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Paying For Health Gains

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Abstract

Payments to healthcare providers are often based on the number of patients they treat according to their particular health condition with well-known limitations. Payment based on health outcomes, a form of pay-for-performance, has long been advocated as a possible solution. This study adopts a contract theory approach and illustrates how it can inform practical implementation of pay-for-performance schemes that reward health outcomes. We first provide a simple but general model on the design of an incentive scheme that rewards providers for improved health, as a function of key parameters related to patient health benefits and provider costs. We then calibrate the model using data from two elective procedures, hip and knee replacement, using patient reported outcome measures. The pricing rule suggests that the bonus should be set to reflect the difference between the provider's marginal cost of a health improvement before the policy intervention and the provider's marginal cost evaluated at the target health set by the purchaser. We provide estimates of the optimal bonus for hip and knee replacement under a range of assumptions about provider cost functions and the value of health improvements.

JEL: I11, I14, L13
Keywords: hospitals; pay for performance; quality; health

1. Introduction

Payments to health care providers are often based on the number of patients with a particular health condition that they treat, a form of *activity-based financing*, and this approach is embodied in the National Tariff Payment System of the English NHS, which is similar to payments based on Diagnosis Related Groups in other OECD countries. There are a number of concerns with the use of these payment mechanisms including the possibility that rewarding activity may provide an incentive to engage in costly activity even where it may not substantially improve health – an example of over-treatment. The fundamental issue is that payment based on activity alone does not take into account the value of treatments being provided and one intuitive response to this is to make prices reflect the additional value of the health outcomes produced. This would require measuring the outcome of treatment in terms of health gain and paying a bonus that rewards health improvements. Payment based on health outcomes has long been discussed and sometimes advocated as a natural development of activity-based finance. Dunbar-Rees (2018) provides a recent summary of the discussion of this approach.

Whilst the appeal of outcome-based payment systems is that they reward what ultimately matters, health gains, it is accepted that health outcomes are difficult to measure. Some commonly available indicators, such as mortality and readmission, can only be applied to treatments where there is sufficient incidence of failure. Moreover, both mortality and readmission rates measure health on one tail of the outcome distribution. More recently, broader measures of health gains have been collected in the NHS in the form of patient reported outcome measures (PROMs) which are now available for a subset of procedures such as hip and knee replacement (NHS England 2013; Gutacker et al. 2013). These measures consider health gains across the whole distribution, not just for failed treatments, and are the motivating focus of this study.

Even with accurate measures of health, there is a lack of consensus on how the incentive bonus should be set. The evidence suggests that providers, hospitals in particular, do not respond to pay-for-performance schemes or their response is limited (Cashin et al. 2014; Milstein and Schreyögg 2016; Mendelson et al. 2017).[1] A possible explanation is that the size of the bonus is relatively small, e.g. about 5% of hospital revenues with some variation across schemes and countries (Cashin et al. 2014), and therefore insufficient to induce changes in provider behaviour.

This study adopts a contract theory approach to determine the appropriate size of the bonus, and therefore to inform practical implementation of pay-for-performance (P4P) schemes that reward health outcomes. The study has two main components. First, it provides a simple but general model for the design of an incentive scheme that rewards health gains, as a function of key parameters related to patient health benefits and provider costs. Second, the model is calibrated based on data from two elective procedures, hip and knee replacements, for which PROMs data have been collected to illustrate the applicability of the framework and to show the sensitivity of the size of the bonus to different assumptions on benefits and costs. By doing so the study aims to bridge the gap between economic theory and policy, and to inform the design of P4P schemes where health is observable and measured accurately.

In line with existing literature (Ellis and McGuire 1986; Chalkley and Malcomson 1998), we assume that providers are altruistically or intrinsically motivated and choose a level of quality that trades off

[1] A notable exception is the Quality and Outcome Framework (QOF) scheme for primary care in England where the incentive payment was initially around 20% of general practice income (Gravelle et al. 2010) although it has since reduced to less than 10%.

the benefits from higher quality against its costs. We then model the purchaser decision regarding the bonus. We first adopt a positive economics perspective where the purchaser specifies a bonus to achieve an objective or target based on the observed empirical distribution across providers (e.g. increasing the average health gain by one standard deviation or to the level of health in the top quartile or quintile of the health distribution). We subsequently explore whether the introduction of the bonus is cost-effective, and whether the value of the health benefits it generates is higher than the additional provider costs. Throughout the analysis, we assume that the purchaser pays the bonus in addition to the basic activity-based price (HRG or DRG tariff), and the latter can be adjusted to ensure that provider revenues cover treatment costs. This implies that the amount reimbursed by the purchaser to the provider is always equal to the provider's costs. Finally, we adopt a welfare function approach and derive the optimal pricing rule that induces a level of health which maximises the difference in the value of patient benefits and provider costs.

Given our applied focus we express the bonus as a function of the post-operative health *before* the introduction of a bonus, and the target post-operative health *after* the introduction of the bonus, as this information is either available or chosen by the purchaser. We show that the optimal pricing rule for the purchaser is to choose a bonus that reflects the difference in the marginal cost of post-operative health (or, more simply, the additional cost of increasing health by one unit) before the policy intervention and the marginal cost of post-operative health evaluated at the level of health set by the purchaser (post policy).

Using data from hip and knee replacements in England, we calibrate the model for the average provider with respect to two key parameters: provider costs and post-operative health. We then compute the bonus payments that the purchaser would have to make to achieve target levels of post-operative health equivalent to improvements of one or two standard deviations of the health distribution observed across providers. To infer the shape of the cost function for the average provider, we make assumptions related to fixed and variable costs. In our calibration for hip replacements, we find that the price for one unit of health improvement as measured by the Oxford Hip Score to achieve an improvement of 1.13 OHS (equivalent to one standard deviation observed in the empirical distribution) ranges between £45 and £226 under different assumptions related to the cost function. For knee replacements, the price for one unit of health improvement as measured by the Oxford Knee Score to achieve an improvement of 1.06 OKS (equivalent to one standard deviation observed in the empirical distribution) ranges between £72 and £254 under different assumptions related to the cost function. The price doubles for a health target of two, rather than one, standard deviation improvement.

When we evaluate the health benefit in quality-adjusted life years (QALYs), for which there are official estimates of the purchasers willingness-to-pay in the English NHS, we generally find that the introduction of the bonus is cost-effective, even at high levels of health targets. In turn, this implies that under a welfare function approach, the optimal health target is high and therefore so is the price per unit of health improvement.

1.1. Related literature

There is a relatively small literature which calibrates theoretical models of financial incentive schemes for healthcare providers. The study which is closest to ours is Kristensen et al. (2016) that presents a stylised model for hospital price setting for (three) process measures of quality. The model is then calibrated using features of the Best Practice Tariffs scheme for emergency stroke care in the English NHS that rewarded hospitals for ensuring treatment in an acute stroke unit, rapid brain imaging, and provision of thrombolytic medication to some patients. Our study differs in several ways. First, we investigate pricing schemes that stimulate quality by targeting health outcomes, rather than process measures of quality. Given that we measure health directly, this requires fewer assumptions in relation to how quality affects health. Second, we derive the pricing rule as a function of pre-policy intervention parameters. Third, we include a positive analysis and a cost-effectiveness approach, in addition to a normative analysis. Finally, our calibration applies to elective care, rather than emergency care.

Lisi et al. (2020) provide a theoretical analysis of pay for performance to encourage reductions in mortality and readmission rates in a model where patients differ in severity, patients choose hospital based on quality, and risk-adjustment is not fully accounted for so that unobserved dimensions of severity remain. They show that the introduction of P4P which rewards lower mortality and/or readmission rates can weaken or strengthen hospitals' incentive to provide quality. Since patients with higher severity have a different probability of exercising patient choice when quality varies, this introduces a selection bias (patient composition effect) which in turn alters quality incentives. They also show that this composition effect increases with the degree of competition. They then calibrate the model based on several features of US P4P programmes aimed at reducing mortality and readmission rates, such as the Premier Hospital Quality Incentive Demonstration launched in 2003, the Hospital Value-Based Purchasing scheme introduced by the Centers for Medicare & Medicaid Services in 2012 and the Hospital Readmission Reduction Program, which have payments that account for about 2-4% of hospitals' revenues. Sa et al. (2019) provide a model of hospital competition in the presence of excess demand and waiting times. They calibrate the model using waiting times and volume for cataract surgery in the English NHS.

Chalkley and Malcomson (2002) investigate the scope for refining hospital fixed price payments (of the DRG type) for treatment of patients with a specified diagnosis by allowing for cost sharing. They show that if providers differ in costs and there is asymmetric information between the purchaser and providers, then total payment can be reduced by cost sharing. They calibrate the model using data from Medicare and estimate that cost savings from cost sharing range from 7% for treatments with low cost variation to 60% for those with high cost variation.

There is a more extensive theoretical literature investigating provider incentives in relation to quality and cost containment under different payment arrangements, which derives qualitative insights on provider behaviour and the features of optimal payment systems under a range of assumptions (see seminal studies by Ellis and McGuire (1986), Ma (1994) and Chalkley and Malcomson (1998) as well as Siciliani (2018) for a review). A smaller literature focuses specifically on pay for performance, in relation to issues such as multitasking (tunnel vision) and gaming or misreporting (see Eijkenaar (2013) for an overview of key design issues). Eggleston (2005) shows that targeting some dimensions of quality might come at the cost of reducing untargeted dimensions of quality when qualities are substitutes, though cost sharing might mitigate this. Kaarboe and Siciliani (2011) show that this implies that the price is reduced as a result. Sherry (2016) finds that when P4P programmes reward multiple health care services in a setting characterised by joint production, the impact on both rewarded and unrewarded services remains ambiguous. Kuhn and Siciliani (2009) and Kuhn and Siciliani (2013) show that gaming of the indicators also generally leads to lower powered incentive schemes. Mak (2018) studies a managed healthcare market with two differentiated hospitals, and analyses the interaction of P4P schemes on contractible quality with other features of the market, such as the presence of copayment and consumers' misperception of quality.

2. Model

The approach we adopt is a familiar one in the contract theory literature. Much of the literature is concerned with whether (and if so how) the purchaser can achieve its aims in respect of health gains when faced with a provider whose aims are only imperfectly aligned with those of the purchaser. We suppose that a principal – the purchaser – can choose a payment mechanism that influences the choice of an agent – the provider, e.g. a hospital. Our focus is specifically on how the payment of a health related bonus affects the provider's decision concerning patient health gain from subsequent treatment. Issues of uncertainty or the heterogeneity of patients are not considered explicitly but we return to these in the concluding section.

We first analyse (Section 2.1) the provider's choice conditional on the payment it receives and its objectives, and then consider different formulations of the purchaser's approach. The stylised setting is of a single provider, choosing how to treat a patient with a given condition and where the provider can expend costly effort to achieve a better health outcome.[2] We define h as the health of the patient as determined by the provider's effort and measured (at some point, e.g. six months) after the surgery.[3] The patient is assumed to have a pre-surgery level of health of h_0. See Table 1 for a full list of variable definitions.

In Section 2.2, we consider the purchaser perspective under three different approaches. We first consider how a purchaser can design a bonus to achieve a target level of health gain (Section 2.2.1), then whether the introduction of a bonus is cost-effective (Section 2.2.2) and finally how to design a bonus which maximises welfare (Section 2.2.3) defined as patient health benefits minus provider costs.

Table 1: Definition of variables

Symbol	Definition
h	patient post-surgery health
h_0	patient pre-surgery health
$\widetilde{h}$	threshold health level above which payment is received
t	prospective DRG/HRG fixed price
p	bonus payment per unit of health improvement
$C(h)$	provider cost function for treating a patient
k	fixed treatment cost component
c	parameter related to marginal cost of health improvement
$\underline{h}$	level of health over which improving health is costly to the provider
α	degree of provider motivation
$\widehat{h}$	purchaser health objective
$H(h)$	patient life-time health gain
W	willingness to pay for health improvement
δ	opportunity cost of public funds
λ	cost-effectiveness threshold

[2] We therefore implicitly assume that all the patients are the same or, equivalently, that the health measures have been risk adjusted. This is important as the lack of risk adjustment could expose the provider to losses (or generate profits) that are due to external factors.

[3] For practical measurement purposes, we can think of patient health h as being measured in EQ-5D utility scores or with a metric developed specifically for a procedure, such as the Oxford Hip Score (OHS).

2.1. The provider perspective

Revenues. For each patient treated, the provider is assumed to be paid through a prospective DRG tariff t and a health-outcome related bonus p that is linear in health improvement.[4] Hospital revenue $R(h)$ is:

$$R(h) = t + p(h - \widetilde{h}), \tag{1}$$

where $\widetilde{h}$ is a threshold health level decided by the purchaser and h is patient post-surgery health.

As an illustrative example, consider a patient in need of a hip replacement and that post-surgery health is measured with the Oxford Hip Score (OHS) on a 0-48 scale with higher values indicating better health. Suppose that the health threshold $\widetilde{h} = 30$, that post-surgery health measured six months after the surgery (post-surgery health) has a score of $h = 38$, and that the price for one point of health improvement on the OHS scale is £100. Then hospital bonus payment from treating a patient, in addition to the HRG tariff, is $p(h - \widetilde{h}) = 100(38 - 30) = £800$.

Equation (1) also encompasses the scenario where the provider has a penalty, rather than a bonus. This can be achieved by setting a threshold $\widetilde{h}$ which is sufficiently high. Suppose for example that the threshold is set at $\widetilde{h} = 42$. If post-surgery health is $h = 38$ then hospital payment is $p(h - \widetilde{h}) = 100(38 - 42) = -£400$, and every additional health improvement reduces such penalty. Notice that, as discussed in more detail below (Section 2.2.1), the purchaser can always change the DRG tariff t to ensure that the provider makes no losses.

Costs. We assume that the provider has the following cost function for treating a patient:

$$C(h) = k + K(h), \tag{2}$$

where k is a fixed treatment cost component, which is independent of health gain (e.g. the cost of an operating theatre, the time of surgeons and nurses, anesthetist) and $K(h)$ is the additional cost of improving the health of the patient, which includes both monetary costs (due to more expensive technology, medicines) and non-monetary costs (e.g. time of nurses and doctors).[5] We assume cost is increasing in health, $\partial K(h)/\partial h > 0$, at an increasing rate, $\partial^2 K(h)/\partial h^2 > 0$. Some health improvements may generate low additional cost or even be costless, but additional health gains will be incrementally more costly to achieve.

To obtain a closed-form solution, which we use for the calibration, we assume that the cost function is quadratic in h:

$$C(h) = k + \frac{c}{2} \left(h - \underline{h}\right)^2, \tag{3}$$

where c is a positive parameter related to the marginal cost of a health improvement, and $\underline{h}$ is the level of health over which improving health is costly for the provider. We could set the latter at the pre-surgery health, $\underline{h} = h_0$. However, it is likely that providers with low levels of costly efforts might still be able to achieve post-surgery health levels that are higher than the pre-surgery health. We therefore allow for

[4] We assume that the volume of patients treated is fixed, and do not consider possible indirect effects of the bonus on volume. For example, by inducing an increase in quality, the provider may respond to the bonus by reducing volume due to pressures on costs.

[5] Within the English NHS both doctors and nurses are salaried. Therefore, any additional time spent with the patient will not increase costs unless they are working at full capacity, and the only way to increase time with the patients is by recruiting additional personnel.

the possibility that improving health up to $\underline{h}$ does not generate any additional costs on top of the fixed treatment costs k.[6]

Motivation. We also assume that the provider is motivated (due to altruism, intrinsic motivation towards quality or other reasons) and will improve the health of the patient even if not financially rewarded (as in Ellis and McGuire (1986) and Chalkley and Malcomson (1998)). We capture the degree of motivation with the function $B(h)$, which is increasing in health. We assume the following linear functional form:

$$B(h) = \alpha(h - h_0), \tag{4}$$

where α is the degree of motivation. This parameter could also be interpreted more broadly as any source of motivation, in addition to altruism and intrinsic motivation, that induces providers to improve health. This could include monitoring and auditing mechanisms that induce providers to improve effort.

Hospital payoff function. We assume that the payoff function of the provider $V(h,p)$ from treating the representative patient includes both financial and non-financial motives, and it is additively separable in the motivation component $B(h)$ and financial surplus $\pi(h,p) = R(h,p) - C(h)$:

$$V(h;p) = B(h) + \pi(h;p) = \alpha(h - h_0) + t + p(h - \widetilde{h}) - k - \frac{c}{2}\left(h - \underline{h}\right)^2. \tag{5}$$

Maximising with respect to the patient post-operative health h, the provider chooses the level of health h^* given by the first-order condition

$$\frac{\partial V(h;p)}{\partial h} = \frac{\partial B(h)}{\partial h} + \frac{\partial \pi(h;p)}{\partial h} = \alpha + p - c\left(h^* - \underline{h}\right) = 0 \tag{6}$$

The provider balances the marginal monetary and non-monetary benefits of increasing the patient's health against the marginal costs of that health improvement. The second-order condition is $\partial^2 V(h;p)/\partial h^2 = -c < 0$.

The hospital's choice of patient post-surgery health is:

$$h^*(p) = \underline{h} + \frac{p+\alpha}{c} \tag{7}$$

which is increasing in p. For simplicity we ignore any upper or lower bound on health gain and assume that for the chosen p and given $\alpha, c$and $\underline{h}$ the provider's choice lies within a feasible range. Figure 1 illustrates the solution, and compares post-surgery health in the absence of a bonus, $h^*(p=0) = \underline{h} + \alpha/c$, with post-surgery health in the presence of a bonus, $h^*(p>0)$ given in Equation (7).[7]

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[6] This assumption is consistent with the empirical findings of Gutacker et al. (2013), which shows that at the sample mean higher health gains do not lead to statistically significant higher monetary costs.

[7] Given the hospital's choice $h^*(p)$ its cost of treating a patient, revenues and financial surplus are: $C(h^*(p)) = k + \frac{(p+\alpha)^2}{2c}$, $R(h^*(p),p) = t + p\left(\frac{p+\alpha}{c} + \underline{h} - \widetilde{h}\right)$, and $\pi(h^*(p),p) = t - k + \frac{p^2-\alpha^2}{2c} - p(\widetilde{h} - \underline{h})$. The introduction of a bonus $p > 0$ always increases costs since, from (7), a higher bonus p increases health and greater health is more costly to achieve: $dC(h^*(p))/dp = (dC/dh)dh^*/dp = (p+\alpha)/c$. The bonus also increases revenue: $dR(h^*(p),p)/dp = (\partial R/\partial h)dh^*/dp + \partial R/\partial h = (2p+\alpha)/c + \underline{h} - \widetilde{h}$. An increase in the bonus always increases the provider utility V and its financial surplus $\pi(\frac{dV(h^*(p),p)}{dp} = \frac{\partial V(h^*(p),p)}{\partial h}\frac{dh^*}{dp} + \frac{\partial V(h^*(p),p)}{\partial p} = \frac{\partial V(h^*(p),p)}{\partial p} = \frac{\partial \pi(h^*(p),p)}{\partial p} = h^*(p) - \tilde{h} > 0)$. This follows because h is chosen to maximise V so that $\partial V(h,p)/\partial h = 0$ by the envelope theorem.

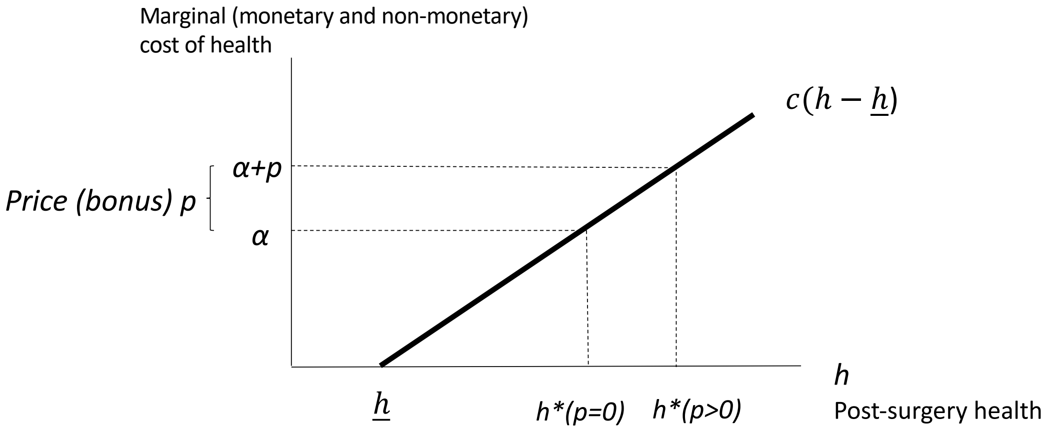


Figure 1: Provider choice of post-surgery health

2.2. The purchaser perspective

We discuss three different approaches the purchaser might adopt in setting up the bonus scheme.

2.2.1. Positive analysis

First, suppose that the purchaser would like to achieve a health objective, given by $\widehat{h}$. The price which can implement this is found by equating $h^* = \widehat{h}$, given by:

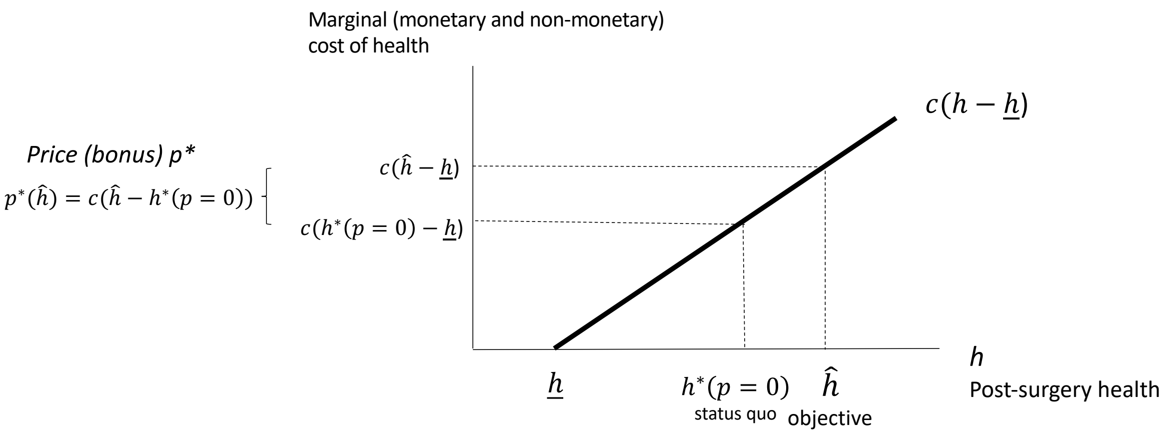
$$p^*(\widehat{h}) = c\left(\widehat{h} - \underline{h}\right) - \alpha. \tag{8}$$

Thus the bonus should be set equal to the marginal cost of post-surgery health at the required target level of health, net of the degree of provider motivation (in line with previous literature, (e.g. Ellis and McGuire 1986; Chalkley and Malcomson 1998; Kristensen et al. 2016)). The greater the degree of motivation, the smaller is the price required to induce the provider to achieve the target health objective.

We can also rewrite the price as a function of post-surgery health in the absence of a bonus system (e.g. before the scheme is implemented). In the absence of the scheme, post-surgery health is $h^*(p = 0) = \underline{h} + \alpha/c$, and hence

$$p^*(\widehat{h}) = c\left(\widehat{h} - h^*(p = 0)\right). \tag{9}$$

This is our main result, which will be used in the calibration of the bonus scheme in Section 3. It suggests that the price should be set equal to the difference in the provider marginal cost evaluated at the target level of post-surgery health that the purchaser would like to achieve, $c\left(\widehat{h} - \underline{h}\right)$, and the marginal cost evaluated at the level of health before the scheme is introduced, $c\left(h^*(p = 0) - \underline{h}\right)$. Figure 2 illustrates the solution. We plot post-surgery health on the x-axis, and the marginal cost of post-surgery health on the y-axis. We then evaluate the marginal cost of post-surgery health before the policy intervention (status quo) and after the policy intervention (at the target health). The price (bonus) per unit of post-surgery health is given by the difference in these two marginal costs.



Note: The optimal price (bonus) is the difference between the (marginal) cost of a health gain evaluated at the health objective minus the marginal cost evaluated at the status quo (health before policy intervention)

Figure 2: Price designed by the funder to achieve a given health objective

The cost, revenue and profit at the new equilibrium are respectively given by:

$$\begin{aligned} C(\widehat{h}) &= k + \frac{c}{2}\left(\widehat{h} - \underline{h}\right)^2, \\ R(\widehat{h}) &= t + c\left(\widehat{h} - h^*(p=0)\right)\left(\widehat{h} - \widetilde{h}\right), \\ \pi(\widehat{h}) &= t - k + c\left[\frac{\widehat{h} + \underline{h}}{2} - h^*(p=0)\right]\left(\widehat{h} - \widetilde{h}\right). \end{aligned} \tag{10}$$

The above expressions hold for a given HRG tariff t. The purchaser has always the option to set the HRG tariff to ensure that the overall hospital revenue for the patient is equal to the cost, $R(\widehat{h}) = C(\widehat{h})$, so that the financial surplus is zero, $\pi(\widehat{h}) = 0$. The tariff $\widehat{t}$ required to ensure that surplus is zero is:

$$\widehat{t} = C(\widehat{h}) - p^*(\widehat{h})(\widehat{h} - \widetilde{h}) = k - c\left[\frac{\widehat{h} + \underline{h}}{2} - h^*(p=0)\right]\left(\widehat{h} - \widetilde{h}\right). \tag{11}$$

Figure 3 illustrates the solution and describes revenues, costs and the HRG tariff for a given health objective $\widehat{h}$ that ensures zero profits. Provider variable costs are given by the grey area A. Total costs are given by the fixed cost k plus the variable costs A. The revenues from the bonus are given by area B. Given that total revenues have to be equal to the costs, the HRG tariff is given by $k + (A - B)$, the fixed cost minus the difference between the variable costs and the revenues from the bonus.

2.2.2. Cost-effectiveness analysis

One issue that the purchaser may need to address in a budget constrained health system is whether the extra health gain is worth the cost of achieving it. The conventional approach to this question in respect of new and costly interventions is to assess cost-effectiveness. Given the target $\widehat{h}$, the difference in provider costs before and after the introduction of the bonus is given by:

$$\Delta C = C(\widehat{h}) - C(h^*(p=0)) = c\left(\widehat{h} - h^*(p=0)\right)\left(\frac{\widehat{h} + h^*(p=0)}{2} - \underline{h}\right). \tag{12}$$

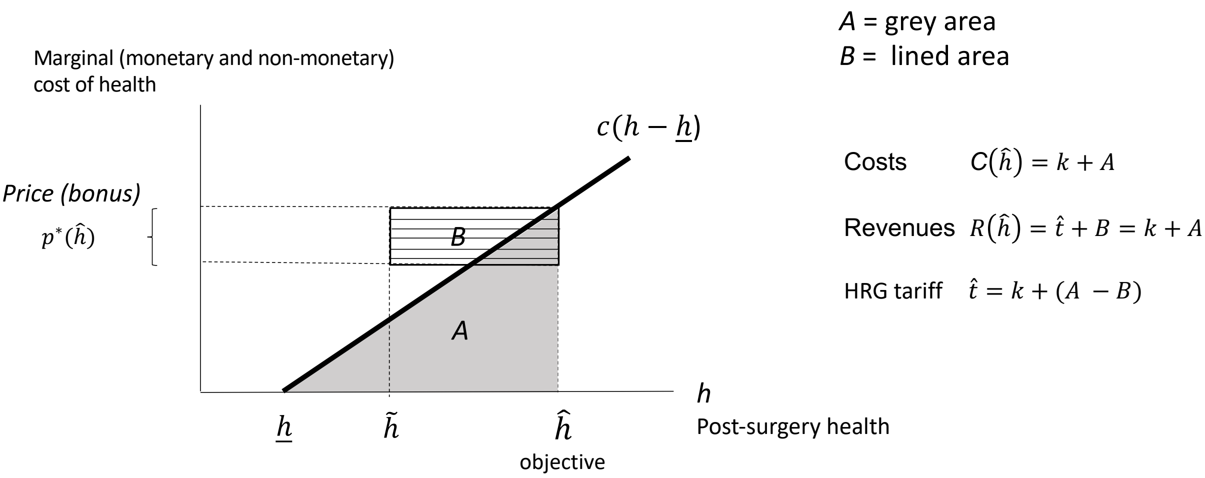


Figure 3: Revenues, costs and basic (HRG) tariff

Since by assumption the purchaser sets the HRG tariff equal to the average cost (so that the financial surplus is zero), this change in costs also gives the change in payments for the purchaser.

Defining $H(h)$ as patient life-time gain in health, e.g. as measured in QALYs, arising from a post-surgery health equal to h. The difference in health benefit with and without the bonus is:

$$\Delta H = H(\widehat{h}) - H(h^*(p = 0)). \tag{13}$$

The cost-effectiveness ratio is then given by:

$$\frac{\Delta C}{\Delta H} = \frac{C(\widehat{h}) - C(h^*(p = 0))}{H(\widehat{h}) - H(h^*(p = 0))}. \tag{14}$$

New treatments are assessed against a threshold value for the cost-effectiveness ratio. Letting λ denote this cost-effectiveness threshold then the bonus is cost-effective if $\Delta C/\Delta H < \lambda$ and is not cost-effective if $\Delta C/\Delta H \geq \lambda$.

2.2.3. Normative analysis

From a conventional welfare economics perspective the approaches outlined above do not place the provider's decision in the context of welfare maximisation and imply either arbitrary or partial approaches to the underlying decision problem. We extend our approach to allow for a purchaser that makes choices that maximise patient benefits, net of provider costs, where the latter are weighted by the opportunity costs of public funds. Define $\Omega(h)$ as welfare, δ as the opportunity cost of public funds (or the opportunity cost of the overall health budget) and W as the willingness to pay for health improvement. Welfare is then given by:

$$\Omega(h) = W\ H(h) - (1 + \delta)C(h). \tag{15}$$

The optimal level of post-surgery health is then given by $\partial\Omega(h)/\partial h = 0$, or more extensively:

$$W\ \frac{\partial H(h)}{\partial h} = (1 + \delta)c\left(h - \underline{h}\right), \tag{16}$$

which gives

$$h^w = \underline{h} + \frac{1}{c}\frac{W}{(1+\delta)}\frac{\partial H(h^w)}{\partial h}. \tag{17}$$

Comparing h^w with h^*, we can compute the price that implements such level of post-surgery health:

$$p^*(h^w) = \frac{W}{(1+\delta)}\frac{\partial H(h^w)}{\partial h} - \alpha, \tag{18}$$

which suggests that the optimal price is equal to the marginal benefit from a health gain, weighted by the opportunity cost of public funds, net of provider degree of motivation. Recalling that $h^*(p=0) = \underline{h} + \alpha/c$, this can also be written as

$$p^*(h^w) = \frac{W}{(1+\delta)}\frac{\partial H(h^w)}{\partial h} - c\left(h^*(p=0) - \underline{h}\right). \tag{19}$$

We can also relate this analysis with the cost-effectiveness approach presented in the previous subsection 2.2.2. For simplicity, set $\lambda = W/(1+\delta)$, and re-define welfare as $\lambda \times H(h) - C(h)$, which within the cost-effectiveness literature is known as the net monetary benefit (Stinnett and Mullahy 1998; Hoch et al. 2002). We can rewrite the optimal post-surgery health as $h^w = \underline{h} + \frac{\lambda}{c}\frac{\partial H(h^w)}{\partial h}$. Starting from a level of post-surgery health below h^w, then any improvement in health is cost-effective as $\lambda \times \frac{\partial H(h)}{\partial h} - \frac{\partial C(h)}{\partial h} > 0$ or equivalently

$$\frac{\partial C(h)/\partial h}{\partial H(h)/\partial h} < \lambda, \tag{20}$$

and any improvement above h^w is not cost-effective as $\frac{\partial C(h)/\partial h}{\partial H(h)/\partial h} \geq \lambda$.

3. Calibration

In order to assess how a bonus scheme described above might work in practice we calibrate the model using English hospital data for two common elective procedures. We use cost and health data for patients receiving a primary unilateral elective hip or knee replacement in 2016-17. To measure hospital costs, we employ reference costs reported annually by each hospital at the Healthcare Resource Group (HRG) level, the English equivalent to Diagnostic Related Groups.[8]

For each hospital we also measure risk-adjusted patient health status six months after the surgery.[9] We obtain this from the PROM dataset, which is constructed from patient survey responses. From April 2009, it has been mandatory for all hospitals to provide patients with these surveys shortly before and six months after undergoing elective (planned) hip and knee replacement. About 55% of patients treated in 2016-17 completed both a pre-operative and post-operative survey (NHS Digital 2018). We use two measures of patient-reported health status from this survey. The first is a condition-specific measure known as the Oxford Hip Score (OHS) for hip replacement and Oxford Knee Score (OKS) for knee replacement (Dawson et al. 1996; Dawson et al. 1998). It measures different dimensions of pain and mobility, and is based on 12 questions giving a score ranging from 0 to 48, with higher values indicating better states of health. The second health measure is the generic EQ-5D-3L instrument (Brooks 1996), which asks patient to report whether they have no, some or extreme problems on five health dimensions: mobility, pain & discomfort, anxiety & depression, ability to wash and dress themselves, and ability to carry out their usual activities. The answers form a health profile for which utility values have been elicited from the UK general population (Dolan 1997). EQ-5D utility scores range from -0.594 to 1 and can be used to calculate quality-adjusted life years (QALYs).

Descriptive statistics are reported in Table 2. Each observation pertains to one hospital.

3.1. Hip replacement

The average cost for a hip replacement across 128 public hospitals (Trusts) in England in 2016-17 was £5859. The average risk-adjusted post-operative health was 39.42 as measured by the OHS.[10]

In the baseline calibration (column I of Table 3), we assume that 80% of the costs are fixed, which implies that variable costs account for £1172, and we explore below the sensitivity of the results to both lower and higher percentages (70% and 90%).[11] We also assume that the value of post-operative health (measured by the OHS) above which it is costly to increase health, defined with $\underline{h}$ in Section 2, is equal to 34. This value is just below the minimum post-operative health observed in the hospital sample (equal to 34.41). We explore below the sensitivity of the results to lower or

[8] Hospitals report the average cost of care for patients with a length of stay shorter than a HRG-specific trim point and the average additional cost per day of caring for patients with a longer length of stay than this trim point. Private providers do not report HRG costs and are therefore excluded.

[9] Case-mix adjustment of post-operative health uses an official model created to monitor hospital performance through Patient Reported Outcomes Measures (PROMs). The model adjusts for pre-operative health, age, gender, ethnicity, deprivation, assistance in completing the PROM form, specific comorbidities, primary diagnosis, disability and history of symptoms. The exact set of variables used is measure-specific, based on significant coefficients from a common set of candidate characteristics (NHS England 2013).

[10] The average pre-operative OHS was instead 17.06 across hospitals. The average health gain across providers was instead 21.44. Notice that the latter is computed for each provider as the risk-adjusted post-operative health minus a constant term given by the average pre-operative health across English hospitals.

[11] One significant fixed cost of a hip replacement is the cost of a prosthesis, which accounts for between 26% and 53% of the total cost (Mota 2013; Clarke et al. 2015).

Table 2: Descriptive statistics, financial year 2016-17

	Mean	SD	Min	Max	N
Hip replacement					
Cost, MFF adjusted (£)	5,859.08	1,372.57	1,659.96	11,293.33	128
Post-operative health (OHS), risk-adjusted	39.42	1.13	34.41	42.07	128
Pre-operative health (OHS)	17.06	1.66	12.05	21.29	128
Health gain (OHS), risk-adjusted	21.44	1.13	16.43	24.08	128
Post-operative health (EQ-5D), risk-adjusted	0.79	0.03	0.67	0.85	128
Pre-operative health (EQ-5D)	0.32	0.06	0.14	0.45	128
Health gain (EQ-5D), risk-adjusted	0.43	0.03	0.31	0.5	128
Knee replacement					
Cost, MFF adjusted (£)	5,798.55	1,231.76	2,386.37	9,827.19	128
Post-operative health (OKS), risk-adjusted	35.58	1.04	31.54	38.21	128
Pre-operative health (OKS)	18.41	1.49	13.64	22.27	128
Health gain (OHS), risk-adjusted	16.38	1.04	12.33	19	128
Post-operative health (EQ-5D), risk-adjusted	0.74	0.02	0.67	0.81	128
Pre-operative health (EQ-5D)	0.39	0.06	0.2	0.52	128
Health gain (EQ-5D), risk-adjusted	0.32	0.02	0.25	0.39	128

Notes: Risk-adjusted post-operative health gain for provider i is equal to: (risk-adjusted post-operative health for provider i) – (pre-operative health averaged across all providers in England).

higher values. Given that $c(h^*(p=0)) = \frac{c}{2}\left(h^*(p=0) - \underline{h}\right)^2$, we can re-cover the cost parameter $c = 2\frac{c(h^*(p=0))}{(h^*(p=0)-\underline{h})^2} = 2\frac{1172}{(39.42-34)^2} = \pounds 79.8$.

In our baseline, we assume that the purchaser sets the objective of the scheme as a level of post-operative health, $\widehat{h}$, equal to 40.55. This corresponds to a health improvement of 1.13, which is one standard deviation in post-operative health across 128 providers in 2016-17 (with a maximum value of 42.07). Using (9), the price per unit of health improvement (one OHS) to achieve the objective $\widehat{h}$ = 40.55 OHS is equal to $p^*(\widehat{h}) = c\left(\widehat{h} - h^*(p=0)\right)$ = £90.1. The cost of a hip replacement at the higher post-operative health is $C(\widehat{h})$ = £6399, and the additional cost relative to pre-policy intervention is $\Delta C = C(\widehat{h}) - C(h^*(p=0))$ = £540.

In terms of provider revenues, the purchaser has to decide the level of post-operative health $\widetilde{h}$ (see Equation (1)) over which the purchaser pays for additional health improvements. We set this level at $\widetilde{h}$ = 38.29, which is equal to the pre-policy post-operative health *minus* one standard deviation in post-operative health (39.42-1.13). This threshold is somewhat arbitrary. In our model, we have assumed that any additional provider revenues arising from the bonus trigger a corresponding reduction in the HRG tariff. In this specific case, the additional revenues from the bonus are $p^*(\widehat{h}) \times \left(\widehat{h} - \widetilde{h}\right) = 90.1 \times (40.55 - 38.29) = \pounds 204$. Given that the total cost of a hip replacement is £6399, the basic HRG tariff to ensure that the provider breaks even is equal to $t(\widehat{h})$ = £6195.

The purchaser could instead choose the lower level of post-operative health threshold $\widetilde{h}$ = 36.06, which corresponds to three standard deviations in post-operative health (rather than one). As it can be seen in column II of Table 3, the optimal price remains unchanged given that the health objective is the same. However, the provider has now larger revenues from the bonus, equal to $p^*(\widehat{h}) \times \left(\widehat{h} - \widetilde{h}\right) = 90.1 \times (40.55 - 36.06) = \pounds 407$, and these are accompanied by a lower basic HRG tariff equal to £5991, which ensures again that total revenues are equal to provider costs (£6399).

The purchaser could also set up the scheme as a penalty rather than a bonus. For example, the purchaser could penalise each provider with a penalty equal to £90.1 for every unit of OHS that is below the higher threshold of 42.81, which is three standard deviations in post-operative health above

Table 3: Hip replacement - calibration under different assumptions on costs and purchaser health objective

	I	II	III	IV	V	VI	VII	VIII	IX
Observed costs and health									
Cost (£)	5,859	5,859	5,859	5,859	5,859	5,859	5,859	5,859	5,859
h^*(p=0)	39.42	39.42	39.42	39.42	39.42	39.42	39.42	39.42	39.42
Assumptions									
% fixed costs	80%	80%	80%	80%	80%	**70%**	**90%**	80%	80%
Fixed costs (£)	4687	4687	4687	4687	4687	4101	5273	4687	4687
Variable costs (£)	1172	1172	1172	1172	1172	1758	586	1172	1172
$\underline{h}$	34.00	34.00	34.00	34.00	34.00	34.00	34.00	**36**	**37**
Cost function parameter c (£)	79.80	79.80	79.80	79.80	79.80	119.70	39.90	200.40	400.20
Objective of the funder, $\widehat{h}$	40.55	40.55	40.55	**41.12**	**41.68**	40.55	40.55	40.55	40.55
Price p per health improvement (£)	90.10	90.10	90.10	135.20	180.30	135.20	45.10	226.40	452.20
Additional costs									
$C(\widehat{h})$ (£)	6399	6399	6399	6707	7040	6668	6129	6761	7209
ΔC (£)	540	540	540	848	1181	809	270	902	1350
Revenues									
$\tilde{h}$	38.29	**36.03**	**42.81**	38.29	38.29	38.29	38.29	38.29	38.29
$p \times \tilde{h}$ (£)	3656	3656	3656	5560	7515	5483	1828	9181	18337
$p \times (\widehat{h} - \widetilde{h})$ (£)	204	407	-204	382	611	306	102	512	1022
HRG tariff $\widehat{t}$ (£)	6195	5991	6602	6325	6429	6363	6027	6250	6187

Note: All health terms (h^*, $\underline{h}$, $\widehat{h}$, $\widetilde{h}$) are expressed in terms of OHS.

the pre-policy level (column III in Table 3). Given that the scheme incentivises the provider to reach a post-operative health equal to 40.55, as for columns I and II, the provider now makes a financial loss of $p^*(\widehat{h}) \times \left(\widehat{h} - \widetilde{h}\right) = -90.1 \times (42.81 - 40.55) = -£204$. Given that the provider has to break even and cover the costs of £6399, now the HRG tariff is increased by the purchaser to £6602.

3.1.1. A more ambitious target

In columns IV and V of Table 3 we assume that the purchaser sets a more ambitious target with a post-operative health which is respectively 1.5 and 2 standard deviations higher (rather than one). If the other assumptions remain the same, this implies a price per unit of OHS improvement now equal to £135.2 and £180.3, respectively.

In the first (second) scenario, costs increase to £6707 (£7040), which implies an additional cost of £848 (£1181), relative to the introduction of the scheme. Under the same assumptions as in column I in Table 3, the revenues from the bonus are now £382 (£611), which implies that the purchaser reduces the basic HRG tariff to £6325 (£6429) to ensure that the costs are covered.

As intuitively expected, the price per unit of health improvement increases with the ambition of the health target. The higher level of health increases costs and revenues, and the purchaser therefore needs to adjust the basic HRG tariff to reflect the higher level of the cost.

3.1.2. Different cost function

We have so far assumed that 80% of costs are fixed. In columns VI and VII of Table 3 we make the same assumptions as in column I but change the % of costs that are fixed to 70% and 90%, respectively. The price per unit of health improvement now increases (reduces) to £135.2 (£45.1). The cost parameter c also increases (reduces) to £119.7 (£39.9). Driven by the higher tariff, the additional revenues from the bonus also increase (reduce). The basic HRG tariff also increases (reduces), despite the higher bonus, and this is driven by the higher (lower) additional costs ΔC = £809 (£270).

We can also vary the minimum level of post-operative health over which costs increase, which so far we have set at $\underline{h}$ = 34 OHS. In columns VIII and IX of Table 3, we maintain the same assumptions as in column I but increase $\underline{h}$ to 36 and 37, respectively. This implies an increase in the cost function parameter c to £200.4 and £400.2, which translate into a higher price per unit of health improvement equal to £226.4 and £452.2. The higher marginal cost of a health improvement implies that costs at the new health target are equal to £6761 and £7209, respectively. The revenues from the bonus are now £512 and £1022, with the basic HRG tariff being re-adjusted to cover the costs.

3.1.3. Cost-effectiveness analysis

To investigate whether the introduction of the incentive scheme is cost-effective, in this subsection we set the health objective of the purchaser as a function of EQ-5D utility scores. Following similar steps as above, column I of Table 4 provides our baseline. The pre-policy post-operative health is now such that it gives a EQ-5D utility score of 0.79 and the purchaser objective is 0.82.[12] To simplify the presentation we measure post-operative health with the EQ-5D utility score multiplied by 100, so that a post-operative health of 0.79 is measured as h = 79.

Under the assumption that 80% of the costs are fixed and $\underline{h}$ = 66.65 (i.e. 0.6665 EQ-5D utility score, about the minimum level observed in the hospital sample), the optimal price is £43.9 per unit of health improvement (or 0.01 EQ-5D utility score). With a payment health threshold of 76 (0.76 EQ-5D utility score), the hospital revenues from the bonus are £255, and the basic HRG tariff is £6214, with an overall provider cost of £6469.

We assume that the health gain over the patient life span for a 0.01 EQ-5D utility score improvement is 0.1149 QALYs (ranging from 0.103 under more conservative estimates to 0.126), computed as follows. We follow Briggs et al. (2004) and Jenkins et al. (2013) and draw from the expected remaining years of life of the general population from Office for National Statistics Life Tables, and use the expected life of patients with the average age of our empirical sample in 2016/17, amounting to 18 years. We then adjust for the mortality risk in each of these years.[13] Finally, we discount future health gains using a time preference discount rate ranging from 1.5% (Claxton et al. 2011) to 3.5% as recommended by HM Treasury. Under these different assumptions the QALY improvement from hip replacement ranges from 0.103 to 0.126 QALYs (see also Appleby et al. (2013) and Schmitz et al. (2019)).

[12] We assume that the health target is specified in post-operative health, and not in QALYs, as the former is what the purchaser observes six months after the surgery. The purchaser can however take into account the QALYs generated by an improvement in post-operative health when setting the health target.

[13] To adjust for the mortality risk in each of these years, we use the mortality ratios indicated in past literature between hip replacement patients and the general population over the long term, which range from 0.7 (Pedersen et al. 2011) to 0.95 (Visuri et al. 2010). Short term mortality (usually the first 90 days following a procedure) is not of concern for us as post-operative health is reported six months after the procedure and so is conditional on survival for this period. We further adjust for a risk of revision based on revision rates of different types of hip replacement over ten years reported in Pennington et al. (2013).

In terms of cost-effectiveness, the incremental cost per QALY is £1831, suggesting that the introduction of the scheme is cost-effective, as this is below the conventional thresholds used in economic evaluation analyses of healthcare programmes (Claxton et al. 2015; Lomas et al. 2019).

Table 4: Hip replacement - cost-effectiveness

	I	II	III	IV	V	VI	VII
Observed costs and health							
Cost (£)	5,859	5,859	5,859	5,859	5,859	5,859	5,859
h^*(p=0), EQ-5D (out of 100)	79.09	79.09	79.09	79.09	79.09	79.09	79.09
Assumptions							
% fixed costs	80%	80%	80%	**70%**	70%	70%	70%
Fixed costs (£)	4687	4687	4687	4101	4101	4101	4101
Variable costs (£)	1172	1172	1172	1758	1758	1758	1758
$\underline{h}$	66.65	**69.55**	**72.45**	72.45	72.45	72.45	72.45
Cost function parameter c (£)	15.1	25.8	53.2	79.7	79.7	79.7	79.7
Objective of the funder, $\widehat{h}$	81.99	81.99	81.99	81.99	**84.89**	84.89	**91.84**
Price p per health improvement (£)	43.9	74.7	154.2	231.2	462.5	462.5	1016.2
Additional costs							
$C(\widehat{h})$ (£)	6469	6680	7106	7730	10271	10271	19082
ΔC (£)	610	821	1247	1871	4412	4412	13223
Revenues							
$\tilde{h}$	76.19	76.19	76.19	76.19	76.19	76.19	76.19
$p \times \tilde{h}$ (£)	3601	6123	12639	18958	39258	39258	93323
$p \times (\widehat{h} - \widetilde{h})$ (£)	255	433	894	1341	4023	4023	15898
HRG tariff $\widehat{t}$ (£)	6214	6247	6212	6389	6247	6247	3184
Cost-effectiveness							
QALY improvement for 0.01 utility gain	0.1149	0.1149	0.1149	0.1149	0.1149	**0.103**	**0.103**
QALY improvement	0.3332	0.3332	0.3332	0.3332	0.6664	0.5974	1.3133
Cost per QALY (£)	1831	2463	3743	5614	6620	7385	10069

Note: All health terms (h^*, $\underline{h}$, $\widehat{h}$, $\widetilde{h}$) are expressed in terms of EQ-5D utility scores.

In column II-VI of Table 4 we investigate whether this result is robust to increasingly less favourable assumptions about the cost function. In columns II and III, we increase $\underline{h}$ to higher values, which increase the cost parameter c from £15.1 to £25.8 and £53.2, leading to the higher prices of £74.7 and £154.2. In column IV we further increase the proportion of variable costs to 30%, which implies a price of £231.2. In column V we maintain the same assumptions as in column IV but set the health target at 84.89, equivalent to a two standard deviation improvement. The price is now 462.5 per unit of health improvement, revenues from the bonus are equal to £4023, and an overall provider cost of £10271. Despite the very high level of costs (relative to pre-policy level of £5859), the introduction of the bonus remains cost-effective with a cost per QALY of £6620. Column VI uses the more conservative estimate of a QALY gain of 0.103 for a 0.01 improvement in EQ-5D utility scores. The cost per QALY is £7385.

This analysis suggests that for the purchaser it is generally cost-effective to set an ambitious health target, which is above the highest level observed in the absence of the scheme.

3.1.4. Normative analysis

Based on the normative analysis (in Section 2.2.3), we can also compute the optimal level of post-operative health which equates purchaser's marginal benefit with its marginal cost, given by $h^w = \underline{h} + \frac{1}{c}\frac{W}{(1+\delta)}\frac{\partial H(h^w)}{\partial h}$. We choose the most conservative parameters with highest costs and lowest benefits used in column VI of Table 4: 30% variable costs and $\underline{h}$ = 72.45, leading to c = £79.70; a QALY improvement from an increase in one unit of post-operative health equal to 0.1030, so that $\frac{\partial H(h^w)}{\partial h}$ = 0.1030; and a willingness to pay for a QALY for the purchaser by $\frac{W}{(1+\delta)}$ = £15000.

By substitution, we obtain an optimal level of post-operative health equal to h^w = 91.8. This is equivalent to an improvement of more than four standard deviations in post-operative health relative to the level before the introduction of the policy, which is well above the maximum post-operative health observed across providers equal to 85 (or 0.85 EQ-5D utility score).

Recall that the optimal pricing rule is $p^*(h^w) = \frac{W}{(1+\delta)}\frac{\partial H(h^w)}{\partial h} - c\left(h^*(p=0) - \underline{h}\right)$. The optimal price which implements the level of post-operative health h^w = 91.8 is then equal to $p^*(h^w) = 15000 * (0.1030) - (79.7)(79.09 - 72.45) = \pounds 1016$. The results are reported in column VII of Table 4. The cost of a hip replacement at such high levels of post-operative health is about three times the cost at the baseline, £19082. Most of the hospital revenues arise from the bonus, £15898, and the remaining from the basic HRG tariff, £3184. The incremental cost per QALY relative to the baseline (given by $\frac{\Delta C}{\Delta H} = \frac{C(\widehat{h})-C(h^*(p=0))}{H(\widehat{h})-H(h^*(p=0))}$) is further increased, and equal to £10069. Notice that the marginal cost-effectiveness ratio evaluated at the optimal post-operative health is instead $\frac{\partial C(h^w)/\partial h}{\partial H(h^w)/\partial h} = \frac{c(h^w-\underline{h})}{0.1030} = \frac{79.7(91.8-72.45)}{0.1030} \approx 15000 = \frac{W}{(1+\delta)}$, which is higher than the incremental cost-effectiveness ratio. The result that the marginal cost-effectiveness ratio is equal to the purchaser willingness to pay holds by construction because the optimal price is computed such that the marginal benefit from an increase in post-operative health equates its cost.

We have chosen conservative measures of parameter values. Both higher measures of benefits or lower measures of costs would increase even further the optimal post-operative health set by the purchaser.

3.2. Knee replacement

The average cost for a knee replacement across 128 public hospitals (Trusts) in England in 2016-17 was $\pounds 5799$. The average risk-adjusted post-operative health was 35.58 as measured by the Oxford Knee Score. In the baseline calibration (column I of Table 5), we assume that 80% of the costs are fixed, and that the value of post-operative health above which it is costly to increase health, $\underline{h}$, is equal to 31.5 OKS, just below the minimum post-operative health observed in the hospital sample (equal to 31.54 OKS). By similar steps as for hip replacement, we re-cover the cost parameter $c = \pounds 139.30$.

The purchaser chooses a target level of post-operative health equal to $\widehat{h}$ = 36.62 on the OKS scale, which corresponds to one standard deviation in post-operative health (equal to 1.04 OKS). Using (9), the price per unit of health improvement (one OKS point) to achieve the objective $\widehat{h}$ = 40.55 is equal to $p^*(\widehat{h}) = c\left(\widehat{h} - h^*(p=0)\right)$ = £144.90. The cost of a knee replacement at the higher post-operative health is $C(\widehat{h})$ = £6465, and the additional cost relative to pre-policy intervention is $\Delta C = C(\widehat{h}) - C(h^*(p=0))$ = £666.

Table 5: Knee replacement- Calibration under different assumptions on costs and purchaser health objective

	I	II	III	IV	V	VI	VII	VIII	IX	X
Observed costs and health										
Cost (£)	5,799	5,799	5,799	5,799	5,799	5,799	5,799	5,799	5,799	5,799
h^*(p=0)	35.58	35.58	35.58	35.58	35.58	35.58	35.58	35.58	35.58	35.58
Assumptions										
% fixed costs	80%	80%	80%	80%	80%	**70%**	**90%**	80%	80%	**70%**
Fixed costs (£)	4639	4639	4639	4639	4639	4059	5219	4639	4639	4059
Variable costs (£)	1160	1160	1160	1160	1160	1740	580	1160	1160	1740
$\underline{h}$	31.50	31.50	31.50	31.50	31.50	31.50	31.50	**32.50**	**33.50**	**33.50**
Cost function parameter c (£)	139.3	139.3	139.3	139.3	139.3	209	69.7	244.4	535.9	803.8
Objective of the funder, $\widehat{h}$	36.62	36.62	36.62	**37.14**	**37.66**	36.62	36.62	36.62	36.62	**37.66**
Price p per health improvement (£)	144.9	144.9	144.9	217.3	289.8	217.3	72.4	254.2	557.3	1672
Additional costs										
$C(\widehat{h})$ (£)	6465	6465	6465	6855	7282	6798	6132	6714	7248	11016
ΔC (£)	666	666	666	1056	1484	1000	333	915	1449	5217
Revenues										
$\tilde{h}$	34.54	**32.46**	**38.70**	34.54	34.54	34.54	34.54	34.54	34.54	34.54
$p \times \tilde{h}$ (£)	5305	5305	5305	8071	10912	7958	2653	9309	20409	62966
$p \times (\widehat{h} - \widetilde{h})$ (£)	301	603	-301	565	904	452	151	529	1159	5216
HRG tariff $\widehat{t}$ (£)	6164	5862	6766	6290	6378	6346	5981	6185	6089	5799

Note: All health terms (h^*, $\underline{h}$, $\widehat{h}$, $\widetilde{h}$) are expressed in terms of OKS.

In terms of provider revenues, we assume again that the purchaser sets the level of post-operative health $\widetilde{h}$ (see (1)) over which the purchaser pays for additional health improvements at $\widetilde{h}$ = 34.54, which is equal to the pre-policy post-operative health *minus* one standard deviation in post-operative health. The additional revenues from the bonus are $p^*(\widehat{h}) \times \left(\widehat{h} - \widetilde{h}\right)$ = £301. Given that the total cost of a knee replacement is £6565, the basic HRG tariff to ensure that the provider breaks even is $t(\widehat{h})$ = £6164.

The purchaser could instead choose the lower level of post-operative health threshold $\widetilde{h}$ = 32.46, which corresponds to three standard deviations (rather than one) in post-operative health (column II in Table 5). Although the price remains unchanged, the provider now has larger revenues from the bonus, equal to £603, and these are accompanied by a lower basic HRG tariff equal to £5862, which ensures again that total revenues are equal to provider costs (£6465).

The purchaser could also set up the scheme as a penalty, by setting the higher threshold of 38.70, which is three standard deviations in post-operative health above the pre-policy level (column III in Table 5). The provider now makes a financial loss of -£301. Given that the provider has to break even, the HRG tariff is increased to £6766.

In columns IV and V of Table 5, we assume that the purchaser sets a more ambitious target with a post-operative health which is respectively 1.5 and 2 standard deviations higher. The price per unit of OKS improvement has now increased, relative to the baseline, to £217.3 and £289.8, respectively.

In columns VI and VII of Table 5 we change, relative to the baseline in column I, the % of costs that are fixed from 80% to 70% and 90%, respectively. The price per unit of health improvement now increases (reduces) to £217.3 (£72.4).

In columns VIII and IX, we increase $\underline{h}$ to 32.5 and 33.5, respectively. This implies an increase in the cost function parameter c to £244.4 and £535.9, which translate into a higher price per unit of health improvement equal to £254.2 and £557.3.

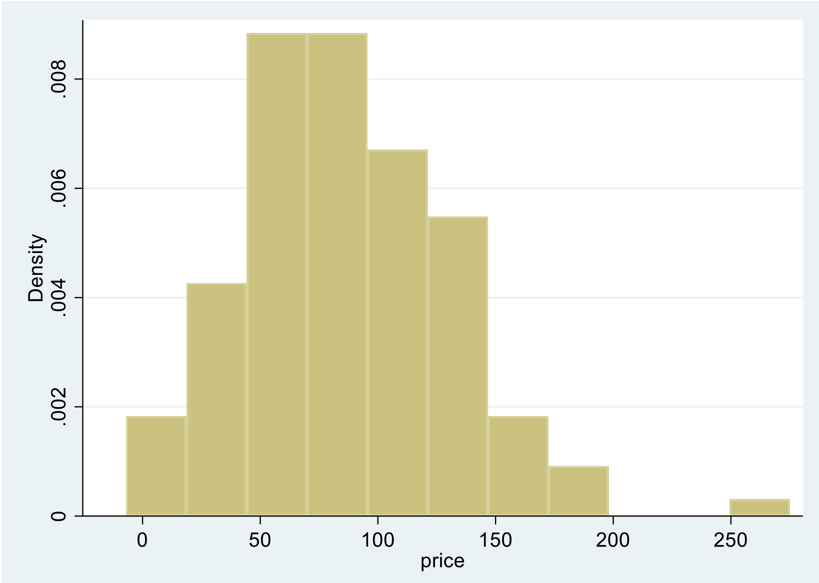
Finally, in column X we combine several assumptions that lead to higher prices: the % of fixed costs is 70%, $\underline{h}$ = 33.50, and the target post-operative health is two standard deviations above the pre-policy level. The price per unit of health improvement is £1672.

Overall, the results for knee replacement are qualitatively and quantitatively similar to those obtained for hip replacement.

3.3. Heterogeneity across providers

We have so far focussed on a representative provider with average costs and post-operative health. Given that the purchaser observes different levels of post-operative health and different costs across providers, the purchaser could differentiate the optimal price for a unit of improvement (and therefore the HRG tariff) for each provider.

Suppose that heterogeneity in costs is due to differences in $\underline{h}$. We set the value of c = 15.1, which is the value derived in column I of Table 4, and assume that it is common across providers. We then set the purchaser target health by two standard deviations above the pre-policy average, $\widehat{h}$ = 84.89 (as in column V and VI or Table 4), to ensure that each provider can improve. From Table 3 we know that post-operative



Note: Heterogeneity in costs due to $\underline{h}$

Figure 4: Price per unit of health improvement

health $h^*(p=0)$ varies between 67 and 85 before the policy is introduced, with an average of 79 and a standard deviation of 3.

Recall that the optimal pricing rule is given by $p^*(\widehat{h}) = c\left(\widehat{h} - h^*(p=0)\right)$. Given the cost parameter c is common across providers, the only difference in the price across providers is driven by different levels of post-operative health before the policy, $h^*(p=0)$. Providers with lower initial starting points will require a higher price per unit of health improvement to achieve the target health. By substituting $h^*(p=0)$, we obtain the optimal price for each provider. The distribution of prices is plotted in Figure 4. The average price per unit of health improvement is £87.60 with a standard deviation of £43.76, and a maximum of £275.44.

Given that $c(h^*(p=0)) = \frac{c}{2}(h^*(p=0) - \underline{h})^2$, we can re-cover the parameter $\underline{h} = h^*(p=0) - \left(\frac{2c(h^*(p=0))}{15.1}\right)^{1/2}$. For example, given a provider with $h^*(p=0) = 78.36$ and a cost of £6239 (with 80% fixed costs), we obtain $\underline{h} = 78.36 - \left(\frac{0.4*6239}{15.1}\right)^{1/2} = 65.504$. Across the sample of providers $\underline{h}$ has an average of 66.72, with a standard deviation of 3.32, a maximum of 73.27 and a minimum of 53.85. Notice that although $\underline{h}$ does not affect the value p, this parameter is required for the purchaser to differentiate the HRG tariff across providers and ensure the providers have overall revenues that equate the costs, given that $\widehat{t} = k - c\left[\frac{\widehat{h}+\underline{h}}{2} - h^*(p=0)\right]\left(\widehat{h} - \widetilde{h}\right)$.

4. Conclusions and policy implications

The availability of routinely collected health outcome measures for some healthcare interventions raises the intuitively appealing possibility of conditioning payment on what really matters in health care – health gains achieved. There are potentially many barriers to the practical implementation of outcomes-based payments, such as ensuring the veracity of measures, ensuring that they are not subject to influence or manipulation and establishing confidence in a new payment system. A better understanding of how they might be made operational and what they could imply for hospital finances is an important first step. The purpose of this study was to establish that first step.

One key question is how any outcome-related bonus should be set. To address this question we analysed a simple but general model based on contract theory, in which the bonus acts as an incentive for the provider to increase the quality of treatment and hence the resulting health of a patient. This model has an immediate practical implication that contrasts with some of the discussion that surrounds this kind of pay-for-performance mechanism. In contrast with approaches that focus on the overall impact of bonus payments on hospital revenues, where these are often viewed as being relatively small (e.g. about 5% of hospital revenues with some variation across schemes and countries; see Cashin et al. (2014)), our analysis highlights that what matters is the price set by the purchaser per unit of health improvement. This is because it is the price which will determine the reward that provider gets from improving health. The model also suggests what information the purchaser requires in order to choose a price that will either achieve any desired level of health, or is consistent with achieving health gains that are cost-effective or welfare maximising. In all cases what is crucial is an assessment of the costs of achieving incremental health gains evaluated before the bonus is introduced (pre-policy intervention), and at desired level of target health.

Although higher prices lead to higher provider revenues, everything else constant, the purchaser can still recover some of these revenues by changing the health thresholds over which the provider is paid, with higher thresholds leading to lower revenues. Moreover, the purchaser can also adjust and reduce the base price – the DRG or HRG tariff to compensate for the higher provider revenues from the bonus. In the end, the purchaser only needs to ensure that the provider has overall revenues (from the HRG tariff plus the bonus) which cover provider costs. However, higher health targets will be costly for the provider, and therefore the higher costs from higher health will have to be covered by the purchaser through higher revenues either from the bonus or the HRG tariff.

The model therefore provides the basis for establishing what level of bonus might be required in practice and to explore this further we examined data on two procedures in the English NHS where health outcome measures are available – hip and knee replacements. In our calibration for hip replacements, we find that the price for one unit of health improvement as measured by the Oxford Hip Score to achieve an improvement of 1.13 OHS (equivalent to one standard deviation observed in the empirical distribution) ranges between £45 and £226 under different assumptions related to the cost function. For knee replacements, the price for one unit of health improvement as measured by the Oxford Knee Score to achieve an improvement of 1.06 OKS (equivalent to one standard deviation observed in the empirical distribution) ranges between £72 and £254 under different assumptions related to the cost function. The price doubles for a health target of two, rather than one, standard deviation improvement.

When we evaluate the health benefits in QALYs, we generally find that the introduction of the bonus is cost-effective, even at high levels of health targets. In turn, this implies that under a welfare function approach, the optimal health target is high and the price per unit of health improvement is even higher than those considered in the previous scenarios.

Whilst we refer to the incentive scheme as a bonus it could also be set up as a penalty for shortfalls from the health target set by the purchaser. Here, the price per health improvement remains critical and can be interpreted as the reduction in the penalty per unit of health improvement. However, if the provider ultimately incurs a loss, the purchaser will have to compensate for such financial loss with a higher HRG tariff to ensure that the provider breaks even.

In terms of possible limitations, the analysis has abstracted from modelling patient heterogeneity in severity. This is because PROMs are risk-adjusted, and include the pre-operative health in the casemix, which is a good proxy of capacity to benefit. Moreover, if the payment scheme is set to improve the health of patients on average, as opposed to an individual patient, any source of unobserved severity will balance out if it is not systematic. Similarly, we may be concerned about measurement error in the health measures, which could expose providers to losses or grant them profits. However, hip and knee replacements are common procedures, with most hospitals treating hundreds of patients. Therefore, any measurement error should balance out with large volumes. If risk adjustment is imperfect and therefore is unaccounted for heterogeneity that providers can observe prior to committing to treatment then as in any such setting where prices are based on activity there is a risk that providers will select patients to treat and potentially shun difficult patients. This issue does not seem particularly relevant in the system we study where hospitals are mostly obligated to treat those patients who are referred to them. Neither have we considered the issue of multitasking (or tunnel vision). This is because our measures of health are comprehensive, therefore any incentive to divert effort from untargeted to targeted care should be minimal. The same argument applies to so-called gaming opportunities.

In terms of future research, we briefly discuss possible extensions. First, we have argued that in our framework provider costs are always equal to purchaser payment. Therefore, there is no distinction between a purchaser perspective that focuses on reimbursement and a provider or welfare perspective that focuses on provider costs. This distinction however could become relevant in frameworks which allow for purchaser payments to differ from costs. Second, we have focused on schemes that target health outcomes. Future work could investigate schemes that target process measures of quality. For example, building on the work by Kristensen et al. (2016) which focuses on stroke care, a similar framework could be applied for hip fracture. The difficulty with schemes with process measures of quality is that the link between process quality and health has to be established, which is not required for schemes that target health outcomes directly. On the other hand, targeting processes has also advantages, as these are more directly under the control of healthcare providers.

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