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PERFORMANCE INDICATORS FOR QUALITY WITH ADVERSE SELECTION, GAMING AND INEQUALITY AVERSION

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ABSTRACT

Performance Indicators for Quality with Adverse Selection, Gaming and Inequality Aversion

Performance indicators are increasingly used to regulate quality in health care and other areas of the public sector. We develop a model of contracting between a purchaser (principal) and a provider (agent) under the following scenarios: a) higher ability increases quality directly and indirectly (through a lower marginal cost of quality); b) the provider can game the system (or misreport); c) the purchaser is averse to inequality. The main results are: 1) if ability has a direct impact on quality, quality effort is lower and distortions from informational rents are higher; under some conditions more able providers exert lower quality effort; 2) gaming or misreporting reduces the optimal level of quality effort but generally increases the level of quality targets (and measured quality). Pooling may be optimal for high types (or all types) if the benefit function is sufficiently concave and the cost of manipulation is at intermediate levels; 3) If patients receive a low benefit from health care because quality is low then higher inequality aversion increases the optimal level of quality and the associated transfer, and reduces quality dispersion.

JEL Classification: D82, I11, I18 and L51
Keywords: adverse selection, falsification, inequality aversion, moral hazard, performance and quality

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1 Introduction

Performance indicators are increasingly used to regulate quality in the healthcare sector and more broadly in the public sector. Examples from the hospital sector include the star rating system in the United Kingdom (Goddard, Mannion and Smith, 2000; Mannion, Davies and Marshall, 2005) and report cards in the US (Dranove et al., 2003; Green and Wintfeld, 1995). Indicators may take the form of risk-adjusted mortality rates, elective and emergency readmission rates, measures of complications and infections, as well as waiting times. In the United Kingdom quality indicators have been developed for general practitioners as well (Roland, 2004; Doran et al., 2006). Examples include the measurement of blood pressure and cholesterol in patients with ischemic heart disease. Financial rewards for better performance can be substantial (about 20% of a general-practitioner's budget).[1]

The theoretical literature on performance indicators in health care is rather limited. Eggleston (2005) analyses the effect of performance indicators within a multi-tasking moral hazard framework. She suggests that if some dimensions of quality are observable through performance indicators while others are not, then rewarding hospitals for better performance in the observable dimensions may come at the expense of quality cuts in the dimensions that are not observable. On the empirical side, Dranove et al. (2003) suggest that the introduction of "report cards" in New York State and Pennsylvania led to an overall reduction in welfare. This was mainly due to the higher incentive for providers to engage in selection of patients with lower severity.

Bird et al. (2005) and Propper and Wilson (2003) provide an informal discussion about the likely effects of performance indicators in health care and the public sector. A common theme

[1] Additional revenues in 2003 from highest performance were £42000 (about $77000) per doctor per financial year. No additional revenues are made available to the lowest performers. Payments are allocated on the basis of a points-based system. Each point is worth £120 and there are at most 1050 points available (see Roland, 2004).

is that performance indicators do not only reflect provider effort (moral hazard), but also other factors like case-mix, ability and environmental factors (adverse selection). Also performance indicators may be *gamed* by the providers: while the purchaser seeks to induce higher effort, the provider may engage in wasteful activities (for example data manipulation; Smith, 1995) which may improve on the performance indicator but are not valued by the purchaser. Examples of gaming, or manipulation, include the following: a) For mortality rates, hospitals can up-code the principal diagnosis (to a more severe condition or procedure) and code every possible comorbidity on every patient so that risk-adjusted death rates will be lower. Also, they can discharge patients earlier, and possibly prematurely, shifting into community settings a proportion of deaths and complications that would otherwise have occurred, and been measured, as in-hospital events (Goldacre et al., 2002). b) For elective-surgery waiting times, there is some evidence that waiting lists have been inappropriately adjusted by staff to improve the Trust's apparent performance. Such inappropriate adjustments range in their severity from junior staff following established but incorrect procedures to senior management driving at apparently deliberate manipulation or misstatement of the figures (NAO, 2001). c) Ambulance services appear to have made perverse changes in classification methods or start times to manipulate the indicator of their performance without genuine enhancement (Bird et al., 2005). d) Some evidence suggests that general practitioners in the UK have attained high levels of performance by excluding a large number of patients from the indicators (Doran et al., 2006).

Although we increasingly observe the use of performance indicators, most of the existing theoretical literature assumes that quality is not contractible (for example Chalkley and Malcomson, 1998a and 1998b). This literature predicts that the introduction of prospective payment systems based on fixed prices clearly induces cost-containment effort, but this may come at the expense of a reduction in quality. For example, if there is excess demand or if demand does not respond to quality, and if the provider is a profit maximiser, then under a purely prospective payment system, quality will drop to a minimum. One possibility is to introduce cost sharing. However, we observe very little use of cost sharing in practice. For example, payment systems based on Diagnosis Related Groups (DRGs) reimburse costs only for outliers. We may infer that perhaps policy makers prefer to control quality through the development of performance indicators, i.e. by making quality *contractible*. Therefore, there is increasing scope to analyse provider incentives when performance indicators are used.

We develop an adverse selection model, where providers differ in their ability to produce quality. We derive the optimal contract, which determines the optimal level of quality and the associated transfer. We focus on three issues: a) higher ability increases quality directly and not only indirectly through a reduction in the marginal cost of quality; c) gaming or misreporting; b) inequality aversion.

The results are as follows. a) The higher is the direct impact of ability on quality, the lower is the optimal quality effort and the higher are the distortions necessary to reduce informational rents (although this does not imply that informational rents will be lower in equilibrium); the transfer is lower for low-ability providers, otherwise it is indeterminate. Interestingly, higher-ability providers have higher reported quality (as measured through the performance indicator), but may exert lower quality effort (in equilibrium) if the benefit function of the patients is sufficiently concave. b) Gaming may occur in the sense that providers may attain a set quality target either by providing 'true' quality effort or by engaging in manipulation. As long as a separating allocation is realised, gaming *reduces* the optimal level of quality effort but generally *increases* the level of the quality target. This arises because the easier it is to manipulate, the more demanding is the purchaser in setting the quality target but also the more costly it is to raise quality effort. A pooling allocation may occur at the top (for high-ability types), so that the payment over a certain quality target is flat. This arises when more able providers engage in so much less manipulation that the purchaser would like to reduce the targets for them. As this would violate incentive compatibility, pooling at the top emerges. The solution is consistent with some incentive schemes implemented in the UK. For example general practitioners are rewarded on the basis of the proportion of patients affected by ischemic heart disease that have their blood pressure measured every 15 months. However there is no extra financial reward if they review more that 70% of the patients affected by this condition (Doran et al., 2006). Furthermore, pooling at the top can be understood as a justification of minimum quality standards, in combinations with fines for underachievement. c) If patients receive a low benefit from health care because the quality of care is low then higher inequality aversion increases the optimal level of quality and the associated transfer, and reduces quality dispersion. A purchaser who is concerned with inequality is more willing to allocate resources to the hospital sector (higher inequality aversion is equivalent to a higher marginal benefit from quality). It is also willing to trade some efficiency to reduce disparities in quality across providers.

This study contributes to the literature on provider payment in healthcare (Ma, 1994; Chalkley and Malcomson, 1998a and 1998b; Bos and DeFraja, 2002) and more broadly in the public sector. Differently from this literature, we assume that quality is contractible (although imperfectly). The above studies do not deal with adverse selection problems, that have been to some extent investigated by De Fraja (2000), Chalkley and Malcomson (2002), Jack (2005), Boadway, Marchand and Sato (2004) and Siciliani (2006).[2] In these studies the asymmetry of information lies respectively on the cost parameter, the degree of altruism and the average severity of illness. Our study differs from the above in several respects. First, it focuses on quality rather than activity. Second, it considers explicitly the inequality aversion of the purchaser. Third, and perhaps most importantly, it allows gaming or misreporting.

[2] Laffont and Tirole (1986, 1993) provide related models of adverse selection in regulation.

Fourth, ability affects quality both directly and indirectly (through the cost function).

Our analysis of gaming (section 3) contributes to the broader principal-agent literature with costly falsification (Lacker and Weinberg, 1989; Maggi and Rodriguez-Clare, 1995; Crocker and Morgan, 1998; Crocker and Slemrod, 2005). This literature assumes that the observable variable for the principal reflects both an adverse selection parameter and a manipulative effort. For example for a public utility the reported cost depends on technology and manipulative effort. Our approach differs from the above studies by considering an additional moral-hazard dimension. In our model the reported quality is the sum of quality effort and manipulative effort. As it turns out, it is the interaction of the two effort variables, which may give rise to non-responsiveness and pooling even for a monotone hazard rate. Such an outcome cannot arise in the present models of costly falsification.

Policy makers often argue that rewarding efficiency in the provision of quality (or quantity) may exacerbate differences in quality across providers. Therefore higher efficiency may come at the cost of an increase in inequity. We model inequality aversion using an isoelastic welfare function, similarly to Fleurbaey, Gary-Bobo and Maguain (2002) whose main focus is on education. Compared to their study, our comparative statics with respect to the degree of inequality aversion are much simpler. This is because transfers do not enter the utility function of the individuals. As a result, inequality aversion affects only the marginal benefit of quality. Interestingly, higher aversion implies higher quality effort and quality dispersion in equilibrium only for low levels of quality.

Although our main focus is on healthcare, the model is quite general and the results are likely to apply in other areas of public services, like education, which shares many features with health care (individuals pay low or zero fees; government pays providers directly; inequality concerns matter; performance indicators are increasingly used). Many states in the U.S. have implemented or plan to implement systems in which schools receive rewards on the basis of students' test scores. However, better scores may not only reflect a higher effort from teachers but also more manipulation, cheating or "teaching to the test". Indeed, some evidence shows that performance schemes based on such tests can generate perverse incentives and seriously inflated scores (Koretz, 2002; Dixit, 2002; Jacob and Levitt, 2003; Jacob, 2005).[3]

Another example, which has been the focus of a considerable volume of empirical work, is the Job Training Partnership Act (JTPA) programme in the US which is aimed at the integration into the labour market of the poor (e.g. Courty and Marschke, 1997 and 2004; Cragg, 1997; Heckmann, Heinrich and Smith, 1997 and 2002). One feature of this programme is that it comes with a system of performance standards in terms of trainee employment, wage rates and earnings levels up to three months after completion of the programme. Local legislators are allowed to link incentive schemes to these indicators. The empirical evidence suggests the presence of gaming. According to Courty and Marschke (1997), for instance, providers time strategically the reporting of success rates by delaying reports on bad outcomes into periods of good labour market conditions where the provider is likely to hit the target anyway. Their empirical analysis suggests that these manipulations are wasteful (Courty and Marschke, 2004).

The remainder of the paper is structured as follows. Section 2 presents the basic model. Sections 3 and 4 extend the analysis by introducing respectively gaming and inequality aversion. Section 5 offers concluding remarks.

[3] In the U.K. universities have to report students' unemployment rates after six or twelve months of graduation: high unemployment rates are interpreted as a signal of poor quality (Smith, McKnight and Naylor, 2000).

2 The basic model

The quality of provision is measurable through a performance indicator, q. We assume that quality reflects both an adverse selection component θ (skills of the doctors, reflecting natural ability and/or sunk investments in human capital) and a moral hazard variable m (doctors and managers make an effort to provide good quality).[4] Ability θ is therefore private information and is distributed according to the continuous density function $f(\theta)$ and cumulative function $F(\theta)$ on the support $[\underline{\theta}, \overline{\theta}]$. We assume $\left(\frac{1-F}{f}\right)' := \frac{\partial[(1-F(\theta))/f(\theta)]}{\partial\theta} < 0$ (monotone hazard rate assumption).

In the basic model true and observed (or reported) quality are both given by $q = \alpha\theta + m$, where $\alpha \geq 0$ is a non-negative parameter. When $\alpha = 0$, quality reflects the moral hazard variable m only. For $\alpha > 0$, quality also depends directly on ability. For example for doctors α may be significantly higher than for nurses, as doctors' performance is likely to depend not only on effort but also on the skills acquired in previous study and training.

The unobservable disutility of a provider of type θ from exerting effort m is given by $\psi(m, \theta)$.[5] We assume that the disutility increases with effort and is a convex function: $\psi_m > 0$, $\psi_{mm} \geq 0$. Also, more able providers have a lower disutility and marginal disutility from effort: $\psi_\theta \leq 0$ and $\psi_{m\theta} < 0$.[6] The transfer to provider θ is denoted by $t(\theta)$. The provider is assumed to maximise the difference between the transfer and the disutility:

[4] Alternatively θ can be interpreted as intrinsic motivation or a public service spirit (Francois, 2000). A third possibility is to interpret θ as an (inverse) measure of patients' severity. There is a wide empirical literature (especially from the U.S.) pointing out that although quality indicators can be risk-adjusted (for some observable charateristics of the patients), variations in quality indicators still reflect large unobserved heterogeneity in the case-mix of the patients across providers (see Iezzoni, 2003).

[5] We will also refer to this as the 'cost of effort'.

[6] We therefore mantain the traditional assumption that more able types have lower marginal cost. Bontems and Bourgeon (2000) argue that in certain situations the opposite assumption may hold, in which case *countervailing incentives* may emerge.

$U(\theta) = t(\theta) - \psi(m,\theta) = t(\theta) - \psi(q - \alpha\theta, \theta)$.

The benefit for patients receiving treatment by provider θ is given by the function $W(q(\theta))$, which increases in quality so that $W_q > 0$ and $W_{qq} \leq 0$. The purchaser maximises patient benefit net of the transfer to the provider:

$$\max_{q(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} [W(q(\theta)) - t(\theta)]\, dF(\theta). \tag{1}$$

We therefore assume that the purchaser attaches no value to the utility of the provider.[7]

The optimal contract takes the following form. The purchaser offers a transfer t to each provider and conditions it to the provision of a certain reported quality, q. The following participation constraints must be satisfied for all θ: $U(\theta) \geq 0$. Moreover, with asymmetric information, the following incentive-compatible constraints need to be satisfied.

Lemma 1 *The provider's truth-telling constraint requires*

$$\frac{\partial U}{\partial \theta} = -\psi_\theta + \alpha\psi_m > 0 \quad \textit{and} \quad \frac{\partial q}{\partial \theta} \geq 0 \tag{2}$$

Providers with higher ability have a higher rent. $\frac{\partial U}{\partial \theta} > 0$ is only a necessary condition for the incentive-compatibility constraints to be satisfied. The *implementability* condition $\frac{\partial q}{\partial \theta} \geq 0$ also needs to be satisfied (see Fudenberg and Tirole, 1991, p.258). $\frac{\partial U}{\partial \theta} > 0$ also implies that $U(\underline{\theta}) = 0$ and $U(\theta) > 0$ for $\theta > \underline{\theta}$. To derive the optimal contract, we need to maximise the purchaser's objective function Eq.(1) subject to the incentive-compatibility constraints and the participation constraints. We shall use the notation $(.)^{as}$ to denote the optimal choices under asymmetric information. Proposition 1 describes the optimal contract:

[7] A more general objective function for the purchaser is $\int_{\underline{\theta}}^{\overline{\theta}} [W(q(\theta)) - (1+\lambda)t(\theta) + \delta U(\theta)]\, dF(\theta)$, where λ is the opportunity cost of public funds and δ is the weight attached to the utility of the provider. The main results of the analysis with this more general specification would be qualitatively similar as long as either $\lambda > 0$ or $\delta < 1$. We therefore focus on the special case where $\lambda = \delta = 0$.

Proposition 1 *(a) The optimal contract offered by the purchaser under asymmetric information satisfies:*

$$q^{as}(\theta): \quad W_q(q^{as}(\theta)) = \psi_m(m^{as}(\theta), \theta) + \frac{1-F(\theta)}{f(\theta)}(-\psi_{\theta m} + \alpha\psi_{mm}), \tag{3}$$

$$t^{as}(\theta) = \psi(m^{as}(\theta), \theta) + U^{as}(\theta) = \psi(m^{as}(\theta), \theta) + \int_{\underline{\theta}}^{\theta}(-\psi_\theta + \alpha\psi_m)\, d\widetilde{\theta}, \tag{4}$$

$$m^{as}(\theta) = q^{as}(\theta) - \alpha\theta.$$

(b) The contract is fully separating, i.e. $\frac{\partial q^{as}}{\partial \theta} \geq 0$*, if* $\psi_{\theta\theta m} + \alpha^2\psi_{mmm} - 2\alpha\psi_{\theta mm} \geq 0$.

Eq.(3) suggests that the optimal level of quality q is found where the marginal benefit from higher quality equals the marginal cost of quality. The marginal cost of quality consists of two parts: the marginal disutility of effort m, ψ_m, and the marginal information rent $\left(\frac{1-F(\theta)}{f(\theta)}(-\psi_{\theta m} + \alpha\psi_{mm}) > 0\right)$. Notice that a higher α increases the marginal rent because the higher is α the lower is the effort necessary for the high-ability provider to mimic the low-ability provider.

Eq.(4) suggests that the transfer to the provider is equal to the sum of the cost of effort and the rent. The following proposition analyses how the transfer and the quality effort vary with the provider's ability.

Proposition 2 *(a)* $\frac{\partial t^{as}}{\partial \theta} > 0$*; (b)* $\frac{\partial m^{as}}{\partial \theta} \lessgtr 0$*. If* α *is positive and the welfare function is sufficiently concave, then* $\frac{\partial m^{as}}{\partial \theta} < 0$*. Otherwise,* $\frac{\partial m^{as}}{\partial \theta} > 0$.

The transfer is higher for high-ability providers ($\frac{\partial t^{as}}{\partial \theta} > 0$). Although reported quality increases with ability ($\frac{\partial q^{as}}{\partial \theta} > 0$), the same does not necessarily apply to effort. Since $\frac{dm^{as}}{d\theta} = \frac{\partial q^{as}}{\partial \theta} - \alpha$, quality effort may either increase or decrease. If the marginal benefit of quality is constant ($W_{qq} = 0$), then effort certainly increases with ability $\frac{\partial m^{as}}{\partial \theta} > 0$. If $-W_{qq} > -\left(\frac{1-F}{f}\right)'\psi_{mm} - \frac{1-F(\theta)}{f(\theta)}\psi_{mm\theta}$ and if α is sufficiently high, then effort reduces with ability $\frac{\partial m^{as}}{\partial \theta} < 0$. In words, if the patient benefit is sufficiently concave, i.e. marginal benefit decreases rapidly, then it is optimal for providers with lower ability to exert a higher effort. Why does this result arise? Since higher ability implies higher quality at no extra effort and cost (through α), it is more efficient for the regulator to induce a higher effort from low ability providers because marginal gains from quality are higher.

We now analyse the effect of α (the share of quality due to ability rather than moral hazard) on the allocation of quality and effort and on the transfer. The main result is that higher α decreases effort but may increase reported quality, as measured through the performance indicator.

Proposition 3 *(a)* $\frac{\partial m^{as}}{\partial \alpha} \leq 0$, *(b)* $\frac{\partial q^{as}}{\partial \alpha} \gtrless 0$ *where* $\frac{\partial q^{as}}{\partial \alpha} > 0$ *for* $\theta \to \overline{\theta}$ *and* $\frac{\partial q^{as}}{\partial \alpha} < 0$ *for* $\theta \to \underline{\theta} \to 0$, *(c)* $\frac{\partial t^{as}(\theta)}{\partial \alpha} \gtrless 0$ *with* $\frac{\partial t^{as}}{\partial \alpha} < 0$ *for* $\theta \to \underline{\theta}$.

(a) Higher α induces a lower effort m^{as}. This is because higher α implies a higher quality arising directly from ability, which reduces the marginal benefit of effort m^{as} ($\theta W_{qq} < 0$). A higher α also implies higher marginal information rents, which increases the marginal disutility of effort $\left(-\frac{(1-F)}{f}\psi_{mm} < 0\right)$. For both reasons effort is lower.

(b) The effect of α on reported quality is ambiguous. This is easy to see when considering the identity $\frac{\partial q^{as}}{\partial \alpha} = \theta + \frac{\partial m^{as}}{\partial \alpha}$. On the one hand, a higher α increases quality directly (by definition). On the other hand, a higher α induces a lower effort m^{as} (as stated in part (a)). This notwithstanding, for high ability types, reported quality tends to increase with α. The converse applies at the lower end of ability if the lowest type approaches zero: with higher α it is optimal to distort downwards the effort of low-ability providers even more (to reduce informational rents). In this case, a stronger direct impact of ability on quality (a higher α) tends to widen the quality spread between the highest and lowest ability types. Also, notice that if the disutility function is linear in m ($\psi_{mm} = 0$), then $\frac{\partial q^{as}}{\partial \alpha} = 0$: the increase in reported quality generated by higher ability is completely offset by a reduction in effort.

(c) The effect of an increase in α on the transfer is indeterminate. Interestingly, higher α

reduces effort and disutility $\left(\psi_m \frac{\partial m^{as}}{\partial \alpha} < 0\right)$, but has an indeterminate effect on informational rents $\left(\frac{\partial U^{as}}{\partial \alpha} \lesseqgtr 0\right)$. As informational rents become negligible towards the bottom end of ability, $\theta \to \underline{\theta}$, the disutility effect tends to dominate so that $\frac{\partial t^{as}(\theta)}{\partial \alpha} < 0$ for low types.

The effect of α on the dispersion of quality, effort and transfer, $\left(\frac{\partial^2 q}{\partial\theta\partial\alpha}, \frac{\partial^2 m}{\partial\theta\partial\alpha}, \frac{\partial^2 t}{\partial\theta\partial\alpha}\right)$ are generally indeterminate.

3 Gaming

One concern with performance indicators is that they can be manipulated by providers. While a rational purchaser will anticipate such undertakings on the part of the provider, there is an issue of how performance indicators should be designed. In order to answer this question we extend the model to allow for manipulation. Specifically, we assume that true quality is entirely determined by the provider's effort m.[8] As before, we assume that m is not directly observable by the purchaser. The purchaser rather observes a performance indicator $q = m + r$, where m is the true quality effort m and r is a 'manipulative' effort aimed at biasing the indicator. In principle, manipulations may be upwards or downwards. We therefore do not a priori impose a sign on r. As an example, m may be the true long-term health state of a patient, whereas q is a readmission rate. While q depends (negatively) on the true health, it can be manipulated upwards or downwards.

The provider incurs a disutility $\psi(m, r, \theta)$, which is increasing in quality effort and convex: $\psi_m > 0$, $\min\{\psi_{rr}, \psi_{mm}\} \geq |\psi_{mr}| \geq 0$, $\psi_{mr} \gtrless 0$. As before, more able providers have a lower marginal disutility of effort, $\psi_{m\theta} < 0$, but may have a higher or lower marginal disutility from manipulation, $\psi_{r\theta} \lesseqgtr 0$ ($\psi_{r\theta} < 0$ if more able providers have a lower marginal disutility of manipulation and viceversa). We also assume that any upward or downward manipulation

[8] Hence, we assume $\alpha = 0$. The more complex case $\alpha > 0$, where quality is directly affected by the provider's ability does not substantively alter our findings. The analysis is available from the authors upon request.

is costly for the provider so that $\psi_r(m, 0, \theta) = 0$, which implies $sgn\psi_r(m, r, \theta) = sgn\,(r)$.[9] The utility of the provider is $U(\theta) = t(\theta) - \psi(m, r, \theta)$. Suppose that a provider of type θ seeks to attain a quality target q. The optimal choice of r and m is thus governed by $\underset{r,m}{max}$ $t(\theta) - \psi(m, r, \theta)$ subject to $q = m + r$ or, after substitution $\underset{r}{max}\ t(\theta) - \psi(q - r, r, \theta)$. The FOC is given by

$$r^*(q, \theta) : \ \psi_m(q - r^*, r^*, \theta) = \psi_r(q - r^*, r^*, \theta), \tag{5}$$

with the provider's best response to q denoted by an asterisk.[10] We obtain immediately $m^*(q, \theta) = q - r^*(q, \theta)$. The optimal manipulative effort r^* is chosen such that the marginal cost saved on quality effort equals the marginal cost from manipulative effort. Notice that

$$\frac{\partial r^*(q, \theta)}{\partial q} = \frac{\psi_{mm} - \psi_{mr}}{\psi_{mm} + \psi_{rr} - 2\psi_{mr}} \geq 0 \tag{6}$$

$$\frac{\partial m^*(q, \theta)}{\partial q} = 1 - \frac{\partial r^*(q, \theta)}{\partial q} = \frac{\psi_{rr} - \psi_{mr}}{\psi_{mm} + \psi_{rr} - 2\psi_{mr}} \geq 0. \tag{7}$$

Hence, a more demanding target induces both, greater quality effort and greater manipulative effort. Furthermore, we obtain

$$\frac{\partial m^*(q, \theta)}{\partial \theta} = -\frac{\partial r^*(q, \theta)}{\partial \theta} = \frac{-\psi_{m\theta} + \psi_{r\theta}}{\psi_{mm} + \psi_{rr} - 2\psi_{mr}}. \tag{8}$$

If $\psi_{r\theta} > 0$ (i.e. more able providers have a higher marginal cost of manipulation), then it is certainly the case that for a given quality target more able providers exert more quality effort and less manipulative effort. This result also holds if $\psi_{r\theta} < 0$ (i.e. more able providers have a lower marginal cost of manipulation) as long as $(-\psi_{m\theta}) > (-\psi_{r\theta})$. Otherwise the result is reversed and more able providers exert lower effort. Note that the disutility function $\psi(m^*(q, \theta), r^*(q, \theta), \theta)$ can now be written in terms of q, with

[9] These assumptions are similar to those made in the models of costly falsification cited in the introduction. We extend this work by considering an additional moral hazard dimension, where the non-contractible effort m has a bearing on the true outcome equal to m, the signal, q and possibly the cost of falsification.

[10] The second order condition is $-\psi_{mm} - \psi_{rr} + 2\psi_{mr} < 0$.

$\psi_q = \psi_m \frac{\partial m^*(q,\theta)}{\partial q} + \psi_r \frac{\partial r^*(q,\theta)}{\partial q} = \psi_m > 0$.[11] In the following, we assume

$$\psi_{m\theta}\left(\psi_{rr} - \psi_{mr}\right) + \left(\psi_{mm} - \psi_{mr}\right)\psi_{r\theta} \leq 0 \tag{9}$$

As we show in the proof of lemma 2, this assumption implies $\frac{\partial^2 U}{\partial\theta\partial q} \geq 0$ so that the single-crossing property is satisfied. Clearly if $\psi_{r\theta} < 0$ (more able provider have a lower marginal cost of manipulation), this condition is always satisfied. It is also satisfied if $\psi_{r\theta} > 0$ as long as $-\psi_{m\theta}\left(\psi_{rr} - \psi_{mr}\right) \geq \psi_{r\theta}\left(\psi_{mm} - \psi_{mr}\right)$.

Lemma 2 *The provider's truth-telling constraint is:* $\frac{\partial U}{\partial \theta} = -\psi_\theta \geq 0$ *and* $\frac{\partial q}{\partial \theta} \geq 0$.

The purchaser's maximisation problem is $\max_{q(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} \left[W(m^*(q,\theta)) - t\left(\theta\right)\right] f\left(\theta\right) d\theta$ subject to $t\left(\theta\right) \geq \psi(m^*(q,\theta), r^*(q,\theta), \theta)$ and $\frac{\partial U}{\partial \theta} = -\psi_\theta$. Assume for the moment that the implementability condition $\frac{\partial q}{\partial \theta} \geq 0$ holds. The following proposition describes the optimal separating contract, where $(.)^{as}$ continues to denote optimal values under asymmetric information.

Proposition 4 *The optimal separating contract offered by the purchaser under asymmetry of information satisfies:*

$$q^{as}(\theta) : W_m - \psi_m - \frac{1-F}{f}\left(-\psi_{m\theta}\right) = \left[\psi_r + \frac{1-F}{f}\left(-\psi_{r\theta}\right)\right] \frac{\partial r^*}{\partial q}\left(\frac{\partial m^*}{\partial q}\right)^{-1} \tag{10}$$

$$t^{as}(\theta) = \psi^{as}\left(\theta\right) + U^{as}(\theta) \qquad \textit{with} \tag{11}$$

$$\psi^{as}\left(\theta\right) = \psi(m^*\left(q^{as}\left(\theta\right), \theta\right), r^*\left(q^{as}\left(\theta\right), \theta\right), \theta)$$

$$U^{as}(\theta) = -\int_{\underline{\theta}}^{\theta} \psi_\theta d\widetilde{\theta}$$

The optimal level of the quality target, $q^{as}\left(\theta\right)$, is chosen such that the marginal benefit of quality equals its marginal cost, which is composed of the marginal disutility of effort and the marginal information rent. Here, the LHS of Eq.(10) corresponds to the optimality condition

[11] The second equality follows after substituting from Eqs.(5) and (7).

in the absence of manipulation, when $\alpha = 0$ (see Eq.(3) in Proposition 1). The RHS embraces the additional marginal cost of quality due to manipulation. The latter depends on the mix of additional quality effort and manipulative effort by which the provider responds to an increase in the target and performance as measured by the indicator. This is captured by the term $\frac{\partial r^*}{\partial q}\left(\frac{\partial m^*}{\partial q}\right)^{-1} = \frac{\psi_{mm}-\psi_{mr}}{\psi_{rr}-\psi_{mr}}$. If an increase in the target induces a provider predominantly to boost quality effort (high $\frac{\partial m^*}{\partial q}$ and low $\frac{\partial r^*}{\partial q}$), then the additional cost of manipulation is low. Note from Eqs.(6) and (7) that this is the case if $\psi_{rr} >> \psi_{mm}$. For example if the disutility is linear in quality effort, $\psi_{mm} = \psi_{mr} = 0$, we obtain $\frac{\partial m^*}{\partial q} = 1$ and $\frac{\partial r^*}{\partial q} = 0$: a higher quality target induces higher effort and has no effect on manipulation, so that manipulation does not bear on the marginal cost of quality. The converse is true if the provider seeks to attain the target mostly by way of manipulation. Corollary 1 describes in more detail the impact of manipulation.

Corollary 1 *(a) Manipulation increases the marginal cost of quality by an amount* $\psi_r \frac{\partial r^*}{\partial q}\left(\frac{\partial m^*}{\partial q}\right)^{-1}$. *(b) Manipulation increases (decreases) marginal information rents, and thus the conditional downward distortion in quality effort, if more able providers have a lower (higher) cost of manipulation, i.e. if* $\psi_{r\theta} < 0$ *(*$\psi_{r\theta} > 0$*).*

The purchaser faces the problem that she can control quality effort m only indirectly by adjusting the performance target q. By engaging in manipulation the provider minimises the cost of meeting the target q but thereby exacerbates the cost of quality m. This is because the purchaser can implement m only by setting a target $q > m$, where the provider diverts resources to non-productive manipulation. As manipulation increases the marginal cost of quality beyond the marginal disutility of quality effort, ψ_m, this leads the purchaser to reduce quality.

Manipulation also alters the marginal information rents. Specifically, manipulation boosts marginal rents when more able types find it easier to manipulate the performance target

($\psi_{r\theta} < 0$). This may be the case, for instance, when gaming the system requires 'knowledge' and 'ability'. In this case the purchaser can extract further rent by distorting quality targets downwards beyond the distortion in the absence of manipulation. By reducing the quality targets the purchaser lowers the interest of manipulation and, thereby, deprives the more able providers of some of the rent they obtain from their advantage in gaming the system.

In contrast, it may be the case that able types find it more costly to engage in manipulation, i.e. $\psi_{r\theta} > 0$. For instance, θ may be a measure of motivation rather than skill and motivated agents suffer a higher disutility from gaming the system. Alternatively, able providers may have a greater reputation to lose when engaging in manipulation. In these instances, the purchaser will curtail the downward distortion. The comparative statics with respect to q^{as} are complex and generally ambiguous due to the interaction of a number of third order effects, which are unamenable to economic interpretation. This rules out any intuitive statement about the conditions under which the implementability condition $\frac{dq^{as}}{d\theta} \geq 0$ is satisfied. In the next section we impose more structure on the problem in order to gain some additional insights.

3.1 Implementability and comparative statics with a quadratic disutility

In the following, we assume that the disutility (cost) of effort takes the quadratic form

$$\psi = (\gamma - \theta)\frac{m^2}{2} + \beta\frac{r^2}{2}, \quad \gamma \geq \overline{\theta};\ \beta \geq 0. \tag{12}$$

As is readily checked, this specification satisfies the properties stated above. Note that $\psi_{r\theta} = 0$ for this specification, which implies that the cost of manipulation is independent of ability. It is readily checked that $m^*(q, \theta, \beta) = \frac{q\beta}{\beta+\gamma-\theta}$ and $r^*(q, \theta, \beta) = \frac{q(\gamma-\theta)}{\beta+\gamma-\theta}$. Thus $\frac{\partial m^*}{\partial q} = \frac{\beta}{\beta+\gamma-\theta} = \frac{m^*}{q}$, $\frac{\partial m^*}{\partial \theta} = \frac{q\beta}{(\beta+\gamma-\theta)^2}$ and $\frac{\partial m^*}{\partial \beta} = \frac{q(\gamma-\theta)}{(\beta+\gamma-\theta)^2}$. Note that for the cost function in (12) quality effort m^* is now unambiguously increasing in ability θ. The FOC for the quality target can then be written as[12]

$$W_m(m^*\left(q^{as},\theta,\beta\right)) - \left[\left(\gamma-\theta\right)q^{as} + \frac{1-F}{f}m^*\left(q^{as},\theta,\beta\right)\right] = 0 \tag{13}$$

and implementability requires

$$\frac{dq^{as}}{d\theta} = -\frac{\left(W_{mm} - \frac{1-F}{f}\right)\frac{\partial m^*}{\partial\theta} + q^{as} - \left(\frac{1-F}{f}\right)' m^*}{\left(W_{mm} - \frac{1-F}{f}\right)\frac{\partial m^*}{\partial q} - \left(\gamma-\theta\right)} \geq 0. \tag{14}$$

The denominator is negative from the SOC, which is always satisfied. Implementability then implies that the numerator be non-negative. The second and third terms of the numerator are positive. However, implementability is not guaranteed as the first term is always non-positive. The following proposition shows that implementability is generally satisfied if manipulation is sufficiently costly.

Proposition 5 *A sufficient condition for a fully separating contract, i.e. for* $\frac{dq^{as}}{d\theta} \geq 0$, *is that manipulation is sufficiently costly, i.e. that* β *is sufficiently large.*

A fully separating contract is implementable if a high cost of manipulation leads to a high level of quality effort m^* for all types.[13] In this case $\frac{\partial m^*}{\partial\theta}$ becomes small, implying that providers do not vary much in the mix of quality effort and manipulation by which they seek to attain *a given target*. In particular, this rules out a situation where, for a given target, providers with higher ability exert so much more quality effort that the purchaser would rather adjust quality targets downward for these providers. We come back to this issue when discussing non-responsiveness at the beginning of section 3.2.

[12] Rearranging Eq.(10) we obtain $W_m\frac{\partial m^*}{\partial q} - \psi_m\frac{\partial m^*}{\partial q} - \psi_r\frac{\partial r^*}{\partial q} - \frac{1-F}{f}\left(-\psi_{m\theta}\frac{\partial m^*}{\partial q} - \psi_{r\theta}\frac{\partial r^*}{\partial q}\right) = 0$. Observing $\psi_m = \psi_r$, $\frac{\partial r^*}{\partial q} = 1 - \frac{\partial m^*}{\partial q}$ and $\frac{\partial m^*}{\partial q} = \frac{m^*}{q}$; inserting the appropriate derivatives from Eq.(12); and dividing through by $\frac{m^*}{q}$ we obtain the subsequent expression.

[13] We should stress that the condition is sufficient. For a uniform distribution of types and a quadratic specification of W, as assumed in the example below, we can show that the separating contract is implementable both for high *and* low β (see Lemma 3 and Figure 1).

For the moment, suppose that implementability is satisfied. It is readily checked that this implies $\frac{dt^{as}}{d\theta} = \psi_m \frac{dq^{as}}{d\theta} > 0$ and $\frac{dm^*}{d\theta} = \frac{\partial m^*}{\partial \theta} + \frac{\partial m^*}{\partial q}\frac{dq^{as}}{d\theta} > 0$. More able providers exert greater quality effort, both as they are prone to provide more effort for a given target (the first term) and as they are set higher targets (the second term).

Consider now the comparative statics with respect to β, a parameter positively related to the (marginal) cost of engaging in manipulation.

Proposition 6 *The comparative static properties for the fully separating contract are given by (a)* $\frac{dq^{as}}{d\beta} < 0$; *(b)* $\frac{dm^*}{d\beta} = \frac{\partial m^*}{\partial \beta} + \frac{\partial m^*}{\partial q}\frac{dq^{as}}{d\beta} > 0$; *(c)* $\frac{dt^{as}}{d\beta} = \psi_\beta + \psi_m \frac{dq^{as}}{d\beta} + U_\beta \lesseqgtr 0$, *where* $\psi_\beta + \psi_m \frac{dq^{as}}{d\beta} > 0$ *if* $W_{mm} = 0$ *and* $\theta \to \overline{\theta}$, *and where* $U_\beta > 0$.

Thus, a lower marginal cost of manipulation leads to an increase in quality targets q^{as} (and performance according to the indicator) but to a reduction in quality effort m^*. In principle the purchaser could offset any degree of (imperfect) manipulation by setting more demanding quality targets q^{as}. However, we have argued above that manipulation tends to exacerbate the marginal cost of quality, m^*. This implies that the purchaser is prepared to settle for lower levels of m^* when the scope for manipulation increases. Thus targets are adjusted upwards in response to greater manipulation but only imperfectly so.

The marginal cost of manipulation has an ambiguous impact on transfers. First, a lower marginal cost of manipulation tends to reduce rents. Note that a provider's rent amounts to the (cumulative) cost advantage of exerting quality effort m. For the convex cost function (12) the advantage increases in the level of m. But then as a lower marginal cost of manipulation induces all providers to engage in more manipulation and cut back on true quality effort, this also curbs the cost advantage held by the more able providers and thus their rents. Second, the impact of manipulation on the cost of effort is ambiguous. On the one hand, a lower cost of manipulation is associated with lower cost throughout, thus pushing towards lower transfers. On the other hand, the increase in quality targets leads to a higher effort cost.

The net effect on cost of manipulation is thus indeterminate. When the benefit of quality is not too concave and/or when ability is sufficiently high, then a lower marginal cost of manipulation leads to a reduction in overall cost. In this case, transfers tend to decrease.

3.2 Non-responsiveness and pooling

We turn now to the case in which full separation is not optimal from the purchaser's point of view. Such a case is known as non-responsiveness (Guesnerie and Laffont 1984), where $\frac{dq^{as}}{d\theta} < 0$ holds for a range of $\theta \in \left[\underline{\theta}, \overline{\theta}\right]$. For the cost specification in Eq.(12) this is the case if the inequality in Eq.(14) is reversed. As $W_{mm} - \frac{1-F}{f} < 0$, this is possible if $\frac{\partial m^*}{\partial \theta} > 0$ sufficiently strong. There are two channels through which non-responsiveness may arise.[14]

The first relates to the concavity of the purchaser's/patient's benefit, i.e. to $W_{mm} < 0$. As more able types tend to provide greater quality effort for any given target, it would thus be optimal in the absence of adverse selection to reduce the target with ability. The conflict with incentive compatibility causes non-responsiveness. The underlying cause is a common value problem, where the purchaser's/patients' benefit W depends directly on the agent's type and not just via the contracting variable. Although the purchaser can control the agent's quality effort $m^* (q, \theta)$ indirectly by setting a contractible target q, she cannot control the *direct* effect of θ on m. For a given target, quality effort and thus the purchaser's benefit continue to vary with θ : a common value problem.

Note that, although m is a moral hazard variable, a common value problem does not arise in the absence of manipulation ($r \equiv 0$). By writing a contract on the signal q the principal can fully control m. The effect of θ on q and m is then identical. But with manipulation a contract on q is no longer equivalent to a contract on m. This is because the agent gains a

[14]Notice that non-responsiveness arises despite the regular monotone hazard-rate assumption. It is more closely related to the non-responsiveness discussed e.g. in Lewis and Sappington (1988), Guesnerie and Laffont (1984) and Laffont and Martimort (2001), p.53-55.

degree of freedom on whether to attain a target q by way of providing quality m or by way of manipulation r. Hence, non-responsiveness is really caused by the interaction of quality effort and manipulation, which cannot be disentangled by the contract.[15]

The second channel through which non-responsiveness may arise relates to a conflict between rent extraction and incentive compatibility. From Eq.(13) we find $\frac{1-F}{f}m^*$ as an expression for the marginal information rent. We then obtain $\frac{\partial}{\partial\theta}\left(\frac{1-F}{f}m^*\right) = \left(\frac{1-F}{f}\right)' m^* + \frac{1-F}{f}\frac{\partial m^*}{\partial\theta}$, implying that the *marginal* rent decreases with the inverse hazard rate (the first term), but increases in quality effort and therefore in ability (the second term). If the latter effect dominates, then the marginal rent increases in ability for a certain interval of types. For reasons of rent extraction, the purchaser may then seek to set lower quality targets for providers with higher ability.[16] As this would violate incentive compatibility, non-responsiveness arises.

Again, it is difficult to obtain general conditions for non-responsiveness and to arrive at a general characterisation of the pooling solution. We, therefore, consider an example to illustrate under which conditions with regard to the parameter β non-responsiveness may occur and how the associated pooling allocation may look like.

3.2.1 Pooling with quadratic benefit function and uniform distribution

Assume in addition to the cost function (12) a benefit function

$$W(m) = am - (b/2)m^2,$$

[15] Note that under a monotone hazard rate condition, non-responsiveness does not arise in the models of costly falsification referenced earlier. This is because in these models manipulation constitutes a single moral hazard variable, akin to models in which productive effort constitutes a single moral hazard variable. The problem in our model which may generate non-responsiveness is the interaction of two effort variables.

[16] This provides, of course, that increasing marginal rents lead to a cost of quality (overall) that increases in ability.

where a and b are positive parameters. Assume also a uniform distribution of θ on $[0,1]$. It is readily verified that $q^{as} = a\left[(\gamma-\theta)+(b+1-\theta)\frac{\beta}{(\beta+\gamma-\theta)}\right]^{-1}$. Define

$$\theta^N(\beta) := \arg\max q^{as}(\theta) = \beta+\gamma-\sqrt{\beta(b+1-\beta-\gamma)},$$

which is readily checked to be a strictly convex function. The following lemma establishes that $\theta^N(\beta)$ is a lower bound for the interval on which non-responsiveness occurs and the conditions under which $\theta^N(\beta)$ is below the maximum ability ($\theta = 1$).

Lemma 3 *Non-responsiveness occurs if and only if (i)* $b \geq \left(3+2\sqrt{2}\right)(\gamma-1)$;[17] *(ii)* $\beta \in \left[\underline{\beta},\overline{\beta}\right]$, *with* $0<\underline{\beta}<\overline{\beta}<\infty$, *and (iii)* $\theta \in \left[\theta^N(\beta),1\right]$.

According to conditions (i) and (ii) non-responsiveness arises for a uniform distribution only if the benefit function $W(m)$ is sufficiently concave and only if the parameter β takes on an intermediate value, such that $\beta \in \left[\underline{\beta},\overline{\beta}\right]$.[18] Only then will the lower bound for non-responsiveness $\theta^N(\beta)$ lie below the maximum ability so that non-responsiveness and pooling occur at the top end of the ability distribution. Figure 1 illustrates.

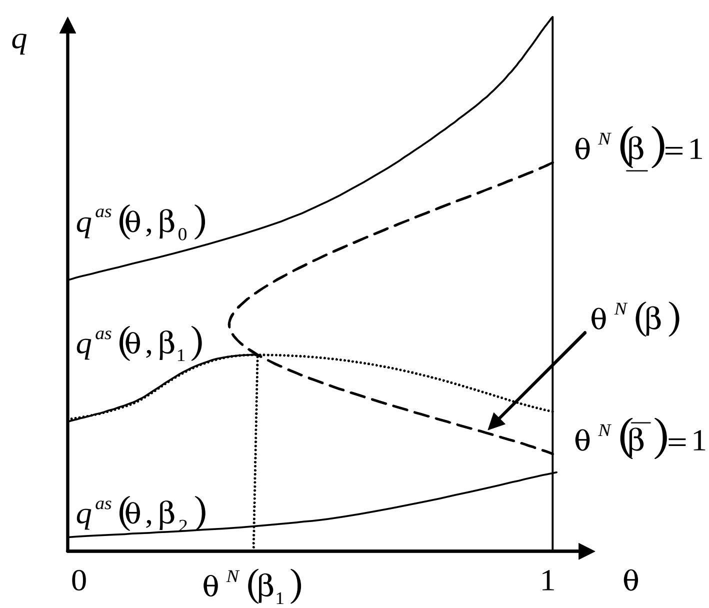

Figure 1

[17] Recall from Eq.(12) that we assume $\gamma \geq \overline{\theta}$. Hence, $\gamma \geq 1$.

[18] More specifically, condition (i) is neccessary for the existence of a non-empty interval $\left[\underline{\beta},\overline{\beta}\right]$.

The figure plots the quality target $q^{as}(\theta,\beta)$ for three exemplary levels of the cost parameter, β_0, β_1 and β_2. These are chosen such that $\beta_0 < \underline{\beta} < \beta_1 < \overline{\beta} < \beta_2$.[19] As $\frac{dq^{as}}{d\beta} < 0$ (see (a) in Proposition 6), we have $q^{as}(\theta,\beta_0) > q^{as}(\theta,\beta_1) > q^{as}(\theta,\beta_2)$. The $\theta^N(\beta)$ schedule defines the locus for which $\frac{dq^{as}(\theta,\beta)}{d\theta} = 0$ obtains as a unique local maximum.[20] Hence, any $q^{as}(\theta,\beta)$-schedule that crosses $\theta^N(\beta)$ will be strictly falling for $\theta > \theta^N(\beta)$, implying non-responsiveness. By their definition, $\theta^N(\underline{\beta}) = \theta^N(\overline{\beta}) = 1$. Thus, for a low marginal cost of manipulation, $\beta = \beta_0 \leq \underline{\beta}$, and for a high marginal cost of manipulation, $\beta = \beta_2 \geq \overline{\beta}$, the contract is fully separating. This is because in either of these cases, $\frac{\partial m^*}{\partial\theta}$ will be small. In contrast, for an intermediate cost, $\beta = \beta_1 \in (\underline{\beta},\overline{\beta})$, non-responsiveness arises for all $\theta \geq \theta^N(\beta_1)$.

The pooling solution can be derived following Guesnerie and Laffont (1984: Theorem 3 and Corollary 3.1). Continuing to denote by $q^{as}(\theta)$ the optimal target under adverse selection, when *disregarding* the *implementability* constraint, recall that $\theta^N = \arg\max q^{as}(\theta)$ corresponds to a single peak in the $q^{as}(\theta)$ schedule. Assuming that $\theta^N \leq 1$, we obtain two possible cases. If θ^N is close to one then the interval over which $\frac{dq^{as}}{d\theta} \leq 0$ holds is not too large. It is then true that $q^{as}(0) \leq q^{as}(1)$. The proposition focuses on this case.[21] Alternatively, if θ^N is close to zero or below zero, then we obtain $q^{as}(0) > q^{as}(1)$, a case on which we comment at the end of this section.

Proposition 7 *For $q^{as}(0) \leq q^{as}(1)$, we obtain pooling on the interval $\theta \in [\theta^P, 1]$, with*

[19] Note that for the functional forms assumed quality q^{as} is bounded from above by $\lim_{\beta\to 0} q^{as} = a(\gamma-\theta)^{-1}$ and from below by $\lim_{\beta\to\infty} q^{as} = a(\gamma+b+1-2\theta)^{-1}$.

[20] In order to understand its location in Figure 1, we note that due to the monotonic relationship $\frac{dq^{as}}{d\beta} < 0$ $\forall\theta$, the convex function $\theta^N(\beta)$ (see proof of Lemma 3) translates into a quasi-convex function $\widehat{\theta}^N(q^{as})$ with $\frac{d\widehat{\theta}^N}{dq^{as}} = \theta^N_\beta \left(\frac{dq^{as}}{d\beta}\right)^{-1}$.

[21] This case obtains if the benefit function is not too concave, i.e if b is close to its boundary value $(3+2\sqrt{2})(\gamma-1)$, or if β is close to either $\underline{\beta}$ or $\overline{\beta}$.

$\theta^P \in (0, \theta^N)$, *where*

$$\theta^P : \int_{\theta^P}^{1} \left[W_m(m^* (q^P, \theta, \beta)) - (\gamma - \theta) q^P - (1 - \theta) m^* (q^P, \theta, \beta)\right] \frac{m^* (q^P, \theta, \beta)}{q^P} d\theta = 0$$

$$q^P = q^{as} (\theta^P)$$

$$t^P = t^{as} (\theta^P) = \psi (m^* (q^P, \theta^P, \beta), r^* (q^P, \theta^P, \beta), \theta^P).$$

Figure 2 presents a graphical outline of the pooling solution.

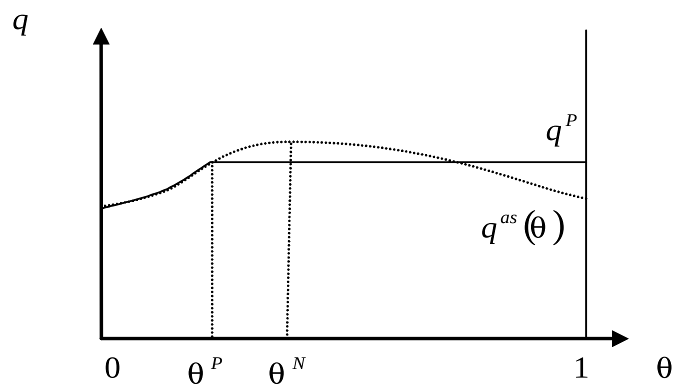

Figure 2

When pooling arises, the quality target q^P and transfer t^P are no longer varied across types. However, since $\frac{dm^*}{d\theta} = \frac{\partial m^*}{\partial \theta} > 0$ holds in a situation of pooling, true quality still increases with type. Quality differences tend to be compressed under pooling, nevertheless, as higher types no longer receive additional incentives through more demanding targets. The pooling quality target q^P is equal to the quality target, $q^{as}(\theta^P)$, that is optimally assigned to the type θ^P at the boundary between separation and pooling. The boundary θ^P is then chosen in such a way that the corresponding quality target $q^P = q^{as}(\theta^P)$ balances out the distortions that arise for each type $\theta \in [\theta^P, 1]$ due to the deviation from $q^{as}(\theta)$.

Similar to Guesnerie and Laffont (1984) a pooling allocation, therefore, involves a certain amount of smoothing in the sense that pooling occurs even for types on the interval $[\theta^P, \theta^N]$, for which a separating contract would still be implementable. In principle, the purchaser would like to minimise the pooling range by setting $\theta^P = \theta^N$. However, the pooling quality target would then exceed the average of the targets that should be allocated to the pooled types, i.e. $q^P = q^{as}\left(\theta^N\right) > \int_{\theta^N}^{1} q^{as}\left(\theta\right) d\theta \left(1-\theta^N\right)^{-1}$. The purchaser therefore increases the pooling range in order to bring better into line q^P with the average $q^{as}\left(\theta\right)$ across the pooled types. For completeness, we should note that $q^{as}\left(0\right) > q^{as}\left(1\right)$ cannot be ruled out.[22] Such a case may give rise to $\theta^P = 0$, where the purchaser pools all types of providers.

3.2.2 Policy implications

We conclude this section by observing that the scope for pooling across certain ranges of ability has a simple policy implication. The pooling level of the indicator $q^P = q^{as}\left(\theta^P\right)$ can be interpreted in two ways:

(i) as a quality threshold, over which the incentive scheme is flat. Therefore, the incentive scheme $t^{as}(q^{as})$ is increasing in reported quality q^{as} for providers with lower ability $\left[\theta, \theta^P\right]$ and it is constant at $t^{as}(q^P)$ when reported quality is above or equal to q^P and providers have higher ability $\left[\theta^P, 1\right]$. The solution is consistent with some incentive schemes observed in the health-care sector. For example general practitioners in the UK are rewarded on the basis of the proportion of patients affected by ischemic heart disease that have their blood pressure measure every 15 months. However there is no extra financial reward if they review more than 70% of the patients affected by this condition (Doran et al., 2006).

(ii) as a minimum quality standard (MQS). This is obvious in the case of pooling across all types, where $\theta^P = 0$. The MQS is set at $q^P = q^{as}\left(0\right)$ and a uniform amount $t^{as}\left(0\right)$ is reimbursed only if the provider meets the MQS. The case of partial pooling with $\theta^P > 0$ can be interpreted as a MQS with a monetary penalty for noncompliance. Providers who meet the MQS receive the transfer $t^{as}\left(\theta^P\right)$. Providers who fail to meet the MQS are fined according

[22] It is readily checked that we obtain $\theta^N\left(\beta\right) \leq 0$ for b sufficiently large and a suitably chosen β. As $\theta^N\left(\beta\right) := \arg\max q^{as}\left(\theta\right)$, this obviously implies $q^{as}\left(0\right) \geq q^{as}\left(\theta\right) \geq q^{as}\left(1\right)$ leading to pooling across all types.

to the short-fall in quality, with the fine given by $\Pi\left(q^P - q^{as}(\theta)\right) = t^{as}\left(q^{as}(\theta)\right) - t^{as}\left(q^P\right).$ Thus less able types fail to meet the standard and are fined accordingly. Nevertheless, this is optimal both from the provider's and purchaser's perspective.

Policy developments within the English NHS point to an increasing reliance on quality standards (Department of Health, 2004). MQS, labelled 'core standards' in the NHS context, are already employed in a number of areas, e.g. nursing care, domiciliary care or independent provision of care. Stated policy goals point at a widening of the approach to all areas of health care and, indeed, to the increasing use of financial incentives linked to these standards. At the same time, there is an increasing drive towards performance related payments. Prima facie it is then unclear as to what might be the role for a uniform MQS in a world where quality incentives can be targeted at individual providers by way of performance pay. By highlighting the scope for pooling outcomes, our analysis can provide a justification for MQS.

4 Inequality aversion

We extend the previous analysis to include inequality aversion. To keep the analysis simple, we assume that $\alpha = 0$, so that $q = m$. Following Fleurbaey, Gary-Bobo and Maguain (2002), we assume that the benefit of the purchaser when patients receive care from provider θ takes the form: $\Phi(W) = \frac{W(m(\theta))^{1-\rho}}{1-\rho}$ for $\rho \neq 1$ and $\log(m)$ if $\rho = 1$, where ρ is an index of social aversion to inequality in the provision of quality. If $\rho = 0$ we obtain the utilitarian welfare function. If $\rho > 0$, some inequality aversion is present. An infinite degree of aversion corresponds to the Rawlsian maximin (min $W(m(\theta))$).[23] The marginal benefit for the purchaser from an increase in the utility of the patient (W) is $\Phi_W(W) = \frac{1}{W^\rho}$. Figure 3 represents different marginal benefit curves for different values of ρ that vary between zero

[23] ρ can be interpreted as a measure of constant relative risk aversion. See also Wagstaff (1991) for an application to health care.

and two. For $\rho = 0$, the marginal benefit is constant and equal to one. For $\rho > 0$, the marginal benefit is larger than one if $W < 1$ and it is lower than one if $W > 1$. If $\rho = 0$, we obtain a utilitarian welfare function: the purchaser attaches the same value to the utility of different patients. If $\rho > 0$, the purchaser attaches a higher value to patients with low utility (i.e. $W < 1$) and a lower value to patients with higher utility (i.e. $W > 1$).

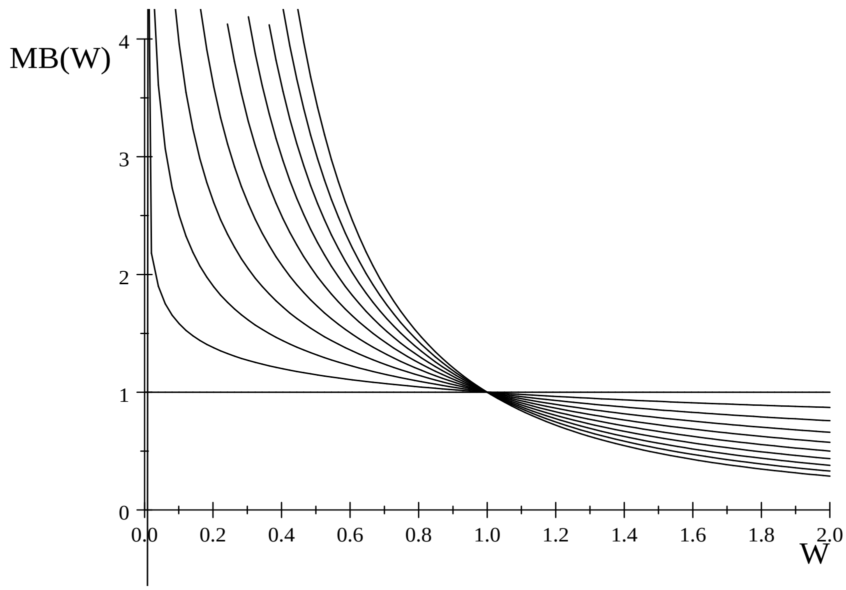

Figure 3

The purchaser's maximisation problem is:

$$\max_{m(\theta)} \int_{\underline{\theta}}^{\overline{\theta}} \left[\frac{W(m(\theta))^{1-\rho}}{1-\rho} - t(\theta) \right] dF(\theta) \tag{15}$$

Given that $\alpha = 0$, the provider's truth-telling constraints requires $\frac{\partial U}{\partial \theta} = -\psi_\theta > 0$.

Proposition 8 *The optimal contract offered by the purchaser under asymmetry of information satisfies:*

$$m^{as}(\theta) : \; W_m W(m^{as}(\theta))^{-\rho} = \psi_m(m^{as}(\theta), \theta) - \frac{1 - F(\theta)}{f(\theta)} \psi_{\theta m} \tag{16}$$

$$t^{as}(\theta) = \psi(m^{as}(\theta), \theta) + U^{as}(\theta) = \psi(m^{as}(\theta), \theta) + \int_{\underline{\theta}}^{\theta} -\psi_\theta d\widetilde{\theta} \tag{17}$$

Eq.(16) suggests that the optimal level of quality m is found where the marginal benefit from higher quality equals the marginal cost of quality. Notice that if the benefit for the patients is low ($W < 1$), then higher inequality ρ implies a higher marginal benefit from quality. On the contrary if benefit is low ($W > 1$), then it implies a lower marginal benefit of quality. The optimal transfer (Eq.17) is simply equal to the sum of the disutility and the informational rent, with $\frac{\partial t^{as}}{\partial \theta} = \psi_m \frac{\partial m^{as}}{\partial \theta} > 0$.[24]

The following proposition describes the effect of ρ on the quality effort and the transfer.

Proposition 9 *An increase in inequality aversion has the following effects: (a)* $\frac{\partial m^{as}}{\partial \rho} > 0$ *if* $W < 1$*;* $\frac{\partial m^{as}}{\partial \rho} < 0$ *if* $W > 1$*; (b)* $\frac{\partial(\partial m^{as}/\partial \theta)}{\partial \rho} < 0$ *if* $W < 1$*;* $\frac{\partial(\partial m^{as}/\partial \theta)}{\partial \rho} \gtrless 0$ *if* $W > 1$*; (c)* $sign \frac{\partial t^{as}(\theta)}{\partial \rho} = sign \frac{\partial m^{as}}{\partial \rho}$*; (d)* $\frac{\partial(\partial t^{as}/\partial \theta)}{\partial \rho} \gtrless 0$.

(a) Higher inequality aversion implies a higher quality effort if $W(m) < 1$. Intuitively, if quality is low, higher aversion implies a higher marginal benefit from quality. Similarly, higher inequality aversion implies lower quality if $W(m) > 1$. If quality is high, higher aversion implies a lower marginal benefit from quality. The case with $W(m) < 1$ seems the more realistic scenario within the health care context. Indeed policy makers introduce performance indicators precisely because the perceived quality is low.

(b) If quality is low (meaning $W(m) < 1$), then an increase in inequality aversion reduces dispersion ($\frac{\partial(\partial m/\partial \theta)}{\partial \rho} < 0$). If quality is high ($W(m) > 1$), then the effect is indeterminate.

(c) $\frac{\partial t(\theta)}{\partial \rho}$ has the same sign as $\frac{\partial m^{as}}{\partial \rho}$. If higher inequality aversion increases (decreases) quality, then the transfer increases (decreases) as well: this arises because both, disutility of effort and information rent increase in quality.

[24] Compared to the analysis on education of Fleurbaey, Gary-Bobo and Maguain (2002), our analysis with inequality aversion is surprisingly simple. This arises because the transfer to the provider does not enter the function with the inequality aversion parameter.

(d) The effect of inequality aversion on the slope of the transfer is indeterminate. Notice that $\frac{\partial(\partial t^{as}/\partial\theta)}{\partial\rho} = \psi_m \frac{\partial m^2}{\partial\theta\partial\rho} + \frac{\partial m^{as}}{\partial\theta}\psi_{mm}\frac{\partial m}{\partial\rho}$. We know that if $\frac{\partial m}{\partial\rho} > 0$, then $\frac{\partial m^2}{\partial\theta\partial\rho} < 0$. Since higher inequality aversion reduces the slope of $\frac{\partial m}{\partial\theta}$, it also reduces the slope of the transfer $\left(\psi_m \frac{\partial m^2}{\partial\theta\partial\rho} < 0\right)$. However, since the marginal disutility is increasing, the transfer tends to be steeper $\left(\frac{\partial m^{as}}{\partial\theta}\psi_{mm}\frac{\partial m}{\partial\rho} > 0\right)$. Overall, the effect is indeterminate. Notice that if marginal disutility is constant, then the transfer is less steep.

In summary, the main result of this section is that, if quality is low enough to generate $W < 1$, higher inequality aversion implies higher quality, lower dispersion in quality, a higher transfer and an indeterminate effect on the slope of the transfer.

5 Conclusions

We have studied the scope for quality related pay within an adverse selection model, where providers of health care or another public service differ in their ability to supply quality. We derive the optimal contract, which determines the optimal level of quality and the associated transfer. The main results are the following. First, if ability has a strong direct impact on quality rather than through the cost of provision alone, distortions due to informational rents are higher and quality effort is lower so that the effect on transfers is indeterminate. Interestingly, it is possible that more able providers exert lower quality effort. Second, if patients receive a low benefit from health care because the quality of care is low, higher inequality aversion increases the optimal level of quality and the associated transfer, and reduces quality dispersion across providers. Third, gaming or misreporting reduces the optimal level of quality effort but generally increases the optimal level of reported quality. The idea is that the purchaser could always take into account the effect of gaming by adjusting upwards the performance targets. If manipulation was costless, the same allocation could then be implemented as in the absence of manipulation. The problem is that manipulation usually wastes resources and, therefore, imposes an additional cost on the provision of quality. It is for this reason that the power of incentives is muted. We also find that if more able providers engage in significantly less manipulation, pooling across the high-ability types may turn out to be optimal, where providers receive the same transfer if the performance is above a certain quality threshold. We provide policy examples for such an outcome and argue that the presence of pooling can be understood as a justification for minimum quality standards, in combinations with fines for underachievement.

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6 Appendix

Lemma 1. Suppose type θ seeks to mimic type $\widehat{\theta}$. Then, a provider of type θ needs to choose $q(\theta) = q\left(\widehat{\theta}\right)$ and receives utility $U(\theta, \widehat{\theta}) = t\left(\widehat{\theta}\right) - \psi(q\left(\widehat{\theta}\right) - \alpha\theta, \theta)$. Truthful reporting requires $\frac{\partial U(\theta,\widehat{\theta})}{\partial \widehat{\theta}} = 0$ or $\frac{\partial t(\widehat{\theta})}{\partial \widehat{\theta}} = \psi_m \frac{\partial q(\widehat{\theta})}{\partial \widehat{\theta}}$. Recall that $U(\theta) = t(\theta) - \psi(q(\theta) - \alpha\theta, \theta)$ with $\frac{\partial U(\theta)}{\partial \theta} = \frac{\partial t(\theta)}{\partial \theta} - \psi_\theta - \psi_m \frac{\partial q(\theta)}{\partial \theta} + \alpha\psi_m$. Substituting $\frac{\partial t(\theta)}{\partial \theta} = \psi_m \frac{\partial q(\theta)}{\partial \theta}$, we obtain $\frac{\partial U(\theta)}{\partial \theta} = -\psi_\theta + \alpha\psi_m$. Implementability requires $\frac{\partial^2 U(\theta)}{\partial\theta\partial q}\frac{\partial q}{\partial \theta} = (-\psi_{\theta m} + \alpha\psi_{mm})\frac{\partial q}{\partial \theta} \geq 0$. Since $-\psi_{\theta m} + \alpha\psi_{mm} > 0$ this requires $\frac{\partial q}{\partial \theta} \geq 0$. ■

Proposition 1. (a) Optimal control techniques can be used to find the optimal solution (see Leonard and van Long, 1992, 127-129). The associated Hamiltonian is: $H = [W(q) - \psi(q - \alpha\theta, \theta) - U(\theta)] f(\theta) + \pi(\theta)(-\psi_\theta + \alpha\psi_m)$, where $\pi(\theta)$ is the costate variable. Integrating $\dot{\pi} = -\frac{\partial H}{\partial U} = f(\theta)$ over the interval $[\theta, \overline{\theta}]$ we obtain $\pi\left(\overline{\theta}\right) - \pi(\theta) = F(\overline{\theta}) - F(\theta)$ where $F(\overline{\theta}) = 1$ and $\pi(\overline{\theta}) = 0$ (since the boundary $\theta = \overline{\theta}$ is unconstrained). Therefore, $\pi^{as}(\theta) = -(1 - F(\theta)) < 0$. The Second Order Condition is $H_{qq} = (W_{qq} - \psi_{mm}) f(\theta) - (1 - F(\theta))(-\psi_{\theta mm} + \alpha\psi_{mmm}) < 0$. We make the technical assumption: $-\psi_{\theta mm} + \alpha\psi_{mmm} \geq 0$ to ensure the global concavity of the problem. (b) The implementability condition is:

$\frac{\partial q^{as}}{\partial \theta} = \frac{(-\psi_{m\theta}+\alpha\psi_{mm})\left(1-\left(\frac{1-F}{f}\right)'\right)+\frac{1-F(\theta)}{f(\theta)}(\psi_{\theta\theta m}+\alpha^2\psi_{mmm}-2\alpha\psi_{\theta mm})}{-H_{qq}/f(\theta)} \geq 0$. Notice that the first part of the numerator is always positive. Therefore, $\psi_{\theta\theta m} + \alpha^2\psi_{mmm} - 2\alpha\psi_{\theta mm} \geq 0$ is a sufficient condition for $\frac{\partial q^{as}}{\partial \theta} \geq 0$ being satisfied.[25] ■

Proposition 2. (a) $\frac{\partial t^{as}}{\partial \theta} = \psi_m \frac{\partial m^{as}}{\partial \theta} + \psi_\theta - \psi_\theta + \alpha\psi_m = \psi_m \left(\frac{\partial m^{as}}{\partial \theta} + \alpha\right) = \psi_m \frac{\partial q^{as}}{\partial \theta} \geq 0$ (see also proof of Lemma 1). (b) $\frac{dm^{as}}{d\theta} = \frac{\partial q^{as}}{\partial \theta} - \alpha$. By substitution,

$$\frac{\partial m^{as}}{\partial \theta} = \frac{\alpha\left[W_{qq}-\left(\frac{1-F}{f}\right)'\psi_{mm}-\frac{1-F(\theta)}{f(\theta)}\psi_{mm\theta}\right]-\psi_{m\theta}\left(1-\left(\frac{1-F}{f}\right)'\right)+\frac{1-F(\theta)}{f(\theta)}\psi_{m\theta\theta}}{(-H_{qq})/f(\theta)} \lesseqgtr 0$$

Consider the square brackets in the numerator. Here, the first term is negative while the second is positive. The third term is ambiguous. ■

Proposition 3. (a) $\frac{\partial m^{as}}{\partial \alpha} = \frac{\theta W_{qq}-\frac{1-F(\theta)}{f(\theta)}\psi_{mm}}{-H_{qq}} \leq 0$;

(b) $\frac{\partial q^{as}}{\partial \alpha} = \theta + \frac{\partial m^{as}}{\partial \alpha} = \frac{\psi_{mm}\left(\theta-\frac{1-F(\theta)}{f(\theta)}\right)-\frac{1-F(\theta)}{f(\theta)}\theta(\psi_{\theta mm}-\alpha\psi_{mmm})}{-H_{qq}/f(\theta)} \gtrless 0$; which is positive if $\theta\psi_{mm} > \frac{1-F(\theta)}{f(\theta)}(\theta\psi_{\theta mm} - \theta\alpha\psi_{mmm} + \psi_{mm})$. The last inequality is satisfied as $\lim_{\theta\to\overline{\theta}} \frac{1-F(\theta)}{f(\theta)} = 0$ but fails as $\theta \to \underline{\theta} \to 0$. (c) $\frac{\partial t(\theta)}{\partial \alpha} = \psi_m \frac{\partial m^{as}}{\partial \alpha} + \int_{\underline{\theta}}^{\theta} \left[\psi_m + (-\psi_{\theta m} + \alpha\psi_{mm}) \frac{\partial m^{as}}{\partial \alpha}\right] d\widetilde{\theta} \lesseqgtr 0$. ■

Lemma 2. Suppose type θ seeks to mimic $\widehat{\theta}$. Then, θ needs to satisfy $q(\theta) = q\left(\widehat{\theta}\right)$ and type θ attains utility: $U\left(\theta, \widehat{\theta}\right) = t\left(\widehat{\theta}\right) - \psi(m^*(q\left(\widehat{\theta}\right), \theta), r^*(q\left(\widehat{\theta}\right), \theta), \theta)$. Truthful reporting requires $\frac{\partial t(\widehat{\theta})}{\partial \widehat{\theta}} = \psi_m \frac{\partial m^*}{\partial q}\frac{\partial q(\widehat{\theta})}{\partial \widehat{\theta}} + \psi_r \frac{\partial r^*}{\partial q}\frac{\partial q(\widehat{\theta})}{\partial \widehat{\theta}}$. Recall that $U(\theta) = t(\theta) - \psi(m^*(q(\theta), \theta), r^*(q(\theta), \theta), \theta)$, with $\frac{\partial U}{\partial \theta} = \frac{\partial t}{\partial \theta} - \psi_\theta - \psi_m \frac{\partial m^*}{\partial q}\frac{\partial q(\theta)}{\partial \theta} - \psi_r \frac{\partial r^*}{\partial q}\frac{\partial q(\theta)}{\partial \theta} - \psi_m \frac{\partial m^*}{\partial \theta} - \psi_r \frac{\partial r^*}{\partial \theta}$. Observing Eq.(5) and Eq.(8) and substituting $\left.\frac{\partial t(\widehat{\theta})}{\partial \widehat{\theta}}\right|_{\widehat{\theta}=\theta}$, we obtain $\frac{\partial U}{\partial \theta} = -\psi_\theta \geq 0$. The second order condition of incentive compatibility requires $\frac{\partial^2 U}{\partial\theta\partial q}\frac{\partial q}{\partial \theta} \geq 0$. Notice that $\frac{\partial^2 U}{\partial\theta\partial q} = -\psi_{\theta m}\frac{\partial m^*}{\partial q} - \psi_{\theta r}\frac{\partial r^*}{\partial q} = -\frac{\psi_{\theta m}(\psi_{rr}-\psi_{mr})+\psi_{\theta r}(\psi_{mm}-\psi_{mr})}{\psi_{mm}+\psi_{rr}-2\psi_{mr}} > 0$ under the assumption in Eq.(9). Therefore $\frac{\partial q}{\partial \theta} \geq 0$ is required. ■

Proposition 4. Write the Hamiltonian as $H = [W(m^*(q, \theta)) - \psi(m^*(q, \theta), r^*(q, \theta), \theta) - U(\theta)] f(\theta) - \pi(\theta)\psi_\theta(m^*(q, \theta), r^*(q, \theta), \theta)$, where $\pi(\theta)$ is the costate variable. Following the proof of

[25] It is readily checked that the condition is satisfied for instance for the specification $\psi = (\gamma - \theta)\frac{m^2}{2}$, where $\psi_{\theta\theta m} = \psi_{mmm} = 0$ and $\psi_{\theta mm} = -1$.

Proposition 1 and observing the best-response functions $m^*(q,\theta)$ and $r^*(q,\theta)$ we obtain the first-order condition $W_m \frac{\partial m^*}{\partial q} - \psi_m \frac{\partial m^*}{\partial q} - \psi_r \frac{\partial r^*}{\partial q} - \frac{1-F}{f}\left(-\psi_{m\theta}\frac{\partial m^*}{\partial q} - \psi_{r\theta}\frac{\partial r^*}{\partial q}\right) = 0$. Dividing through by $\frac{\partial m^*}{\partial q}$ and rearranging terms, we obtain the expression as stated in Eq.(10). The transfer $t^{as}(\theta)$ follows immediately. ■

Proposition 5. In order to facilitate the subsequent exposition, define

$$\begin{aligned}\Omega\left(q^{as},\theta,\beta\right) &:= W_m(m^*\left(q^{as},\theta,\beta\right)) - \left[\left(\gamma-\theta\right)q^{as} + \frac{1-F}{f}m^*\left(q^{as},\theta,\beta\right)\right] \\ &= W_m(m^*\left(q^{as},\theta,\beta\right)) - q^{as}\left[\left(\gamma-\theta\right) + \frac{1-F}{f}\frac{\beta}{\beta+\gamma-\theta}\right] = 0, \qquad (18)\end{aligned}$$

with

$$\Omega_q := \left(W_{mm} - \frac{1-F}{f}\right)\frac{\partial m^*}{\partial q} - \left(\gamma-\theta\right) < 0, \qquad (19)$$

$$\begin{aligned}\Omega_\theta &= \left(W_{mm} - \frac{1-F}{f}\right)\frac{\partial m^*}{\partial \theta} + q^{as} - \left(\frac{1-F}{f}\right)' m^* \\ &= q^{as}\left[\left(W_{mm} - \frac{1-F}{f}\right)\frac{\beta}{\left(\beta+\gamma-\theta\right)^2} + 1 - \left(\frac{1-F}{f}\right)'\frac{\beta}{\beta+\gamma-\theta}\right]. \qquad (20)\end{aligned}$$

The second equalities in Eqs.(18) and (20) follow after substituting $\frac{\partial m^*}{\partial \theta} = \frac{m^*}{\beta+\gamma-\theta}$ and $m^* = \frac{\beta q^{as}}{\beta+\gamma-\theta}$. Implementability requires $\frac{dq^{as}}{d\theta} = -\frac{\Omega_\theta}{\Omega_q} \geq 0$,which in turn implies $\Omega_\theta \geq 0$. This is satisfied if and only if the expression in square brackets in Eq.(20) is positive.

We prove the proposition by showing that $\Omega_\theta \geq 0$ for the limiting case $\beta \to \infty$ and then evoking a continuity argument. Intuitively, as manipulation becomes infinitely costly for $\beta \to \infty$ we always have $r^* = 0$ and, thus, $m^* = q^{as}$. We are then back to the baseline model with $\alpha = 0$ for which the separating contract is implementable. Consider, thus, $\lim_{\beta\to\infty}\Omega\left(q^{as},\theta,\beta\right) = W_m\left(q^{as}\right) - \left[\left(\gamma-\theta\right) + \frac{1-F}{f}\right]q^{as}$, where we observe $\lim_{\beta\to\infty} m^*\left(q^{as},\theta,\beta\right) = q^{as}$. It can then be checked that $\lim_{\beta\to\infty} q^{as} = \widetilde{q}$ is finite and non-negative. As $\widetilde{q}$ is finite, it is also generally true that W_{mm} is finite. Hence, it is readily verified from Eq.(20) that $\lim_{\beta\to\infty}\Omega_\theta = \widetilde{q}\left[1 - \left(\frac{1-F}{f}\right)'\right] > 0$. By continuity $\Omega_\theta > 0$ extends to a range of large but finite values of β. ■

Proposition 6. (a) From Eq.(18) $\frac{dq^{as}}{d\beta} = -\frac{\left(W_{mm}-\frac{1-F}{f}\right)}{\Omega_q}\frac{\partial m^*}{\partial\beta} < 0$, where $\frac{\partial m^*}{\partial\beta} > 0$. (b) Using the result from (a) together with Eq.(19) and observing $\frac{\partial m^*}{\partial q} = \frac{m^*}{q^{as}}$ we find $\frac{dm^*}{d\beta} = \left[1 - \frac{m^*}{q^{as}}\frac{\left(W_{mm}-\frac{1-F}{f}\right)}{\Omega_q}\right]\frac{\partial m^*}{\partial\beta} = \frac{-(\gamma-\theta)}{\Omega_q}\frac{\partial m^*}{\partial\beta} > 0$. (c) $\frac{dt^{as}}{d\beta} = \psi_\beta + \psi_m\frac{dq^{as}}{d\beta} + U_\beta$ is readily checked, where $U_\beta = -\int_{\underline{\theta}}^{\theta}\psi_{\theta m}\frac{dm^*}{d\beta}d\widetilde{\theta} = \int_{\underline{\theta}}^{\theta}m^*\frac{dm^*}{d\beta}d\widetilde{\theta} > 0$. Furthermore, $\psi_\beta + \psi_m\frac{dq^{as}}{d\beta} = \frac{r^{*2}}{2} - (\gamma-\theta)\,m^*\frac{\left(W_{mm}-\frac{1-F}{f}\right)}{\Omega_q}\frac{\partial m^*}{\partial\beta} = \frac{-r^{*2}\left[\left(W_{mm}-\frac{1-F}{f}\right)\frac{m^*}{q^{as}}+(\gamma-\theta)\right]}{2\Omega_q}$, where the second equality follows after substituting $(\gamma-\theta)\frac{\partial m^*}{\partial\beta} = \frac{r^{*2}}{q}$ and collecting terms. Note that the term in square brackets is ambiguous but equals $(\gamma-\theta) > 0$ for $W_{mm} = 0$ and $\lim\limits_{\theta\to\overline{\theta}}\frac{1-F}{f} = 0$. ■

Lemma 3. As is readily verified, $\frac{dq^{as}}{d\theta} = \frac{(q^{as})^2}{a(\beta+\gamma-\theta)^2}\xi(\theta)$, where $\xi(\theta) = (\beta+\gamma-\theta)^2 - \beta(b+1-\beta-\gamma)$. Hence, $\frac{dq^{as}}{d\theta} \le 0 \Leftrightarrow \xi(\theta) \le 0$. Since $\xi_\theta < 0$, it is true that $\xi(\theta) \le 0 \Leftrightarrow \theta \ge \beta+\gamma-\sqrt{\beta(b+1-\beta-\gamma)} =: \theta^N(\beta)$, where $\theta^N(\beta)$ is strictly convex in β. Define $d := \frac{b-3(\gamma-1)}{4}$. It can be verified that $\theta^N(\beta) \le 1 \Leftrightarrow 2\beta^2 - 4\beta d + (\gamma-1)^2 \le 0$. Solving the last inequality for β we obtain $\theta^N(\beta) \le 1 \Leftrightarrow \beta \in \left[\underline{\beta},\overline{\beta}\right]$, where $\underline{\beta} := d - \frac{1}{2}\sqrt{4d^2 - 2(\gamma-1)^2}$ and $\overline{\beta} := d + \frac{1}{2}\sqrt{4d^2 - 2(\gamma-1)^2}$. Here, we note that the roots $\underline{\beta}$ and $\overline{\beta}$ are real if and only if $2d^2 \ge (\gamma-1)^2$ or, using the definition of d, if and only if $b \ge \left(3+2\sqrt{2}\right)(\gamma-1)$. Otherwise, $\theta^N(\beta) > 1$ holds for all β. Hence, given $b \ge \left(3+2\sqrt{2}\right)(\gamma-1)$ and $\beta \in \left[\underline{\beta},\overline{\beta}\right]$, we have $\frac{dq^{as}}{d\theta} \le 0$ for all $\theta \in \left[\theta^N(\beta),1\right]$. ■

Proposition 7. Define $x(\theta) := \frac{dq(\theta)}{d\theta}$. When $x(\theta) < 0$ cannot be ruled out, the maximisation problem can be stated as follows.

$$\max_{x(\theta)}\int_0^1 \left[W\left(m^*(q,\theta,\beta)\right) - \psi\left(m^*(q,\theta,\beta), r^*(q,\theta,\beta), \theta\right) + (1-\theta)\,\psi_\theta\right]d\theta$$

$$\text{s.t. } x(\theta) = \frac{dq(\theta)}{d\theta} \text{ and } x(\theta) \ge 0,$$

where we note that $F(\theta) = \theta$ and $f(\theta) = 1$ for a uniform distribution. The corresponding Hamiltonian is

$$H = \left[W(m^*) - \psi(\cdot) + (1-\theta)\,\psi_\theta\right] + \delta(\theta)\,x(\theta),$$

leading to the first-order conditions

$$
\begin{aligned}
&x(\theta) \text{ maximises } H \text{ s.t. } x(\theta) \geq 0 \\
&\frac{dq(\theta)}{d\theta} = x(\theta) \\
&\frac{d\delta(\theta)}{d\theta} = -\Omega(q,\theta,\beta)\,\frac{m^*(q,\theta,\beta)}{q} \qquad (21) \\
&\delta(0) = \delta(1) = 0. \qquad (22)
\end{aligned}
$$

Here, we note that $\frac{d\delta(\theta)}{d\theta} = -\frac{\partial H}{\partial q} = -\left[W_m(m^*)\frac{\partial m^*}{\partial q} - (\gamma-\theta)\,m^* - (1-\theta)\,m^*\frac{\partial m^*}{\partial q}\right]$. Substituting $\frac{\partial m^*}{\partial q} = \frac{m^*}{q}$ and collecting terms, we then obtain the expression in Eq.(21) with $\Omega(q,\theta,\beta)$ as defined in Eq.(18). The transversality condition (22) follows from the fact that by treating $x(\theta)$ as a control, we obtain what is effectively a free-endpoint problem. Consider first the separating interval $\left[0,\theta^P\right]$. By definition, we have $x(\theta) > 0$ and $\delta(\theta) = 0$ within this interval. But then $\frac{d\delta(\theta)}{d\theta} = 0$ must also hold and thus from Eq.(21) $\Omega(q,\theta,\beta) = 0$. Recall that this implies $q = q^{as}(\theta)$. Now consider the pooling interval $\left[\theta^P,1\right]$, where $x(\theta) = 0$. Integrating Eq.(21) between θ^P and 1 we obtain

$$\delta(1) - \delta\left(\theta^P\right) = 0 = -\int_{\theta^P}^{1}\Omega\left(q^P,\theta,\beta\right)\frac{m^*\left(q^P,\theta,\beta\right)}{q^P}d\theta. \qquad (23)$$

The first equality follows from the transversality condition $\delta(1) = 0$ and from a continuity argument, where $x\left(\theta^P-\varepsilon\right) > 0$ and $\delta\left(\theta^P-\varepsilon\right) = 0$ for some small $\varepsilon > 0$ implies $\delta\left(\theta^P\right) = 0$. From the same continuity argument we obtain $q^P = q^{as}\left(\theta^P\right)$. Observing that q^P is a constant on the interval $\left[\theta^P,1\right]$, the second equality in Eq.(23) implies $0 = \int_{\theta^P}^{1}\Omega\left(q^P,\theta,\beta\right)\left(m^*/q^P\right)d\theta$ as reported in the proposition. To prove that $\theta^P \in \left(0,\theta^N\right)$, where $\theta^N = \arg\max q^{as}(\theta)$, with $\theta^N < 1$ for pooling to be relevant, we first rule out $\theta^P \in \left(\theta^N,1\right]$ as this would imply $\frac{dq^{as}(\theta)}{d\theta} < 0$ for $\theta \in \left(\theta^N,\theta^P\right]$. Next, consider $\theta^P = 0$. Then $q^P = q^{as}(0)$, where $q^{as}(0) \leq q^{as}(1)$. From the concavity of $q^{as}(\theta)$ it then follows that $q^{as}(0) < q^{as}(\theta)\ \forall\theta \in (0,1)$, and consequently from the concavity of the objective function it must be true that $\Omega\left(q^P,\theta,\beta\right) = \Omega\left(q^{as}(0),\theta,\beta\right) >$

$\Omega\left(q^{as}\left(0\right),0,\beta\right)=0\ \forall\theta\in\left(0,1\right),$ and $\Omega\left(q^{as}\left(0\right),1,\beta\right)\geq\Omega\left(q^{as}\left(0\right),0,\beta\right).$ But then

$$\int_{0}^{1}\Omega\left(q^{P},\theta,\beta\right)\left(m^{*}/q^{P}\right)d\theta=\int_{0}^{1}\Omega\left(q^{as}\left(0\right),\theta,\beta\right)\left(m^{*}/q^{as}\left(0\right)\right)d\theta>0. \tag{24}$$

This is a contradiction and rules out $\theta^{P}=0$. Next, consider $\theta^{P}=\theta^{N}$. Since $\theta^{N}=\arg\max q^{as}\left(\theta\right),$ it must be true that $q^{P}=q^{as}\left(\theta^{N}\right)>q^{as}\left(\theta\right)\ \forall\theta\in\left(\theta^{N},1\right]$ and, therefore, $\Omega\left(q^{P},\theta,\beta\right)=\Omega\left(q^{as}\left(\theta^{N}\right),\theta,\beta\right)<\Omega\left(q^{as}\left(\theta^{N}\right),\theta^{N},\beta\right)=0\ \forall\theta\in\left(\theta^{N},1\right].$ Hence,

$$\int_{\theta^{N}}^{1}\Omega\left(q^{P},\theta,\beta\right)\left(m^{*}/q^{P}\right)d\theta=\int_{\theta^{N}}^{1}\Omega\left(q^{as}\left(\theta^{N}\right),\theta,\beta\right)\left(m^{*}/q^{as}\left(\theta^{N}\right)\right)d\theta<0. \tag{25}$$

This contradicts $\theta^{P}=\theta^{N}$. Finally, consider some $\theta'\in\left(0,\theta^{N}\right).$ For a variation in θ' we obtain

$$\begin{aligned}&\frac{d}{d\theta'}\left[\int_{\theta'}^{1}\Omega\left(q^{as}\left(\theta'\right),\theta,\beta\right)\frac{m^{*}\left(q^{as}\left(\theta'\right),\theta,\beta\right)}{q^{as}\left(\theta'\right)}d\theta\right]\\&=\int_{\theta'}^{1}\Omega_{q}\left(q^{as}\left(\theta'\right),\theta,\beta\right)\frac{m^{*}\left(q^{as}\left(\theta'\right),\theta,\beta\right)}{q^{as}\left(\theta'\right)}\frac{dq^{as}\left(\theta'\right)}{d\theta'}d\theta<0,\end{aligned}$$

where the equality follows under observation that $\Omega\left(q^{as}\left(\theta'\right),\theta',\beta\right)=0$ and that $\frac{m^{*}(q^{as}(\theta'),\theta,\beta)}{q^{as}(\theta')}=\frac{\beta}{\beta+\gamma-\theta}$ is constant with respect to θ'. The inequality follows when noting that $\Omega_{q}\left(q^{as}\left(\theta'\right),\theta,\beta\right)<0\ \forall\theta$. Together with Eq.(24) and Eq.(25) this implies a unique $\theta^{P}\in\left(0,\theta^{N}\right).$

Observing $\frac{dt^{as}(\theta)}{d\theta}\Big|_{\theta\in[\theta^{P},1]}=\psi_{m}\frac{dq(\theta)}{d\theta}\Big|_{\theta\in[\theta^{P},1]}=\psi_{m}x\left(\theta\right)\Big|_{\theta\in[\theta^{P},1]}=0$ it follows that $t^{P}=t^{as}\left(\theta^{P}\right)=\psi\left(m^{*}\left(q^{P},\theta^{P},\beta\right),r^{*}\left(q^{P},\theta^{P},\beta\right),\theta^{P}\right).$ This completes the proof. ■

Proposition 8. The associated Hamiltonian is:

$H=\left[\frac{W(m(\theta))^{1-\rho}}{1-\rho}-\psi(m\left(\theta\right),\theta)-U\left(\theta\right)\right]f\left(\theta\right)+\pi\left(\theta\right)\left(-\psi_{\theta}\right),$ where $\pi^{as}\left(\theta\right)=-\left(1-F(\theta)\right)<0$ follows in analogy to the proof of Proposition 1. Eq.(19) is obtained by setting $H_{m}=0$ and dividing by $f(\theta)$. The Second Order Condition is $H_{mm}=\left(\frac{W_{mm}}{W(m)^{\rho}}-\frac{\rho W_{m}^{2}}{W(m)^{\rho+1}}-\psi_{mm}\right)f\left(\theta\right)-\left(1-F(\theta)\right)\psi_{\theta mm}<0$. Eq.(19) represents an optimal solution if and only if m^{as} is *implementable* (i.e. if and only if $\frac{\partial m}{\partial\theta}\geq0$), which is always the case as $\frac{\partial m}{\partial\theta}=\frac{-\psi_{m\theta}\left[1-\left(\frac{1-F}{f}\right)'\right]+\frac{1-F(\theta)}{f(\theta)}\psi_{m\theta\theta}}{(-H_{mm})/f(\theta)}>0$. ■

Proposition 9. (a) Totally differentiating Eq.(16), we obtain

$(H_{mm}/f(\theta))\,\partial m - W_m W(m)^{-\rho}\log(W(m))\partial\rho = 0$, so that $\frac{\partial m}{\partial \rho} = \frac{-W_m W(m)^{-\rho}\log(W(m))}{(-H_{mm})/f(\theta)} > 0$ $\Leftrightarrow W(m) < 1$;[26]

(b) $\frac{\partial(\partial m/\partial\theta)}{\partial\rho} = -\frac{-\psi_{m\theta}\left[1-\left(\frac{1-F}{f}\right)'\right]+\frac{(1-F(\theta))}{f(\theta)}\psi_{m\theta\theta}}{(-H_{mm})^2/f(\theta)}\frac{\partial(-H_{mm})}{\partial\rho}$,

where $\frac{\partial(-H_{mm})}{\partial\rho} = -\frac{f(\theta)}{W(m)^{\rho}}\left(\ln(W(m))\left((-W_{mm})+\rho\frac{W_m^2}{W(m)}\right)-\frac{W_m^2}{W(m)}\right)$, so that $\frac{\partial(\partial m/\partial\theta)}{\partial\rho} = \frac{-\psi_{m\theta}\left[1-\left(\frac{1-F}{f}\right)'\right]+\frac{(1-F(\theta))}{f(\theta)}\psi_{m\theta\theta}}{(-H_{mm})^2 W(m)^{\rho}}\left(\ln(W(m))\left(-W_{mm}+\rho\frac{W_m^2}{W(m)}\right)-\frac{W_m^2}{W(m)}\right)f(\theta)^2$. Notice that the first term of this expression is positive (see the implementability condition in the previous proposition). Therefore, the sign of $\frac{\partial(\partial m/\partial\theta)}{\partial\rho}$ depends on the sign of $\ln(W(m))\left(-W_{mm}+\rho\frac{W_m^2}{W(m)}\right)-\frac{W_m^2}{W(m)}$. It is apparent that $W<1$ implies that the above is negative while if $W>1$ then the sign is indeterminate. (c) $\frac{\partial t(\theta)}{\partial\rho} = \psi_m\frac{\partial m^{as}}{\partial\rho} + \int_{\underline{\theta}}^{\theta} -\psi_{\theta m}\frac{\partial m^{as}}{\partial\rho}d\widetilde{\theta}$ < 0 if $\frac{\partial m^{as}}{\partial\rho} < 0$ and vice versa. (d) $\frac{\partial(\partial t^{as}/\partial\theta)}{\partial\rho} = \psi_m\frac{\partial m^2}{\partial\theta\partial\rho} + \frac{\partial m^{as}}{\partial\theta}\psi_{mm}\frac{\partial m}{\partial\rho}$ (see more detailed discussion below). ■

7 References

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[26] Notice that $\log(W_m W(m)^{-\rho}) = \log(W_m) - \rho\log(W(m))$ with $\frac{\partial\log(W_m W(m)^{-\rho})}{\partial\rho} = \frac{1}{W_m W(m)^{-\rho}}\frac{\partial(W_m W(m)^{-\rho})}{\partial\rho} = -\log(W(m))$. Therefore, $\frac{\partial(W_m W(m)^{-\rho})}{\partial\rho} = -W_m W(m)^{-\rho}\log(W(m))$.

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