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First do no harm – The impact of financial incentives on dental x-rays

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Abstract

This article assesses the impact of dentist remuneration on the incidence of potentially harmful dental x-rays. We use unique panel data which provide details of 1.3 million treatment claims by Scottish NHS dentists made between 1998 and 2007. Controlling for unobserved heterogeneity of both patients and dentists we estimate a series of fixed-effects models that are informed by a theoretical model of x-ray delivery and identify the effects on dental x-raying of dentists moving from a fixed salary to fee-for-service and patients moving from co-payment to exemption. We establish that there are significant increases in x-rays when dentists receive fee-for-service rather than salary payments and when patients are made exempt from payment.
JEL Code I11. Keywords: Healthcare, incentives, matched data, dentistry.

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1 Introduction

> "In 1992, shortly after Gerd Gigerenzer[1] moved to Chicago, he took his six-year-old daughter to the dentist. She didn't have toothache, but he thought it was about time she got acquainted with the routine of sitting in the big reclining chair and being prodded with pointy objects. The clinic had other ideas. 'The dentist wanted to x-ray her,' Gigerenzer recalls. 'I told first the nurse, and then him, that she had no pains and I wanted him to do a clinical examination, not an x-ray.' "

Dental x-rays are one of the most common sources of x-ray exposure. Whilst they are an important diagnostic tool, x-rays are a known human carcinogen and there is no threshold below which exposure is considered totally safe. So clinical guidance indicates that x-rays should only be undertaken if the clinical benefits to the patient warrant the risk. The financial arrangements of the physician or their patient should not come into play. In this article we examine the extent to which, notwithstanding that clinical imperative, they actually do. Specifically we estimate the effect of a dentist changing from a fee-for-service to a salaried arrangement on the probability that they x-ray a patient over the course of treatment and of the effect of a patient changing from co-payment to full exemption on that same probability.

Health economists have long posited that financial incentives matter and have constructed and tested models of the impact of different financial arrangements on numerous aspects of medical treatment. The idea that insulating patients from the costs of treatment might induce excessive treatment has a very long heritage (see, for example Zweifel and Manning, 2000) whilst physician remuneration viewed in the context of agency relationships as described in McGuire (2000) suggests that fee-for-service payment may induce more treatment. This aspect of fee-for-service has led to calls for its phasing out (Schroeder and Frist, 2013). As with the majority of studies the recent contribution by Clemens and Gottlieb (2014) finds very little effect of excess treatment on patient well-being. Many treatments – routine examinations and investigations – do not pose health risks for patients so whilst extra treatment induced by fee-for-service may result in waste, it might be benign

[1]Gerd Gigerenzer is director of the Harding Center for Risk Literacy in Berlin and this quotation appeared in a British Broadcasting Corporation internet article commenting on attitudes of physicians to risk; see, http://www.bbc.co.uk/news/magazine-28166019

in regard to health. This cannot be said for x-rays and ours is the first study to bring the interpretative lens of the economics of incentives and empirical evidence onto this potentially harmful treatment.

Ionizing radiation can directly induce cell death but the low doses used in dental imaging are more likely to induce DNA damage and can result in cancer and leukaemia (Little, 2003). A widely accepted concept in this context is the *linear non-threshold hypothesis* which postulates that the likelihood of developing cancer increases linearly with radiation dose and that there is no threshold level of radiation exposure below which carcinogenesis does not occur (Kellerer, 2000). Empirical evidence about the impact of low radiation doses, such as those caused by dental x-rays, on carcinogenesis is relatively sparse due to sample sizes which often are too small for detecting significant relations (White and Mallya, 2012). However, some studies, such as Memon *et al* (2010) and Preston-Martin and White (1990), suggest that dental imaging is specifically associated with meningiomas, salivary gland tumours and thyroid tumours. A recent population-based case-control retrospective study by Claus *et al* (2012) found that patients with meningioma have twice the likelihood of reporting having ever had a bitewing examination than patients without meningioma. This and similar evidence about potential risks of x-raying substantiates the recommendation of the International Commission on Radiological Protection (ICRP) that activities that cause exposure to radiation can only be justified if they do more good than harm (ICRP, 2008) for the patient. In this context evidence that the remuneration of a dentist positively impacts on the decision to carry out an x-ray examination is concerning since such remuneration is not a clinical benefit to the patient.

To examine whether, contrary to clinical guidance, x-ray use responds to financial arrangements we make use of an extensive and detailed dataset concerning the incidence of x-ray imaging in dental treatment in the NHS in Scotland. Our data follow patients and dentists over multiple treatment episodes for 10 years and thus track changes in the use of x-rays associated with changes in a dentist's method of reimbursement whilst also permitting us to control for changes in a particular patient's circumstance, including whether or not they contribute to the cost of their treatment, and to account for time invariant unobserved patient and dentist characteristics. We interpret these data in the context of a model of interactions between physician and patient and their respective financial arrangements. Our results indicate that a dentist's reimbursement method induces a significant impact on x-ray use with dentists who are paid a separate fee for each x-ray providing more x-rays. This effect is greater if the patient is also exempt from payment. We also find an effect *ceteris paribus* of a patient being made exempt and again the effect is to increase the number of x-rays they receive and to a greater extent if the dentist is paid fee-for-service. Whilst our findings cannot establish whether harm is done by the prevalence of dental x-rays in our study population, they do establish that financial incentives are not consistent with the avoidance of harm. Furthermore they establish that harm is significantly more likely when a dentist is paid under fee-for-service (relative to salary) and their patient is exempt from charges. Based on these results, current regulatory arrangements for reducing the potential risks of dental imaging may be insufficient, whilst proposals to modify the remuneration of dentists or patient charges need to be mindful of the potential impact on x-ray use of these financial incentives, both individually and jointly.

Previous empirical evidence regarding the effect of dentists' financial incentives is limited. Findings by Birch (1988) suggest that there are incentives for over-treatment for dentists receiving fee-for-service payments in the British NHS. Similarly, Chalkley *et al* (2010), Chalkley and Tilley (2006) and Listl and Chalkley (2014) have investigated the effects of different dentists' reimbursement schemes in Scotland focusing respectively on intensity of treatment and prevalence of check-ups. Whittaker and Birch (2012) investigate how access to treatment varies according to a change in reimbursement mechanisms. In agreement with studies from other areas of medical practice these show that dentists receiving fee-for-service payments treat patients more intensively than their salaried counterparts. For Norway, Grytten *et al* (2009) also find that "the transition to an incentive-based remuneration system led to an increase in the number of individuals under supervision, without either a fall in quality or a patient selection effect". Whilst all of these studies provide evidence of the effect of financial incentives on various measures of dental treatment none are able to focus on a potentially harmful treatment. Some support for potentially harmful effects of excessive dental treatment is provided by McDonald *et al* (2012) but their study does not access individual longitudinal data of the kind we consider, cannot identify a specific treatment item and cannot account for unobserved heterogeneity.

Establishing a causal linkage between financial arrangements and treatment requires not only detailed data permitting identification but also a plausible causal mechanism. To establish the latter, in Section 2 we set out a theoretical framework that is conducive to understanding the interaction between a dentist and their patient and the consequences of that interaction for the probability of observing an x-ray examination. Understanding our data necessitates a description of the institutional arrangements that generate them and we describe these arrangements in Section 3. We then describe our data and our empirical strategy for examining the relationship between dentist remuneration and the incidence of x-ray examinations. We present and describe our key findings in Section 4, and Section 5 concludes.

2 Theoretical framework

We adopt a framework in the spirit of Dranove (1988) which places emphasis on the interaction between a physician, in our case a dentist, and their patient. We model an x-ray examination that takes place depending on the physician being prepared to supply *and* the patient being prepared to accept.

In what follows we assume that the dentist is a monopoly supplier at the point of treatment[2] and the only treatment decision under direct consideration is whether to undertake an x-ray examination[3]. We allow for heterogeneity across patients captured by $i \in [\underline{I}, \overline{I}]$ distributed with density $f(i)$ and heterogeneity across dentists captured by $j \in [\underline{J}, \overline{J}]$ distributed with density $g(j)$. Before presenting for treatment we assume the patient receives a random drawing determining their state of dental health, $Z \in [0, \overline{Z}]$ from a distribution of health states $\phi(Z)$, which reflects all of the relevant information to inform a treatment decision; we normalise such that $Z = 0$ corresponds to a patient who exhibits no symptoms indicating the need for an x-ray. Both dentist and patient know Z for each interaction. Finally, we assume that the the expected health impact of an x-ray on patient i with state Z as evaluated by dentist j is given by $h(Z, i, j)$ which is increasing in Z, but may be negative if the x-ray will produce little useful information. In the publicly funded health system we study the health impacts of treatments reflected in h are usually measured in terms of QALYs.

[2] One justification for this assumption could be that patients will likely have a preference for repeated interactions with one trusted dentist rather than switching between various dentists.

[3] The extension to consider subsequent treatment and the potential value of an x-ray in informing that treatment is discussed in Section 2.3.

2.1 Avoiding harm

An important feature of x-rays is the potential to cause harm. Thus whilst $h(Z, i, j)$ may be negative the principle of "first do no harm" implies that no x-ray should be undertaken when that is the case. This also accords with the optimal choice of x-rays in a health care system for which the objective is to maximise patient health for a given budget. If the total cost[4] of delivering an x-ray is c, and the opportunity cost of funds (the health gain that would be lost if an extra unit of expenditure is devoted to an x-ray) is δ then the delivery of an x-ray should satisfy a *cost-effectiveness* threshold; $h(Z, i, j) \geq \delta c$.

An alternative formulation of this policy is to note that conditional upon a realisation of i and j it specifies a *health-state* threshold such that an x-ray should only be undertaken if the patient's health state exceeds a critical value. Specifically if Z^* satisfies $h(Z^*, i, j) = \delta c > 0$ then an x-ray should only be undertaken if $Z > Z^*(i, j)$ which indicates that the decision is independent of any financial payments to (or from) the dentist (patient). Denoting an indicator of when an x-ray will occur by I_{ah}, then the avoidance of harm requires that

$$I_{ah}(Z, i, j) = 1 \text{ if } Z \geq Z^*(i, j) \\ = 0 \text{ otherwise,} \tag{1}$$

and this can be used to determine the probability that an x-ray will be observed in an encounter between a patient of type i and a dentist of type j, denoted $P_{ah}(i, j)$ as:

$$P_{ah}(i, j) = \int_0^\infty I(Z, i, j) f(Z) dZ. \tag{2}$$

Equation (2) indicates that the avoidance of harm requires that the probability of an x-ray being taken can depend on the characteristics of both the patient and dentist and the patient's health state but not on the financial status of the patient or the method of remunerating the dentist.

[4]This cost includes the value of all resources used to conduct an x-ray and thus the value of the dentist's time.

2.2 Dentist-patient interactions

The conduct of an x-ray can only occur if both parties are willing and the prevailing financial system can be expected to affect that willingness. To examine this issue further we consider the dentist's and the patient's assessments of the value of an x-ray and where these differ we allow for the dentist to expend effort to persuade the patient of its worth. We then consider what decision rule for determining when to x-ray will result – and upon what it will depend.

We assume that a patient of type i derives utility from their expectation of the health impact from having an x-ray conditional on their health state, denoted $H(Z, i)$, and their wealth W adjusted for any financial implications of treatment. We denote by e the effort that the dentist expends in convincing the patient and for convenience we denominate effort in money equivalent terms. We assume that the patient pays a price of p for the x-ray and therefore[5] write

$$(3) \qquad \begin{aligned} U^p(Z, i, p, W, e) &= u(H(Z, i)), W - p + e), \text{ if an x-ray is received} \\ &= u(0, W) \text{ otherwise.} \end{aligned}$$

The dentist derives utility from the health gain[6] consequent on carrying out an x-ray and from any financial surplus or deficit that results. The dentist bears a cost C in conducting an x-ray, receives a transfer T (which may be zero, less or more than C) and expends effort e. We write their utility as an increasing function v of the patient's health impact and their own financial reward and summarise this in the function V, written as

$$(4) \qquad \begin{aligned} V^d(Z, i, j, T, C, e) &= v(h(Z, i, j), T - C - e) \text{ if an x-ray is given} \\ &= 0 \text{ otherwise.} \end{aligned}$$

Since the dentist observes the patient's condition Z and type i they can determine how much effort would be required to persuade the patient to undergo an x-ray. Denoting the effort required to just persuade the patient

[5]If the patient anticipates further treatment in the absence of an x-ray the term following the second equals sign can be replaced with $u(\underline{H}(, Z, i), W - \underline{p})$, where underscore indicates the relevant values in the absence of an x-ray.

[6]Hence, in this formulation the dentist is altruistic in being concerned about the patient's health status.

to undergo treatment by $\tilde{e}$, this satisfies

$$u(H(Z,i)), W - p + \tilde{e}) - u(0, W) = 0 \tag{5}$$

and on the condition that effort is non-negative the minimum effort required to be input by the dentist is given by

$$e^m(i, Z, p) = \max[0, \tilde{e}(i, Z, p)]. \tag{6}$$

Since by assumption H is increasing in Z then $\tilde{e}$ in (5) is decreasing in Z and hence e^m is decreasing in Z. Given this minimum effort the dentist will determine whether it is worthwhile doing an x-ray according to whether $v(h(Z,i,j), T - C - e^m(i, Z, p))$ is positive in which case they will expend effort $e^m(i, Z)$ and carry out the x-ray. Otherwise no x-ray will be given and the patient is either sent away, or other treatment items are undertaken.[7]

This approach again defines a critical cut-off health state Z for an x-ray being given but the cutoff will depend on i, j, p, C and T. Hence we define $\tilde{Z}(i, j, T, p, c)$ such that:

$$v(h(\tilde{Z}, i, j), T - C - e^m(i, \tilde{Z}, p)) = 0. \tag{7}$$

As previously established, e^m is decreasing in Z whilst by assumption v is increasing in h and $T - C - e^m(i, \tilde{Z}, p)$ and hence $\tilde{Z}$ is decreasing in T and increasing in p. In contrast with the decision rule required implying no harm (given by Z^*) the propensity to x-ray responds to financial incentives and there exist values of T for which some patient - dentist interactions can result in harm. Using an indicator of when an x-ray will occur of I_{dp}, this satisfies

$$\begin{aligned} I_{dp}(Z, i, j, T, p, C) &= 1 \text{ if } Z \geq \tilde{Z}(i, j, T, p, C) \\ &= 0 \text{ otherwise,} \end{aligned} \tag{8}$$

[7]The model set out here also accords with the approach adopted by Chandra, Cutler and Song (2012) which views the quantity of treatment being observed as the minimum of the doctor's (supply) and patient's (demand) choices. We differ in allowing for a doctor to transfer resources to the patient (effort) in order to convince them of the efficacy of their chosen treatment. We view such a transfer as inherent in the patient-physician interaction, whereas side-payments from the patient to their physician to induce higher than medically advised treatment would run foul of medical ethics.

and this can be used to determine the probability of observing an x-ray in an encounter between a patient of type i and a dentist of type j, denoted $P_{dp}(i, j)$ as:

$$P_{dp}(i, j) = \int_0^\infty I_{dp}(Z, i, j, T, p, c) f(Z) dZ. \tag{9}$$

As previously established $\tilde{Z}$ is decreasing in T and increasing in p so the model indicates that the probability that an x-ray occurring is greater if the dentist is paid more or the patient is charged less.

2.3 Interpretation and generalisation

The model suggests that the probability that an x-ray is observed in any particular patient-dentist encounter will depend on the characteristics (the types j and i) of dentist and patient, the dentist's remuneration, the extent to which the patient pays and the patient's dental health state at the time of the interaction. When, as described subsequently we observe characteristics of the dentist and patient that relate to their respective types and the patient's dental health state, it is natural to use these as explanatory variables for the observation of an x-ray examination. No set of observable variables will completely capture patients' and dentists' types but repeated observations of given individuals can be used to control for any time invariant unobserved heterogeneity. We operationalise this model by estimating a linear probability empirical analogue of equation (9) in which a dentist changing from fee-for-service to salary corresponds to T being reduced to zero, and a patient moving from co-payment to exemption corresponds to p being reduced to zero.

The key purposes of the model are to motivate the empirical estimation of the impact of financial variables on the incidence of x-rays and to indicate that the imperative of doing no harm suggests that those financial variables should not be relevant. Hence, finding statistically significant effects of a dentist's remuneration or their patient's exemption status is a cause for concern.

Whilst the model is stylised its implications regarding the likely impact of financial variables on the incidence of x-rays will survive a number of extensions and generalisations.

In practice the patient will undergo further treatment whether or not they have an x-ray and the framework set out can accommodate this possibility in which x-rays are *informative* of a patients treatment requirements. In such a setting $h(Z, i, j)$ can be interpreted as the *expected health gain* to a patient conditional on their receiving an x-ray and is the difference between the health gain that would follow from treatment informed by an x-ray and the health gain from treatment determined solely on the basis of a visual examination. In this setting the transfer T to the dentist can be interpreted as the payment the dentist receives for the x-ray plus any surplus between what they receive for subsequent treatment and what that treatment costs to deliver. In equation (4) the second equality can be replaced with $\underline{T}$ and would reflect the surplus of revenue over cost of any treatment carried out without the information derived from an x-ray. The subsequent analysis is not altered, save for the additional term $\underline{T}$ appearing in the expressions for $\tilde{Z}$. In terms of further treatment, where the same treatment and health impact would occur *irrespective* of the result of the x-ray, then by definition $h(Z, i, j) < 0$. Thus a necessary condition for not causing harm is that subsequent treatment should depend on the outcome of the x-ray. If, for example, monitoring by means of visual-tactile inspection or periodontal probing is the preferred treatment an x-ray should not be given.

We have considered dentists to be altruistic, in the sense of taking account of the health impact of carrying out an x-ray. Whilst that has been allowed to be an individual dentist's assessment it could correspond exactly to an objective measure of health impact but the key implications of the model would persist, in that as long as the dentist is at all concerned (derives utility from) their financial payment their decision of whether to x-ray will depend upon that. In our data we observe whether a patient is visiting a particular dentist for the first time, i.e. whether they have visited a different dentist previously. Whilst not formally modelled here, it is plausible that such switching is correlated with i and j, so that patients who have more (or less) pressing dental problems seek out a more (or less) treatment focused dentist. It is also possible that the cost a dentist incurs in convincing a patient of the value of treatment depends on the long term relationship that they have developed. Hence, the model gives some insight into why patients that are new to a particular dentist may be more or less likely to receive x-rays.

3 Empirical framework

3.1 Institutional background

Primary dental care in Scotland is provided by both the public and private sectors. The majority of public sector primary dental care is provided by the General Dental Service (GDS). The reimbursement of GDS dentists takes two different forms. Non-salaried GDS dentists are self-employed and are paid under a mixed system consisting of capitation and fee-for-service elements. They receive a fixed payment for every person registered with them and a fee for every treatment procedure performed (Scottish Dental Practice Board, 2001). Salaried GDS dentists are employed by the public sector and as such receive a salary independent of the actual treatments they perform. The exact arrangements of GDS reimbursement are constituted in the Statement of Dental Remuneration which is described in Scottish Dental Practice Board (2001). These arrangements persisted over our study period as unlike in England there was no new dental contract introduced in 2006. Dentists can also provide treatment to privately paying patients. Our data do not enable us to determine potential spillover effects between the private and NHS dental services. For example, non-salaried NHS dentists might also privately provide x-rays to patients, particularly if this yields higher reimbursement rates than provision of x-rays according to the NHS fees scheme. In this sense, the findings of our study might be considered lower bound estimates of the impact of financial incentives because private provision of dental services (outside the NHS) is arguably most likely to occur if a dentist is paid fee-for-service and the patient is exempt from treatment charges.

Patients who are treated by the GDS may be exempt from paying any charges for one of several reasons[8] or non-exempt in which case they pay 80% of the treatment fee up to a limit[9].

3.2 Dataset and variables

The data used for our study originate from the Management Information and Dental Accounting System (MIDAS). This database includes claims by

[8]These include being below below 18 years of age, being in full-time education if aged 19, receiving income support, receiving family credit, receiving income based jobseekers allowance, pregnancy and being a nursing mother (Scottish Dental Practice Board, 2001)

[9]This limit was £278 in 2004.

GDS dentists. Our dataset is a 5% random sample of treatment claims made between January 1998 and September 2007. For reasons of data protection, sampling was on the basis of claims rather than patients. Whilst our sample does not include complete treatment histories for all patients, it nevertheless contains multiple treatment episodes for many patients both within and across dentists. The sample was created by extracting claims made by salaried dentists and non-salaried self-employed dentists. In total, our sample contains 1,300,665 treatment claims made by Scottish GDPs. Because there are specific arrangements for treatment as a consequence of dental trauma (accidents) and for persons aged 18 years or below, these claims are not considered for the purposes of this article so the resulting number of observations we analyse comprises 1,294,012 treatment claims, covering 200,326 separate patients and 3,144 separate dentists. The database provides the advantage of following individual patients and dentists continuously and these panel characteristics enable us to examine the impact on the utilization of x-rays of changes in a patient's exemption status and changes in a dentist's method of remuneration.

Our regression models utilise a binary variable as dependent variable; **x-ray** indicates whether a small dental x-ray (a 'dental film') was provided during treatment, irrespective of any accompanying treatments. In the sample such an x-ray occurs in 19.3 per cent of treatments (see Table 2 for summary statistics). The identification of the impact of financial incentives relies on dentists who change their remuneration status, and because we allow the impact to vary with patients' exemption, on patients who switch exemption status. The first column in Table 1 summarises the extent of the movement between payment and remuneration categories.

Patient characteristics are controlled for by the variable **Patient age** and a variable for deprivation category **Deprivation** which is measured on a scale from 1 (most affluent) to 7 (least affluent). This refers to the postcode of the dental practice but the assumption that most patients utilize dental care where they live allows this variable to be applied as a proxy for patients' deprivation. We also control for **Dentist age** (on average, dentists are 41 years old), the **Claims per day** issued per dentist, and in the OLS models for the time period during which treatment claims were issued (variable **Financial year**, see Table 2)[10].

[10] In models with fixed effects, this covariate is dropped because of perfect collinearity with dentist's/patient's age.

To capture the potential effect of a patient changing their dentist we construct a number of variables to distinguish between whether a patient who is seeing the dentist for the first time is, or is not, exempt from treatment charges and whether they are visiting a salaried or a fee-for-service dentist. The summary statistics for the resulting dummy variables are described in Table 2 with the prefix **New patient:**. Finally, **Months' since last visit** is included in order to assess whether the coefficients of interest are affected by the duration of time that has elapsed since the patient's last visit. By inclusion of this variable we control for potential effects due to accumulated treatment needs over time. The inclusion of the two aforementioned categories of control variables (new patient; time since last visit) results in further loss of observations because there is no information regarding duration since last visit or which dentist was attended the last time for a patient's first appearance in the panel.

3.3 Estimation strategy

We seek to establish the effect of financial arrangements on the incidence of x-rays, when these arrangements are not assigned randomly but are potentially the consequence of choices made by dentists and patients that might be influenced by the need of the patient for an x-ray. There is the usual endogeneity problem associated with selection, wherein the estimated *effect* of a change in remuneration might be a reflection of a change in the patient's health status and hence the need for an x-ray. Two standard approaches to this issue are the use of *changes* in remuneration and payment status for given individuals and instrumental variables. The use of instrumental variables implies well-known untested exclusion restrictions and is not readily implementable in the setting we study where we do not have any obvious instruments for remuneration status. We therefore follow the former approach and exploit the quasi-panel nature of the data with repeated observations on both dentists and patients to establish the effect of a change in a given dentist's remuneration subject to a given patient's exemption status. We thus take account of any time-constant unobserved heterogeneity across both patients and dentists. We do this using both patient and dentist fixed effects.

Selection endogeneity bias could still prevail if there are time varying factors that cause patients and dentists to select into a financial arrangement. Overall, the chronic nature of oral diseases on the one hand and the fact that treatment skills of dentists have been acquired throughout several years of dental education would seem to argue against frequent time varying effects, but we cannot test for these. For patients they might arise if, when they discover the need of an x-ray, the patient switches to a dentist that they infer is more likely to give them an x-ray. The usual assumed asymmetry of information between physician and patient argues against this mechanism, but we further take account of this possibility by controlling for when a patient is newly arrived at a dentist, and refine that further by allowing for the interaction of new arrival and financial arrangements. For dentists, the selection mechanism might imply that upon learning some new information that leads them to wish to engage in more x-rays they choose to switch the contract they are paid under. This is analogous to decision makers who are subject to changing preferences and there is no means by which we can control for unobserved variation in the motivation of individuals. We share this limitation with any study based on observational data in which there is limited information that might proxy for preferences. There are, however, two mitigating factors. First we include the dentist's age as a time varying characteristic, so that if new information is monotonic in age this will control for its arrival and second we note that in the health system we study dentists cannot easily switch remuneration status. Once employed, a dentist has to give notice and then set themselves up as a self-employed practitioner. If they are currently self-employed a dentist wishing to change remuneration status has to find an employment slot and these have traditionally been limited.

Our dependent variable is binary and thus gives rise to the possibility of using non-linear regression models. However we utilise a linear probability framework for reasons of computational speed (given the large dimensionality of fixed effects), for ease of interpretation of marginal effects and for ease of reporting a nested set of models across which to compare results. Since we are not concerned with forecasting probabilities of x-rays the issue of out-of-range estimates for these is not a problem and whilst the linear model can exhibit bias and inconsistency this has been shown to be limited when the probabilities that fall outside the unit interval are small (Horrace and Oaxaca, 2006) which is the case in our model. To address the problem that linear estimation imposes heteroskedasticity in the case of a binary response variable we report heteroskedasticity-robust standard error estimates.

The general form of our regressions is:

$$y_{ijk} = \mu + \phi_{ij} + \beta w_{ijk} + \gamma x_{ijk} + \epsilon_{ijk}, \tag{10}$$

where y_{ijk} is an indicator of an x-ray provided by dentist j to patient i during course of treatment k; w_{ijk} is a vector of dummy variables indicating the combination of patient i's payment status (exempt or not) and dentist j's remuneration status during treatment k; x_{ijk} is a vector of additional controls that vary across dentists, patients and their treatment courses; μ is a constant;ϵ_{ijk} is an error term and ϕ_{ij} is given by

ν_j	for patient-specific effects;
η_i	for dentist-specific effects.
$\nu_j + \eta_i$	for patient & dentist-specific effects.

The estimated parameters of primary interest, contained in the vector β, enable us to recover the effect of a dentist's financial incentives and patients exemption status as the theoretical framework suggests it might. All estimations were carried out using STATA/SE 12.0 (StataCorp, College Station,Texas, USA). Estimation of fixed effects models was implemented via the commands *xtreg* and *felsdvreg*. A conservative approach was used for statistical inference so that the largest standard errors were chosen amongst heteroscedasticity robust and clustered standard errors (Angrist and Pischke, 2009). Clustered standard errors were clustered on the patient-level (patient fixed-effects models), the dentist-level (dentist fixed-effects models), and the patient/dentist-level (OLS and two-way fixed-effects models), respectively.

4 Results

Our primary regression results are set out in Table 3 and we focus on the role of dentist reimbursement and its interaction with a patient's exemption status. All regressions include the control variables discussed in Section 3 and described in Table 2. The omitted reference category is a non-exempt patient treated by a salaried dentist, which our theoretical model suggests will be the category with the lowest incidence of x-rays.

We report results for OLS and separately for patient and dentist fixed effects and combined patient and dentist fixed effects. Columns F3 and F4 differ in the inclusion in the latter of the *New patient* variables. The coefficients of interest and their estimated standard errors vary across the different specification of fixed effects (columns F1 to F4 in the table). In regard to model selection the F-statistics in columns F3 and F4 indicate that patient and dentist fixed effects are separately and jointly significant so that there is the potential for bias in models that omit one or other category of fixed effects. The *New patient* variables are mostly significant (the coefficients are reported in Table 5) and so their omission will cause potential bias and we therefore focus on the coefficient estimates in column F4. As indicated by R^2 values the various models' explanation of variation in x-rays ranges from 4% in OLS to 25% in the most general fixed effects model.

Using column F4 in the table it can be seen that the financial status of the patient and the dentist's remuneration significantly affect the probability of an x-ray, in the direction predicted by our model. Interactions between dentists who receive a separate fee for an x-ray (analogous to T in the model) and patients who are exempt from charges ($p = 0$ in our model) exhibit a 9.4 percentage point increase in the probability of an x-ray during treatment, relative to interactions between a salaried dentist and a non-exempt patient. The separate effects of a dentist's and their patient's financial arrangements can be inferred from the regression estimates as follows. For a salaried dentist the consequence of a patient changing to exempt from non-exempt is 2.6 percentage points (the difference between the estimated coefficients in the first and fourth rows of column F4). For a fee-for-service dentist the same change increases the probability of an x-ray by 3.4 percentage points (the difference between the second and third rows). For an exempt patient, their dentist changing from salary to fee-for-service increases the probability of an x-ray by 6.8 percentage points (the difference between the second and fourth rows) whilst for a non-exempt patient the same change implies a 6 percentage point increase. These changes can be related to the mean incidence of x-rays in treatments which from Table 2 is 19.3%. Hence, we find strong evidence of statistically significant and substantial impacts of financial incentives on the incidence of x-rays – impacts that the imperative of "doing no harm" suggests should not exist.

To check the robustness of our findings we report in Table 4 a number of variants of the model reported in column F4. In the first column (R1) we drop those treatments for which there is good evidence that an x-ray would in any case be required. We cannot identify the precise condition of patients from administrative records but by focusing on some procedures it is possible to determine proxies for conditions for which an x-ray would usually be required.

We do this for endodontic treatments which include root-canal fillings and where x-rays are used to establish the exact nature of the required procedure. Whilst the coefficient estimates change slightly when these treatments are dropped their pattern and magnitude remains the same. If it were the case that salaried dentists were skimping on necessary x-rays we might expect to see some substantial differences between the estimates in columns F4 and R1, but we do not. In column R2 we consider substantially restricting the sample of treatments to only those where patients have had at least ten courses of treatment over the study period. We expect such patients to be subject to a lower probability of an x-ray in any one treatment since they will likely have had x-rays over the course of their numerous interactions. Whilst the magnitude of financial effects is now much smaller and not everywhere significant there remains a 4.1 percentage point increase in the probability of an x-ray for an exempt patient treated by a fee-for-service dentist (relative to a non-exempt patient, treated by a salaried dentist). Regular dental care use therefore mutes the role of financial incentives but it does not eliminate it. In column R3 we simplify the model and include only the patient's and dentist's financial arrangements, not their interaction. This is a check that the interaction effects are consistent with a simpler, if misspecified model and provides an easier way of expressing the impact of incentives. The coefficient estimates indicates that a dentist switching to fee-for-service from salary status increases the probability of an x-ray by 6.3 percentage points. A switch by a patient from non-exempt status to exemption increases the probability of an x-ray by 3.4 percentage points. Finally in column R4 we report the results of a placebo test of our model. The theoretical framework does not give any cause to expect an anticipation effect of a dentist changing remuneration. We therefore replace the dentist's current remuneration status with their future remuneration status (reflected in how they are paid in 100 courses of treatment in advance of the current treatment). As expected we find a zero impact of this future remuneration status.

The preferred model includes a number of control variables which whilst not the focus of our study provide evidence of the drivers of dental x-rays. We therefore report the full regression results for the model F4 in Table 5. Significant effects are indicated for the dentist's age (increases the probability of an x-ray) and the patient's age (decreases the probability of an x-ray). In many studies of medical care, deprivation increases need and utilisation but we do not find any evidence of this for dental x-rays. The controls for a patient arriving newly at a dentist are mostly significant and positive suggesting that newly arrived patients have between 2.3 and 10.2 percentage points increase in the probability of receiving an x-ray, with the exception of exempt patients newly arrived at a salaried dentist (zero effect).

Thus overall the results indicate a number of significant and quantitatively large effects on the incidence of x-rays of a dentist's remuneration in combination with the patient's exemption status. The former effects are suggested directly by our theoretical framework; whether a dentist who has a financial incentive to deliver an x-ray actually does so depends on whether the patient who they are treating is exempt (or not) from contributing to the cost of that x-ray because the effort required to persuade the patient is lower in the former case.

5 Discussion

Accounting for treatment variation is a longstanding and ongoing concern in healthcare. Economics suggests that the remuneration of the physician can have an effect, but disentangling that is challenging on account of confounding factors including the changing payment status of patients. Our findings constitute a new perspective for the literature on the impact of financial incentives in health care because we have focused on a potentially harmful treatment and we have explicitly considered the role of a patient's exemption status on their dentist's incentives to provide x-rays under different remuneration methods.

Dental x-rays are an important element of treatment because whilst beneficial to diagnosis there are well-documented and potentially severe health implications of ionising radiation. The data we have utilised track both the dentist and their patient over time and thus provide a unique opportunity to identify the impact of financial incentives whilst accounting for unobserved heterogeneity on the part of both patient and dentist. The conceptual framework for understanding this form of match-specific effect in determining treatment has been set out by others but we have adapted and extended that framework to the particular setting of our study.

Submitting more than 1 million courses of treatment to fixed effects regression analysis we are able to conclude that; simultaneously accounting for heterogeneity specific to both patient and provider is important; that the impact of a dentist's financial incentives and a patient's financial incentives interact; that x-ray use increases substantially and significantly when dentists are paid fee-for service and that x-ray use increases substantially and significantly when patients switch dentists in some particular circumstances.

Overall our results confirm the role and importance of physician financial incentives in contributing to variation in health care treatment because in the system we have studied there are variations in provider remuneration, which if eliminated would reduce the variation in the incidence of x-rays. Thus, our results have a bearing on health care policy. We conclude that allowing variation in provider remuneration contributes to potentially harmful variation in treatment and that both provider remuneration and patient financial incentives have important roles to play in mitigating this potential harm.

As with any natural experiment our results are potentially affected by selection. The relevant treatment effects therefore need to be considered with care. As is standard in a fixed effects framework our estimates relate to those individuals for whom the relevant variation occurs. The impact of a dentist's remuneration is estimated using the small number of dentists who switch between salaried and fee-for-service remuneration. If dentists select into the role of switching remuneration as a consequence of a predisposition to respond more strongly to financial incentives than their non-switching counterparts, then our results provide an estimate of the effect of abolishing fee-for-service only on those specific dentists, who represent about 13 % of all dentists in our sample. The policy intervention that our results predict the effect of in this case is mandating that any dentist who is salaried cannot be retained on a fee-for-service contract. More generally, however, the nature of the potential harm caused by x-rays, the fact that risks increase linearly with usage (there is no safe threshold) and the ubiquity of fee-for-service arrangements for dentistry make our results of potential interest and concern worldwide.

The case we have studied also highlights the difficulty in establishing what might be an appropriate incentive structure in health care. First, our results suggest that the supply-side and demand-side of the market cannot safely be treated separately. But perhaps more fundamentally by considering a treatment that can be harmful we highlight the difficult ethical challenges in designing incentives. From an ethical perspective it may be particularly challenging that patients with similar characteristics receive significantly different amounts of dental x-rays when this is caused by different methods of provider payment. For a patient, the risk-benefit ratio of dental x-raying should be independent of provider's financial incentives. Even if patients may voluntarily opt to receive a lower level of x-raying than would be optimal from a risk-benefit perspective, it nevertheless seems ethically questionable that the amount of x-rays received by patients who are exempt from treatment charges is significantly higher if the provider is paid fee-for-service than if (s)he is paid salary. This either means that patients treated by salaried dentists receive less x-rays than optimal for their oral health or that exempt patients treated by fee-for-service dentists receive too many x-rays.

Our findings suggest that financial incentives have a substantial impact on dental x-raying. Given that we identify significant interaction effects between provider payment and patient exemption, any policy intervention which addresses either alone will not hit its intended target. This interaction of incentives and their empirical magnitude is thus of importance for those who want to ensure an adequate use of x-rays and limit their harmful side-effects. Future research is encouraged to analyse the differential impacts of dentist remuneration and patient co-payment status on the utilization of various specific types of treatment such as tooth extractions, restorative treatment, and preventive care. Given the specific characteristics of these various components alongside the dental care continuum and their potentially differential implications for patients and dentists, the impact of financial incentives might differ between different treatment modalities.

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Table 1: Movers and Switchers

Patients — non-exempt to exempt	27,631
Patients — exempt to non-exempt	35,197
Patients — from fee-for-service to salaried dentist	8224
Patients — from salaried to fee-for-service dentist	6225
Dentists — from fee-for-service to salaried	291
Dentists — from salaried to fee-for-service	216

Table 2: Summary Statistics

Variable	Description	Mean	Std. Dev.	N
x-ray	Equals 1 if "small x-ray" was claimed	19.3 %		1,294,012
Deprivation	Deprivation category of dentist's practice			1,294,012
	1 (most affluent)	6.0 %		1,294,012
	2	14.3 %		1,294,012
	3	19.6 %		1,294,012
	4	28.5 %		1,294,012
	5	16.1 %		1,294,012
	6	9.4 %		1,294,012
	7 (least affluent)	6.1 %		1,294,012
Patient age	Patient's age in years	43.841	14.578	1,294,012
Months since last visit	Duration since last visit (months)	8.545	9.331	1,095,993
Claims per day	Number of claims per dentist per day (5% random sample)	0.348	0.219	1,294,012
Dentist age	Dentist's age in years	41.172	9.804	1,294,012
Salaried dentist treating non-exempt patient	Equals 1 if patient is non-exempt from charges and dentist is salaried	2.0 %		1,294,012
Salaried dentist treating exempt patient	Equals 1 if patient is exempt from charges and dentist is salaried	0.9 %		1,294,012

Continued on next page...

... table 2 continued

Variable	Description	Mean	Std. Dev.	N
Fee-for-service dentist treating non-exempt patient	Equals 1 if patient is non-exempt from charges and dentist is fee-for-service	71.0 %		1,294,012
Fee-for-service dentist treating exempt patient	Equals 1 if patient is exempt from charges and dentist is fee-for-service	26.1 %		1,294,012
Financial year	time period during which claim was issued			1,294,012
	year 1	10.0 %		1,294,012
	year 2	10.0 %		1,294,012
	year 3	10.0 %		1,294,012
	year 4	10.0 %		1,294,012
	year 5	10.0 %		1,294,012
	year 6	10.0 %		1,294,012
	year 7	10.0 %		1,294,012
	year 8	10.0 %		1,294,012
	year 9	10.0 %		1,294,012
	year 10	10.0 %		1,294,012
New patient: NS	Equals 1 if patient non-exempt from treatment charges switched to salaried dentist	0.8 %		1,093,686
New patient: ES	Equals 1 if patient exempt from treatment charges switched to salaried dentist	0.4 %		1,093,686
New patient: NF	Equals 1 if patient non-exempt from treatment charges switched to fee-for-service dentist	12.5 %		1,093,686

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... table 2 continued

Variable	Description	Mean	Std. Dev.	N
New patient: EF	Equals 1 if patient exempt from treatment charges switched to fee-for-service dentist	5.8 %		1,093,686

Table 3: MAIN RESULTS

	OLS	Fixed Effects Models			
		[F1]	[F2]	[F3]	[F4]
Salaried dentist treating non-exempt patient	(ref)	(ref)	(ref)	(ref)	(ref)
Fee-for-service dentist treating exempt patient	0.083*** (0.003)	0.195*** (0.006)	0.070*** (0.018)	0.106*** (0.011)	0.094*** (0.012)
Fee-for-service dentist treating non-exempt patient	0.061*** (0.003)	0.165*** (0.005)	0.050*** (0.018)	0.077*** (0.011)	0.060*** (0.012)
Salaried dentist treating exempt patient	-0.038*** (0.005)	-0.013 (0.008)	-0.009 (0.005)	0.008 (0.007)	0.026** (0.011)
Patient fixed effects		Yes	No	Yes	Yes
Dentist fixed effects		No	Yes	Yes	Yes
Controls for new patient				No	Yes
F-statistic (patients)	-	1.69***	-	1.48***	1.46***
F-statistic (dentists)	-	-	16.88***	6.45***	6.32***
F-statistic (combined)	-	-	-	1.82***	1.79***
R^2	0.03	0.23	0.08	0.25	0.25
N (claims)	1,093,355				1,088,829
N (patients)	146,205				145,549
N (dentists)	3,081				3,063

All models control for dentist age and number of claims issued per month, patient age, deprivation category and duration since last visit. * denotes $p < 0.10$ ** denotes $p < 0.05$ and *** denotes $p < 0.01$; clustered standard errors are in parentheses and are clustered on patient-level in patient-fixed-effect-model, dentist-level in dentist-fixed-effects-model and patient/dentist-level in OLS and two-way-fixed-effects models)

Table 4: Robustness results

	[R1]	[R2]	[R3]	[R4]
Salaried dentist treating non-exempt patient	(ref)	(ref)	-	-
Fee-for-service dentist treating exempt patient	0.092***	0.041***	-	-
	(0.023)	(0.016)	-	-
Fee-for-service dentist treating non-exempt patient	0.058***	0.006	-	-
	(0.013)	(0.016)	-	-
Salaried dentist treating exempt patient	0.028**	-0.001	-	-
	(0.012)	(0.016)	-	-
Salaried dentist	-	-	(ref)	(ref)
Fee-for-service dentist	-	-	0.063***	-0.007
	-	-	(0.012)	(0.009)
Non-exempt patient	-	-	(ref)	(ref)
Exempt patient	-	-	0.034***	0.035***
	-	-	(0.002)	(0.002)
Patient fixed effects	Yes	Yes	Yes	Yes
Dentist fixed effects	Yes	Yes	Yes	Yes
Controls for new patient	Yes	Yes	Yes	Yes
F-statistic (patients)	1.446***	1.66***	1.46****	1.44***
F-statistic (dentists)	6.36***	2.19***	6.32***	1.74***
F-statistic (combined)	1.79***	4.52***	1.79****	6.09***
R^2 0.03	0.23	0.08	0.25	0.25
N (claims)	1,056,633	756,900	1,088,829	867,169
N (patients)	145,805	756,900	145,549	131,787
N (dentists)	2,971	2,974	3,063	2,109

In [R1] the sample restricted to treatment courses without endodontic treatment; [R2] sample restricted to patients with at least ten treatment courses throughout the ten years observation period; [R3] interacted variables for dentist reimbursement status and patient co-payment status replaced by variables detecting the non-interacted effects of reimbursement status and patient co-payment; [R4] placebo test: variable for dentists reimbursement status (fee-for-service vs. salary) modified such that it represents the dentist's reimbursement status 100 subsequent claims later for the same dentist (in the sense of a lead variable). All models control for provider age and number of claims issued per month, patient age, deprivation category and duration since last visit; denotes * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; clustered standard errors in parentheses (clustered on: patient-level in patient-fixed-effect-model; dentist-level in dentist-fixed-effects-model; patient/dentist-level in OLS and two-way-fixed-effects models).

Table 5: Full results for model F4

	Fixed Effects Model F4	
Salaried dentist treating non-exempt patient	(ref)	(ref)
Fee-for-service dentist treating exempt patient	0.094***	(0.012)
Fee-for-service dentist treating non-exempt patient	0.060***	(0.012)
Salaried dentist treating exempt patient	0.026**	(0.011)
Dentist age	0.006***	(< 0.01)
Patient age	-0.008***	(< 0.01)
Deprivation category		
...1	(ref)	(ref)
...2	-0.002	(0.009)
...4	0.021**	(0.009)
...4	0.012	(0.009)
...5	0.006	(0.009)
...6	0.018*	(0.010)
...7	-0.008	(0.012)
Number of claims per month	-0.0004***	(< 0.01)
Days since last visit	0.004***	(< 0.01)
New patient ES	-0.004	(0.010)
New patient NS	0.023***	(0.008)
New patient EF	0.080***	(0.002)
New patient NF	0.102***	(0.002)
R^2	0.25	
N (claims)	1,088,829	
N (patients)	145549	
N (dentists)	3063	

* denotes $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; clustered standard errors (patient/dentist-level) in parentheses.