	471.8	217.4	71.7	368.8
2019Q2	27,263.0	1,399.0	10,973.9	721.5	3,553.4	468.8	228.0	71.7	370.3
2019Q3	28,567.7	1,378.9	11,426.8	754.0	3,774.6	488.5	256.6	75.4	410.7
2019Q4	27,214.2	1,312.8	11,073.7	740.8	3,652.3	455.3	228.2	75.5	402.1
Total 2019	**110,013.1**	**5,277.8**	**44,453.3**	**2,925.6**	**14,506.1**	**1,884.4**	**930.2**	**294.4**	**1,552.2**
Percent change total 2001 to total 2019*	**75.1**	**399.6**	**150.4**	**95.7**	**211.1**	**23.2**	**47.7**	**146.5**	**199.0**

Table 1 continued

Time period (Year and quarter)	Rate of CT per 100,000 eligible population							
	Abdomen/Pelvis	Pelvis	Spine	Chest/Abdomen /Pelvis	Extremity	Spiral Angiography	Interventional	Cone Beam
2001Q1	250.0	17.5		54.5	46.8	18.9	21.3	
2001Q2	252.3	16.6		54.5	48.8	20.6	22.2	
2001Q3	256.0	17.9		57.9	50.8	22.5	25.1	
2001Q4	260.5	16.5		60.3	48.8	23.5	26.7	
Total 2001	**1,018.9**	**68.5**	**NA**	**227.3**	**195.3**	**85.5**	**95.4**	**NA**
2007Q1	423.2	21.4	431.6	136.7	90.6	62.9	77.1	
2007Q2	422.8	21.0	430.5	132.5	93.8	66.9	79.2	
2007Q3	418.7	22.1	425.0	138.1	96.0	73.7	80.1	
2007Q4	423.0	25.1	430.9	142.3	94.1	70.1	84.8	
Total 2007	**1,687.7**	**89.5**	**1,718.1**	**549.7**	**374.5**	**273.7**	**321.3**	**NA**
2013Q1	509.4	26.0	491.5	222.1	145.0	128.2	168.7	72.0
2013Q2	529.2	27.4	501.1	225.9	154.1	143.9	182.6	80.9
2013Q3	525.8	28.9	497.8	229.4	156.8	154.6	190.3	92.9
2013Q4	517.4	29.4	482.9	230.5	154.1	148.4	197.1	96.8
Total 2013	**2,081.9**	**111.7**	**1,973.2**	**907.9**	**610.1**	**575.2**	**738.9**	**342.7**
2019Q1	640.5	69.0	565.4	317.1	234.4	220.7	263.8	46.8
2019Q2	633.0	73.3	545.1	309.5	242.9	243.9	277.6	49.0
2019Q3	652.6	84.6	577.7	314.2	259.3	265.0	292.3	50.0
2019Q4	638.9	86.5	548.9	312.2	252.3	257.2	300.2	46.0
Total 2019	**2,565.0**	**313.5**	**2,237.1**	**1,253.0**	**989.1**	**987.0**	**1,134.0**	**191.8**
Percent change total 2001 to total 2019*	**151.7**	**357.8**	**30.2**	**451.3**	**406.5**	**1,053.9**	**1,089.2**	**-44.0**

MBS: Medicare Benefit Scheme; US: Ultrasound; Nuc Med: Nuclear Medicine; NA = Item not available
Q1 January to March, Q2 April to June, Q3 July to August, Q4 September to December.
Grey cells indicates that MBS funded services were not available for all or part of the specified time period
*Where MBS item was not available in for the whole of 2001 percentage change is calculated from first year it was available in all quarters

Figure 1 shows the results of the ITSA evaluating changes in the use of CT following the PSR actions, by state/territory; values informing the figure are in Appendix 3. On average after adjusting for seasonality and autocorrelation there was a significant reduction in the level parameter (-237.7 CTs per 100,000 Medicare eligible persons [95% Cl -333.4 to -141.9]) indicating an immediate response. However, no significant change in the slope parameter was observed, indicating no sustained effect i.e. following the initial drop in utilisation, growth in CT scanning continued at its previous rate. Despite there being no sustained change, over the post-intervention period (Qtr 4 2009-Qtr 4 2019) the cumulative rate (i.e. the net change) of CT use reduced by 9,744.3 per 100,000 due to the initial level change, compared with the counterfactual. This can be readily observed graphically in Figure 2. Across Australian states and territories, the response differed (Figure 1). In all states/territories except the Northern Territory there was a significant reduction in the level; however, the response in the slope parameter differed. In New South Wales, South Australia and Victoria there was a significant reduction in the slope parameter (i.e. sustained reduction), in Tasmania there was no significant change in the slope, while in the Australian Capital Territory, Queensland, Western Australia and the Northern Territory after the initial reduction in level there was a significant increase in the slope parameter.

Figure 3 shows the results of the ITSA according to type of CT scanning in Australia (values in Appendix 3). The majority of CT scanning types showed an immediate significant reduction in level, the exceptions being CT angiography and chest/abdomen/pelvis CT which showed no change, and interventional CT, which showed an increase in level. With respect to sustained change (i.e. slope) there was a much larger variation across type with reductions (head, face, abdomen/pelvis, spine CT and CT angiography), increases (chest, extremity, soft tissue neck, brain/chest/upper abdomen and interventional CT) and on one occasion no change (pelvis CT) observed. Figure 3 also shows the results of the analysis for MRI, which showed no response in either parameter and all diagnostic imaging excluding CT, which showed no change in the level but an increase in the slope parameter.

Discussion

CT use reduced significantly following the 2008-09 PSR annual report, associated sanctions and subsequent media coverage of CT risks. Following this short-term decline, CT use continued increasing at the pre-intervention rate, though results differed by scan type/region

and state/territory. Findings indicate that major reviews including financial penalties and surrounding coverage have potential to decrease overtesting, but that reductions may not be sustained.

Being an observational study we cannot assume causation, though we highlight some important points in considering this. There was a close temporal relationship between the PSR report and the changes in CT use, which would be expected if changes were causal. The face validity of a causative relationship can be considered via the overtesting framework developed by Lam *et al*.[6] Interpersonal drivers of overtesting may have influenced CT use as the mass media coverage outlined radiation risks to patients and included some discussion of the role of patient expectations in driving imaging requests.[21-23] On the provider side, fear of reputational damage following a reprimand is also an interpersonal factor. Environmental drivers may have changed if providers grew concerned about financial penalties from the PSR for excessive imaging. Intrapersonally, the risk aversion that drives overtesting in the search for a definitive diagnosis may have been countered by improved knowledge of radiation risks. The risk of reputational damage or financial penalties was low, with the PSR report discussing two providers sanctioned for inappropriate CT. However, these cases were widely disseminated, via the *Report to the Professions* describing these cases (and others) to 50,000 providers, and the PSR director speaking at medical conferences and to the media.[17] Penalties for inappropriate CT appeared in the 2009-10 and 2011-12 PSR annual reports, however there was no specific discussion in the director's reports nor are we aware of media coverage following these reports. A 2011 review of diagnostic imaging noted that the 2008-09 PSR had likely impacted practice, and that private providers had expressed concerns regarding profitability following this.[33]

There is prior evidence in Australia of educational interventions reducing CT. In 2013 the National Prescribing Service's (NPS) MedicineWise program ran an intervention to reduce inappropriate CT for acute lower back pain.[34] This included a report to GPs comparing their referral rates for lower back CT to their peers, an online decision support tool and a symptom self-management prescription pad. The intervention reduced lower back CT by over 10%, which persisted through 20-months follow-up. This demonstrates some receptiveness to messaging regarding CT overtesting, though mechanisms of action by which the PSR may have influenced practice would differ. Similarly, the introduction of a Choosing Wisely recommendation to reduce imaging for lower-back pain in the United States in 2012 was followed by a 4% reduction in such imaging.[35] The Choosing Wisely campaign regarding lower back CT in the USA did not involve any financial disincentives such as the PSR actions in the

current study, though did garner substantial media attention[35] so some drivers of change may have been comparable. A review of interventions to reduce overuse care suggested that educational interventions targeted at both clinicians and patients are among the most effective type,[36] supporting the notion that media coverage on CT overtesting may have influenced practice.

Results here differed between states/territories and CT type. Differences in results across CT type do not appear to be driven by differences in the radiation dosages associated with each type, given that Chest / Abdomen / Pelvis scans showed no change in either parameter following the PSR action but expose patients to some of the highest effective doses.[37] Differences observed between states / territories may have resulted from differences in the baseline level of CT use; this is likely as availability of CT scanners, one driver of overtesting, does differ between jurisdictions.[14] These differences may have also resulted from differences in messaging in each state / territory, caused by either different levels of media coverage of this issue (as some coverage appeared in local[22] rather than national newspapers), or addresses by the PSR director to medical conferences in some states but not others. Baseline attitudes towards CT, and hence the capacity for reductions in use, may have also differed between networks of providers, given the concentration of scanners and providers in capital cities[14] which are in many cases geographically isolated.

There were differences observed between CT and other modalities. In contrast with the drop in CT use following the PSR, MRI showed no change following the 2008-09 PSR report, while for all diagnostic imaging excluding CT the slope increased significantly, while the level parameter showed a large but non-significant increase. This may represent substitution for modalities with lower or no associated radiation exposures (e.g. x-ray or ultrasound, respectively). MRI use increased steadily through the study period, reflecting an increase in availability of MR machines from below- to above-average in comparison to other Organisation for Economic Co-operation and Development countries.[38] There was no additional increase in use of MRI following the PSR actions, however, likely because licensing of MR devices is constrained by the Federal Government and most MRI investigations are not reimbursed by Medicare when referred by a GP, limiting potential for substitution.[39, 40] Alternatively, there may have been an increase in privately funded MRI which would be unobservable in the Medicare data used here.

Implications

These findings will be of interest to researchers and policymakers wanting to understand mechanisms to prevent overtesting, though contextual factors are important in understanding how effective such actions may be elsewhere. Provider and patient education regarding radiation risks, threats of financial penalties and reputational damage following exposure of inappropriate practice would likely be influential mechanisms across settings. The degree of response to such mechanisms, however, would depend in part on the baseline level of overtesting, driven in part by health system design. In health systems where providers are paid via capitation or salary rather than FFS overtesting may be less common, with FFS systems known to incentivise service volumes.[41] Similarly, in some health systems patients register with a practice[42] and cannot 'doctor-shop' as is the case in Australia. In such systems providers are not financially incentivised to increase patient satisfaction by delivering requested services, as patients cannot simply access the service via another practice. Overtesting may be incentivised where pay-for-performance programs prioritise patient satisfaction, as providers may feel pressured to refer patients for requested imaging services so as to maintain satisfaction ratings.[43] Relationships between providers referring for imaging and those performing imaging may also influence overtesting, e.g. ownership by physicians of radiology services is associated with increased radiology use.[44] A shift from a volume-driven to a value-driven system could prevent overtesting by focusing on the delivery of interventions to maximise patient outcomes rather than service delivery.[45] Finally, the PSR actions studied here were facilitated in part by the existence of the PSR which has oversight of all Medicare-funded services and authority to impose penalties. Although the PSR objectives of patient safety and cost containment are priorities globally, mechanisms available to regulators will differ elsewhere.

Strengths

This study benefited from the use of whole of population administrative data, improving generalisability and preventing loss to follow-up or nonresponse. The data cover a long study period both prior to and following the PSR action, improving effect estimates, and covers multiple imaging modalities. The analysis accounted for potential seasonality in the use of CT and non-linearity in post-intervention trends.

Limitations

Data were limited to services funded via Medicare Australia. Comparable data concerning patients in public hospitals were not available, and we cannot comment on potential trends in that setting.

There was no comparator available, which may have supported a more rigorous design. The PSR has a national scope, meaning there was no setting without the PSR action against which to compare trends. Different sets of MBS items were assessed as comparators in the hope of providing control for broader health system changes, but no items could be found for which pre-intervention trends resembled CT.

This study examines an action consisting of multiple components, and we are not able to assess, for example, mass media coverage in isolation from the publication of financial penalties for overtesting.

Conclusion

This study suggests that regulatory body action may influence provider behaviour within a FFS context. However, it also suggests that point-in-time interventions have limited longevity. The combination of financial incentives (i.e. penalties for excessive use), patient and provider education, and risks to reputation via potential for publicising of investigation outcomes was followed by reduced CT use. Further research examining how best to couple such actions with more sustained reinforcement over time to influence behaviour would be useful, in addition to studies assessing the proportionate impacts of individual components.

Author Contributions

RM conducted analyses for this paper. DY and RM prepared the first draft manuscript. RM, JD, POL, JS and CW developed the grant application under which this work was funded. All authors collaborated on writing the paper and approve the submitted version.

Ethics approval

Ethics approval was provided by the Curtin University Human Research Ethics Committee, approval number SMEC-80-10. Participant consent was not sought as data were a publicly available, aggregated collection of data on service volumes. There is no possible way to identify any of the people receiving the services the data relate to, nor to contact them for the purpose of obtaining consent.

Patient consent for publication

None required.

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Data sharing

Data used in these analyses can be requested from the authors.

Competing interests

None declared.

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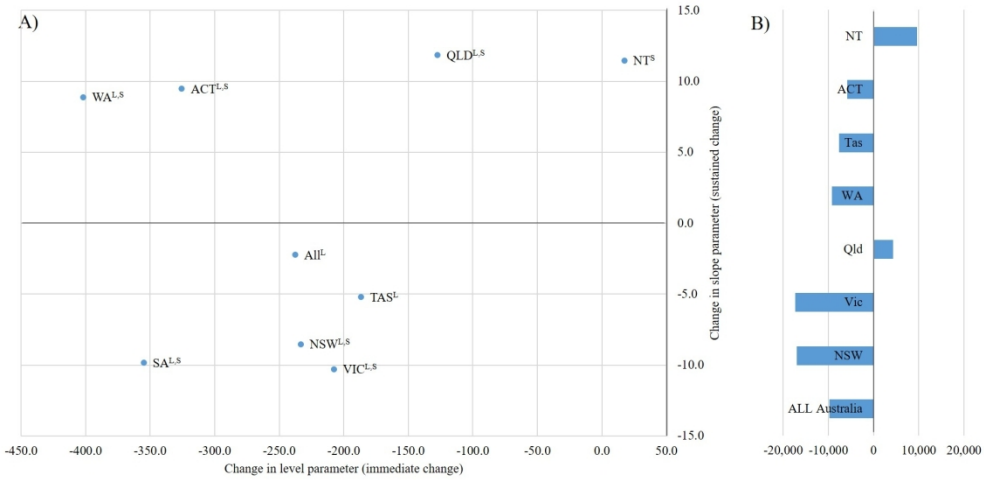
Figure legends

Figure 1: Part A indicates change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publication of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B indicates net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by State.

Figure 2: Impact of the 2008-9 professional services review on the rate of Medicare funded CT scanning (per 100,000 Medicare eligible population) in Australia. Part A indicates quarterly rate of all MBS funded CT scans showing counterfactual and post-intervention fitted line (seasonality removed for simplification). Part B is a representation of the seasonally adjusted area under and between the curves used to estimate net effect of the response to the MBS professional services review 2008-9.

Figure 3: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B displays net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by type / anatomical area.



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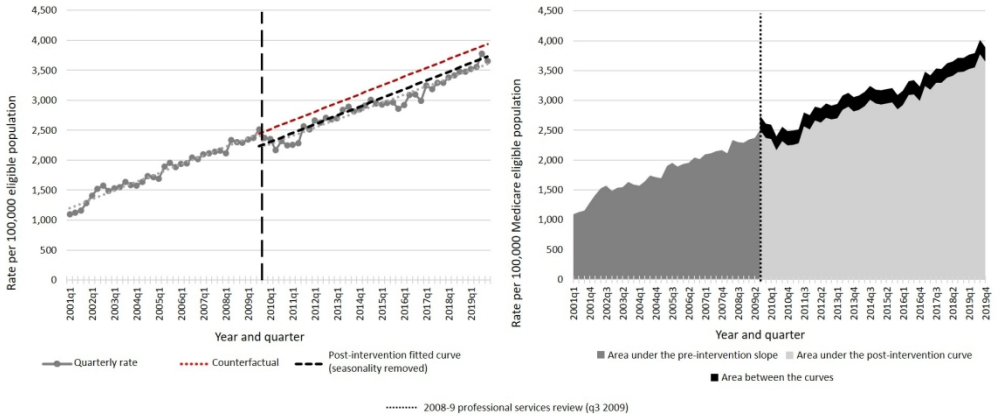
332x163mm (150 x 150 DPI)



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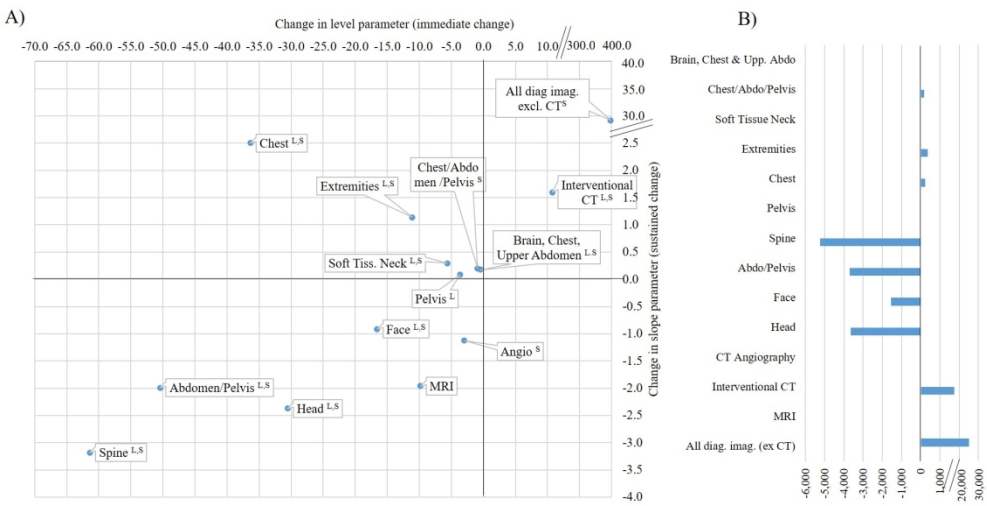
320x135mm (150 x 150 DPI)



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332x170mm (150 x 150 DPI)

Appendix 1: Grouping of CT MBS items according to anatomical location or technique

Group	MBS item number	Description
Head	56001 / 56041	Brain (Non-contrast)
	56007 / 56047	Brain (Contrast)
	56010 / 56050	Pituitary fossa (+/- Contrast)
	56016 / 56056	Petrous bones (+/- Contrast)
Facial bones	56028 /56036 /56068	Facial bones / sinuses or both (Contrast)
	56022 / 56062	Facial bones / sinuses or both (Non-contrast)
	56076 / 56030 / 56070	Facial bones / sinuses or both + Brain (+/- Contrast)
	56013 /56053	Orbits (+/- Contrast)
Neck (soft tissue)	56101 /56141	Soft tissue neck (Non-contrast)
	56107 / 56147	Soft tissue neck (Pre and post contrast)
Chest	56301 / 56341	Chest +/- upper abdo (Non-contrast)
	56307 / 56347	Chest +/- upper abdo (Pre + post contrast)
Abdomen (+/-Pelvis)	56401 / 56441	Upper Abdo -diaphragm to iliac crest (Non-contrast)
	56407 / 56447	Upper Abdo -diaphragm to iliac crest (Contrast)
	56501 / 56541	Abdo/Pelvis (Non-contrast)
	56507 / 56547	Abdo/Pelvis (Contrast)
	56549 / 56551 / 56552 / 56553/ 56554 / 56555	Virtual Colonoscopy
Pelvis only	56409 / 56449	Pelvis (Non-contrast)
	56412 /56452	Pelvis (Contrast)
Chest/Abdo/Pelvis	56801 /56841	Chest/Abdo/Pelvis +/- neck (Non-contrast)
	56807 / 56847	Chest/Abdo/Pelvis +/- neck (Pre + post contrast)
Brain, Chest and Upper Abdomen	57001 /57041	Head + Chest+/-upper abdomen without contrast
	57007 / 57047	Head + Chest +/- upper abdomen with contrast

Spine	56220 / 56227	Cervical spine (Non-contrast)
	56224 / 56230	Cervical spine (Contrast + Non Contrast)
	56221 / 56228	Thoracic spine (Non-contrast)
	56225 / 56231	Thoracic spine (Contrast + Non Contrast)
	56223 / 56229	Lumbar spine (Non-contrast)
	56226 / 56232	Lumbar spine (Contrast + Non Contrast)
	56219 / 56259	Spine - 1 or more regions (With Intrathecal Contrast)
	56233 / 56235	Spine (2 exams of any (C, T or L) kind Non-contrast)
	56234 / 56236	Spine (2 exams of any kind (C, T or L) with Contrast + Without Contrast)
	56237 / 56239	Spine (3 regions C,T,L Non-contrast)
	56238 /56240	Spine (3 regions C,T,L With Contrast + Non Contrast)
Extremities	56619 / 56620/ 56622/ 56623/ 56625	CT of extremities one or more regions (Non-contrast)
	56626 /56627/ 56628/ 56629/ 56630/ 56659 / 56665	CT of extremities one or more regions (Non-contrast)
Spiral Angiography*	57350-57356	Spiral angiography (Pre + post contrast)
	57360/57361	CT of the coronary arteries
Cone Beam CT	56025/56026/57362/57363	Cone Beam CT of teeth and supporting bone structures
Pelvimetry	57201 / 57247	Pelvimetry
Interventional CT	57341 / 57345	CT in conjunction with a surgical procedure using interventional techniques

MBS: Medicare Benefit Scheme

*Spiral angiographic CT item codes relate specify several broad clinical settings relating to their use.

Appendix 2: Size of the Medicare eligible population, and numbers of imaging procedures performed by type, per quarter

Year and quarter	Medicare eligible population	Number of imaging procedures per quarter, by type (excl C&E)					
		ALL MBS	All Diagnostic Imaging	Diagnostic Imaging excluding CT	ALL MRI	All US	All Nuc Med
2001Q1	19,974,075	53,913,292	3,080,396	2,862,100	47,080	875,892	72,556
2001Q2	20,058,815	54,612,217	3,163,585	2,937,355	52,845	890,270	74,655
2001Q3	20,139,806	57,160,177	3,250,431	3,017,862	56,588	901,629	78,692
2001Q4	20,215,957	53,802,181	3,129,899	2,869,771	55,782	900,319	74,530
2002Q1	20,296,405	52,698,145	3,050,855	2,764,530	53,730	877,966	71,292
2002Q2	20,374,998	57,043,850	3,321,404	3,010,541	60,267	949,968	78,445
2002Q3	20,451,273	58,573,985	3,462,073	3,140,545	64,444	995,302	82,390
2002Q4	20,525,042	54,100,126	3,234,123	2,929,308	61,043	961,803	77,054
2003Q1	20,574,715	53,702,789	3,235,168	2,919,654	60,331	974,715	75,127
2003Q2	20,640,449	55,029,284	3,296,996	2,977,779	65,296	982,227	77,892
2003Q3	20,724,986	58,373,440	3,492,688	3,153,252	69,926	1,028,635	81,564
2003Q4	20,805,416	55,102,234	3,316,288	2,986,225	67,265	1,009,242	79,271
2004Q1	20,892,413	55,237,593	3,251,558	2,923,221	65,887	993,179	75,292
2004Q2	20,971,967	57,668,884	3,397,421	3,053,659	70,744	1,025,832	79,572
2004Q3	21,040,363	60,479,828	3,630,147	3,264,529	73,164	1,088,136	84,727
2004Q4	21,020,468	58,681,495	3,497,953	3,137,363	73,483	1,074,598	79,970
2005Q1	20,395,854	55,265,155	3,272,212	2,926,937	68,650	1,018,953	73,814
2005Q2	20,482,464	61,889,434	3,736,003	3,347,527	81,138	1,157,994	84,654
2005Q3	20,535,311	63,925,592	3,864,039	3,463,294	86,186	1,201,410	86,013
2005Q4	20,570,360	59,950,302	3,634,302	3,245,994	83,508	1,157,675	81,138
2006Q1	20,651,536	61,070,666	3,673,330	3,273,759	86,366	1,166,540	80,584
2006Q2	20,738,739	62,420,316	3,749,991	3,345,574	90,248	1,190,679	82,258
2006Q3	20,834,970	65,739,068	3,981,768	3,556,490	98,377	1,254,468	88,615
2006Q4	20,918,630	62,183,136	3,802,035	3,380,338	94,248	1,241,269	84,811
2007Q1	21,023,544	64,047,623	3,909,736	3,469,566	97,875	1,276,478	85,374

2007Q2	21,075,599	65,922,562	3,961,046	3,515,224	103,019	1,285,806	87,332
2007Q3	21,156,498	70,587,243	4,164,895	3,711,184	108,799	1,331,460	90,249
2007Q4	21,213,097	68,075,447	4,052,075	3,593,258	103,894	1,326,226	92,717
2008Q1	21,300,775	66,111,755	3,932,797	3,481,827	97,289	1,284,795	86,786
2008Q2	21,382,498	73,943,872	4,374,974	3,876,485	113,767	1,446,356	100,177
2008Q3	21,474,007	73,411,004	4,347,958	3,854,001	114,660	1,437,929	100,593
2008Q4	21,542,093	72,757,668	4,268,041	3,775,261	113,590	1,442,680	98,530
2009Q1	21,611,182	72,990,845	4,265,199	3,758,331	109,507	1,442,832	101,325
2009Q2	21,712,379	74,849,371	4,450,168	3,935,534	121,502	1,515,593	106,838
2009Q3	21,799,725	79,059,828	4,735,321	4,188,550	134,373	1,592,771	114,116
2009Q4	21,864,719	77,132,787	4,439,849	3,921,910	124,633	1,539,685	108,432
2010Q1	21,995,898	73,945,829	4,423,973	3,905,995	119,415	1,535,498	109,394
2010Q2	22,116,286	78,262,472	4,554,003	4,075,502	132,075	1,583,459	115,291
2010Q3	22,225,493	80,332,900	4,845,036	4,329,256	134,639	1,668,768	125,165
2010Q4	22,322,182	79,520,986	4,697,780	4,196,325	134,158	1,655,431	124,342
2011Q1	22,430,782	78,696,720	4,686,355	4,180,032	129,057	1,642,691	121,167
2011Q2	22,536,170	80,591,361	4,846,047	4,332,553	140,184	1,695,068	127,800
2011Q3	22,646,567	86,000,221	5,159,265	4,578,841	153,104	1,832,694	139,046
2011Q4	22,752,945	80,099,988	4,912,101	4,339,480	142,800	1,789,169	139,453
2012Q1	22,869,958	83,090,073	5,107,472	4,499,155	143,874	1,862,446	143,865
2012Q2	22,975,129	83,419,449	5,146,458	4,542,312	151,104	1,875,437	145,229
2012Q3	23,083,927	87,331,463	5,406,664	4,781,580	157,745	1,955,461	150,517
2012Q4	23,186,999	88,148,306	5,209,940	4,589,199	155,520	1,940,993	146,353
2013Q1	23,301,712	81,070,495	5,204,538	4,575,455	151,607	1,941,553	147,521
2013Q2	23,415,863	87,420,296	5,572,789	4,907,148	172,931	2,092,082	158,845
2013Q3	23,526,793	91,269,394	5,764,539	5,084,337	181,946	2,156,469	162,931
2013Q4	23,516,579	87,442,632	5,546,788	4,885,276	197,653	2,101,276	158,443
2014Q1	23,726,126	87,365,616	5,647,377	4,972,344	214,246	2,126,548	157,860
2014Q2	23,816,689	92,173,285	5,845,674	5,153,281	230,868	2,186,482	162,773
2014Q3	23,923,051	94,962,398	6,089,946	5,370,449	246,153	2,265,530	165,754

2014Q4	23,997,461	92,135,078	5,897,348	5,190,581	237,560	2,242,799	164,672
2015Q1	24,105,563	90,560,806	5,901,602	5,195,336	233,585	2,242,250	162,921
2015Q2	24,179,690	95,743,360	6,060,642	5,346,902	253,841	2,293,992	168,956
2015Q3	24,278,495	98,437,227	6,261,986	5,542,495	262,668	2,373,981	170,088
2015Q4	24,366,559	95,229,471	5,967,569	5,272,222	245,411	2,328,097	156,482
2016Q1	24,453,229	92,813,393	5,997,592	5,283,310	240,294	2,338,670	156,130
2016Q2	24,553,190	102,637,644	6,440,165	5,682,508	272,750	2,512,656	170,212
2016Q3	24,636,038	100,005,965	6,462,300	5,698,777	275,305	2,487,482	171,942
2016Q4	24,711,652	95,516,816	6,123,586	5,384,207	256,559	2,387,030	164,289
2017Q1	24,821,154	100,586,254	6,557,448	5,752,386	272,317	2,567,688	175,505
2017Q2	24,924,168	103,376,540	6,547,871	5,755,139	294,158	2,565,789	174,498
2017Q3	25,007,901	104,773,012	6,770,682	5,947,070	301,470	2,608,763	179,662
2017Q4	25,078,863	104,675,460	6,625,438	5,799,977	293,524	2,610,899	172,694
2018Q1	25,182,661	101,038,400	6,725,986	5,873,983	290,847	2,653,510	180,775
2018Q2	25,267,605	109,365,729	6,882,768	6,020,760	315,569	2,722,980	177,872
2018Q3	25,353,168	106,249,390	7,057,888	6,177,536	328,216	2,764,644	182,907
2018Q4	25,436,468	106,876,163	6,867,102	5,982,682	312,607	2,764,861	179,849
2019Q1	25,520,089	105,168,957	6,881,495	5,981,931	302,827	2,801,529	180,979
2019Q2	25,595,189	111,352,700	6,978,029	6,068,535	358,070	2,808,803	184,667
2019Q3	25,675,916	113,030,934	7,335,021	6,365,854	354,051	2,933,923	193,589
2019Q4	25,754,980	108,011,995	7,009,009	6,068,363	338,103	2,852,030	190,786
TOTAL 2001-2019		**5,986,242,372**	**369,444,996**	**327,257,812**	**12,158,315**	**161,610,743**	**9,438,609**
Percent of all MBS activity			**6.17**	**5.47**	**0.20**	**2.20**	**0.16**
Percent of all Diagnostic Imaging				**88.58**	**3.29**	**35.62**	**2.55**
Percent of all CT scanning							

Table continued

Year and quarter	Number of CT examinations per quarter, by type						
	ALL CT	Head CT	Facial bones CT	Neck (soft tissue) CT	Chest CT	Chest/Abdo/Pelvis CT	Abdomen (+/- pelvis) CT
2001Q1	218,296	75,243	29,194	5,846	25,038	10,890	49,942
2001Q2	226,230	78,787	31,520	5,939	25,496	10,934	50,612
2001Q3	232,569	77,870	34,130	6,000	26,799	11,658	51,566
2001Q4	260,128	75,556	31,757	6,216	26,987	12,194	52,659
2002Q1	286,325	72,827	28,723	5,943	26,344	12,515	54,436
2002Q2	310,863	80,824	32,855	6,477	28,191	13,491	57,619
2002Q3	321,528	82,648	35,417	6,737	30,494	14,510	59,259
2002Q4	304,815	74,501	31,611	6,479	29,060	14,286	58,314
2003Q1	315,514	78,396	30,083	6,508	28,524	15,133	61,638
2003Q2	319,217	79,059	32,590	6,549	28,936	15,241	61,802
2003Q3	339,436	83,562	34,796	6,976	31,994	16,793	64,927
2003Q4	330,063	78,264	31,652	6,996	31,908	17,194	64,729
2004Q1	328,337	76,190	29,486	7,002	30,747	17,864	66,617
2004Q2	343,762	80,273	33,374	6,994	31,536	18,311	69,139
2004Q3	365,618	85,257	36,384	7,272	35,081	19,594	71,178
2004Q4	360,590	82,754	35,066	7,179	35,066	19,973	70,097
2005Q1	345,275	76,760	31,309	6,939	32,483	20,226	69,673
2005Q2	388,476	88,306	37,094	7,862	35,613	22,142	76,537
2005Q3	400,745	91,158	38,797	7,793	37,585	23,170	77,325
2005Q4	388,308	84,502	36,127	7,904	36,823	23,263	76,871
2006Q1	399,571	86,081	35,311	8,134	36,452	24,976	80,765
2006Q2	404,417	86,807	38,138	7,731	36,276	25,075	81,175
2006Q3	425,278	92,095	41,594	8,055	39,001	26,017	83,082
2006Q4	421,697	87,923	38,381	8,577	38,946	26,911	83,321

2007Q1	440,170	92,093	37,067	8,779	39,326	28,744	88,975
2007Q2	445,822	94,631	40,052	8,245	38,678	27,920	89,103
2007Q3	453,711	93,891	42,974	8,724	41,238	29,226	88,578
2007Q4	458,817	95,095	41,294	8,837	42,434	30,196	89,730
2008Q1	450,970	93,195	38,146	8,545	39,569	29,798	90,417
2008Q2	498,489	101,530	45,024	9,678	43,118	32,623	98,675
2008Q3	493,957	97,072	47,054	9,072	44,512	32,685	96,012
2008Q4	492,780	97,102	43,048	9,254	44,864	33,423	96,361
2009Q1	506,868	98,536	41,934	9,479	43,779	35,884	102,656
2009Q2	514,634	101,302	45,716	9,636	43,969	36,118	102,856
2009Q3	546,771	107,069	50,834	10,075	48,233	37,953	106,818
2009Q4	517,939	100,708	44,414	9,594	45,591	37,405	100,455
2010Q1	517,978	100,254	41,898	9,628	43,424	39,023	103,770
2010Q2	478,501	93,538	40,507	8,960	40,803	37,635	95,304
2010Q3	515,780	98,321	46,458	9,666	45,428	39,354	99,595
2010Q4	501,455	94,719	42,363	9,825	46,193	39,372	96,336
2011Q1	506,323	95,129	39,688	9,981	45,948	41,563	100,132
2011Q2	513,494	96,725	43,280	9,797	45,808	41,894	100,369
2011Q3	580,424	102,851	50,301	10,775	50,818	45,041	107,854
2011Q4	572,621	98,347	44,683	10,532	50,612	44,780	108,030
2012Q1	608,317	105,042	45,525	11,083	51,598	49,684	116,058
2012Q2	604,146	104,413	46,932	11,013	51,212	48,006	113,052
2012Q3	625,084	106,380	50,286	11,121	54,646	49,262	113,827
2012Q4	620,741	101,520	46,030	11,208	55,158	50,048	114,814
2013Q1	629,083	105,860	44,546	11,554	53,664	51,746	118,692
2013Q2	665,641	111,194	49,730	12,124	57,601	52,886	123,927
2013Q3	680,202	111,494	52,005	12,030	60,202	53,962	123,695
2013Q4	661,512	102,227	47,646	12,089	59,847	54,211	121,680
2014Q1	675,033	104,173	46,951	12,169	59,405	56,972	126,579
2014Q2	692,393	105,582	49,645	12,308	61,240	56,573	127,207

2014Q3	719,497	106,283	54,941	13,046	66,686	58,574	128,500
2014Q4	706,767	104,179	49,805	13,241	67,660	59,008	130,637
2015Q1	706,266	107,198	49,464	13,017	65,311	60,743	133,591
2015Q2	713,740	108,814	52,771	13,231	68,186	60,704	132,644
2015Q3	719,491	108,195	54,781	13,098	72,485	61,291	129,284
2015Q4	695,347	101,454	47,878	13,227	70,426	62,371	128,975
2016Q1	714,282	105,362	47,179	13,505	69,763	64,773	133,961
2016Q2	757,657	111,103	53,315	14,490	74,077	65,588	140,232
2016Q3	763,523	110,128	55,826	14,755	78,893	66,953	138,167
2016Q4	739,379	104,499	50,328	14,453	77,701	65,310	133,437
2017Q1	805,062	115,414	52,521	15,667	81,219	71,433	149,116
2017Q2	792,732	112,646	53,677	15,661	80,405	69,606	144,232
2017Q3	823,612	117,302	59,970	15,577	87,261	71,379	145,531
2017Q4	825,461	114,373	53,565	16,273	86,954	71,591	148,272
2018Q1	852,003	118,695	54,068	16,751	85,878	76,133	156,420
2018Q2	862,008	118,600	57,084	16,811	87,963	74,992	156,527
2018Q3	880,352	119,379	62,327	16,995	91,688	75,550	155,815
2018Q4	884,420	118,096	56,790	17,477	94,604	77,554	157,633
2019Q1	899,564	120,415	55,471	18,299	94,124	80,924	163,452
2019Q2	909,494	119,984	58,368	18,347	94,789	79,216	162,030
2019Q3	969,167	125,420	65,879	19,370	105,447	80,680	167,554
2019Q4	940,646	117,270	58,760	19,454	103,562	80,410	164,552
TOTAL 2001-2019	**42,187,184**	**7,450,445**	**3,366,188**	**816,634**	**4,019,380**	**3,211,131**	**7,955,402**
Percent of all MBS activity	**0.70**	**0.12**	**0.06**	**0.01**	**0.07**	**0.05**	**0.13**
Percent of all Diagnostic Imaging	**11.42**	**2.02**	**0.91**	**0.22**	**1.09**	**0.87**	**2.15**
Percent of all CT scanning		**17.66**	**7.98**	**1.94**	**9.53**	**7.61**	**18.86**

Table continued

Year and quarter	Number of CT examinations per quarter, by type							
	Brain/Chest/ Upper Abdo CT	Pelvis CT	Spine CT	Extremities CT	Spiral Angiography CT	Interventional CT	Cone Beam CT	CT Pelvimetry
2001Q1	484	3,501	33	9,355	3,770	4,249	0	751
2001Q2	520	3,339	33	9,787	4,140	4,455	0	668
2001Q3	458	3,595	21	10,231	4,535	5,059	0	647
2001Q4	511	3,326	30,308	9,873	4,745	5,402	0	594
2002Q1	570	3,369	61,118	9,803	4,659	5,447	0	571
2002Q2	603	3,658	63,786	11,201	5,430	6,124	0	604
2002Q3	594	3,685	63,611	11,630	5,923	6,439	0	581
2002Q4	569	3,641	62,401	11,023	5,844	6,623	0	463
2003Q1	606	3,703	66,897	11,128	5,674	6,697	0	527
2003Q2	601	3,774	64,279	11,809	6,578	7,524	0	475
2003Q3	825	4,032	66,834	12,383	7,588	8,236	0	490
2003Q4	799	3,801	65,897	12,119	7,375	8,872	0	457
2004Q1	785	3,938	66,965	12,053	7,391	8,777	0	522
2004Q2	816	4,007	68,064	13,134	8,454	9,247	0	413
2004Q3	905	3,933	72,040	13,971	9,539	9,983	0	481
2004Q4	944	3,905	71,700	13,196	9,487	10,770	0	453
2005Q1	895	3,729	70,464	13,115	8,846	10,420	0	416
2005Q2	991	4,144	76,683	15,638	10,946	12,081	0	439
2005Q3	1,065	4,260	77,925	15,741	12,808	12,706	0	412
2005Q4	973	3,957	76,276	15,480	12,381	13,422	0	329
2006Q1	1,153	4,092	80,785	15,887	12,450	13,113	0	372
2006Q2	1,108	4,253	79,022	17,140	13,247	14,100	0	345
2006Q3	1,209	4,385	83,153	18,105	13,158	15,063	0	361
2006Q4	1,161	4,530	84,528	17,970	12,964	16,177	0	308
2007Q1	1,149	4,489	90,737	19,050	13,219	16,211	0	331

2007Q2	1,192	4,420	90,739	19,767	14,103	6,683	0	289
2007Q3	1,309	4,673	89,921	20,303	15,602	6,954	0	318
2007Q4	1,388	5,321	91,415	19,958	14,875	7,995	0	279
2008Q1	1,349	5,088	92,935	20,092	14,167	7,414	0	255
2008Q2	1,500	6,200	100,562	22,752	16,368	0,187	0	272
2008Q3	1,415	5,261	99,498	23,278	17,377	0,489	0	232
2008Q4	1,471	4,650	100,134	23,436	16,636	2,185	0	216
2009Q1	1,588	4,801	104,771	24,479	16,201	2,558	0	202
2009Q2	1,538	4,980	101,581	25,436	17,557	3,715	0	230
2009Q3	1,755	5,293	107,077	26,983	19,439	4,995	0	247
2009Q4	1,680	4,702	102,250	25,472	18,485	6,978	0	205
2010Q1	1,699	4,738	103,685	25,789	17,685	6,216	0	169
2010Q2	1,648	4,555	85,806	24,382	18,201	6,982	0	180
2010Q3	1,767	4,882	95,385	25,813	20,374	8,567	0	170
2010Q4	1,849	4,763	90,398	24,944	19,597	0,959	0	137
2011Q1	1,963	4,826	92,963	26,139	18,653	9,167	0	171
2011Q2	1,880	4,780	91,462	27,106	19,789	0,453	0	151
2011Q3	2,172	5,466	102,125	30,104	26,968	2,923	12,871	155
2011Q4	2,221	5,125	100,847	28,793	27,474	4,778	16,263	136
2012Q1	2,482	5,636	110,377	31,655	27,675	4,698	16,625	179
2012Q2	2,403	5,608	107,295	32,250	29,264	5,854	16,696	148
2012Q3	2,415	5,753	109,471	33,365	31,617	8,847	17,949	145
2012Q4	2,442	5,752	110,166	33,269	30,578	1,714	17,897	145
2013Q1	2,591	6,047	114,534	33,797	29,866	9,310	16,768	108
2013Q2	2,838	6,423	117,335	36,080	33,694	2,769	18,941	99
2013Q3	2,937	6,806	117,109	36,896	36,368	4,764	21,846	88
2013Q4	2,994	6,918	113,552	36,228	34,893	6,352	22,773	102
2014Q1	3,002	6,976	120,699	37,594	32,916	5,383	22,106	108
2014Q2	3,130	7,468	119,988	38,547	35,930	9,130	25,549	96
2014Q3	3,224	7,554	123,541	40,648	38,353	0,291	27,768	88

2014Q4	3,212	7,817	123,566	41,177	37,057	2,224	17,135	49
2015Q1	3,401	7,898	128,899	41,151	35,762	0,077	9,672	82
2015Q2	3,347	8,294	123,016	41,336	39,666	1,910	9,739	82
2015Q3	3,879	9,304	121,370	41,927	41,299	2,865	9,645	68
2015Q4	3,927	9,217	113,166	40,710	39,087	5,872	8,978	59
2016Q1	4,293	9,823	123,714	41,669	38,340	2,317	9,521	62
2016Q2	4,695	10,472	125,323	44,811	44,471	7,181	11,836	63
2016Q3	4,957	11,141	124,856	45,329	46,254	6,064	10,142	58
2016Q4	4,987	10,832	120,430	44,823	44,577	8,579	9,351	72
2017Q1	5,870	12,380	137,018	48,798	45,657	9,527	10,370	72
2017Q2	5,992	12,618	129,849	48,133	48,847	0,995	10,015	56
2017Q3	6,278	12,830	133,361	49,085	52,435	1,656	10,899	48
2017Q4	6,563	13,081	134,986	49,347	52,331	5,607	12,472	46
2018Q1	7,668	14,379	144,524	52,592	51,199	3,111	10,549	36
2018Q2	7,997	15,461	139,015	54,608	55,177	5,107	12,623	43
2018Q3	8,565	16,172	140,824	56,911	58,989	5,395	11,699	43
2018Q4	8,943	16,841	139,773	57,016	57,800	0,336	11,510	47
2019Q1	9,524	17,606	144,280	59,830	56,311	7,328	11,956	44
2019Q2	10,235	18,763	139,531	62,173	62,432	1,045	12,537	44
2019Q3	12,202	21,726	148,339	66,588	68,053	5,046	12,834	29
2019Q4	12,594	22,274	141,373	64,977	66,237	7,304	11,840	39
TOTAL 2001-2019	**221,265**	**541,440**	**7,428,394**	**2,239,168**	**1,963,837**	**2,466,053**	**489,375**	**18,472**
Percent of all MBS activity	**0.00**	**0.01**	**0.12**	**0.04**	**0.03**	**0.04**	**0.01**	**0.00**
Percent of all Diagnostic Imaging	**0.06**	**0.15**	**2.01**	**0.61**	**0.53**	**0.67**	**0.13**	**0.00**
Percent of all CT scanning	**0.52**	**1.28**	**17.61**	**5.31**	**4.66**	**5.85**	**1.16**	**0.04**

MBS: Medicare Benefit Scheme

Q1: January to March, Q2: April to June, Q3: July to August, Q4: September to December

US: Ultrasound, Nuc Med: Nuclear Medicine

Appendix 3, Table 1: Change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publications of the MBS professional services review (2008-9) and associated media attention

Classification of the change[a]	Geographic location[#]	Magnitude of change						Net change[b] in the rate of CTs performed (Qtr3 2009-Qtr 4 2019)
		Level*			Slope*			
		Point estimate	95% CL		Point estimate	95% CL		
			Lower	Upper		Lower	Upper	
1A	NSW	-233.4	-344.3	-122.4	-8.5	-13.8	-3.2	-16,943.6
	SA	-355.0	-449.9	-260.2	-9.8	-15.7	-4.0	-22,843.0
	Vic	-207.7	-307.1	-108.3	-10.3	-15.1	-5.4	-17,344.1
1B	ALL Australia	-237.7	-333.4	-141.9	-2.2	-7.2	2.8	-9,744.3
	Tas	-186.7	-308.3	-65.0	-5.2	-13.0	2.6	-7,652.7
1C	WA	-402.0	-568.7	-235.3	8.9	0.0	17.7	-9,197.4
	ACT	-325.5	-405.2	-245.8	9.5	5.5	13.5	-5,857.7
	Qld	-127.3	-230.9	-23.7	11.8	7.3	16.4	4,274.8
2C	NT[C]	17.3	-170.4	205.0	11.5	4.4	18.7	9,665.8

MBS: Medicare Benefit Scheme; CT: Computed Tomography scanning

[a]Classification of change: 1A: Significant reduction in both the level and slope; 1B: Significant reduction in the level but no change in the slope; 1C: Significant reduction in the level with a significant increase in the slope; 2A: No significant change in the level with a significant reduction in the slope; 2B: No significance change in the level or slope; 2C: No significant change in the level with a significant increase in the slope; 3A: Significant increase in the level with a significant reduction in the slope; 3B: Significant increase in the level with no change in the slope; 3C: Significant increase in both the level and the slope.

[#]ACT: Australian Capital Territory; NSW: New South Wales; NT: Northern Territory; Qld: Queensland; SA: South Australia; Tas: Tasmania; Vic: Victoria; WA: Western Australia.

*Both the level and slope changes are expressed per 100,000 eligible population residing in the location specified at the time of the service provision

95% CL: 95% confidence limits around the point estimate

p values < 0.05 (95% CL that do not cross zero) are considered as significant changes in level and slope; greyed cells indicate non-significant changes

Values are estimated from the seasonally adjusted single interrupted time series model with autocorrelation correction as required for the data

[b]The net change in the rate was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of MBS funded CT scans. Negative values result from the area below the counterfactual being larger than the area above it and indicate a net reduction in the rate of CT scans undertaken over the post-intervention time period; positive values indicate the reverse. In cases where the post-intervention trend was non-linear the net change is limited to the period prior to further disruptions in the trend.

[c]Post intervention phase was non-linear therefore change reported in the level and slope are limited to the initial post-intervention period prior to any significant further disruption of the trend.

Appendix 3, Table 2: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention

Classification of the change[a]	Type of medical imaging service	Magnitude of change						Net change[b] in the rate of CTs performed (Qtr3 2009-Qtr 4 2019)
		Level*			Slope*			
		Point estimate	95% CL		Point estimate	95% CL		
			Lower	Upper		Lower	Upper	
1A	Head CT	-30.5	-43.5	-17.6	-2.4	-3.1	-1.6	-3,637.4
	Face CT	-16.6	-23.0	-10.2	-0.9	-1.4	-0.5	-1,549.7
	Abdomen/Pelvis CT	-50.4	-63.4	-37.4	-2.0	-2.5	-1.4	-3,695.2
	Spine CT	-61.4	-83.6	-39.1	-3.2	-4.2	-2.2	-5,230.1
1B	Pelvis CT[c]	-3.6	-5.8	-1.5	0.1	0.1	0.2	-47.3
1C	Chest CT	-36.4	-46.4	-26.3	2.5	2.0	3.0	273.4
	Brain, Chest and Upper Abdomen CT[C]	-0.5	-0.9	-0.1	0.2	0.1	0.2	31.1
	Extremities CT	-11.1	-19.0	-3.2	1.1	0.5	1.8	366.5
	Soft Tissue Neck CT	-5.6	-7.4	-3.8	0.3	0.2	0.4	3.9
2A	CT Angiography[C]	-3.0	-6.2	0.3	-1.1	-1.7	-0.6	-16.9
2B	MRI[c]	-9.8	-33.0	13.4	-2.0	-4.6	0.7	0.0
2C	Chest/Abdomen/Pelvis CT	-0.9	-6.2	4.3	0.2	-0.1	0.4	167.9
	All diagnostic imaging (excl CT)	393.8	-68.4	856.0	29.2	3.0	55.4	25,137.6
3C	Interventional CT	10.7	3.0	18.4	1.6	1.2	2.0	1,739.6

MBS: Medicare Benefit Scheme; MRI: Magnetic Resonance Imaging; CT: Computed Tomography scanning

[a]Classification of change: 1A: Significant reduction in both level and slope; 1B: Significant reduction in level but no change in the slope; 1C: Significant reduction in the level and a significant increase in the slope; 2A: No significant change in level with a significant reduction in slope; 2B: No significance change in the level or slope; 2C: No significant change in level with a significant increase in slope; 3C: Significant increase in both level and slope.

*Both the level and slope changes are expressed per 100,000 eligible population residing in Australia at the time of the service provision

95% CL: 95% confidence limits around the point estimate

p values < 0.05 (95% CL that do not cross zero)are considered as significant changes in level and slope; greyed cells indicate non-significant changes

[b]The net change in the rate was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of MBS-funded medical imaging services. Negative values result from the area below the counterfactual being larger than the area above it and indicate a net reduction in the rate of CT scans undertaken over the post-intervention time period; positive values indicate the reverse. In cases where the post-intervention trend was non-linear the net change is limited to the period prior to further disruptions in the trend.

[C]Post intervention phase was non-linear therefore change reported in the level and slope are limited to the intial post-intervention period prior to any significant further disruption of the trend.

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract - Methods Abstract – Methods N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Throughout Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses			Last paragraph of Introduction, page 4
Methods					
Study Design	4	Present key elements of study design early in the paper			First sentence of Methods, page 4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Methods – Data source subheading, page 4

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case		RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	Methods – Data source subheading; Appendix 1 Codes in Appendix 1. Validation / algorithms N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Appendix 1. No confounding variables, though counterfactual is described in Methods – Statistical analysis subheading page 5
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).			Methods subheadings Data Source and Quarterly rate of

		Describe comparability of assessment methods if there is more than one group			imaging, pages 4-5
Bias	9	Describe any efforts to address potential sources of bias			Methods subheading Statistical Analysis, page 5, and Limitations, page 13
Study size	10	Explain how the study size was arrived at			Population for denominator in rates described in Methods – Quarterly rate of imaging, page 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods – Data source subheading, page 4
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical			Methods – Statistical analysis, page 5 N/A N/A No loss to follow-up N/A N/A

		methods taking account of sampling strategy (e) Describe any sensitivity analyses			N/A
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	N/A
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Results first paragraph, page 6 (concerning imaging examinations, not persons)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders			N/A, unit of analysis is imaging procedure rather than persons

		(b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			Results, first two paragraphs, pages 6-7
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Results, unadjusted estimates in paragraph 2, adjusted through remainder
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			
Discussion					
Key results	18	Summarise key results with reference to study objectives			First paragraph, page 10

Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	Limitations subheading, page 13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			Throughout discussion
Generalisability	21	Discuss the generalisability (external validity) of the study results			Implications subheading, page 13
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based			Page 14
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Page 14

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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Impact of regulatory body actions and subsequent media coverage on use of services in a fee-for-service system: A longitudinal cohort study of computed tomography scanning in Australia

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Title page

Title: Impact of regulatory body actions and subsequent media coverage on use of services in a fee-for-service system: A longitudinal cohort study of computed tomography scanning in Australia

Author names and affiliations:

David Youens* [a], Jenny Doust [b], Thi Ninh Ha [a], Peter O'Leary [a, c, d], John Slavotinek [e, f], Cameron Wright [a, g, h, i], Rachael Moorin [a, j]

* Corresponding author. David.youens@curtin.edu.au. GPO Box U1987, Perth, Western Australia, 6845

a Health Economics and Data Analytics, School of Population Health, Curtin University, Perth, Australia

b Centre for Longitudinal and Life Course Research, Faculty of Medicine, University of Queensland

c Obstetrics and Gynaecology, Medical School, Faculty of Health and Medical Sciences, The University of Western Australia, Perth, Western Australia, Australia

d PathWest Laboratory Medicine, QE2 Medical Centre, Nedlands, Western Australia, Australia

e SA Medical Imaging, SA Health

f College of Medicine and Public Health, Flinders University, Adelaide, South Australia

g Fiona Stanley Fremantle Hospitals Group, Western Australia, Australia

h Medical School, Faculty of Health and Medical Sciences, The University of Western Australia, Western Australia, Australia

i School of Medicine, College of Health & Medicine, University of Tasmania, Tasmania, Australia

j School of Population and Global Health, The University of Western Australia, Western Australia, Australia

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Abstract

Objective: The Professional Service Review (PSR) is an Australian Government agency aiming to reduce inappropriate practices funded via Medicare, Australia's public insurer. Our objective was to examine changes in Computed Tomography (CT) following the 2008-09 PSR annual report, which noted excessive CT use.

Design: Interrupted Time Series Analysis examined trends in CT use following the 2008-09 PSR report, estimating both change in the immediate rate of CT and the slope of the trend in usage post-intervention.

Setting: Medicare-funded imaging (most out-of-hospital imaging) in Australia.

Participants: Patients receiving Medicare-funded CT and other imaging

Intervention: The 2008-09 PSR report highlighted concerns regarding excessive CT use. Two providers were financially penalised for CT overuse with these cases detailed in the PSR report and highlighted in an associated *Report to the Professions*, distributed to 50,000 providers. Media articles on radiation risks followed.

Outcomes: Quarterly rates of out-of-hospital CT, magnetic resonance imaging (MRI, as a comparator), and all other Medicare-funded diagnostic imaging examinations 2001-2019.

Results: CT scanning increased from 4,663.5 per 100,000 person-years in 2001 to 14,506 in 2019 (211% increase), with substantial variation by type and anatomical region. The 2008-09 PSR report was followed by an immediate reduction in CT scanning of 237.7 CTs per 100,000 people per quarter (95% CI -333.4 to -141.9) though growth in use soon continued at the pre-intervention rate. The degree of change in utilisation following the report differed between states/territories and by scan type, both in terms of the immediate change and the slope. For other diagnostic imaging modalities there was an increase in the slope, while for MRI there was no change in either parameter.

Conclusion: Actions consisting of financial disincentives for service overtesting and provider / public education components may limit excessive use of diagnostic imaging in fee-for-service systems, however effects observed here were only short-lived.

Keywords: Diagnostic Imaging, Fee-for-Service, Computed Tomography, Medical Overuse,

Strengths and limitations of this study

- This study made use of whole of population administrative data, improving generalisability and preventing loss to follow-up or non response
- Multiple imaging modalities were examined, allowing for an assessment of CT (the target of the PSR actions) and potential substitution by other modes
- Only data on publicly-funded services accessed in the out-of-hospital setting were available; trends in in-hospital CT use were not examined
- The PSR actions involved multiple components and it was not possible to examine specific components in isolation from each other

Introduction

Overtesting is defined as the use of non-recommended screening tests in asymptomatic patients or more testing than necessary to diagnose patients.[1] Overtesting is problematic due to the wasted resources it incurs and the potential for patient harm. Harms of overtesting may fall under six domains:[2] physical, psychological, treatment burden, social, financial, and dissatisfaction with health care. Overtesting with CT may manifest in many of these areas, for example physical harms resulting from radiation exposure [3, 4] psychological harms resulting from incidental findings[5] plus additional physical harms when these findings lead to further procedures or diagnostic tests.[6] Overtesting also consumes healthcare expenditure without improving outcomes,[1] imposing an opportunity cost. Overtesting may result from intrapersonal (e.g. fear of litigation, risk aversion, intolerance of uncertainty), interpersonal (e.g. pressure from patients and colleagues) or contextual (e.g. guidelines, financial incentives, time constraints, test availability) factors.[7] Studies in different countries have shown that over 10% of CT scans reflect overtesting,[8, 9] indicating substantial room for improvement in this area.

CT scanning in Australia is delivered in public and private hospitals, or in the out-of-hospital setting on referral from a general practitioner (GP) or specialist. Most out-of-hospital CT is performed by private clinics[10] which are reimbursed on a fee-for-service (FFS) basis by the Federal Government via Medicare, Australia's public insurer, which covers almost all Australian citizens and permanent residents[11] (with prisoners an exception). Similarly, GPs operate in private practices which are reimbursed by Medicare on a FFS basis hence are incentivised to maximise service volumes.[12] Patients do not register with practices and are free to change providers at any time, so multiple providers compete for services in the out-of-hospital environment, potentially driving overtesting where patients expect certain medical interventions (such as diagnostic CT) and providers feel compelled to meet patient expectations so as to prevent the patient from being 'lost' to another GP who provides or refers for the expected service.[13, 14] Note that decisions regarding out-of-hospital CT scanning are primarily made by referrers (GPs and specialists); radiologists at private clinics generally do not know the setting or patient and are not well positioned to deny scans requested. Although Medicare provides reimbursement for CT scans referred by a GP, MRI scans are generally only reimbursed when referred by a specialist (with some exceptions since 2011).[15] Furthermore, MRI machines must be licensed by the Federal Government in order for scans using that

machine to attract reimbursement, with license availability restricted.[15] This may limit substitution of CT scans by MRI. No such restrictions exist for other modalities.

One of the bodies regulating healthcare in Australia is the Professional Services Review (PSR), which has responsibility for preventing inappropriate practice, both to protect patients from risk and to reduce Government funding of inappropriate care.[16] The PSR reviews the activities of practitioners where unusual service volumes or prescribing patterns suggest inappropriate care. Upon investigation by the PSR, a practitioner found to have engaged in inappropriate practice (as determined by a peer panel of practitioners) may be partially or fully disqualified from claiming Medicare reimbursements for some time, may be required to repay reimbursements claimed for delivery of inappropriate care, or may face suspension from practice.[17] In the 2008-09 PSR annual report published in October 2009, two providers were penalised for CT overtesting. In addition, the Director's report within the annual report commented on CT overtesting, noting concerns about use of CT screening for lower back pain.[18] Alongside this annual report was the dissemination by the PSR of a *Report to the Professions* to 50,000 health providers detailing these cases (and others), and the PSR director also spoke at medical conferences and to the media.[18] This was followed by a period of media interest concerning CT risks, including the publication of articles highlighting the risks of CT, targeted at both clinical audiences[19, 20] and the general public.[21-24] These articles, published through 2010 and 2011 in national[22, 24] and state-specific media,[23] outlined the PSR director's concerns, cancer risks associated with CT, the role of patient expectations as a factor and alternative imaging modalities. These events are collectively referred to as "the PSR actions" throughout this paper for simplicity. Any change in CT scanning resulting from the PSR actions may reflect either a change in imaging levels overall, or shifts to other modalities.

The aim of this project was to examine the impact of the PSR actions on the rate of CT scanning in Australia, to determine if regulatory body action influences overtesting in the FFS context.

Methods

This was a retrospective whole-of-population longitudinal cohort study using aggregate-level administrative data. Reporting follows the Reporting of studies Conducted using Observational Routinely-collected health Data (RECORD) guidelines.[25]

Data source

Quarterly utilisation data for Australia and for each Australian state/territory from Jan-March 2001 to Oct-Dec 2019 inclusive were sourced from publicly available Medicare Benefits Schedule (MBS) records.[26] Data pertaining to CT were extracted using MBS item reports. Data for other Medical Imaging modalities (Ultrasound, Nuclear Medicine and MRI) were extracted using the Group report for Category 5 Diagnostic Imaging Services. Data included only those services performed by a registered provider for services that qualify for Medicare Benefits and for which Services Australia had processed a claim. Data excluded services provided by hospital doctors to public patients in public hospitals and services that qualified for a benefit under the Department of Veterans' Affairs National Treatment Account. These services are not within the purview of the PSR, nor are records of these services available with the MBS data used for the current study. The location services were provided (state/territory) was based on patient address. Calendar quarter was determined by the date of processing by Services Australia, not the date the service was provided to the patient. Note that date of processing is typically within days of the service date. For the denominator the Medicare eligible population for each state/territory was sourced from Medicare enrolment data quarterly standard reports.[27]

CT scanning data were aggregated into fourteen groups reflecting either anatomical area of the scan (e.g. head, chest etc.) or, due to lack of anatomical location on the MBS coding, grouped according to technique (cone beam CT, pelvimetry, spiral angiography and interventional CT) using the MBS item codes in Appendix 1. Since MBS items are for re-imbursement rather than clinical purposes, several items covered multiple CT examinations (Chest, Abdomen/Pelvis and Brain, Chest/Upper Abdomen). For analysis, all CT scanning records pertaining to these items were counted as a single CT scanning event. In the analysis by type of CT these items were grouped separately (see Appendix 2) and were not included in the analysis of their relevant sub-groups (i.e. brain, chest or abdomen/pelvis).

Quarterly rate of imaging

The annual rate of MBS funded imaging per 100,000 eligible persons was calculated for all Australia and by state/territory by dividing the number of services processed in that year by the eligible Medicare population for that year multiplied by 100,000.

Statistical analysis

Interrupted time series analysis (ITSA) was used to evaluate the impact of the PSR actions on the quarterly rate of medical imaging excluding CT, MRI, all CT scanning and type of CT scanning for all Australia and by state/territory.

The analysis was conducted using the '*itsa*' package[28] in Stata version 15.[29] Since the PSR actions affected the whole of Australia a control group was not available for comparison, therefore the model was a single-group ITSA (i.e. the preintervention trend was projected into the postintervention period to serve as the counterfactual) with a dummy indicator variable set to quarter 4 2009 representing the PSR action. Coefficients were estimated using ordinary least squares regression with Newey-West standard errors to handle autocorrelation and heteroskedasticity.

Each model was first fitted with lag 0 specified (i.e. no autocorrelation), following which autocorrelation in the error distribution was tested for using the program '*actest'*[30] and the appropriate lag used in the final model. The model was implemented after adjustment for seasonality using Fourier terms (pairs of sine and cosine functions)[31] using the program '*circular*'.[32] Following Imbens and Lemieux[33] the median timepoint (quarter 4 2004) of the preintervention period was used as a robustness test to determine if the underlying assumption of stability in time-varying unmeasured confounders should be challenged. Where the post-intervention trend was non-linear, multiple dummy variables were used to adequately capture the shape of the post-intervention trend so that a more accurate estimation of the immediate change in the trend and change in level resulting from the PSR action could be estimated.

Classification of response to the 2009-10 Professional Services Review

For each model the direction and statistical significance of the estimates of the level (initial change in the quarterly rate of CT use) and slope (gradient of the trend in quarterly CT use) parameters in the post-intervention period (or for the slope the immediate post-intervention segment where a non-linear trend was observed) were used to classify the response to the PSR action. The primary typology was based on the direction and significance of the level parameter as follows: Type 1: significant reduction in the level; Type 2: no significant change in the level and Type 3: significant increase in the level. Each type was further classified into sub-types based on the change in the slope parameter: a) significant reduction; b) no significant change and c) significant increase.

Calculation of net change in CT imaging procedures following the PSR action

The net change in the CT procedures performed was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of imaging procedures. To reduce over-estimation of the net change where

no significant difference was observed between the pre and post-intervention slopes (i.e. sub type b) the pre-intervention slope parameter was used to define the post-intervention slope rather than the point estimate provided in the ITSA model. Similarly, where no significant difference in level was observed (i.e. type 2), the post-intervention curve was defined with the level change set to zero. When the post-intervention trend was non-linear the net change was only calculated until the beginning of the subsequent change in trend. The net change could be negative (i.e. net reduction in the rate of imaging examinations through the post-intervention period) or positive.

Patient and public involvement

As this is an analysis of secondary data, there was no patient or public involvement.

Results

Over the 19-year study period 369.5 million Medicare funded medical imaging examinations were undertaken in Australia (6.2% of all Medicare funded activity) of which CT scanning comprised 11.4% (42.2 million) (Appendix 2). The most frequently performed type of CT scan was abdomen/pelvis comprising 18.8% [~8 million] of all CT examinations, closely followed by head CT (17.6% [7.5 million]) and spinal CT (17.6% [7.4 million]).

As shown in Table 1 the rate of CT scanning increased from 4,662.2 per 100,000 Medicare eligible persons in 2001 to 14,505.2 per 100,000 in 2019. The increase of 211% was much larger than the increases observed for Ultrasound (+150%) and Nuclear Medicine (+96%), or for diagnostic imaging overall (75%). While the largest increase in the rate of imaging (by modality) was observed for MRI (increasing by ~400% over the study period), the absolute rate was still 64% lower than the rate of CT scanning in 2019. Table 1 also shows the rate of CT scanning according to type across the study period. In 2001 the top three types of CT scanning, ranked according to the rate performed per 100,000 persons, were head CT (1,529.9), followed by abdomen/pelvis CT (1,018.9) and CT of the facial bones (629.9). However, by 2019 this ranking had changed such that abdomen/pelvis CT had the highest rate per 100,000 (2,565.0); spinal CT was now ranked second (2,237.2) and head CT third (1,884.4). The largest relative change in the rate of CT scanning by type from 2001 to 2019 was observed in interventional CT which increased by 1,089% (from 95.3 per 100,000 in 2001 to 1,133.8 in 2019. Similarly, the rate of spiral angiographic CT scanning also rose by 1,054% (from 85.5 per 100,000 in 2001 to 986.8 in 2019). Other notably very large relative increases (i.e. more than tripling of the 2001 rate) were observed for chest/abdomen/pelvis CT (+451%), CT of the

extremities (+407%) and pelvis CT (+358%). Rate increases of over 100% were observed for chest CT (+199%), abdomen/pelvis CT (+152%) and soft tissue neck CT (+147%). The only type of CT scan to reduce in rate was cone beam CT which was first funded under Medicare in 2011 (quarter 3).

Table 1 Annual rate of MBS funded diagnostic imaging by modality and type of CT scanning services in Australia across the study period

Year	Rate per 100,000 eligible population					Rate of CT per 100,000 eligible population			
	All diagnostic imaging	MRI	US	Nuc Med	All CT	Head	Face	Soft tissue Neck	Chest
2001	62,815.20	1,056.10	17,753.80	1,494.80	4,662.20	1,529.90	629.9	1197	519
2002	64,018.20	1,173.00	18,540.80	1,514.50	5,993.70	1,522.60	630	1252	558.8
2003	64,489.60	1,270.30	19,310.30	1,517.10	6,304.30	1,543.40	624.1	1305	586.6
2004	65,657.10	1,350.00	19,929.00	1,522.90	6,663.80	1,546.30	640	1354	631.1
2005	70,767.70	1,558.40	22,127.80	1,588.50	7,428.70	1,662.20	699.2	1488	695.2
2006	73,155.60	1,776.10	23,344.80	1,617.60	7,941.90	1,697.70	738	1561	724.8
2007	76,179.30	1,958.40	24,717.90	1,684.10	8,516.50	1,779.10	764.1	1631	765.5
2008	78,983.80	2,050.00	26,189.10	1,801.80	9,036.20	1,815.10	808.6	1705	803
2009	82,260.00	2,252.70	28,004.90	1,980.30	9,592.60	1,874.30	840.9	1787	834.9
2010	83,548.70	2,346.90	29,065.00	2,138.80	9,085.60	1,745.40	772.4	1719	793.2
2011	86,766.50	2,501.10	30,801.00	2,334.20	9,615.50	1,739.70	787.5	1813	854.9
2012	90,623.80	2,640.90	33,148.70	2,544.40	10,674.40	1,812.40	819.7	1927	923.1
2013	94,223.40	3,003.00	35,368.00	2,677.70	11,246.60	1,837.80	827.2	2039	986.7
2014	98,378.10	3,891.20	36,959.40	2,727.90	11,705.00	1,760.80	843.5	2127	1,068.20
2015	99,830.50	4,107.90	38,121.70	2,717.40	11,698.90	1,756.70	845.6	2177	1,140.50
2016	101,767.50	4,249.20	39,553.80	2,694.50	12,098.00	1,753.30	840.3	2324	1,221.70
2017	106,182.50	4,653.20	41,481.60	2,814.20	13,008.90	1,842.10	880.3	2531	1,345.50
2018	108,783.70	4,927.40	43,087.80	2,850.30	13,744.10	1,875.90	909.7	2682	1,422.70
2019	110,010.00	5,277.30	44,452.10	2,925.40	14,505.20	1,884.40	930.1	2941	1,552.00
Percent change total 2001 to total 2019*	**75.1**	**399.6**	**150.4**	**95.7**	**211.1**	**23.2**	**47.7**	**146.5**	**199**

Year	Rate of CT per 100,000 eligible population							
	Abdomen/ Pelvis	Pelvis	Spine	Chest / Abdomen / Pelvis	Extremity	Spiral Angiography	Interventional CT	Cone Beam
2001	1,018.90	68.5	N/A	227.2	195.3	85.5	95.3	N/A
2002	1,124.90	70.3	1,229.20	268.4	213.8	107	120.6	N/A
2003	1,223.40	74	1,275.80	311.1	229.3	131.5	151.4	N/A
2004	1,320.30	75.2	1,328.60	361	249.5	166.2	184.8	N/A
2005	1,465.50	78.5	1,470.10	433.2	292.6	219.4	237.2	N/A
2006	1,579.60	83	1,575.40	495.4	332.4	249.3	281.1	N/A
2007	1,687.70	89.5	1,718.10	549.7	374.5	273.7	321.2	N/A
2008	1,780.40	99	1,834.80	599.8	417.9	301.2	374.6	N/A
2009	1,898.20	90.9	1,911.50	677.6	470.7	329.5	451.6	N/A
2010	1,782.40	85.4	1,693.50	701	455.4	342.2	508.4	N/A
2011	1,842.80	89.4	1,714.50	766.9	496.3	410.8	563.4	N/A
2012	1,987.80	98.8	1,899.00	855.4	566.8	517.2	656	300.3
2013	2,081.80	111.7	1,973.20	907.8	610	575	738.7	342.5
2014	2,149.10	124.9	2,043.80	968.4	661.8	604.3	825.4	387.9
2015	2,164.60	143.2	2,007.80	1,011.50	681.4	642.9	869.5	157
2016	2,219.80	171.9	2,010.50	1,068.10	718.3	706	911.5	166.1
2017	2,352.60	204	2,144.50	1,138.00	782.8	798.3	992.7	175.3
2018	2,474.90	248.3	2,229.00	1,202.00	873.6	881.6	1,042.70	183.2
2019	2,565.00	313.4	2,237.20	1,253.00	989	986.8	1,133.80	191.8
Percent change total 2001 to total 2019*	**151.7**	**357.8**	**30.2**	**451.3**	**406.5**	**1,053.90**	**1,089.20**	**-44**

MBS: Medicare Benefit Scheme; US: Ultrasound; Nuc Med: Nuclear Medicine; NA = Item not available

Grey cells indicates that MBS funded services were not available for all or part of the specified time period

*Where MBS item was not available in for the whole of 2001 percentage change is calculated from first year it was available in all quarters

Figure 1 shows the results of the ITSA evaluating changes in the use of CT following the PSR actions, by state/territory; values informing the figure are in Appendix 3. On average after adjusting for seasonality and autocorrelation there was a significant reduction in the level parameter (-237.7 CTs per 100,000 Medicare eligible persons [95% Cl -333.4 to -141.9]) indicating an immediate response. However, no significant change in the slope parameter was observed, indicating no sustained effect i.e. following the initial drop in utilisation, growth in CT scanning continued at its previous rate. Despite there being no sustained change, over the post-intervention period (Qtr 4 2009-Qtr 4 2019) the cumulative rate (i.e. the net change) of CT use reduced by 9,744.3 per 100,000 due to the initial level change, compared with the counterfactual. This can be readily observed graphically in Figure 2. Across Australian states and territories, the response differed (Figure 1). In all states/territories except the Northern Territory there was a significant reduction in the level; however, the response in the slope parameter differed. In New South Wales, South Australia and Victoria there was a significant reduction in the slope parameter (i.e. sustained reduction), in Tasmania there was no significant change in the slope, while in the Australian Capital Territory, Queensland, Western Australia and the Northern Territory after the initial reduction in level there was a significant increase in the slope parameter.

Figure 3 shows the results of the ITSA according to type of CT scanning in Australia (values in Appendix 3). The majority of CT scanning types showed an immediate significant reduction in level, the exceptions being CT angiography and chest/abdomen/pelvis CT which showed no change, and interventional CT, which showed an increase in level. With respect to sustained change (i.e. slope) there was a much larger variation across type with reductions (head, face, abdomen/pelvis, spine CT and CT angiography), increases (chest, extremity, soft tissue neck, brain/chest/upper abdomen and interventional CT) and on one occasion no change (pelvis CT) observed. Figure 3 also shows the results of the analysis for MRI, which showed no response in either parameter and all diagnostic imaging excluding CT, which showed no change in the level but an increase in the slope parameter. Changes for all diagnostic imaging excluding CT are also presented in Figure 4, displaying the change in the slope parameter through the post-intervention period.

Discussion

CT use reduced significantly following the 2008-09 PSR annual report, associated sanctions and subsequent media coverage of CT risks. Following this short-term decline, CT use continued increasing at the pre-intervention rate, though results differed by scan type/region and state/territory. Findings indicate that major reviews including financial penalties and surrounding coverage have potential to decrease overtesting, but that reductions may not be sustained.

Being an observational study we cannot assume causation, though we highlight some important points in considering this. There was a close temporal relationship between the PSR report and the changes in CT use, which would be expected if changes were causal. The face validity of a causative relationship can be considered via the overtesting framework developed by Lam *et al*.[7] Interpersonal drivers of overtesting may have influenced CT use as the mass media coverage outlined radiation risks to patients and included some discussion of the role of patient expectations in driving imaging requests.[22-24] On the provider side, fear of reputational damage following a reprimand is also an interpersonal factor. Environmental drivers may have changed if providers grew concerned about financial penalties from the PSR for excessive imaging. Intrapersonally, the risk aversion that drives overtesting in the search for a definitive diagnosis may have been countered by improved knowledge of radiation risks.

The risk of reputational damage or financial penalties was low, with the PSR report discussing two providers sanctioned for inappropriate CT. However, these cases were widely disseminated, via the *Report to the Professions* describing these cases (and others) to 50,000 providers. Furthermore the PSR director speaks at national medical conferences and to the media about PSR activities,[18] and attends meetings of medical colleges and the Australian Medical Association to further raise awareness of PSR activities.[34] Although we are not aware of any surveys or other material describing awareness of the PSR among providers or patients, the dissemination activities outlined above likely led to a reasonable degree of awareness among providers. Moreover, a 2011 review of diagnostic imaging noted that the 2008-09 PSR had likely impacted practice, and that private providers had expressed concerns regarding profitability following this.[35] Penalties for inappropriate CT appeared in the 2009-10 and 2011-12 PSR annual reports, however there was no specific discussion of CT in the director's reports nor are we aware of media coverage following these reports.

There is prior evidence in Australia of educational interventions reducing CT. In 2013 the National Prescribing Service's (NPS) MedicineWise program ran an intervention to reduce

inappropriate CT for acute lower back pain.[36] This included a report to GPs comparing their referral rates for lower back CT to their peers, an online decision support tool and a symptom self-management prescription pad. The intervention reduced lower back CT by over 10%, which persisted through 20-months follow-up. This demonstrates some receptiveness to messaging regarding CT overtesting, though mechanisms of action by which the PSR may have influenced practice would differ. Similarly, the introduction of a Choosing Wisely recommendation to reduce imaging for lower-back pain in the United States in 2012 was followed by a 4% reduction in such imaging.[37] The Choosing Wisely campaign regarding lower back CT in the USA did not involve any financial disincentives such as the PSR actions in the current study, though did garner substantial media attention[37] so some drivers of change may have been comparable. A review of interventions to reduce overuse care suggested that educational interventions targeted at both clinicians and patients are among the most effective type,[38] supporting the notion that media coverage on CT overtesting may have influenced practice.

Results here differed between states/territories and CT type. Differences in results across CT type do not appear to be driven by differences in the radiation dosages associated with each type, given that Chest / Abdomen / Pelvis scans showed no change in either parameter following the PSR action but expose patients to some of the highest effective doses.[39] Differences observed between states / territories may have resulted from differences in the baseline level of CT use; this is likely as availability of CT scanners, one driver of overtesting, does differ between jurisdictions.[15] These differences may have also resulted from differences in messaging in each state / territory, caused by either different levels of media coverage of this issue (as some coverage appeared in local[23] rather than national newspapers), or addresses by the PSR director to medical conferences in some states but not others. Baseline attitudes towards CT, and hence the capacity for reductions in use, may have also differed between networks of providers, given the concentration of scanners and providers in capital cities[15] which are in many cases geographically isolated.

There were differences observed between CT and other modalities. In contrast with the drop in CT use following the PSR, MRI showed no change following the 2008-09 PSR report, while for all diagnostic imaging excluding CT the slope increased significantly, while the level parameter showed a large but non-significant increase. This may represent substitution for modalities with lower or no associated radiation exposures (e.g. x-ray or ultrasound, respectively). MRI use increased steadily through the study period, reflecting an increase in

availability of MR machines from below- to above-average in comparison to other Organisation for Economic Co-operation and Development countries.[40] There was no additional increase in use of MRI following the PSR actions, however, likely because licensing of MR devices is constrained by the Federal Government and most MRI investigations are not reimbursed by Medicare when referred by a GP, limiting potential for substitution.[41, 42] Alternatively, there may have been an increase in privately funded MRI which would be unobservable in the Medicare data used here.

Implications

Although the PSR actions were followed by a reduction in CT use, growth then continued at the pre-intervention rate. This suggests that although such actions may be influential, any resulting changes in behaviour may not be sustained in the absence of ongoing intervention. As the PSR publishes annual reports there may be opportunities to replicate the actions assessed here, if media interest in the topic could be sustained, which may produce longer-term changes in CT use.

These findings will be of interest to researchers and policymakers wanting to understand mechanisms to prevent overtesting, though contextual factors are important in understanding how effective such actions may be elsewhere. Provider and patient education regarding radiation risks, threats of financial penalties and reputational damage following exposure of inappropriate practice would likely be influential mechanisms across settings. The degree of response to such mechanisms, however, would depend in part on the baseline level of overtesting, driven in part by health system design. In health systems where providers are paid via capitation or salary rather than FFS overtesting may be less common, with FFS systems known to incentivise service volumes.[43] Similarly, in some health systems patients register with a practice[44] and cannot 'doctor-shop' as is the case in Australia. In such systems providers are not financially incentivised to increase patient satisfaction by delivering requested services, as patients cannot simply access the service via another practice. Overtesting may be incentivised where pay-for-performance programs prioritise patient satisfaction, as providers may feel pressured to refer patients for requested imaging services so as to maintain satisfaction ratings.[45] Relationships between providers referring for imaging and those performing imaging may also influence overtesting, e.g. ownership by physicians of radiology services is associated with increased radiology use.[46] A shift from a volume-driven to a value-driven system could prevent overtesting by focusing on the delivery of interventions to maximise patient outcomes

rather than service delivery.[47] Finally, the PSR actions studied here were facilitated in part by the existence of the PSR which has oversight of all Medicare-funded services and authority to impose penalties. Although the PSR objectives of patient safety and cost containment are priorities globally, mechanisms available to regulators will differ elsewhere.

Strengths

This study benefited from the use of whole of population administrative data, improving generalisability and preventing loss to follow-up or nonresponse. The data cover a long study period both prior to and following the PSR action, improving effect estimates, and covers multiple imaging modalities. The analysis accounted for potential seasonality in the use of CT and non-linearity in post-intervention trends.

Limitations

Data were limited to services funded via Medicare Australia. Comparable data concerning patients in public hospitals were not available, and we cannot comment on potential trends in that setting.

There was no comparator available, which may have supported a more rigorous design. The PSR has a national scope, meaning there was no setting without the PSR action against which to compare trends. Different sets of MBS items were assessed as comparators in the hope of providing control for broader health system changes, but no items could be found for which pre-intervention trends resembled CT.

The data used did not allow for services to be assessed at the level of individual provider. As the PSR targets providers with unusually high volumes of services, it is possible that CT reductions following the PSR were concentrated among a small number of practitioners with high CT referral rates, alternatively it is possible that media messaging led to a more uniform change across providers. We could not assess provider-specific effects due to this data limitation.

Rates here used the Medicare-eligible population as the denominator, though changes in the number of people presenting for care may also be a suitable denominator as changes in this may impact CT use. The quarterly counts of GP contacts were included and show no change around the time of the PSR actions which would account for changes in the rates of CT observed.

This study examines an action consisting of multiple components, and we are not able to assess, for example, mass media coverage in isolation from the publication of financial penalties for overtesting.

Conclusion

This study suggests that regulatory body action may influence provider behaviour within a FFS context. However, it also suggests that point-in-time interventions have limited longevity. The combination of financial incentives (i.e. penalties for excessive use), patient and provider education, and risks to reputation via potential for publicising of investigation outcomes was followed by reduced CT use. Further research examining how best to couple such actions with more sustained reinforcement over time to influence behaviour would be useful, in addition to studies assessing the proportionate impacts of individual components.

Author Contributions

RM conducted analyses for this paper. DY and RM prepared the first draft manuscript. RM, JD, POL, JS and CW developed the grant application under which this work was funded. All authors collaborated on writing the paper and approve the submitted version.

Ethics approval

Ethics approval was provided by the Curtin University Human Research Ethics Committee, approval number SMEC-80-10. Participant consent was not sought as data were a publicly available, aggregated collection of data on service volumes. There is no possible way to identify any of the people receiving the services the data relate to, nor to contact them for the purpose of obtaining consent.

Patient consent for publication

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Data sharing

Data used in these analyses can be requested from the authors.

Competing interests

None declared.

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Figure legends

Figure 1: Part A indicates change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publication of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B indicates net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by State.

Figure 2: Impact of the 2008-9 professional services review on the rate of Medicare funded CT scanning (per 100,000 Medicare eligible population) in Australia. Part A indicates quarterly rate of all MBS funded CT scans showing counterfactual and post-intervention fitted line (seasonality removed for simplification). Part B is a representation of the seasonally adjusted area under and between the curves used to estimate net effect of the response to the MBS professional services review 2008-9.

Figure 3: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention. Superscript L and S

indicate significant changes in the level and slope parameters, respectively. Part B displays net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by type / anatomical area.

Figure 4: Impact of the 2008-9 professional services review on the rate of Medicare funded diagnostic imaging excluding CT) (per 100,000 Medicare eligible population) in Australia. Figure indicates quarterly rate of all MBS imaging claims (excluding CT) showing counterfactual and post-intervention fitted line (seasonality removed for simplification).

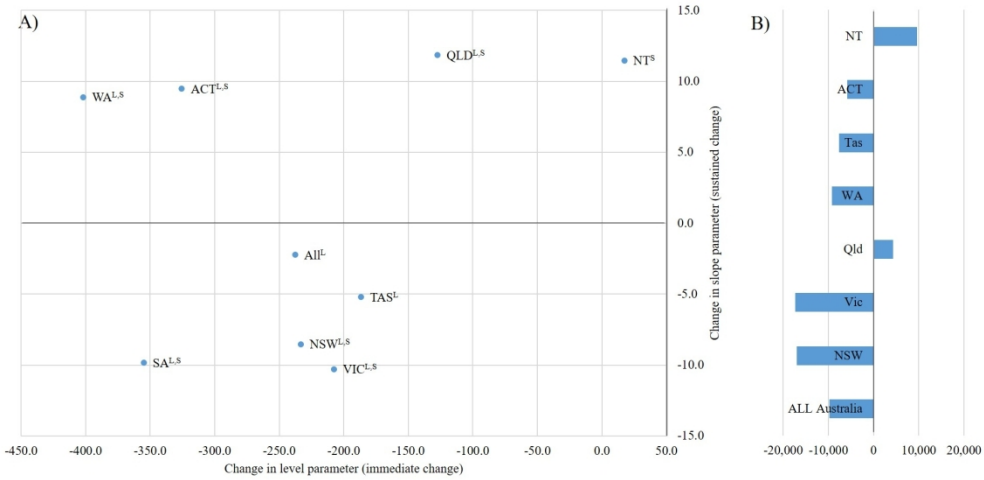

Figure 1. Part A indicates change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publication of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B indicates net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by State.

332x163mm (150 x 150 DPI)

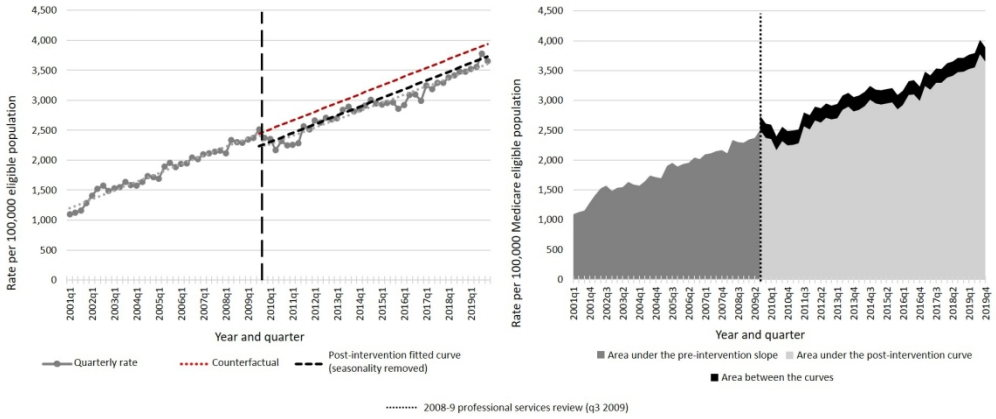

Figure 2: Impact of the 2008-9 professional services review on the rate of Medicare funded CT scanning (per 100,000 Medicare eligible population) in Australia. Part A indicates quarterly rate of all MBS funded CT scans showing counterfactual and post-intervention fitted line (seasonality removed for simplification). Part B is a representation of the seasonally adjusted area under and between the curves used to estimate net effect of the response to the MBS professional services review 2008-9.

320x135mm (150 x 150 DPI)

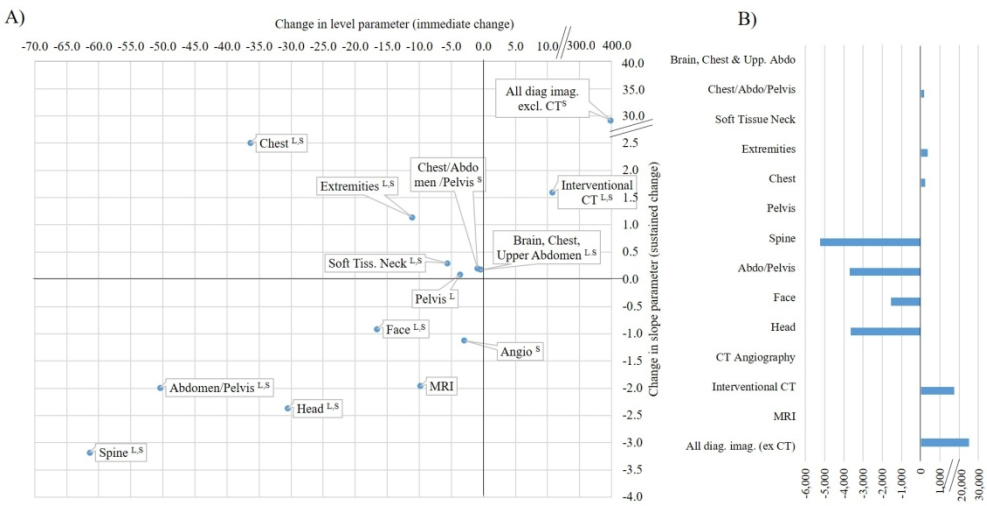

Figure 3: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B displays net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by type / anatomical area.

332x170mm (150 x 150 DPI)

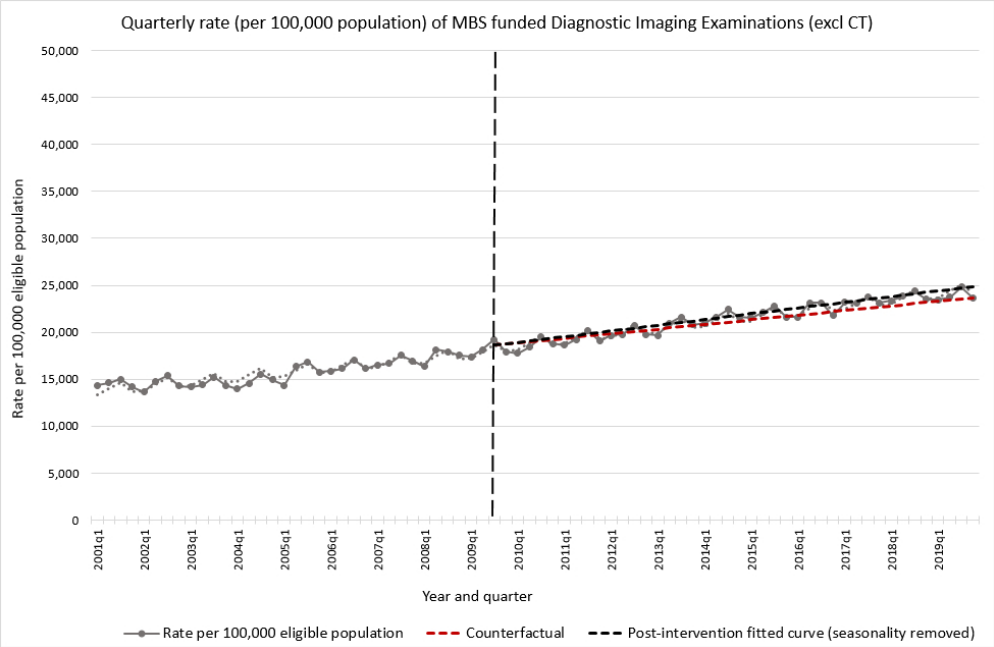

Figure 4: Impact of the 2008-9 professional services review on the rate of Medicare funded diagnostic imaging excluding CT) (per 100,000 Medicare eligible population) in Australia. Figure indicates quarterly rate of all MBS imaging claims (excluding CT) showing counterfactual and post-intervention fitted line (seasonality removed for simplification).

655x428mm (38 x 38 DPI)

Appendix 1: Grouping of CT MBS items according to anatomical location or technique

Group	MBS item number	Description
Head	56001 / 56041	Brain (Non-contrast)
	56007 / 56047	Brain (Contrast)
	56010 / 56050	Pituitary fossa (+/- Contrast)
	56016 / 56056	Petrous bones (+/- Contrast)
Facial bones	56028 /56036 /56068	Facial bones / sinuses or both (Contrast)
	56022 / 56062	Facial bones / sinuses or both (Non-contrast)
	56076 / 56030 / 56070	Facial bones / sinuses or both + Brain (+/- Contrast)
	56013 /56053	Orbits (+/- Contrast)
Neck (soft tissue)	56101 /56141	Soft tissue neck (Non-contrast)
	56107 / 56147	Soft tissue neck (Pre and post contrast)
Chest	56301 / 56341	Chest +/- upper abdo (Non-contrast)
	56307 / 56347	Chest +/- upper abdo (Pre + post contrast)
Abdomen (+/-Pelvis)	56401 / 56441	Upper Abdo -diaphragm to iliac crest (Non-contrast)
	56407 / 56447	Upper Abdo -diaphragm to iliac crest (Contrast)
	56501 / 56541	Abdo/Pelvis (Non-contrast)
	56507 / 56547	Abdo/Pelvis (Contrast)
	56549 / 56551 / 56552 / 56553/ 56554 / 56555	Virtual Colonoscopy
Pelvis only	56409 / 56449	Pelvis (Non-contrast)
	56412 /56452	Pelvis (Contrast)
Chest/Abdo/Pelvis	56801 /56841	Chest/Abdo/Pelvis +/- neck (Non-contrast)
	56807 / 56847	Chest/Abdo/Pelvis +/- neck (Pre + post contrast)
Brain, Chest and Upper Abdomen	57001 /57041	Head + Chest+/-upper abdomen without contrast
	57007 / 57047	Head + Chest +/- upper abdomen with contrast

Spine	56220 / 56227	Cervical spine (Non-contrast)
	56224 / 56230	Cervical spine (Contrast + Non Contrast)
	56221 / 56228	Thoracic spine (Non-contrast)
	56225 / 56231	Thoracic spine (Contrast + Non Contrast)
	56223 / 56229	Lumbar spine (Non-contrast)
	56226 / 56232	Lumbar spine (Contrast + Non Contrast)
	56219 / 56259	Spine - 1 or more regions (With Intrathecal Contrast)
	56233 / 56235	Spine (2 exams of any (C, T or L) kind Non-contrast)
	56234 / 56236	Spine (2 exams of any kind (C, T or L) with Contrast + Without Contrast)
	56237 / 56239	Spine (3 regions C,T,L Non-contrast)
	56238 /56240	Spine (3 regions C,T,L With Contrast + Non Contrast)
Extremities	56619 / 56620/ 56622/ 56623/ 56625	CT of extremities one or more regions (Non-contrast)
	56626 /56627/ 56628/ 56629/ 56630/ 56659 / 56665	CT of extremities one or more regions (Non-contrast)
Spiral Angiography*	57350-57356	Spiral angiography (Pre + post contrast)
	57360/57361	CT of the coronary arteries
Cone Beam CT	56025/56026/57362/57363	Cone Beam CT of teeth and supporting bone structures
Pelvimetry	57201 / 57247	Pelvimetry
Interventional CT	57341 / 57345	CT in conjunction with a surgical procedure using interventional techniques

MBS: Medicare Benefit Scheme

*Spiral angiographic CT item codes relate specify several broad clinical settings relating to their use.

Appendix 2: Size of the Medicare eligible population, and numbers of imaging procedures performed by type, per quarter

		Number of imaging procedures per quarter, by type (excl CT)						
Year and quarter	**Medicare eligible population**	**ALL MBS**	**General Practitioner visits**	**All Diagnostic Imaging**	**Diagnostic Imaging excluding CT**	**ALL MRI**	**All US**	**All Nuc Med**
2001Q1	19,974,075	53,913,292	22,535,443	3,080,396	2,862,100	47,080	875,892	72,556
2001Q2	20,058,815	54,612,217	23,208,144	3,163,585	2,937,355	52,84	890,270	74,655
2001Q3	20,139,806	57,160,177	24,425,178	3,250,431	3,017,862	56,58	901,629	78,692
2001Q4	20,215,957	53,802,181	22,153,529	3,129,899	2,869,771	55,78	900,319	74,530
2002Q1	20,296,405	52,698,145	21,476,055	3,050,855	2,764,530	53,73	877,966	71,292
2002Q2	20,374,998	57,043,850	23,767,570	3,321,404	3,010,541	60,26	949,968	78,445
2002Q3	20,451,273	58,573,985	24,368,388	3,462,073	3,140,545	64,44	995,302	82,390
2002Q4	20,525,042	54,100,126	21,792,309	3,234,123	2,929,308	61,04	961,803	77,054
2003Q1	20,574,715	53,702,789	21,315,160	3,235,168	2,919,654	60,33	974,715	75,127
2003Q2	20,640,449	55,029,284	22,356,470	3,296,996	2,977,779	65,29	982,227	77,892
2003Q3	20,724,986	58,373,440	24,129,408	3,492,688	3,153,252	69,92	1,028,635	81,564
2003Q4	20,805,416	55,102,234	21,673,949	3,316,288	2,986,225	67,26	1,009,242	79,271
2004Q1	20,892,413	55,237,593	21,666,698	3,251,558	2,923,221	65,88	993,179	75,292
2004Q2	20,971,967	57,668,884	22,696,197	3,397,421	3,053,659	70,74	1,025,832	79,572
2004Q3	21,040,363	60,479,828	24,247,888	3,630,147	3,264,529	73,16	1,088,136	84,727
2004Q4	21,020,468	58,681,495	22,853,173	3,497,953	3,137,363	73,48	1,074,598	79,970
2005Q1	20,395,854	55,265,155	21,262,334	3,272,212	2,926,937	68,65	1,018,953	73,814
2005Q2	20,482,464	61,889,434	24,051,201	3,736,003	3,347,527	81,13	1,157,994	84,654
2005Q3	20,535,311	63,925,592	25,233,583	3,864,039	3,463,294	86,18	1,201,410	86,013
2005Q4	20,570,360	59,950,302	22,770,828	3,634,302	3,245,994	83,50	1,157,675	81,138
2006Q1	20,651,536	61,070,666	22,888,207	3,673,330	3,273,759	86,36	1,166,540	80,584
2006Q2	20,738,739	62,420,316	23,652,256	3,749,991	3,345,574	90,24	1,190,679	82,258
2006Q3	20,834,970	65,739,068	25,539,356	3,981,768	3,556,490	98,37	1,254,468	88,615
2006Q4	20,918,630	62,183,136	23,051,071	3,802,035	3,380,338	94,24	1,241,269	84,811

2007Q1	21,023,544	64,047,623	23,223,619	3,909,736	3,469,566	97,875	1,276,478	85,374
2007Q2	21,075,599	65,922,562	24,130,232	3,961,046	3,515,224	103,019	1,285,806	87,332
2007Q3	21,156,498	70,587,243	26,691,515	4,164,895	3,711,184	108,799	1,331,460	90,249
2007Q4	21,213,097	68,075,447	24,303,827	4,052,075	3,593,258	103,894	1,326,226	92,717
2008Q1	21,300,775	66,111,755	23,520,354	3,932,797	3,481,827	97,289	1,284,795	86,786
2008Q2	21,382,498	73,943,872	26,298,507	4,374,974	3,876,485	113,767	1,446,356	100,177
2008Q3	21,474,007	73,411,004	26,802,312	4,347,958	3,854,001	114,660	1,437,929	100,593
2008Q4	21,542,093	72,757,668	25,038,849	4,268,041	3,775,261	113,596	1,442,680	98,530
2009Q1	21,611,182	72,990,845	24,512,108	4,265,199	3,758,331	109,507	1,442,832	101,325
2009Q2	21,712,379	74,849,371	26,821,617	4,450,168	3,935,534	121,503	1,515,593	106,838
2009Q3	21,799,725	79,059,828	27,838,442	4,735,321	4,188,550	134,373	1,592,771	114,116
2009Q4	21,864,719	77,132,787	26,394,306	4,439,849	3,921,910	124,631	1,539,685	108,432
2010Q1	21,995,898	73,945,829	25,424,324	4,423,973	3,905,995	119,415	1,535,498	109,394
2010Q2	22,116,286	78,262,472	26,549,056	4,554,003	4,075,502	132,073	1,583,459	115,291
2010Q3	22,225,493	80,332,900	28,142,355	4,845,036	4,329,256	134,639	1,668,768	125,165
2010Q4	22,322,182	79,520,986	26,438,106	4,697,780	4,196,325	134,156	1,655,431	124,342
2011Q1	22,430,782	78,696,720	26,010,154	4,686,355	4,180,032	129,057	1,642,691	121,167
2011Q2	22,536,170	80,591,361	27,413,666	4,846,047	4,332,553	140,184	1,695,068	127,800
2011Q3	22,646,567	86,000,221	29,054,464	5,159,265	4,578,841	153,104	1,832,694	139,046
2011Q4	22,752,945	80,099,988	26,848,618	4,912,101	4,339,480	142,808	1,789,169	139,453
2012Q1	22,869,958	83,090,073	27,328,488	5,107,472	4,499,155	143,874	1,862,446	143,865
2012Q2	22,975,129	83,419,449	28,489,105	5,146,458	4,542,312	151,104	1,875,437	145,229
2012Q3	23,083,927	87,331,463	29,872,637	5,406,664	4,781,580	157,747	1,955,461	150,517
2012Q4	23,186,999	88,148,306	27,973,187	5,209,940	4,589,199	155,520	1,940,993	146,353
2013Q1	23,301,712	81,070,495	27,558,438	5,204,538	4,575,455	151,607	1,941,553	147,521
2013Q2	23,415,863	87,420,296	30,105,954	5,572,789	4,907,148	172,931	2,092,082	158,845
2013Q3	23,526,793	91,269,394	31,279,774	5,764,539	5,084,337	181,946	2,156,469	162,931
2013Q4	23,516,579	87,442,632	28,772,106	5,546,788	4,885,276	197,659	2,101,276	158,443
2014Q1	23,726,126	87,365,616	29,058,733	5,647,377	4,972,344	214,246	2,126,548	157,860
2014Q2	23,816,689	92,173,285	30,602,781	5,845,674	5,153,281	230,866	2,186,482	162,773

2014Q3	23,923,051	94,962,398	32,149,396	6,089,946	5,370,449	246,153	2,265,530	165,754
2014Q4	23,997,461	92,135,078	29,577,466	5,897,348	5,190,581	237,565	2,242,799	164,672
2015Q1	24,105,563	90,560,806	29,192,987	5,901,602	5,195,336	233,585	2,242,250	162,921
2015Q2	24,179,690	95,743,360	32,217,965	6,060,642	5,346,902	253,841	2,293,992	168,956
2015Q3	24,278,495	98,437,227	33,192,194	6,261,986	5,542,495	262,668	2,373,981	170,088
2015Q4	24,366,559	95,229,471	30,215,723	5,967,569	5,272,222	245,417	2,328,097	156,482
2016Q1	24,453,229	92,813,393	29,917,061	5,997,592	5,283,310	240,294	2,338,670	156,130
2016Q2	24,553,190	102,637,644	33,843,841	6,440,165	5,682,508	272,756	2,512,656	170,212
2016Q3	24,636,038	100,005,965	33,410,503	6,462,300	5,698,777	275,305	2,487,482	171,942
2016Q4	24,711,652	95,516,816	30,979,374	6,123,586	5,384,207	256,559	2,387,030	164,289
2017Q1	24,821,154	100,586,254	31,735,405	6,557,448	5,752,386	272,317	2,567,688	175,505
2017Q2	24,924,168	103,376,540	33,864,514	6,547,871	5,755,139	294,155	2,565,789	174,498
2017Q3	25,007,901	104,773,012	35,065,253	6,770,682	5,947,070	301,476	2,608,763	179,662
2017Q4	25,078,863	104,675,460	32,269,893	6,625,438	5,799,977	293,524	2,610,899	172,694
2018Q1	25,182,661	101,038,400	32,092,680	6,725,986	5,873,983	290,847	2,653,510	180,775
2018Q2	25,267,605	109,365,729	35,737,557	6,882,768	6,020,760	315,569	2,722,980	177,872
2018Q3	25,353,168	106,249,390	34,517,832	7,057,888	6,177,536	328,216	2,764,644	182,907
2018Q4	25,436,468	106,876,163	33,190,019	6,867,102	5,982,682	312,607	2,764,861	179,849
2019Q1	25,520,089	105,168,957	32,968,083	6,881,495	5,981,931	302,827	2,801,529	180,979
2019Q2	25,595,189	111,352,700	37,391,585	6,978,029	6,068,535	358,076	2,808,803	184,667
2019Q3	25,675,916	113,030,934	36,443,353	7,335,021	6,365,854	354,052	2,933,923	193,589
2019Q4	25,754,980	108,011,995	33,510,224	7,009,009	6,068,363	338,102	2,852,030	190,786
TOTAL 2001-2019		**5,986,242,372**	**2,089,094,937**	**369,444,996**	**327,257,812**	**12,158,315**	**131,610,743**	**9,438,609**
Percent of all MBS activity			**34.9**	**6.17**	**5.47**	**0.2**	**2.2**	**0.16**
Percent of all Diagnostic Imaging					**88.58**	**3.29**	**35.62**	**2.55**
Percent of all CT scanning								

Table continued

Year and quarter	Number of CT examinations per quarter, by type						
	ALL CT	Head CT	Facial bones CT	Neck (soft tissue) CT	Chest CT	Chest/Abdo/Pelvis CT	Abdomen (+/- pelvis) CT
2001Q1	218,296	75,243	29,194	5,846	25,038	10,890	49,942
2001Q2	226,230	78,787	31,520	5,939	25,496	10,934	50,612
2001Q3	232,569	77,870	34,130	6,000	26,799	11,658	51,566
2001Q4	260,128	75,556	31,757	6,216	26,987	12,194	52,659
2002Q1	286,325	72,827	28,723	5,943	26,344	12,515	54,436
2002Q2	310,863	80,824	32,855	6,477	28,191	13,491	57,619
2002Q3	321,528	82,648	35,417	6,737	30,494	14,510	59,259
2002Q4	304,815	74,501	31,611	6,479	29,060	14,286	58,314
2003Q1	315,514	78,396	30,083	6,508	28,524	15,133	61,638
2003Q2	319,217	79,059	32,590	6,549	28,936	15,241	61,802
2003Q3	339,436	83,562	34,796	6,976	31,994	16,793	64,927
2003Q4	330,063	78,264	31,652	6,996	31,908	17,194	64,729
2004Q1	328,337	76,190	29,486	7,002	30,747	17,864	66,617
2004Q2	343,762	80,273	33,374	6,994	31,536	18,311	69,139
2004Q3	365,618	85,257	36,384	7,272	35,081	19,594	71,178
2004Q4	360,590	82,754	35,066	7,179	35,066	19,973	70,097
2005Q1	345,275	76,760	31,309	6,939	32,483	20,226	69,673
2005Q2	388,476	88,306	37,094	7,862	35,613	22,142	76,537
2005Q3	400,745	91,158	38,797	7,793	37,585	23,170	77,325
2005Q4	388,308	84,502	36,127	7,904	36,823	23,263	76,871
2006Q1	399,571	86,081	35,311	8,134	36,452	24,976	80,765
2006Q2	404,417	86,807	38,138	7,731	36,276	25,075	81,175
2006Q3	425,278	92,095	41,594	8,055	39,001	26,017	83,082
2006Q4	421,697	87,923	38,381	8,577	38,946	26,911	83,321

2007Q1	440,170	92,093	37,067	8,779	39,326	28,744	88,975
2007Q2	445,822	94,631	40,052	8,245	38,678	27,920	89,103
2007Q3	453,711	93,891	42,974	8,724	41,238	29,226	88,578
2007Q4	458,817	95,095	41,294	8,837	42,434	30,196	89,730
2008Q1	450,970	93,195	38,146	8,545	39,569	29,798	90,417
2008Q2	498,489	101,530	45,024	9,678	43,118	32,623	98,675
2008Q3	493,957	97,072	47,054	9,072	44,512	32,685	96,012
2008Q4	492,780	97,102	43,048	9,254	44,864	33,423	96,361
2009Q1	506,868	98,536	41,934	9,479	43,779	35,884	102,656
2009Q2	514,634	101,302	45,716	9,636	43,969	36,118	102,856
2009Q3	546,771	107,069	50,834	10,075	48,233	37,953	106,818
2009Q4	517,939	100,708	44,414	9,594	45,591	37,405	100,455
2010Q1	517,978	100,254	41,898	9,628	43,424	39,023	103,770
2010Q2	478,501	93,538	40,507	8,960	40,803	37,635	95,304
2010Q3	515,780	98,321	46,458	9,666	45,428	39,354	99,595
2010Q4	501,455	94,719	42,363	9,825	46,193	39,372	96,336
2011Q1	506,323	95,129	39,688	9,981	45,948	41,563	100,132
2011Q2	513,494	96,725	43,280	9,797	45,808	41,894	100,369
2011Q3	580,424	102,851	50,301	10,775	50,818	45,041	107,854
2011Q4	572,621	98,347	44,683	10,532	50,612	44,780	108,030
2012Q1	608,317	105,042	45,525	11,083	51,598	49,684	116,058
2012Q2	604,146	104,413	46,932	11,013	51,212	48,006	113,052
2012Q3	625,084	106,380	50,286	11,121	54,646	49,262	113,827
2012Q4	620,741	101,520	46,030	11,208	55,158	50,048	114,814
2013Q1	629,083	105,860	44,546	11,554	53,664	51,746	118,692
2013Q2	665,641	111,194	49,730	12,124	57,601	52,886	123,927
2013Q3	680,202	111,494	52,005	12,030	60,202	53,962	123,695
2013Q4	661,512	102,227	47,646	12,089	59,847	54,211	121,680
2014Q1	675,033	104,173	46,951	12,169	59,405	56,972	126,579
2014Q2	692,393	105,582	49,645	12,308	61,240	56,573	127,207

2014Q3	719,497	106,283	54,941	13,046	66,686	58,574	128,500
2014Q4	706,767	104,179	49,805	13,241	67,660	59,008	130,637
2015Q1	706,266	107,198	49,464	13,017	65,311	60,743	133,591
2015Q2	713,740	108,814	52,771	13,231	68,186	60,704	132,644
2015Q3	719,491	108,195	54,781	13,098	72,485	61,291	129,284
2015Q4	695,347	101,454	47,878	13,227	70,426	62,371	128,975
2016Q1	714,282	105,362	47,179	13,505	69,763	64,773	133,961
2016Q2	757,657	111,103	53,315	14,490	74,077	65,588	140,232
2016Q3	763,523	110,128	55,826	14,755	78,893	66,953	138,167
2016Q4	739,379	104,499	50,328	14,453	77,701	65,310	133,437
2017Q1	805,062	115,414	52,521	15,667	81,219	71,433	149,116
2017Q2	792,732	112,646	53,677	15,661	80,405	69,606	144,232
2017Q3	823,612	117,302	59,970	15,577	87,261	71,379	145,531
2017Q4	825,461	114,373	53,565	16,273	86,954	71,591	148,272
2018Q1	852,003	118,695	54,068	16,751	85,878	76,133	156,420
2018Q2	862,008	118,600	57,084	16,811	87,963	74,992	156,527
2018Q3	880,352	119,379	62,327	16,995	91,688	75,550	155,815
2018Q4	884,420	118,096	56,790	17,477	94,604	77,554	157,633
2019Q1	899,564	120,415	55,471	18,299	94,124	80,924	163,452
2019Q2	909,494	119,984	58,368	18,347	94,789	79,216	162,030
2019Q3	969,167	125,420	65,879	19,370	105,447	80,680	167,554
2019Q4	940,646	117,270	58,760	19,454	103,562	80,410	164,552
TOTAL 2001-2019	**42,187,184**	**7,450,445**	**3,366,188**	**816,634**	**4,019,380**	**3,211,131**	**7,955,402**
Percent of all MBS activity	**0.70**	**0.12**	**0.06**	**0.01**	**0.07**	**0.05**	**0.13**
Percent of all Diagnostic Imaging	**11.42**	**2.02**	**0.91**	**0.22**	**1.09**	**0.87**	**2.15**
Percent of all CT scanning		**17.66**	**7.98**	**1.94**	**9.53**	**7.61**	**18.86**

Table continued

Year and quarter	Number of CT examinations per quarter, by type							
	Brain/Chest/ Upper Abdo CT	Pelvis CT	Spine CT	Extremities CT	Spiral Angiography CT	Interventional CT	Cone Beam CT	CT Pelvimetry
2001Q1	484	3,501	33	9,355	3,770	4,249	0	751
2001Q2	520	3,339	33	9,787	4,140	4,455	0	668
2001Q3	458	3,595	21	10,231	4,535	5,059	0	647
2001Q4	511	3,326	30,308	9,873	4,745	5,402	0	594
2002Q1	570	3,369	61,118	9,803	4,659	5,447	0	571
2002Q2	603	3,658	63,786	11,201	5,430	6,124	0	604
2002Q3	594	3,685	63,611	11,630	5,923	6,439	0	581
2002Q4	569	3,641	62,401	11,023	5,844	6,623	0	463
2003Q1	606	3,703	66,897	11,128	5,674	6,697	0	527
2003Q2	601	3,774	64,279	11,809	6,578	7,524	0	475
2003Q3	825	4,032	66,834	12,383	7,588	8,236	0	490
2003Q4	799	3,801	65,897	12,119	7,375	8,872	0	457
2004Q1	785	3,938	66,965	12,053	7,391	8,777	0	522
2004Q2	816	4,007	68,064	13,134	8,454	9,247	0	413
2004Q3	905	3,933	72,040	13,971	9,539	9,983	0	481
2004Q4	944	3,905	71,700	13,196	9,487	10,770	0	453
2005Q1	895	3,729	70,464	13,115	8,846	10,420	0	416
2005Q2	991	4,144	76,683	15,638	10,946	12,081	0	439
2005Q3	1,065	4,260	77,925	15,741	12,808	12,706	0	412
2005Q4	973	3,957	76,276	15,480	12,381	13,422	0	329
2006Q1	1,153	4,092	80,785	15,887	12,450	13,113	0	372
2006Q2	1,108	4,253	79,022	17,140	13,247	14,100	0	345
2006Q3	1,209	4,385	83,153	18,105	13,158	15,063	0	361
2006Q4	1,161	4,530	84,528	17,970	12,964	16,177	0	308
2007Q1	1,149	4,489	90,737	19,050	13,219	16,211	0	331

2007Q2	1,192	4,420	90,739	19,767	14,103	6,683	0	289
2007Q3	1,309	4,673	89,921	20,303	15,602	6,954	0	318
2007Q4	1,388	5,321	91,415	19,958	14,875	7,995	0	279
2008Q1	1,349	5,088	92,935	20,092	14,167	7,414	0	255
2008Q2	1,500	6,200	100,562	22,752	16,368	0,187	0	272
2008Q3	1,415	5,261	99,498	23,278	17,377	0,489	0	232
2008Q4	1,471	4,650	100,134	23,436	16,636	2,185	0	216
2009Q1	1,588	4,801	104,771	24,479	16,201	2,558	0	202
2009Q2	1,538	4,980	101,581	25,436	17,557	3,715	0	230
2009Q3	1,755	5,293	107,077	26,983	19,439	4,995	0	247
2009Q4	1,680	4,702	102,250	25,472	18,485	6,978	0	205
2010Q1	1,699	4,738	103,685	25,789	17,685	6,216	0	169
2010Q2	1,648	4,555	85,806	24,382	18,201	6,982	0	180
2010Q3	1,767	4,882	95,385	25,813	20,374	8,567	0	170
2010Q4	1,849	4,763	90,398	24,944	19,597	0,959	0	137
2011Q1	1,963	4,826	92,963	26,139	18,653	9,167	0	171
2011Q2	1,880	4,780	91,462	27,106	19,789	0,453	0	151
2011Q3	2,172	5,466	102,125	30,104	26,968	2,923	12,871	155
2011Q4	2,221	5,125	100,847	28,793	27,474	4,778	16,263	136
2012Q1	2,482	5,636	110,377	31,655	27,675	4,698	16,625	179
2012Q2	2,403	5,608	107,295	32,250	29,264	5,854	16,696	148
2012Q3	2,415	5,753	109,471	33,365	31,617	8,847	17,949	145
2012Q4	2,442	5,752	110,166	33,269	30,578	1,714	17,897	145
2013Q1	2,591	6,047	114,534	33,797	29,866	9,310	16,768	108
2013Q2	2,838	6,423	117,335	36,080	33,694	2,769	18,941	99
2013Q3	2,937	6,806	117,109	36,896	36,368	4,764	21,846	88
2013Q4	2,994	6,918	113,552	36,228	34,893	6,352	22,773	102
2014Q1	3,002	6,976	120,699	37,594	32,916	5,383	22,106	108
2014Q2	3,130	7,468	119,988	38,547	35,930	9,130	25,549	96
2014Q3	3,224	7,554	123,541	40,648	38,353	0,291	27,768	88

2014Q4	3,212	7,817	123,566	41,177	37,057	72,224	17,135	49
2015Q1	3,401	7,898	128,899	41,151	35,762	70,077	9,672	82
2015Q2	3,347	8,294	123,016	41,336	39,666	71,910	9,739	82
2015Q3	3,879	9,304	121,370	41,927	41,299	72,865	9,645	68
2015Q4	3,927	9,217	113,166	40,710	39,087	75,872	8,978	59
2016Q1	4,293	9,823	123,714	41,669	38,340	72,317	9,521	62
2016Q2	4,695	10,472	125,323	44,811	44,471	77,181	11,836	63
2016Q3	4,957	11,141	124,856	45,329	46,254	76,064	10,142	58
2016Q4	4,987	10,832	120,430	44,823	44,577	78,579	9,351	72
2017Q1	5,870	12,380	137,018	48,798	45,657	79,527	10,370	72
2017Q2	5,992	12,618	129,849	48,133	48,847	80,995	10,015	56
2017Q3	6,278	12,830	133,361	49,085	52,435	81,656	10,899	48
2017Q4	6,563	13,081	134,986	49,347	52,331	85,607	12,472	46
2018Q1	7,668	14,379	144,524	52,592	51,199	83,111	10,549	36
2018Q2	7,997	15,461	139,015	54,608	55,177	85,107	12,623	43
2018Q3	8,565	16,172	140,824	56,911	58,989	85,395	11,699	43
2018Q4	8,943	16,841	139,773	57,016	57,800	90,336	11,510	47
2019Q1	9,524	17,606	144,280	59,830	56,311	87,328	11,956	44
2019Q2	10,235	18,763	139,531	62,173	62,432	91,045	12,537	44
2019Q3	12,202	21,726	148,339	66,588	68,053	95,046	12,834	29
2019Q4	12,594	22,274	141,373	64,977	66,237	97,304	11,840	39
TOTAL 2001-2019	**221,265**	**541,440**	**7,428,394**	**2,239,168**	**1,963,837**	**2,466,053**	**489,375**	**18,472**
Percent of all MBS activity	**0.00**	**0.01**	**0.12**	**0.04**	**0.03**	**0.04**	**0.01**	**0.00**
Percent of all Diagnostic Imaging	**0.06**	**0.15**	**2.01**	**0.61**	**0.53**	**0.67**	**0.13**	**0.00**
Percent of all CT scanning	**0.52**	**1.28**	**17.61**	**5.31**	**4.66**	**5.85**	**1.16**	**0.04**

MBS: Medicare Benefit Scheme

Q1: January to March, Q2: April to June, Q3: July to August, Q4: September to December

US: Ultrasound, Nuc Med: Nuclear Medicine

Appendix 3, Table 1: Change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publications of the MBS professional services review (2008-9) and associated media attention

Classification of the change[a]	Geographic location[#]	Magnitude of change						Net change[b] in the rate of CTs performed (Qtr3 2009-Qtr 4 2019)
		Level*			Slope*			
		Point estimate	95% CL		Point estimate	95% CL		
			Lower	Upper		Lower	Upper	
1A	NSW	-233.4	-344.3	-122.4	-8.5	-13.8	-3.2	-16,943.6
	SA	-355.0	-449.9	-260.2	-9.8	-15.7	-4.0	-22,843.0
	Vic	-207.7	-307.1	-108.3	-10.3	-15.1	-5.4	-17,344.1
1B	ALL Australia	-237.7	-333.4	-141.9	-2.2	-7.2	2.8	-9,744.3
	Tas	-186.7	-308.3	-65.0	-5.2	-13.0	2.6	-7,652.7
1C	WA	-402.0	-568.7	-235.3	8.9	0.0	17.7	-9,197.4
	ACT	-325.5	-405.2	-245.8	9.5	5.5	13.5	-5,857.7
	Qld	-127.3	-230.9	-23.7	11.8	7.3	16.4	4,274.8
2C	NT[C]	17.3	-170.4	205.0	11.5	4.4	18.7	9,665.8

MBS: Medicare Benefit Scheme; CT: Computed Tomography scanning

[a]Classification of change: 1A: Significant reduction in both the level and slope; 1B: Significant reduction in the level but no change in the slope; 1C: Significant reduction in the level with a significant increase in the slope; 2A: No significant change in the level with a significant reduction in the slope; 2B: No significance change in the level or slope; 2C: No significant change in the level with a significant increase in the slope; 3A: Significant increase in the level with a significant reduction in the slope; 3B: Significant increase in the level with no change in the slope; 3C: Significant increase in both the level and the slope.

[#]ACT: Australian Capital Territory; NSW: New South Wales; NT: Northern Territory; Qld: Queensland; SA: South Australia; Tas: Tasmania; Vic: Victoria; WA: Western Australia.

*Both the level and slope changes are expressed per 100,000 eligible population residing in the location specified at the time of the service provision

95% CL: 95% confidence limits around the point estimate

p values < 0.05 (95% CL that do not cross zero) are considered as significant changes in level and slope; greyed cells indicate non-significant changes

Values are estimated from the seasonally adjusted single interrupted time series model with autocorrelation correction as required for the data

[b]The net change in the rate was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of MBS-funded CT scans. Negative values result from the area below the counterfactual being larger than the area above it and indicate a net reduction in the rate of CT scans undertaken over the post-intervention time period; positive values indicate the reverse. In cases where the post-intervention trend was non-linear the net change is limited to the period prior to further disruptions in the trend.

[C]Post intervention phase was non-linear therefore change reported in the level and slope are limited to the initial post-intervention period prior to any significant further disruption of the trend.

Appendix 3, Table 2: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention

Classification of the change[a]	Type of medical imaging service	Magnitude of change						Net change[b] in the rate of CTs performed (Qtr3 2009-Qtr 4 2019)
		Level*			Slope*			
		Point estimate	95% CL		Point estimate	95% CL		
			Lower	Upper		Lower	Upper	
1A	Head CT	-30.5	-43.5	-17.6	-2.4	-3.1	-1.6	-3,637.4
	Face CT	-16.6	-23.0	-10.2	-0.9	-1.4	-0.5	-1,549.7
	Abdomen/Pelvis CT	-50.4	-63.4	-37.4	-2.0	-2.5	-1.4	-3,695.2
	Spine CT	-61.4	-83.6	-39.1	-3.2	-4.2	-2.2	-5,230.1
1B	Pelvis CT[c]	-3.6	-5.8	-1.5	0.1	0.1	0.2	-47.3
1C	Chest CT	-36.4	-46.4	-26.3	2.5	2.0	3.0	273.4
	Brain, Chest and Upper Abdomen CT[C]	-0.5	-0.9	-0.1	0.2	0.1	0.2	31.1
	Extremities CT	-11.1	-19.0	-3.2	1.1	0.5	1.8	366.5
	Soft Tissue Neck CT	-5.6	-7.4	-3.8	0.3	0.2	0.4	3.9
2A	CT Angiography[C]	-3.0	-6.2	0.3	-1.1	-1.7	-0.6	-16.9
2B	MRI[c]	-9.8	-33.0	13.4	-2.0	-4.6	0.7	0.0
2C	Chest/Abdomen/Pelvis CT	-0.9	-6.2	4.3	0.2	-0.1	0.4	167.9
	All diagnostic imaging (excl CT)	393.8	-68.4	856.0	29.2	3.0	55.4	25,137.6
3C	Interventional CT	10.7	3.0	18.4	1.6	1.2	2.0	1,739.6

MBS: Medicare Benefit Scheme; MRI: Magnetic Resonance Imaging; CT: Computed Tomography scanning

[a]Classification of change: 1A: Significant reduction in both level and slope; 1B: Significant reduction in level but no change in the slope; 1C: Significant reduction in the level and a significant increase in the slope; 2A: No significant change in level with a significant reduction in slope; 2B: No significance change in the level or slope; 2C: No significant change in level with a significant increase in slope; 3C: Significant increase in both level and slope.

*Both the level and slope changes are expressed per 100,000 eligible population residing in Australia at the time of the service provision

95% CL: 95% confidence limits around the point estimate

p values < 0.05 (95% CL that do not cross zero)are considered as significant changes in level and slope; greyed cells indicate non-significant changes

[b]The net change in the rate was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of MBS-funded medical imaging services. Negative values result from the area below the counterfactual being larger than the area above it and indicate a net reduction in the rate of CT scans undertaken over the post-intervention time period; positive values indicate the reverse. In cases where the post-intervention trend was non-linear the net change is limited to the period prior to further disruptions in the trend.

[c]Post intervention phase was non-linear therefore change reported in the level and slope are limited to the intial post-intervention period prior to any significant further disruption of the trend.

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract - Methods Abstract – Methods N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Throughout Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses			Last paragraph of Introduction, page 4
Methods					
Study Design	4	Present key elements of study design early in the paper			First sentence of Methods, page 4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Methods – Data source subheading, page 4

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case		RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	Methods – Data source subheading; Appendix 1 Codes in Appendix 1. Validation / algorithms N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Appendix 1. No confounding variables, though counterfactual is described in Methods – Statistical analysis subheading page 5
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).			Methods subheadings Data Source and Quarterly rate of

		Describe comparability of assessment methods if there is more than one group			imaging, pages 4-5
Bias	9	Describe any efforts to address potential sources of bias			Methods subheading Statistical Analysis, page 5, and Limitations, page 13
Study size	10	Explain how the study size was arrived at			Population for denominator in rates described in Methods – Quarterly rate of imaging, page 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods – Data source subheading, page 4
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical			Methods – Statistical analysis, page 5 N/A N/A No loss to follow-up N/A N/A

		methods taking account of sampling strategy (e) Describe any sensitivity analyses			N/A
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	N/A
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Results first paragraph, page 6 (concerning imaging examinations, not persons)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders			N/A, unit of analysis is imaging procedure rather than persons

		(b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			Results, first two paragraphs, pages 6-7
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Results, unadjusted estimates in paragraph 2, adjusted through remainder
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			
Discussion					
Key results	18	Summarise key results with reference to study objectives			First paragraph, page 10

Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	Limitations subheading, page 13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			Throughout discussion
Generalisability	21	Discuss the generalisability (external validity) of the study results			Implications subheading, page 13
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based			Page 14
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Page 14

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

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The association of regulatory body actions and subsequent media coverage with use of services in a fee-for-service system: A longitudinal cohort study of computed tomography scanning in Australia

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Title page

Title: The association of regulatory body actions and subsequent media coverage with use of services in a fee-for-service system: A longitudinal cohort study of computed tomography scanning in Australia

Author names and affiliations:

David Youens* [a], Jenny Doust [b], Thi Ninh Ha [a], Peter O'Leary [a, c, d], John Slavotinek [e, f], Cameron Wright [a, g, h, i], Rachael Moorin [a, j]

* Corresponding author. David.youens@curtin.edu.au. GPO Box U1987, Perth, Western Australia, 6845

a Health Economics and Data Analytics, School of Population Health, Curtin University, Perth, Australia

b Centre for Longitudinal and Life Course Research, Faculty of Medicine, University of Queensland

c Obstetrics and Gynaecology, Medical School, Faculty of Health and Medical Sciences, The University of Western Australia, Perth, Western Australia, Australia

d PathWest Laboratory Medicine, QE2 Medical Centre, Nedlands, Western Australia, Australia

e SA Medical Imaging, SA Health

f College of Medicine and Public Health, Flinders University, Adelaide, South Australia

g Fiona Stanley Fremantle Hospitals Group, Western Australia, Australia

h Medical School, Faculty of Health and Medical Sciences, The University of Western Australia, Western Australia, Australia

i School of Medicine, College of Health & Medicine, University of Tasmania, Tasmania, Australia

j School of Population and Global Health, The University of Western Australia, Western Australia, Australia

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Abstract

Objective: The Professional Service Review (PSR) is an Australian Government agency aiming to reduce inappropriate practices funded via Medicare, Australia's public insurer. Our objective was to examine changes in Computed Tomography (CT) following the 2008-09 PSR annual report, which noted excessive CT use.

Design: Interrupted Time Series Analysis examined trends in CT use following the 2008-09 PSR report, estimating both change in the immediate rate of CT and the slope of the trend in usage post-intervention.

Setting: Medicare-funded imaging (most out-of-hospital imaging) in Australia.

Participants: Patients receiving Medicare-funded CT and other imaging

Intervention: The 2008-09 PSR report highlighted concerns regarding excessive CT use. Two providers were financially penalised for CT overuse with these cases detailed in the PSR report and highlighted in an associated *Report to the Professions*, distributed to 50,000 providers. Media articles on radiation risks followed.

Outcomes: Quarterly rates of out-of-hospital CT, magnetic resonance imaging (MRI, as a comparator), and all other Medicare-funded diagnostic imaging examinations 2001-2019.

Results: CT scanning increased from 4,663.5 per 100,000 person-years in 2001 to 14,506 in 2019 (211% increase), with substantial variation by type and anatomical region. The 2008-09 PSR report was followed by an immediate reduction in CT scanning of 237.7 CTs per 100,000 people per quarter (95% CI -333.4 to -141.9) though growth in use soon continued at the pre-intervention rate. The degree of change in utilisation following the report differed between states/territories and by scan type, both in terms of the immediate change and the slope. For other diagnostic imaging modalities there was an increase in the slope, while for MRI there was no change in either parameter.

Conclusion: Actions consisting of financial disincentives for service overtesting and provider / public education components may limit excessive use of diagnostic imaging in fee-for-service systems, however effects observed here were only short-lived.

Keywords: Diagnostic Imaging, Fee-for-Service, Computed Tomography, Medical Overuse,

Strengths and limitations of this study

- This study made use of whole of population administrative data, improving generalisability and preventing loss to follow-up or non response
- Multiple imaging modalities were examined, allowing for an assessment of CT (the target of the PSR actions) and potential substitution by other modes
- Only data on publicly-funded services accessed in the out-of-hospital setting were available; trends in in-hospital CT use were not examined
- The PSR actions involved multiple components and it was not possible to examine specific components in isolation from each other

Introduction

Overtesting is defined as the use of non-recommended screening tests in asymptomatic patients or more testing than necessary to diagnose patients.[1] Overtesting is problematic due to the wasted resources it incurs and the potential for patient harm. Harms of overtesting may fall under six domains:[2] physical, psychological, treatment burden, social, financial, and dissatisfaction with health care. Overtesting with CT may manifest in many of these areas, for example physical harms resulting from radiation exposure [3, 4] psychological harms resulting from incidental findings[5] plus additional physical harms when these findings lead to further procedures or diagnostic tests.[6] Overtesting also consumes healthcare expenditure without improving outcomes,[1] imposing an opportunity cost. Overtesting may result from intrapersonal (e.g. fear of litigation, risk aversion, intolerance of uncertainty), interpersonal (e.g. pressure from patients and colleagues) or contextual (e.g. guidelines, financial incentives, time constraints, test availability) factors.[7] Studies in different countries have shown that over 10% of CT scans reflect overtesting,[8, 9] indicating substantial room for improvement in this area.

CT scanning in Australia is delivered in public and private hospitals, or in the out-of-hospital setting on referral from a general practitioner (GP) or specialist. Most out-of-hospital CT is performed by private clinics[10] which are reimbursed on a fee-for-service (FFS) basis by the Federal Government via Medicare, Australia's public insurer, which covers almost all Australian citizens and permanent residents[11] (with prisoners an exception). Similarly, GPs operate in private practices which are reimbursed by Medicare on a FFS basis hence are incentivised to maximise service volumes.[12] Patients do not register with practices and are free to change providers at any time, so multiple providers compete for services in the out-of-hospital environment, potentially driving overtesting where patients expect certain medical interventions (such as diagnostic CT) and providers feel compelled to meet patient expectations so as to prevent the patient from being 'lost' to another GP who provides or refers for the expected service.[13, 14] Note that decisions regarding out-of-hospital CT scanning are primarily made by referrers (GPs and specialists); radiologists at private clinics generally do not know the setting or patient and are not well positioned to deny scans requested. Although Medicare provides reimbursement for CT scans referred by a GP, MRI scans are generally only reimbursed when referred by a specialist (with some exceptions since 2011).[15] Furthermore, MRI machines must be licensed by the Federal Government in order for scans using that

machine to attract reimbursement, with license availability restricted.[15] This may limit substitution of CT scans by MRI. No such restrictions exist for other modalities.

One of the bodies regulating healthcare in Australia is the Professional Services Review (PSR), which has responsibility for preventing inappropriate practice, both to protect patients from risk and to reduce Government funding of inappropriate care.[16] The PSR reviews the activities of practitioners where unusual service volumes or prescribing patterns suggest inappropriate care. Upon investigation by the PSR, a practitioner found to have engaged in inappropriate practice (as determined by a peer panel of practitioners) may be partially or fully disqualified from claiming Medicare reimbursements for some time, may be required to repay reimbursements claimed for delivery of inappropriate care, or may face suspension from practice.[17] In the 2008-09 PSR annual report published in October 2009, two providers were penalised for CT overtesting. In addition, the Director's report within the annual report commented on CT overtesting, noting concerns about use of CT screening for lower back pain.[18] Alongside this annual report was the dissemination by the PSR of a *Report to the Professions* to 50,000 health providers detailing these cases (and others), and the PSR director also spoke at medical conferences and to the media.[18] This was followed by a period of media interest concerning CT risks, including the publication of articles highlighting the risks of CT, targeted at both clinical audiences[19, 20] and the general public.[21-24] These articles, published through 2010 and 2011 in national[22, 24] and state-specific media,[23] outlined the PSR director's concerns, cancer risks associated with CT, the role of patient expectations as a factor and alternative imaging modalities. These events are collectively referred to as "the PSR actions" throughout this paper for simplicity. Any change in CT scanning resulting from the PSR actions may reflect either a change in imaging levels overall, or shifts to other modalities.

The aim of this project was to examine the impact of the PSR actions on the rate of CT scanning in Australia, to determine if regulatory body action influences overtesting in the FFS context.

Methods

This was a retrospective whole-of-population longitudinal cohort study using aggregate-level administrative data. Reporting follows the Reporting of studies Conducted using Observational Routinely-collected health Data (RECORD) guidelines.[25]

Data source

Quarterly utilisation data for Australia and for each Australian state/territory from Jan-March 2001 to Oct-Dec 2019 inclusive were sourced from publicly available Medicare Benefits Schedule (MBS) records.[26] Data pertaining to CT were extracted using MBS item reports. Data for other Medical Imaging modalities (Ultrasound, Nuclear Medicine and MRI) were extracted using the Group report for Category 5 Diagnostic Imaging Services. Data included only those services performed by a registered provider for services that qualify for Medicare Benefits and for which Services Australia had processed a claim. Data excluded services provided by hospital doctors to public patients in public hospitals and services that qualified for a benefit under the Department of Veterans' Affairs National Treatment Account. These services are not within the purview of the PSR, nor are records of these services available with the MBS data used for the current study. The location services were provided (state/territory) was based on patient address. Calendar quarter was determined by the date of processing by Services Australia, not the date the service was provided to the patient. Note that date of processing is typically within days of the service date. For the denominator the Medicare eligible population for each state/territory was sourced from Medicare enrolment data quarterly standard reports.[27]

CT scanning data were aggregated into fourteen groups reflecting either anatomical area of the scan (e.g. head, chest etc.) or, due to lack of anatomical location on the MBS coding, grouped according to technique (cone beam CT, pelvimetry, spiral angiography and interventional CT) using the MBS item codes in Appendix 1. Since MBS items are for re-imbursement rather than clinical purposes, several items covered multiple CT examinations (Chest, Abdomen/Pelvis and Brain, Chest/Upper Abdomen). For analysis, all CT scanning records pertaining to these items were counted as a single CT scanning event. In the analysis by type of CT these items were grouped separately (see Appendix 2) and were not included in the analysis of their relevant sub-groups (i.e. brain, chest or abdomen/pelvis).

Quarterly rate of imaging

The annual rate of MBS funded imaging per 100,000 eligible persons was calculated for all Australia and by state/territory by dividing the number of services processed in that year by the eligible Medicare population for that year multiplied by 100,000.

Statistical analysis

Interrupted time series analysis (ITSA) was used to evaluate the impact of the PSR actions on the quarterly rate of medical imaging excluding CT, MRI, all CT scanning and type of CT scanning for all Australia and by state/territory.

The analysis was conducted using the '*itsa*' package[28] in Stata version 15.[29] Since the PSR actions affected the whole of Australia a control group was not available for comparison, therefore the model was a single-group ITSA (i.e. the preintervention trend was projected into the postintervention period to serve as the counterfactual) with a dummy indicator variable set to quarter 4 2009 representing the PSR action. Coefficients were estimated using ordinary least squares regression with Newey-West standard errors to handle autocorrelation and heteroskedasticity.

Each model was first fitted with lag 0 specified (i.e. no autocorrelation), following which autocorrelation in the error distribution was tested for using the program '*actest'*[30] and the appropriate lag used in the final model. The model was implemented after adjustment for seasonality using Fourier terms (pairs of sine and cosine functions)[31] using the program '*circular*'.[32] Following Imbens and Lemieux[33] the median timepoint (quarter 4 2004) of the preintervention period was used as a robustness test to determine if the underlying assumption of stability in time-varying unmeasured confounders should be challenged. Where the post-intervention trend was non-linear, multiple dummy variables were used to adequately capture the shape of the post-intervention trend so that a more accurate estimation of the immediate change in the trend and change in level resulting from the PSR action could be estimated.

Classification of response to the 2009-10 Professional Services Review

For each model the direction and statistical significance of the estimates of the level (initial change in the quarterly rate of CT use) and slope (gradient of the trend in quarterly CT use) parameters in the post-intervention period (or for the slope the immediate post-intervention segment where a non-linear trend was observed) were used to classify the response to the PSR action. The primary typology was based on the direction and significance of the level parameter as follows: Type 1: significant reduction in the level; Type 2: no significant change in the level and Type 3: significant increase in the level. Each type was further classified into sub-types based on the change in the slope parameter: a) significant reduction; b) no significant change and c) significant increase.

Calculation of net change in CT imaging procedures following the PSR action

The net change in the CT procedures performed was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of imaging procedures. To reduce over-estimation of the net change where

no significant difference was observed between the pre and post-intervention slopes (i.e. sub type b) the pre-intervention slope parameter was used to define the post-intervention slope rather than the point estimate provided in the ITSA model. Similarly, where no significant difference in level was observed (i.e. type 2), the post-intervention curve was defined with the level change set to zero. When the post-intervention trend was non-linear the net change was only calculated until the beginning of the subsequent change in trend. The net change could be negative (i.e. net reduction in the rate of imaging examinations through the post-intervention period) or positive.

Patient and public involvement

As this is an analysis of secondary data, there was no patient or public involvement.

Results

Over the 19-year study period 369.5 million Medicare funded medical imaging examinations were undertaken in Australia (6.2% of all Medicare funded activity) of which CT scanning comprised 11.4% (42.2 million) (Appendix 2). The most frequently performed type of CT scan was abdomen/pelvis comprising 18.8% [~8 million] of all CT examinations, closely followed by head CT (17.6% [7.5 million]) and spinal CT (17.6% [7.4 million]).

As shown in Table 1 the rate of CT scanning increased from 4,662.2 per 100,000 Medicare eligible persons in 2001 to 14,505.2 per 100,000 in 2019. The increase of 211% was much larger than the increases observed for Ultrasound (+150%) and Nuclear Medicine (+96%), or for diagnostic imaging overall (75%). While the largest increase in the rate of imaging (by modality) was observed for MRI (increasing by ~400% over the study period), the absolute rate was still 64% lower than the rate of CT scanning in 2019. Table 1 also shows the rate of CT scanning according to type across the study period. In 2001 the top three types of CT scanning, ranked according to the rate performed per 100,000 persons, were head CT (1,529.9), followed by abdomen/pelvis CT (1,018.9) and CT of the facial bones (629.9). However, by 2019 this ranking had changed such that abdomen/pelvis CT had the highest rate per 100,000 (2,565.0); spinal CT was now ranked second (2,237.2) and head CT third (1,884.4). The largest relative change in the rate of CT scanning by type from 2001 to 2019 was observed in interventional CT which increased by 1,089% (from 95.3 per 100,000 in 2001 to 1,133.8 in 2019. Similarly, the rate of spiral angiographic CT scanning also rose by 1,054% (from 85.5 per 100,000 in 2001 to 986.8 in 2019). Other notably very large relative increases (i.e. more than tripling of the 2001 rate) were observed for chest/abdomen/pelvis CT (+451%), CT of the

extremities (+407%) and pelvis CT (+358%). Rate increases of over 100% were observed for chest CT (+199%), abdomen/pelvis CT (+152%) and soft tissue neck CT (+147%). The only type of CT scan to reduce in rate was cone beam CT which was first funded under Medicare in 2011 (quarter 3).

Table 1 Annual rate of MBS funded diagnostic imaging by modality and type of CT scanning services in Australia across the study period

Year	Rate per 100,000 eligible population					Rate of CT per 100,000 eligible population			
	All diagnostic imaging	MRI	US	Nuc Med	All CT	Head	Face	Soft tissue Neck	Chest
2001	62,815.20	1,056.10	17,753.80	1,494.80	4,662.20	1,529.90	629.9	1197	519
2002	64,018.20	1,173.00	18,540.80	1,514.50	5,993.70	1,522.60	630	1252	558.8
2003	64,489.60	1,270.30	19,310.30	1,517.10	6,304.30	1,543.40	624.1	1305	586.6
2004	65,657.10	1,350.00	19,929.00	1,522.90	6,663.80	1,546.30	640	1354	631.1
2005	70,767.70	1,558.40	22,127.80	1,588.50	7,428.70	1,662.20	699.2	1488	695.2
2006	73,155.60	1,776.10	23,344.80	1,617.60	7,941.90	1,697.70	738	1561	724.8
2007	76,179.30	1,958.40	24,717.90	1,684.10	8,516.50	1,779.10	764.1	1631	765.5
2008	78,983.80	2,050.00	26,189.10	1,801.80	9,036.20	1,815.10	808.6	1705	803
2009	82,260.00	2,252.70	28,004.90	1,980.30	9,592.60	1,874.30	840.9	1787	834.9
2010	83,548.70	2,346.90	29,065.00	2,138.80	9,085.60	1,745.40	772.4	1719	793.2
2011	86,766.50	2,501.10	30,801.00	2,334.20	9,615.50	1,739.70	787.5	1813	854.9
2012	90,623.80	2,640.90	33,148.70	2,544.40	10,674.40	1,812.40	819.7	1927	923.1
2013	94,223.40	3,003.00	35,368.00	2,677.70	11,246.60	1,837.80	827.2	2039	986.7
2014	98,378.10	3,891.20	36,959.40	2,727.90	11,705.00	1,760.80	843.5	2127	1,068.20
2015	99,830.50	4,107.90	38,121.70	2,717.40	11,698.90	1,756.70	845.6	2177	1,140.50
2016	101,767.50	4,249.20	39,553.80	2,694.50	12,098.00	1,753.30	840.3	2324	1,221.70
2017	106,182.50	4,653.20	41,481.60	2,814.20	13,008.90	1,842.10	880.3	2531	1,345.50
2018	108,783.70	4,927.40	43,087.80	2,850.30	13,744.10	1,875.90	909.7	2682	1,422.70
2019	110,010.00	5,277.30	44,452.10	2,925.40	14,505.20	1,884.40	930.1	2941	1,552.00
Percent change total 2001 to total 2019*	**75.1**	**399.6**	**150.4**	**95.7**	**211.1**	**23.2**	**47.7**	**146.5**	**199**

Year	Rate of CT per 100,000 eligible population							
	Abdomen/ Pelvis	Pelvis	Spine	Chest / Abdomen / Pelvis	Extremity	Spiral Angiography	Interventional CT	Cone Beam
2001	1,018.90	68.5	N/A	227.2	195.3	85.5	95.3	N/A
2002	1,124.90	70.3	1,229.20	268.4	213.8	107	120.6	N/A
2003	1,223.40	74	1,275.80	311.1	229.3	131.5	151.4	N/A
2004	1,320.30	75.2	1,328.60	361	249.5	166.2	184.8	N/A
2005	1,465.50	78.5	1,470.10	433.2	292.6	219.4	237.2	N/A
2006	1,579.60	83	1,575.40	495.4	332.4	249.3	281.1	N/A
2007	1,687.70	89.5	1,718.10	549.7	374.5	273.7	321.2	N/A
2008	1,780.40	99	1,834.80	599.8	417.9	301.2	374.6	N/A
2009	1,898.20	90.9	1,911.50	677.6	470.7	329.5	451.6	N/A
2010	1,782.40	85.4	1,693.50	701	455.4	342.2	508.4	N/A
2011	1,842.80	89.4	1,714.50	766.9	496.3	410.8	563.4	N/A
2012	1,987.80	98.8	1,899.00	855.4	566.8	517.2	656	300.3
2013	2,081.80	111.7	1,973.20	907.8	610	575	738.7	342.5
2014	2,149.10	124.9	2,043.80	968.4	661.8	604.3	825.4	387.9
2015	2,164.60	143.2	2,007.80	1,011.50	681.4	642.9	869.5	157
2016	2,219.80	171.9	2,010.50	1,068.10	718.3	706	911.5	166.1
2017	2,352.60	204	2,144.50	1,138.00	782.8	798.3	992.7	175.3
2018	2,474.90	248.3	2,229.00	1,202.00	873.6	881.6	1,042.70	183.2
2019	2,565.00	313.4	2,237.20	1,253.00	989	986.8	1,133.80	191.8
Percent change total 2001 to total 2019*	**151.7**	**357.8**	**30.2**	**451.3**	**406.5**	**1,053.90**	**1,089.20**	**-44**

MBS: Medicare Benefit Scheme; US: Ultrasound; Nuc Med: Nuclear Medicine; NA = Item not available

Grey cells indicates that MBS funded services were not available for all or part of the specified time period

*Where MBS item was not available in for the whole of 2001 percentage change is calculated from first year it was available in all quarters

Figure 1 shows the results of the ITSA evaluating changes in the use of CT following the PSR actions, by state/territory; values informing the figure are in Appendix 3. On average after adjusting for seasonality and autocorrelation there was a significant reduction in the level parameter (-237.7 CTs per 100,000 Medicare eligible persons [95% Cl -333.4 to -141.9]) indicating an immediate response. However, no significant change in the slope parameter was observed, indicating no sustained effect i.e. following the initial drop in utilisation, growth in CT scanning continued at its previous rate. Despite there being no sustained change, over the post-intervention period (Qtr 4 2009-Qtr 4 2019) the cumulative rate (i.e. the net change) of CT use reduced by 9,744.3 per 100,000 due to the initial level change, compared with the counterfactual. This can be readily observed graphically in Figure 2. Across Australian states and territories, the response differed (Figure 1). In all states/territories except the Northern Territory there was a significant reduction in the level; however, the response in the slope parameter differed. In New South Wales, South Australia and Victoria there was a significant reduction in the slope parameter (i.e. sustained reduction), in Tasmania there was no significant change in the slope, while in the Australian Capital Territory, Queensland, Western Australia and the Northern Territory after the initial reduction in level there was a significant increase in the slope parameter.

Figure 3 shows the results of the ITSA according to type of CT scanning in Australia (values in Appendix 3). The majority of CT scanning types showed an immediate significant reduction in level, the exceptions being CT angiography and chest/abdomen/pelvis CT which showed no change, and interventional CT, which showed an increase in level. With respect to sustained change (i.e. slope) there was a much larger variation across type with reductions (head, face, abdomen/pelvis, spine CT and CT angiography), increases (chest, extremity, soft tissue neck, brain/chest/upper abdomen and interventional CT) and on one occasion no change (pelvis CT) observed. Figure 3 also shows the results of the analysis for MRI, which showed no response in either parameter and all diagnostic imaging excluding CT, which showed no change in the level but an increase in the slope parameter. Changes for all diagnostic imaging excluding CT are also presented in Figure 4, displaying the change in the slope parameter through the post-intervention period.

Discussion

CT use reduced significantly following the 2008-09 PSR annual report, associated sanctions and subsequent media coverage of CT risks. Following this short-term decline, CT use continued increasing at the pre-intervention rate, though results differed by scan type/region and state/territory. Findings indicate that major reviews including financial penalties and surrounding coverage have potential to decrease overtesting, but that reductions may not be sustained.

Being an observational study we cannot assume causation, though we highlight some important points in considering this. There was a close temporal relationship between the PSR report and the changes in CT use, which would be expected if changes were causal. The face validity of a causative relationship can be considered via the overtesting framework developed by Lam *et al*.[7] Interpersonal drivers of overtesting may have influenced CT use as the mass media coverage outlined radiation risks to patients and included some discussion of the role of patient expectations in driving imaging requests.[22-24] On the provider side, fear of reputational damage following a reprimand is also an interpersonal factor. Environmental drivers may have changed if providers grew concerned about financial penalties from the PSR for excessive imaging. Intrapersonally, the risk aversion that drives overtesting in the search for a definitive diagnosis may have been countered by improved knowledge of radiation risks.

The risk of reputational damage or financial penalties was low, with the PSR report discussing two providers sanctioned for inappropriate CT. However, these cases were widely disseminated, via the *Report to the Professions* describing these cases (and others) to 50,000 providers. Furthermore the PSR director speaks at national medical conferences and to the media about PSR activities,[18] and attends meetings of medical colleges and the Australian Medical Association to further raise awareness of PSR activities.[34] Although we are not aware of any surveys or other material describing awareness of the PSR among providers or patients, the dissemination activities outlined above likely led to a reasonable degree of awareness among providers. Moreover, a 2011 review of diagnostic imaging noted that the 2008-09 PSR had likely impacted practice, and that private providers had expressed concerns regarding profitability following this.[35] Penalties for inappropriate CT appeared in the 2009-10 and 2011-12 PSR annual reports, however there was no specific discussion of CT in the director's reports nor are we aware of media coverage following these reports.

There is prior evidence in Australia of educational interventions reducing CT. In 2013 the National Prescribing Service's (NPS) MedicineWise program ran an intervention to reduce

inappropriate CT for acute lower back pain.[36] This included a report to GPs comparing their referral rates for lower back CT to their peers, an online decision support tool and a symptom self-management prescription pad. The intervention reduced lower back CT by over 10%, which persisted through 20-months follow-up. This demonstrates some receptiveness to messaging regarding CT overtesting, though mechanisms of action by which the PSR may have influenced practice would differ. Similarly, the introduction of a Choosing Wisely recommendation to reduce imaging for lower-back pain in the United States in 2012 was followed by a 4% reduction in such imaging.[37] The Choosing Wisely campaign regarding lower back CT in the USA did not involve any financial disincentives such as the PSR actions in the current study, though did garner substantial media attention[37] so some drivers of change may have been comparable. A review of interventions to reduce overuse care suggested that educational interventions targeted at both clinicians and patients are among the most effective type,[38] supporting the notion that media coverage on CT overtesting may have influenced practice.

Results here differed between states/territories and CT type. Differences in results across CT type do not appear to be driven by differences in the radiation dosages associated with each type, given that Chest / Abdomen / Pelvis scans showed no change in either parameter following the PSR action but expose patients to some of the highest effective doses.[39] Differences observed between states / territories may have resulted from differences in the baseline level of CT use; this is likely as availability of CT scanners, one driver of overtesting, does differ between jurisdictions.[15] These differences may have also resulted from differences in messaging in each state / territory, caused by either different levels of media coverage of this issue (as some coverage appeared in local[23] rather than national newspapers), or addresses by the PSR director to medical conferences in some states but not others. Baseline attitudes towards CT, and hence the capacity for reductions in use, may have also differed between networks of providers, given the concentration of scanners and providers in capital cities[15] which are in many cases geographically isolated.

There were differences observed between CT and other modalities. In contrast with the drop in CT use following the PSR, MRI showed no change following the 2008-09 PSR report, while for all diagnostic imaging excluding CT the slope increased significantly, while the level parameter showed a large but non-significant increase. This may represent substitution for modalities with lower or no associated radiation exposures (e.g. x-ray or ultrasound, respectively). MRI use increased steadily through the study period, reflecting an increase in

availability of MR machines from below- to above-average in comparison to other Organisation for Economic Co-operation and Development countries.[40] There was no additional increase in use of MRI following the PSR actions, however, likely because licensing of MR devices is constrained by the Federal Government and most MRI investigations are not reimbursed by Medicare when referred by a GP, limiting potential for substitution.[41, 42] Alternatively, there may have been an increase in privately funded MRI which would be unobservable in the Medicare data used here.

Implications

Although the PSR actions were followed by a reduction in CT use, growth then continued at the pre-intervention rate. This suggests that although such actions may be influential, any resulting changes in behaviour may not be sustained in the absence of ongoing intervention. As the PSR publishes annual reports there may be opportunities to replicate the actions assessed here, if media interest in the topic could be sustained, which may produce longer-term changes in CT use.

These findings will be of interest to researchers and policymakers wanting to understand mechanisms to prevent overtesting, though contextual factors are important in understanding how effective such actions may be elsewhere. Provider and patient education regarding radiation risks, threats of financial penalties and reputational damage following exposure of inappropriate practice would likely be influential mechanisms across settings. The degree of response to such mechanisms, however, would depend in part on the baseline level of overtesting, driven in part by health system design. In health systems where providers are paid via capitation or salary rather than FFS overtesting may be less common, with FFS systems known to incentivise service volumes.[43] Similarly, in some health systems patients register with a practice[44] and cannot 'doctor-shop' as is the case in Australia. In such systems providers are not financially incentivised to increase patient satisfaction by delivering requested services, as patients cannot simply access the service via another practice. Overtesting may be incentivised where pay-for-performance programs prioritise patient satisfaction, as providers may feel pressured to refer patients for requested imaging services so as to maintain satisfaction ratings.[45] Relationships between providers referring for imaging and those performing imaging may also influence overtesting, e.g. ownership by physicians of radiology services is associated with increased radiology use.[46] A shift from a volume-driven to a value-driven system could prevent overtesting by focusing on the delivery of interventions to maximise patient outcomes

rather than service delivery.[47] Finally, the PSR actions studied here were facilitated in part by the existence of the PSR which has oversight of all Medicare-funded services and authority to impose penalties. Although the PSR objectives of patient safety and cost containment are priorities globally, mechanisms available to regulators will differ elsewhere.

Strengths

This study benefited from the use of whole of population administrative data, improving generalisability and preventing loss to follow-up or nonresponse. The data cover a long study period both prior to and following the PSR action, improving effect estimates, and covers multiple imaging modalities. The analysis accounted for potential seasonality in the use of CT and non-linearity in post-intervention trends.

Limitations

Data were limited to services funded via Medicare Australia. Comparable data concerning patients in public hospitals were not available, and we cannot comment on potential trends in that setting.

There was no comparator available, which may have supported a more rigorous design. The PSR has a national scope, meaning there was no setting without the PSR action against which to compare trends. Different sets of MBS items were assessed as comparators in the hope of providing control for broader health system changes, but no items could be found for which pre-intervention trends resembled CT.

The data used did not allow for services to be assessed at the level of individual provider. As the PSR targets providers with unusually high volumes of services, it is possible that CT reductions following the PSR were concentrated among a small number of practitioners with high CT referral rates, alternatively it is possible that media messaging led to a more uniform change across providers. We could not assess provider-specific effects due to this data limitation.

Rates here used the Medicare-eligible population as the denominator, though changes in the number of people presenting for care may also be a suitable denominator as changes in this may impact CT use. The quarterly counts of GP contacts were included and show no change around the time of the PSR actions which would account for changes in the rates of CT observed.

This study examines an action consisting of multiple components, and we are not able to assess, for example, mass media coverage in isolation from the publication of financial penalties for overtesting.

Conclusion

This study suggests that regulatory body action may influence provider behaviour within a FFS context. However, it also suggests that point-in-time interventions have limited longevity. The combination of financial incentives (i.e. penalties for excessive use), patient and provider education, and risks to reputation via potential for publicising of investigation outcomes was followed by reduced CT use. Further research examining how best to couple such actions with more sustained reinforcement over time to influence behaviour would be useful, in addition to studies assessing the proportionate impacts of individual components.

Author Contributions

RM conducted analyses for this paper. DY and RM prepared the first draft manuscript. RM, JD, POL, JS, TH and CW developed the grant application under which this work was funded. All authors collaborated on writing the paper and approve the submitted version.

Ethics approval

Ethics approval was provided by the Curtin University Human Research Ethics Committee, approval number SMEC-80-10. Participant consent was not sought as data were a publicly available, aggregated collection of data on service volumes. There is no possible way to identify any of the people receiving the services the data relate to, nor to contact them for the purpose of obtaining consent.

Patient consent for publication

None required.

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Data sharing

Data used in these analyses can be requested from the authors.

Competing interests

None declared.

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Figure legends

Figure 1: Part A indicates change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publication of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B indicates net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by State.

Figure 2: Impact of the 2008-9 professional services review on the rate of Medicare funded CT scanning (per 100,000 Medicare eligible population) in Australia. Part A indicates quarterly rate of all MBS funded CT scans showing counterfactual and post-intervention fitted line (seasonality removed for simplification). Part B is a representation of the seasonally adjusted area under and between the curves used to estimate net effect of the response to the MBS professional services review 2008-9.

Figure 3: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention. Superscript L and S

indicate significant changes in the level and slope parameters, respectively. Part B displays net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by type / anatomical area.

Figure 4: Impact of the 2008-9 professional services review on the rate of Medicare funded diagnostic imaging excluding CT) (per 100,000 Medicare eligible population) in Australia. Figure indicates quarterly rate of all MBS imaging claims (excluding CT) showing counterfactual and post-intervention fitted line (seasonality removed for simplification).

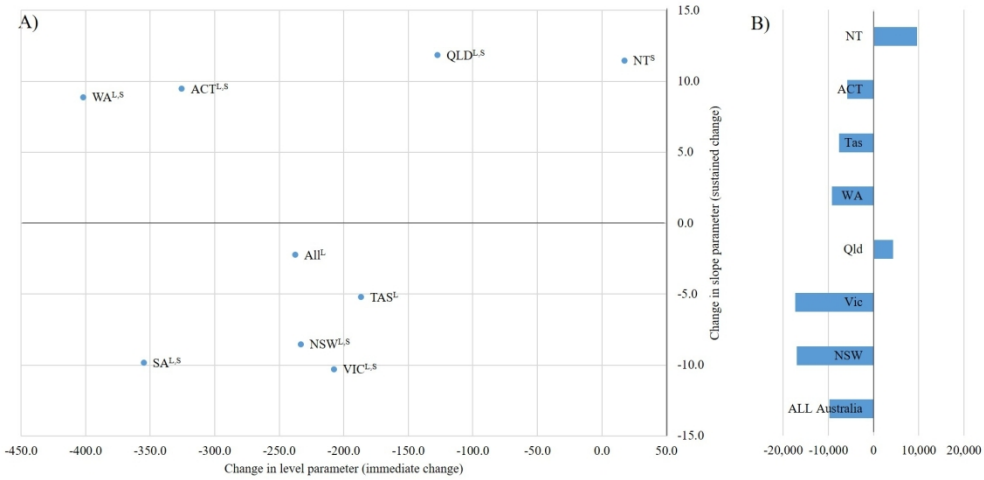

Figure 1. Part A indicates change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publication of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B indicates net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by State.

332x163mm (150 x 150 DPI)

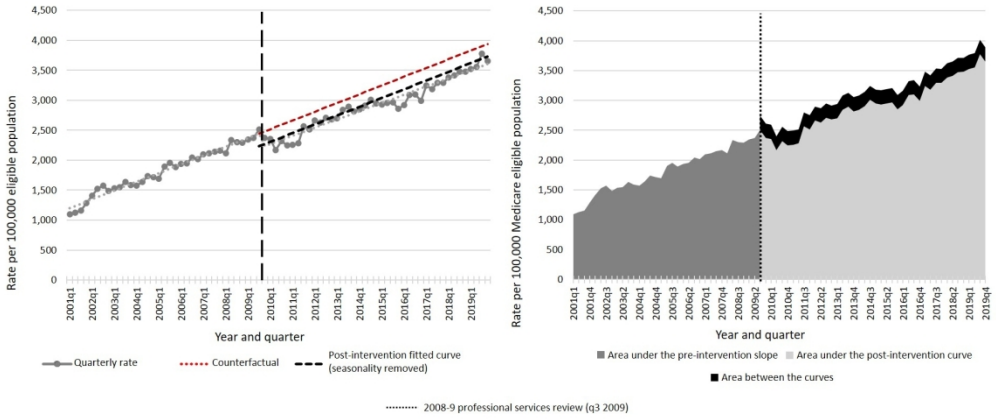

Figure 2: Impact of the 2008-9 professional services review on the rate of Medicare funded CT scanning (per 100,000 Medicare eligible population) in Australia. Part A indicates quarterly rate of all MBS funded CT scans showing counterfactual and post-intervention fitted line (seasonality removed for simplification). Part B is a representation of the seasonally adjusted area under and between the curves used to estimate net effect of the response to the MBS professional services review 2008-9.

320x135mm (150 x 150 DPI)

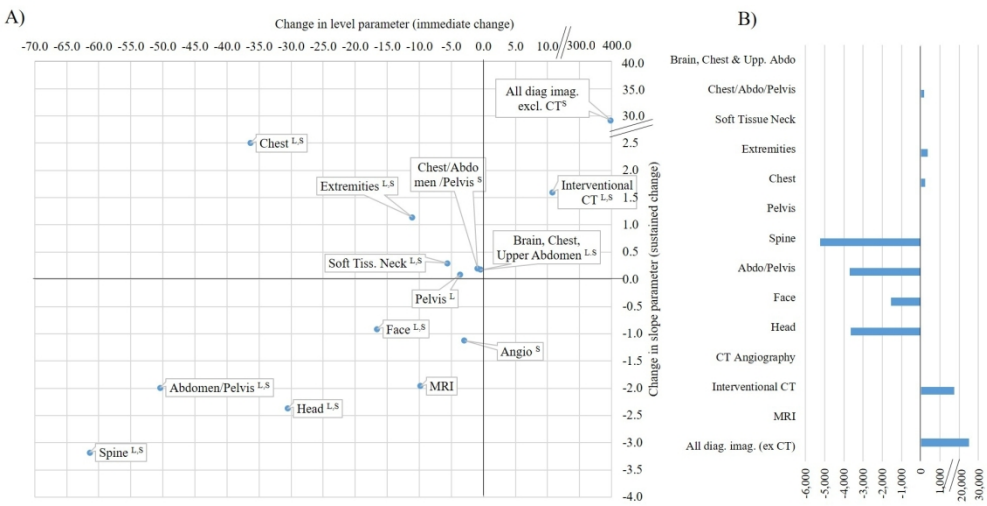

Figure 3: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention. Superscript L and S indicate significant changes in the level and slope parameters, respectively. Part B displays net change in rate of CTs performed Qtr3 2009 - Qtr4 2019, by type / anatomical area.

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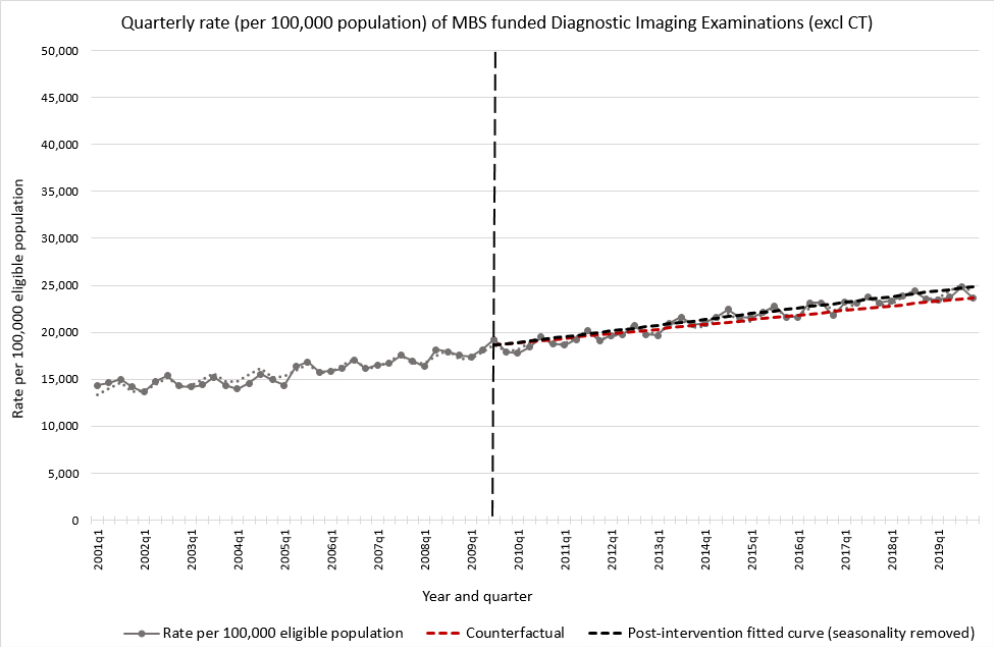

Figure 4: Impact of the 2008-9 professional services review on the rate of Medicare funded diagnostic imaging excluding CT) (per 100,000 Medicare eligible population) in Australia. Figure indicates quarterly rate of all MBS imaging claims (excluding CT) showing counterfactual and post-intervention fitted line (seasonality removed for simplification).

655x428mm (38 x 38 DPI)

Appendix 1: Grouping of CT MBS items according to anatomical location or technique

Group	MBS item number	Description
Head	56001 / 56041	Brain (Non-contrast)
	56007 / 56047	Brain (Contrast)
	56010 / 56050	Pituitary fossa (+/- Contrast)
	56016 / 56056	Petrous bones (+/- Contrast)
Facial bones	56028 /56036 /56068	Facial bones / sinuses or both (Contrast)
	56022 / 56062	Facial bones / sinuses or both (Non-contrast)
	56076 / 56030 / 56070	Facial bones / sinuses or both + Brain (+/- Contrast)
	56013 /56053	Orbits (+/- Contrast)
Neck (soft tissue)	56101 /56141	Soft tissue neck (Non-contrast)
	56107 / 56147	Soft tissue neck (Pre and post contrast)
Chest	56301 / 56341	Chest +/- upper abdo (Non-contrast)
	56307 / 56347	Chest +/- upper abdo (Pre + post contrast)
Abdomen (+/-Pelvis)	56401 / 56441	Upper Abdo -diaphragm to iliac crest (Non-contrast)
	56407 / 56447	Upper Abdo -diaphragm to iliac crest (Contrast)
	56501 / 56541	Abdo/Pelvis (Non-contrast)
	56507 / 56547	Abdo/Pelvis (Contrast)
	56549 / 56551 / 56552 / 56553/ 56554 / 56555	Virtual Colonoscopy
Pelvis only	56409 / 56449	Pelvis (Non-contrast)
	56412 /56452	Pelvis (Contrast)
Chest/Abdo/Pelvis	56801 /56841	Chest/Abdo/Pelvis +/- neck (Non-contrast)
	56807 / 56847	Chest/Abdo/Pelvis +/- neck (Pre + post contrast)
Brain, Chest and Upper Abdomen	57001 /57041	Head + Chest+/-upper abdomen without contrast
	57007 / 57047	Head + Chest +/- upper abdomen with contrast

Spine	56220 / 56227	Cervical spine (Non-contrast)
	56224 / 56230	Cervical spine (Contrast + Non Contrast)
	56221 / 56228	Thoracic spine (Non-contrast)
	56225 / 56231	Thoracic spine (Contrast + Non Contrast)
	56223 / 56229	Lumbar spine (Non-contrast)
	56226 / 56232	Lumbar spine (Contrast + Non Contrast)
	56219 / 56259	Spine - 1 or more regions (With Intrathecal Contrast)
	56233 / 56235	Spine (2 exams of any (C, T or L) kind Non-contrast)
	56234 / 56236	Spine (2 exams of any kind (C, T or L) with Contrast + Without Contrast)
	56237 / 56239	Spine (3 regions C,T,L Non-contrast)
	56238 /56240	Spine (3 regions C,T,L With Contrast + Non Contrast)
Extremities	56619 / 56620/ 56622/ 56623/ 56625	CT of extremities one or more regions (Non-contrast)
	56626 /56627/ 56628/ 56629/ 56630/ 56659 / 56665	CT of extremities one or more regions (Non-contrast)
Spiral Angiography*	57350-57356	Spiral angiography (Pre + post contrast)
	57360/57361	CT of the coronary arteries
Cone Beam CT	56025/56026/57362/57363	Cone Beam CT of teeth and supporting bone structures
Pelvimetry	57201 / 57247	Pelvimetry
Interventional CT	57341 / 57345	CT in conjunction with a surgical procedure using interventional techniques

MBS: Medicare Benefit Scheme

*Spiral angiographic CT item codes relate specify several broad clinical settings relating to their use.

Appendix 2: Size of the Medicare eligible population, and numbers of imaging procedures performed by type, per quarter

		Number of imaging procedures per quarter, by type (excl CT)						
Year and quarter	**Medicare eligible population**	**ALL MBS**	**General Practitioner visits**	**All Diagnostic Imaging**	**Diagnostic Imaging excluding CT**	**ALL MRI**	**All US**	**All Nuc Med**
2001Q1	19,974,075	53,913,292	22,535,443	3,080,396	2,862,100	47,080	875,892	72,556
2001Q2	20,058,815	54,612,217	23,208,144	3,163,585	2,937,355	52,84	890,270	74,655
2001Q3	20,139,806	57,160,177	24,425,178	3,250,431	3,017,862	56,58	901,629	78,692
2001Q4	20,215,957	53,802,181	22,153,529	3,129,899	2,869,771	55,78	900,319	74,530
2002Q1	20,296,405	52,698,145	21,476,055	3,050,855	2,764,530	53,73	877,966	71,292
2002Q2	20,374,998	57,043,850	23,767,570	3,321,404	3,010,541	60,26	949,968	78,445
2002Q3	20,451,273	58,573,985	24,368,388	3,462,073	3,140,545	64,44	995,302	82,390
2002Q4	20,525,042	54,100,126	21,792,309	3,234,123	2,929,308	61,04	961,803	77,054
2003Q1	20,574,715	53,702,789	21,315,160	3,235,168	2,919,654	60,33	974,715	75,127
2003Q2	20,640,449	55,029,284	22,356,470	3,296,996	2,977,779	65,29	982,227	77,892
2003Q3	20,724,986	58,373,440	24,129,408	3,492,688	3,153,252	69,92	1,028,635	81,564
2003Q4	20,805,416	55,102,234	21,673,949	3,316,288	2,986,225	67,26	1,009,242	79,271
2004Q1	20,892,413	55,237,593	21,666,698	3,251,558	2,923,221	65,88	993,179	75,292
2004Q2	20,971,967	57,668,884	22,696,197	3,397,421	3,053,659	70,74	1,025,832	79,572
2004Q3	21,040,363	60,479,828	24,247,888	3,630,147	3,264,529	73,16	1,088,136	84,727
2004Q4	21,020,468	58,681,495	22,853,173	3,497,953	3,137,363	73,48	1,074,598	79,970
2005Q1	20,395,854	55,265,155	21,262,334	3,272,212	2,926,937	68,65	1,018,953	73,814
2005Q2	20,482,464	61,889,434	24,051,201	3,736,003	3,347,527	81,13	1,157,994	84,654
2005Q3	20,535,311	63,925,592	25,233,583	3,864,039	3,463,294	86,18	1,201,410	86,013
2005Q4	20,570,360	59,950,302	22,770,828	3,634,302	3,245,994	83,50	1,157,675	81,138
2006Q1	20,651,536	61,070,666	22,888,207	3,673,330	3,273,759	86,36	1,166,540	80,584
2006Q2	20,738,739	62,420,316	23,652,256	3,749,991	3,345,574	90,24	1,190,679	82,258
2006Q3	20,834,970	65,739,068	25,539,356	3,981,768	3,556,490	98,37	1,254,468	88,615
2006Q4	20,918,630	62,183,136	23,051,071	3,802,035	3,380,338	94,24	1,241,269	84,811

2007Q1	21,023,544	64,047,623	23,223,619	3,909,736	3,469,566	97,875	1,276,478	85,374
2007Q2	21,075,599	65,922,562	24,130,232	3,961,046	3,515,224	103,019	1,285,806	87,332
2007Q3	21,156,498	70,587,243	26,691,515	4,164,895	3,711,184	108,799	1,331,460	90,249
2007Q4	21,213,097	68,075,447	24,303,827	4,052,075	3,593,258	103,894	1,326,226	92,717
2008Q1	21,300,775	66,111,755	23,520,354	3,932,797	3,481,827	97,289	1,284,795	86,786
2008Q2	21,382,498	73,943,872	26,298,507	4,374,974	3,876,485	113,767	1,446,356	100,177
2008Q3	21,474,007	73,411,004	26,802,312	4,347,958	3,854,001	114,660	1,437,929	100,593
2008Q4	21,542,093	72,757,668	25,038,849	4,268,041	3,775,261	113,596	1,442,680	98,530
2009Q1	21,611,182	72,990,845	24,512,108	4,265,199	3,758,331	109,507	1,442,832	101,325
2009Q2	21,712,379	74,849,371	26,821,617	4,450,168	3,935,534	121,503	1,515,593	106,838
2009Q3	21,799,725	79,059,828	27,838,442	4,735,321	4,188,550	134,373	1,592,771	114,116
2009Q4	21,864,719	77,132,787	26,394,306	4,439,849	3,921,910	124,631	1,539,685	108,432
2010Q1	21,995,898	73,945,829	25,424,324	4,423,973	3,905,995	119,415	1,535,498	109,394
2010Q2	22,116,286	78,262,472	26,549,056	4,554,003	4,075,502	132,073	1,583,459	115,291
2010Q3	22,225,493	80,332,900	28,142,355	4,845,036	4,329,256	134,639	1,668,768	125,165
2010Q4	22,322,182	79,520,986	26,438,106	4,697,780	4,196,325	134,156	1,655,431	124,342
2011Q1	22,430,782	78,696,720	26,010,154	4,686,355	4,180,032	129,057	1,642,691	121,167
2011Q2	22,536,170	80,591,361	27,413,666	4,846,047	4,332,553	140,184	1,695,068	127,800
2011Q3	22,646,567	86,000,221	29,054,464	5,159,265	4,578,841	153,104	1,832,694	139,046
2011Q4	22,752,945	80,099,988	26,848,618	4,912,101	4,339,480	142,808	1,789,169	139,453
2012Q1	22,869,958	83,090,073	27,328,488	5,107,472	4,499,155	143,874	1,862,446	143,865
2012Q2	22,975,129	83,419,449	28,489,105	5,146,458	4,542,312	151,104	1,875,437	145,229
2012Q3	23,083,927	87,331,463	29,872,637	5,406,664	4,781,580	157,747	1,955,461	150,517
2012Q4	23,186,999	88,148,306	27,973,187	5,209,940	4,589,199	155,520	1,940,993	146,353
2013Q1	23,301,712	81,070,495	27,558,438	5,204,538	4,575,455	151,607	1,941,553	147,521
2013Q2	23,415,863	87,420,296	30,105,954	5,572,789	4,907,148	172,931	2,092,082	158,845
2013Q3	23,526,793	91,269,394	31,279,774	5,764,539	5,084,337	181,946	2,156,469	162,931
2013Q4	23,516,579	87,442,632	28,772,106	5,546,788	4,885,276	197,659	2,101,276	158,443
2014Q1	23,726,126	87,365,616	29,058,733	5,647,377	4,972,344	214,246	2,126,548	157,860
2014Q2	23,816,689	92,173,285	30,602,781	5,845,674	5,153,281	230,866	2,186,482	162,773

2014Q3	23,923,051	94,962,398	32,149,396	6,089,946	5,370,449	246,153	2,265,530	165,754
2014Q4	23,997,461	92,135,078	29,577,466	5,897,348	5,190,581	237,565	2,242,799	164,672
2015Q1	24,105,563	90,560,806	29,192,987	5,901,602	5,195,336	233,585	2,242,250	162,921
2015Q2	24,179,690	95,743,360	32,217,965	6,060,642	5,346,902	253,841	2,293,992	168,956
2015Q3	24,278,495	98,437,227	33,192,194	6,261,986	5,542,495	262,668	2,373,981	170,088
2015Q4	24,366,559	95,229,471	30,215,723	5,967,569	5,272,222	245,417	2,328,097	156,482
2016Q1	24,453,229	92,813,393	29,917,061	5,997,592	5,283,310	240,294	2,338,670	156,130
2016Q2	24,553,190	102,637,644	33,843,841	6,440,165	5,682,508	272,756	2,512,656	170,212
2016Q3	24,636,038	100,005,965	33,410,503	6,462,300	5,698,777	275,305	2,487,482	171,942
2016Q4	24,711,652	95,516,816	30,979,374	6,123,586	5,384,207	256,559	2,387,030	164,289
2017Q1	24,821,154	100,586,254	31,735,405	6,557,448	5,752,386	272,317	2,567,688	175,505
2017Q2	24,924,168	103,376,540	33,864,514	6,547,871	5,755,139	294,155	2,565,789	174,498
2017Q3	25,007,901	104,773,012	35,065,253	6,770,682	5,947,070	301,476	2,608,763	179,662
2017Q4	25,078,863	104,675,460	32,269,893	6,625,438	5,799,977	293,524	2,610,899	172,694
2018Q1	25,182,661	101,038,400	32,092,680	6,725,986	5,873,983	290,847	2,653,510	180,775
2018Q2	25,267,605	109,365,729	35,737,557	6,882,768	6,020,760	315,569	2,722,980	177,872
2018Q3	25,353,168	106,249,390	34,517,832	7,057,888	6,177,536	328,216	2,764,644	182,907
2018Q4	25,436,468	106,876,163	33,190,019	6,867,102	5,982,682	312,607	2,764,861	179,849
2019Q1	25,520,089	105,168,957	32,968,083	6,881,495	5,981,931	302,827	2,801,529	180,979
2019Q2	25,595,189	111,352,700	37,391,585	6,978,029	6,068,535	358,076	2,808,803	184,667
2019Q3	25,675,916	113,030,934	36,443,353	7,335,021	6,365,854	354,052	2,933,923	193,589
2019Q4	25,754,980	108,011,995	33,510,224	7,009,009	6,068,363	338,102	2,852,030	190,786
TOTAL 2001-2019		**5,986,242,372**	**2,089,094,937**	**369,444,996**	**327,257,812**	**12,158,315**	**131,610,743**	**9,438,609**
Percent of all MBS activity			**34.9**	**6.17**	**5.47**	**0.2**	**2.2**	**0.16**
Percent of all Diagnostic Imaging					**88.58**	**3.29**	**35.62**	**2.55**
Percent of all CT scanning								

Table continued

Year and quarter	Number of CT examinations per quarter, by type						
	ALL CT	Head CT	Facial bones CT	Neck (soft tissue) CT	Chest CT	Chest/Abdo/Pelvis CT	Abdomen (+/- pelvis) CT
2001Q1	218,296	75,243	29,194	5,846	25,038	10,890	49,942
2001Q2	226,230	78,787	31,520	5,939	25,496	10,934	50,612
2001Q3	232,569	77,870	34,130	6,000	26,799	11,658	51,566
2001Q4	260,128	75,556	31,757	6,216	26,987	12,194	52,659
2002Q1	286,325	72,827	28,723	5,943	26,344	12,515	54,436
2002Q2	310,863	80,824	32,855	6,477	28,191	13,491	57,619
2002Q3	321,528	82,648	35,417	6,737	30,494	14,510	59,259
2002Q4	304,815	74,501	31,611	6,479	29,060	14,286	58,314
2003Q1	315,514	78,396	30,083	6,508	28,524	15,133	61,638
2003Q2	319,217	79,059	32,590	6,549	28,936	15,241	61,802
2003Q3	339,436	83,562	34,796	6,976	31,994	16,793	64,927
2003Q4	330,063	78,264	31,652	6,996	31,908	17,194	64,729
2004Q1	328,337	76,190	29,486	7,002	30,747	17,864	66,617
2004Q2	343,762	80,273	33,374	6,994	31,536	18,311	69,139
2004Q3	365,618	85,257	36,384	7,272	35,081	19,594	71,178
2004Q4	360,590	82,754	35,066	7,179	35,066	19,973	70,097
2005Q1	345,275	76,760	31,309	6,939	32,483	20,226	69,673
2005Q2	388,476	88,306	37,094	7,862	35,613	22,142	76,537
2005Q3	400,745	91,158	38,797	7,793	37,585	23,170	77,325
2005Q4	388,308	84,502	36,127	7,904	36,823	23,263	76,871
2006Q1	399,571	86,081	35,311	8,134	36,452	24,976	80,765
2006Q2	404,417	86,807	38,138	7,731	36,276	25,075	81,175
2006Q3	425,278	92,095	41,594	8,055	39,001	26,017	83,082
2006Q4	421,697	87,923	38,381	8,577	38,946	26,911	83,321

2007Q1	440,170	92,093	37,067	8,779	39,326	28,744	88,975
2007Q2	445,822	94,631	40,052	8,245	38,678	27,920	89,103
2007Q3	453,711	93,891	42,974	8,724	41,238	29,226	88,578
2007Q4	458,817	95,095	41,294	8,837	42,434	30,196	89,730
2008Q1	450,970	93,195	38,146	8,545	39,569	29,798	90,417
2008Q2	498,489	101,530	45,024	9,678	43,118	32,623	98,675
2008Q3	493,957	97,072	47,054	9,072	44,512	32,685	96,012
2008Q4	492,780	97,102	43,048	9,254	44,864	33,423	96,361
2009Q1	506,868	98,536	41,934	9,479	43,779	35,884	102,656
2009Q2	514,634	101,302	45,716	9,636	43,969	36,118	102,856
2009Q3	546,771	107,069	50,834	10,075	48,233	37,953	106,818
2009Q4	517,939	100,708	44,414	9,594	45,591	37,405	100,455
2010Q1	517,978	100,254	41,898	9,628	43,424	39,023	103,770
2010Q2	478,501	93,538	40,507	8,960	40,803	37,635	95,304
2010Q3	515,780	98,321	46,458	9,666	45,428	39,354	99,595
2010Q4	501,455	94,719	42,363	9,825	46,193	39,372	96,336
2011Q1	506,323	95,129	39,688	9,981	45,948	41,563	100,132
2011Q2	513,494	96,725	43,280	9,797	45,808	41,894	100,369
2011Q3	580,424	102,851	50,301	10,775	50,818	45,041	107,854
2011Q4	572,621	98,347	44,683	10,532	50,612	44,780	108,030
2012Q1	608,317	105,042	45,525	11,083	51,598	49,684	116,058
2012Q2	604,146	104,413	46,932	11,013	51,212	48,006	113,052
2012Q3	625,084	106,380	50,286	11,121	54,646	49,262	113,827
2012Q4	620,741	101,520	46,030	11,208	55,158	50,048	114,814
2013Q1	629,083	105,860	44,546	11,554	53,664	51,746	118,692
2013Q2	665,641	111,194	49,730	12,124	57,601	52,886	123,927
2013Q3	680,202	111,494	52,005	12,030	60,202	53,962	123,695
2013Q4	661,512	102,227	47,646	12,089	59,847	54,211	121,680
2014Q1	675,033	104,173	46,951	12,169	59,405	56,972	126,579
2014Q2	692,393	105,582	49,645	12,308	61,240	56,573	127,207

2014Q3	719,497	106,283	54,941	13,046	66,686	58,574	128,500
2014Q4	706,767	104,179	49,805	13,241	67,660	59,008	130,637
2015Q1	706,266	107,198	49,464	13,017	65,311	60,743	133,591
2015Q2	713,740	108,814	52,771	13,231	68,186	60,704	132,644
2015Q3	719,491	108,195	54,781	13,098	72,485	61,291	129,284
2015Q4	695,347	101,454	47,878	13,227	70,426	62,371	128,975
2016Q1	714,282	105,362	47,179	13,505	69,763	64,773	133,961
2016Q2	757,657	111,103	53,315	14,490	74,077	65,588	140,232
2016Q3	763,523	110,128	55,826	14,755	78,893	66,953	138,167
2016Q4	739,379	104,499	50,328	14,453	77,701	65,310	133,437
2017Q1	805,062	115,414	52,521	15,667	81,219	71,433	149,116
2017Q2	792,732	112,646	53,677	15,661	80,405	69,606	144,232
2017Q3	823,612	117,302	59,970	15,577	87,261	71,379	145,531
2017Q4	825,461	114,373	53,565	16,273	86,954	71,591	148,272
2018Q1	852,003	118,695	54,068	16,751	85,878	76,133	156,420
2018Q2	862,008	118,600	57,084	16,811	87,963	74,992	156,527
2018Q3	880,352	119,379	62,327	16,995	91,688	75,550	155,815
2018Q4	884,420	118,096	56,790	17,477	94,604	77,554	157,633
2019Q1	899,564	120,415	55,471	18,299	94,124	80,924	163,452
2019Q2	909,494	119,984	58,368	18,347	94,789	79,216	162,030
2019Q3	969,167	125,420	65,879	19,370	105,447	80,680	167,554
2019Q4	940,646	117,270	58,760	19,454	103,562	80,410	164,552
TOTAL 2001-2019	**42,187,184**	**7,450,445**	**3,366,188**	**816,634**	**4,019,380**	**3,211,131**	**7,955,402**
Percent of all MBS activity	**0.70**	**0.12**	**0.06**	**0.01**	**0.07**	**0.05**	**0.13**
Percent of all Diagnostic Imaging	**11.42**	**2.02**	**0.91**	**0.22**	**1.09**	**0.87**	**2.15**
Percent of all CT scanning		**17.66**	**7.98**	**1.94**	**9.53**	**7.61**	**18.86**

Table continued

Year and quarter	Number of CT examinations per quarter, by type							
	Brain/Chest/ Upper Abdo CT	Pelvis CT	Spine CT	Extremities CT	Spiral Angiography CT	Interventional CT	Cone Beam CT	CT Pelvimetry
2001Q1	484	3,501	33	9,355	3,770	4,249	0	751
2001Q2	520	3,339	33	9,787	4,140	4,455	0	668
2001Q3	458	3,595	21	10,231	4,535	5,059	0	647
2001Q4	511	3,326	30,308	9,873	4,745	5,402	0	594
2002Q1	570	3,369	61,118	9,803	4,659	5,447	0	571
2002Q2	603	3,658	63,786	11,201	5,430	6,124	0	604
2002Q3	594	3,685	63,611	11,630	5,923	6,439	0	581
2002Q4	569	3,641	62,401	11,023	5,844	6,623	0	463
2003Q1	606	3,703	66,897	11,128	5,674	6,697	0	527
2003Q2	601	3,774	64,279	11,809	6,578	7,524	0	475
2003Q3	825	4,032	66,834	12,383	7,588	8,236	0	490
2003Q4	799	3,801	65,897	12,119	7,375	8,872	0	457
2004Q1	785	3,938	66,965	12,053	7,391	8,777	0	522
2004Q2	816	4,007	68,064	13,134	8,454	9,247	0	413
2004Q3	905	3,933	72,040	13,971	9,539	9,983	0	481
2004Q4	944	3,905	71,700	13,196	9,487	10,770	0	453
2005Q1	895	3,729	70,464	13,115	8,846	10,420	0	416
2005Q2	991	4,144	76,683	15,638	10,946	12,081	0	439
2005Q3	1,065	4,260	77,925	15,741	12,808	12,706	0	412
2005Q4	973	3,957	76,276	15,480	12,381	13,422	0	329
2006Q1	1,153	4,092	80,785	15,887	12,450	13,113	0	372
2006Q2	1,108	4,253	79,022	17,140	13,247	14,100	0	345
2006Q3	1,209	4,385	83,153	18,105	13,158	15,063	0	361
2006Q4	1,161	4,530	84,528	17,970	12,964	16,177	0	308
2007Q1	1,149	4,489	90,737	19,050	13,219	16,211	0	331

2007Q2	1,192	4,420	90,739	19,767	14,103	6,683	0	289
2007Q3	1,309	4,673	89,921	20,303	15,602	6,954	0	318
2007Q4	1,388	5,321	91,415	19,958	14,875	7,995	0	279
2008Q1	1,349	5,088	92,935	20,092	14,167	7,414	0	255
2008Q2	1,500	6,200	100,562	22,752	16,368	0,187	0	272
2008Q3	1,415	5,261	99,498	23,278	17,377	0,489	0	232
2008Q4	1,471	4,650	100,134	23,436	16,636	2,185	0	216
2009Q1	1,588	4,801	104,771	24,479	16,201	2,558	0	202
2009Q2	1,538	4,980	101,581	25,436	17,557	3,715	0	230
2009Q3	1,755	5,293	107,077	26,983	19,439	4,995	0	247
2009Q4	1,680	4,702	102,250	25,472	18,485	6,978	0	205
2010Q1	1,699	4,738	103,685	25,789	17,685	6,216	0	169
2010Q2	1,648	4,555	85,806	24,382	18,201	6,982	0	180
2010Q3	1,767	4,882	95,385	25,813	20,374	8,567	0	170
2010Q4	1,849	4,763	90,398	24,944	19,597	0,959	0	137
2011Q1	1,963	4,826	92,963	26,139	18,653	9,167	0	171
2011Q2	1,880	4,780	91,462	27,106	19,789	0,453	0	151
2011Q3	2,172	5,466	102,125	30,104	26,968	2,923	12,871	155
2011Q4	2,221	5,125	100,847	28,793	27,474	4,778	16,263	136
2012Q1	2,482	5,636	110,377	31,655	27,675	4,698	16,625	179
2012Q2	2,403	5,608	107,295	32,250	29,264	5,854	16,696	148
2012Q3	2,415	5,753	109,471	33,365	31,617	8,847	17,949	145
2012Q4	2,442	5,752	110,166	33,269	30,578	1,714	17,897	145
2013Q1	2,591	6,047	114,534	33,797	29,866	9,310	16,768	108
2013Q2	2,838	6,423	117,335	36,080	33,694	2,769	18,941	99
2013Q3	2,937	6,806	117,109	36,896	36,368	4,764	21,846	88
2013Q4	2,994	6,918	113,552	36,228	34,893	6,352	22,773	102
2014Q1	3,002	6,976	120,699	37,594	32,916	5,383	22,106	108
2014Q2	3,130	7,468	119,988	38,547	35,930	9,130	25,549	96
2014Q3	3,224	7,554	123,541	40,648	38,353	0,291	27,768	88

2014Q4	3,212	7,817	123,566	41,177	37,057	72,224	17,135	49
2015Q1	3,401	7,898	128,899	41,151	35,762	70,077	9,672	82
2015Q2	3,347	8,294	123,016	41,336	39,666	71,910	9,739	82
2015Q3	3,879	9,304	121,370	41,927	41,299	72,865	9,645	68
2015Q4	3,927	9,217	113,166	40,710	39,087	75,872	8,978	59
2016Q1	4,293	9,823	123,714	41,669	38,340	72,317	9,521	62
2016Q2	4,695	10,472	125,323	44,811	44,471	77,181	11,836	63
2016Q3	4,957	11,141	124,856	45,329	46,254	76,064	10,142	58
2016Q4	4,987	10,832	120,430	44,823	44,577	78,579	9,351	72
2017Q1	5,870	12,380	137,018	48,798	45,657	79,527	10,370	72
2017Q2	5,992	12,618	129,849	48,133	48,847	80,995	10,015	56
2017Q3	6,278	12,830	133,361	49,085	52,435	81,656	10,899	48
2017Q4	6,563	13,081	134,986	49,347	52,331	85,607	12,472	46
2018Q1	7,668	14,379	144,524	52,592	51,199	83,111	10,549	36
2018Q2	7,997	15,461	139,015	54,608	55,177	85,107	12,623	43
2018Q3	8,565	16,172	140,824	56,911	58,989	85,395	11,699	43
2018Q4	8,943	16,841	139,773	57,016	57,800	90,336	11,510	47
2019Q1	9,524	17,606	144,280	59,830	56,311	87,328	11,956	44
2019Q2	10,235	18,763	139,531	62,173	62,432	91,045	12,537	44
2019Q3	12,202	21,726	148,339	66,588	68,053	95,046	12,834	29
2019Q4	12,594	22,274	141,373	64,977	66,237	97,304	11,840	39
TOTAL 2001-2019	**221,265**	**541,440**	**7,428,394**	**2,239,168**	**1,963,837**	**2,466,053**	**489,375**	**18,472**
Percent of all MBS activity	**0.00**	**0.01**	**0.12**	**0.04**	**0.03**	**0.04**	**0.01**	**0.00**
Percent of all Diagnostic Imaging	**0.06**	**0.15**	**2.01**	**0.61**	**0.53**	**0.67**	**0.13**	**0.00**
Percent of all CT scanning	**0.52**	**1.28**	**17.61**	**5.31**	**4.66**	**5.85**	**1.16**	**0.04**

MBS: Medicare Benefit Scheme

Q1: January to March, Q2: April to June, Q3: July to August, Q4: September to December

US: Ultrasound, Nuc Med: Nuclear Medicine

Appendix 3, Table 1: Change in the quarterly rate of MBS funded CT scans per 100,000 eligible population according to geographic location of service provision following publications of the MBS professional services review (2008-9) and associated media attention

Classification of the change[a]	Geographic location[#]	Magnitude of change						Net change[b] in the rate of CTs performed (Qtr3 2009-Qtr 4 2019)
		Level*			Slope*			
		Point estimate	95% CL		Point estimate	95% CL		
			Lower	Upper		Lower	Upper	
1A	NSW	-233.4	-344.3	-122.4	-8.5	-13.8	-3.2	-16,943.6
	SA	-355.0	-449.9	-260.2	-9.8	-15.7	-4.0	-22,843.0
	Vic	-207.7	-307.1	-108.3	-10.3	-15.1	-5.4	-17,344.1
1B	ALL Australia	-237.7	-333.4	-141.9	-2.2	-7.2	2.8	-9,744.3
	Tas	-186.7	-308.3	-65.0	-5.2	-13.0	2.6	-7,652.7
1C	WA	-402.0	-568.7	-235.3	8.9	0.0	17.7	-9,197.4
	ACT	-325.5	-405.2	-245.8	9.5	5.5	13.5	-5,857.7
	Qld	-127.3	-230.9	-23.7	11.8	7.3	16.4	4,274.8
2C	NT[C]	17.3	-170.4	205.0	11.5	4.4	18.7	9,665.8

MBS: Medicare Benefit Scheme; CT: Computed Tomography scanning

[a]Classification of change: 1A: Significant reduction in both the level and slope; 1B: Significant reduction in the level but no change in the slope; 1C: Significant reduction in the level with a significant increase in the slope; 2A: No significant change in the level with a significant reduction in the slope; 2B: No significance change in the level or slope; 2C: No significant change in the level with a significant increase in the slope; 3A: Significant increase in the level with a significant reduction in the slope; 3B: Significant increase in the level with no change in the slope; 3C: Significant increase in both the level and the slope.

[#]ACT: Australian Capital Territory; NSW: New South Wales; NT: Northern Territory; Qld: Queensland; SA: South Australia; Tas: Tasmania; Vic: Victoria; WA: Western Australia.

*Both the level and slope changes are expressed per 100,000 eligible population residing in the location specified at the time of the service provision

95% CL: 95% confidence limits around the point estimate

p values < 0.05 (95% CL that do not cross zero) are considered as significant changes in level and slope; greyed cells indicate non-significant changes

Values are estimated from the seasonally adjusted single interrupted time series model with autocorrelation correction as required for the data

[b]The net change in the rate was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of MBS-funded CT scans. Negative values result from the area below the counterfactual being larger than the area above it and indicate a net reduction in the rate of CT scans undertaken over the post-intervention time period; positive values indicate the reverse. In cases where the post-intervention trend was non-linear the net change is limited to the period prior to further disruptions in the trend.

[C]Post intervention phase was non-linear therefore change reported in the level and slope are limited to the initial post-intervention period prior to any significant further disruption of the trend.

Appendix 3, Table 2: Change in the quarterly rate of MBS funded medical imaging undertaken in Australia per 100,000 eligible population according to type of service following publications of the MBS professional services review (2008-9) and associated media attention

Classification of the change[a]	Type of medical imaging service	Magnitude of change						Net change[b] in the rate of CTs performed (Qtr3 2009-Qtr 4 2019)
		Level*			Slope*			
		Point estimate	95% CL		Point estimate	95% CL		
			Lower	Upper		Lower	Upper	
1A	Head CT	-30.5	-43.5	-17.6	-2.4	-3.1	-1.6	-3,637.4
	Face CT	-16.6	-23.0	-10.2	-0.9	-1.4	-0.5	-1,549.7
	Abdomen/Pelvis CT	-50.4	-63.4	-37.4	-2.0	-2.5	-1.4	-3,695.2
	Spine CT	-61.4	-83.6	-39.1	-3.2	-4.2	-2.2	-5,230.1
1B	Pelvis CT[c]	-3.6	-5.8	-1.5	0.1	0.1	0.2	-47.3
1C	Chest CT	-36.4	-46.4	-26.3	2.5	2.0	3.0	273.4
	Brain, Chest and Upper Abdomen CT[C]	-0.5	-0.9	-0.1	0.2	0.1	0.2	31.1
	Extremities CT	-11.1	-19.0	-3.2	1.1	0.5	1.8	366.5
	Soft Tissue Neck CT	-5.6	-7.4	-3.8	0.3	0.2	0.4	3.9
2A	CT Angiography[C]	-3.0	-6.2	0.3	-1.1	-1.7	-0.6	-16.9
2B	MRI[c]	-9.8	-33.0	13.4	-2.0	-4.6	0.7	0.0
2C	Chest/Abdomen/Pelvis CT	-0.9	-6.2	4.3	0.2	-0.1	0.4	167.9
	All diagnostic imaging (excl CT)	393.8	-68.4	856.0	29.2	3.0	55.4	25,137.6
3C	Interventional CT	10.7	3.0	18.4	1.6	1.2	2.0	1,739.6

MBS: Medicare Benefit Scheme; MRI: Magnetic Resonance Imaging; CT: Computed Tomography scanning

[a]Classification of change: 1A: Significant reduction in both level and slope; 1B: Significant reduction in level but no change in the slope; 1C: Significant reduction in the level and a significant increase in the slope; 2A: No significant change in level with a significant reduction in slope; 2B: No significance change in the level or slope; 2C: No significant change in level with a significant increase in slope; 3C: Significant increase in both level and slope.

*Both the level and slope changes are expressed per 100,000 eligible population residing in Australia at the time of the service provision

95% CL: 95% confidence limits around the point estimate

p values < 0.05 (95% CL that do not cross zero)are considered as significant changes in level and slope; greyed cells indicate non-significant changes

[b]The net change in the rate was calculated from the area between the counterfactual (i.e. pre-intervention slope with no level change) and the post-intervention observed (defined using the seasonally adjusted model level and slope parameters) curves of the quarterly rate of MBS-funded medical imaging services. Negative values result from the area below the counterfactual being larger than the area above it and indicate a net reduction in the rate of CT scans undertaken over the post-intervention time period; positive values indicate the reverse. In cases where the post-intervention trend was non-linear the net change is limited to the period prior to further disruptions in the trend.

[c]Post intervention phase was non-linear therefore change reported in the level and slope are limited to the intial post-intervention period prior to any significant further disruption of the trend.

The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Abstract - Methods Abstract – Methods N/A
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Throughout Introduction
Objectives	3	State specific objectives, including any prespecified hypotheses			Last paragraph of Introduction, page 4
Methods					
Study Design	4	Present key elements of study design early in the paper			First sentence of Methods, page 4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Methods – Data source subheading, page 4

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case		RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	Methods – Data source subheading; Appendix 1 Codes in Appendix 1. Validation / algorithms N/A N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Appendix 1. No confounding variables, though counterfactual is described in Methods – Statistical analysis subheading page 5
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).			Methods subheadings Data Source and Quarterly rate of

		Describe comparability of assessment methods if there is more than one group			imaging, pages 4-5
Bias	9	Describe any efforts to address potential sources of bias			Methods subheading Statistical Analysis, page 5, and Limitations, page 13
Study size	10	Explain how the study size was arrived at			Population for denominator in rates described in Methods – Quarterly rate of imaging, page 5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods – Data source subheading, page 4
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical			Methods – Statistical analysis, page 5 N/A N/A No loss to follow-up N/A N/A

		methods taking account of sampling strategy (e) Describe any sensitivity analyses			N/A
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	N/A
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	N/A
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Results first paragraph, page 6 (concerning imaging examinations, not persons)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders			N/A, unit of analysis is imaging procedure rather than persons

		(b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			Results, first two paragraphs, pages 6-7
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Results, unadjusted estimates in paragraph 2, adjusted through remainder
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			
Discussion					
Key results	18	Summarise key results with reference to study objectives			First paragraph, page 10

Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	Limitations subheading, page 13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			Throughout discussion
Generalisability	21	Discuss the generalisability (external validity) of the study results			Implications subheading, page 13
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based			Page 14
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Page 14

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.