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Physician Incentive Management in University Hospitals: Inducing Efficient Behavior Through the Allocation of Research Facilities

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Abstract

The imperative to improve healthcare efficiency is now stronger than ever. Rapidly increasing healthcare demand and the prospect of healthcare cost exploding require that measures be taken to make healthcare organizations become more efficiency-aware. Alignment of organizational interests is therefore important. One of the main hurdles to overcome is the provision of the right incentives to healthcare workers, in particular physicians.

In this research we investigate the incentive system for physicians in university hospitals. We present an inquiry held in a large university hospital in the Netherlands and show that non-financial incentives receive significantly more support among physicians than financial incentives. Over 95 percent of the physicians indicated they derive more work stimulus from research possibilities or scientific status than from wage. Over 80 percent of the physicians also indicated they prefer to be able to do more research. We therefore identified a broad class of non-financial incentives aimed at physicians in university hospitals: research facilities.

The main tradeoff in using research facilities within an incentive system is between efficient resource utilization and inducement effects. This thesis constructs a principal-multi-agent model where agents engage in both care and research and which includes heterogeneity and private information. We study how research facilities incentives can be used to improve hospital performance if the current wage system is left intact. We show that research facilities are optimally used as incentives for both care and research activities, and that the hospital offers different contracts depending on physician ability and valuation. Moreover, if physicians need to reveal their valuations for research facilities, the hospital finds it optimal to allow physicians to make a rent. We discuss some implications of extending the theoretical results to practice.

Keywords: *Health care management – Incentive contracts – Mechanism design – Principal agent problem*

Contents

Chapter 1

Introduction

1.1 The aim of this research

The healthcare sector has evolved rapidly throughout the last decades, both in terms of quality of care and in terms of its cost. Since 1970 the inflation adjusted government spending on healthcare throughout the developed world has risen by nearly 5 percent per year (Hagist & Kotlikoff, 2005) and according to OECD (2008) figures it currently averages around 10 percent of GDP of OECD countries. While there is a strongly embodied ethical paradigm to provide the best patient care available, there is a limit on what can be spend to achieve this. Yet healthcare expenditure keeps facing upward pressure as patients become more demanding and new technologies spread. Moreover, societal ageing and lengthening lifetimes, which are important factors in healthcare cost, lead to increased future demand for quality and quantity of care and to major acceleration in the rise of healthcare cost (see e.g. Freund and Smeeding, 2002). Reducing healthcare cost therefore is a socially important objective and it is now more important than ever to consider the efficiency of healthcare organizations.

A fundamental problem in creating efficient and effective organizations – whether in healthcare or elsewhere – is the design of *incentive-compatible* protocols that, despite the self-interest of individual agents, lead to system wide alignment and optimal performance on the system level. What we mean by this is that organizational protocols (e.g. couplings between performance of the organization and individual reward) need to provide executive agents with incentives to behave such that organization output is optimized, even though the agents may be self interested, hold private information and personal goals, and may not be so much concerned about the performance of the entire organization. The design of such incentive-compatible protocols, which we will label together as an incentive system, is a fundamental part of the framework for efficient organizations.

In this research we address incentive-compatible protocols in a specific type of health care organizations: university hospitals. In particular we focus on the design of an efficiency-promoting incentive system for these hospitals. We consider the measures available to stimulate the university hospital's departments and its individual healthcare workers (in this case the physicians) to deliver high and efficient performance. Physicians are of primary importance as their decisions directly influence health care operations and their willingness to accept efficient work plans (for e.g. surgery planning) is paramount to the success of such plans. In typical non-profit university hospitals, as in the Netherlands, extensive monetary incentives are no option. Such incentives within the semi-public sector are hard to justify socially in the current political (and economical) climate. Therefore, after consideration and discussion with involved health care professionals[1], we consider a special principle inherent to university hospitals but not present in regular hospitals: the allocation of research facilities.

Research is one of the key pillars of university hospitals. It is an important factor in the determination of the status of a hospital, and indirectly impacts the number of treatments the hospital can do. Moreover, discussions with a hospital department head suggested that obtaining (scientific) status, delivering research performance, and working on challenging specialized cases, while using class leading techniques and state-of-the-art equipment are key drivers for physicians in university hospitals. Research facilities such as research budget and operating room time – which stimulate the above criteria – can therefore be used to provide incentives to departments and physicians in university hospitals, and thus can be used to promote efficiency and to increase overall performance. At the same time, awarding more research facilities to physicians who perform well on regular care may lead to inefficiencies regarding resource utilization. Physicians who are naturally better at research, but perform less well at care, cannot make full resource-advantage. Therefore it is important to determine the right protocol for allocating research facilities.

The aim of this research is as follows:

Determine a mechanism for the allocation of research facilities to physicians in university hospitals that maximizes hospital performance.

We will first examine the literature related to this problem. We also present empirical findings from a survey we held at the Erasmus Medical Center for the usability of research facilities within an incentive system. Thereafter we begin the analysis by constructing a framework capturing the dynamics of performance and manipulability that are involved with a research facilities allocation mechanism to physicians in university hospitals. We analyze this framework

[1] For this study we held discussions with a department head of the Erasmus Medical Center in the Netherlands, and held discussions within a dedicated discussion group of that hospital.

under scenarios of complete and incomplete contractibility. Next we try to construct a research facilities allocation mechanism that is optimal with respect to this framework under private information. We want to assess the equilibrium behavior under this mechanism, the involved design trade-offs, and whether, and under what conditions, the university hospital should implement this research facilities allocation mechanism. We will mainly do this from an economic point of view, but will also briefly touch some of the non-economic dilemmas involved.

We begin, however, by broadly describing the incentive problem in creating efficient organizations, and the importance and difficulty of incentive management as a solution to it. We then precisely define the problem of research facilities based incentive management in university hospitals and some of the motivation behind it. We conclude this introduction with a guide to the remainder of our work.

1.2 Incentive management

There are many wide-ranging claims about the importance of incentives, but effectively, incentives are at the base of all human behavior – in particular economic behavior. Incentives are any factors (remunerable, moral or otherwise) that drive people towards their goals. They enable or motivate a particular course of action, or count as a reason for preferring one choice to alternatives. Incentive systems therefore are central to economic activity, both in terms of individual decision making and in terms of cooperation and competition in a larger institutional structure. There is ample scientific evidence as a foundation to this claim (see e.g. Jenkins, Mitra, Gupta and Shaw (1998), or for the healthcare sector: Hillman, Pauly and Kerstein (1989)).

As it is important for organizations that interests are aligned, and that workers are stimulated to communicate, (co)operate and collaborate in order to meet the organizations interests and goals, the provision of a proper incentive system is important for the success of organizations. The problem of designing the incentive system is in a broader sense also referred to as the principal-agent problem, addressing the two groups of agents involved: principals and executive agents. Typically the system performance is in the direct interest of the principals (e.g. management) who need the executive agents (e.g. workers) to realize high system performance. If the goals of the agents and the principal are not aligned, the performance of the system may not be optimal. In order to achieve alignment the principals have an array of incentive options available. Remunerable incentives (commonly captured in so called incentive contracts) are one of them, but there are many others such as awards, trainee programs, research grants, etc. The problem lies in identifying and selecting the right and applicable incentives, in selecting the measures by which agents are assessed, and in deciding the rules by which measures are translated and rewards are allocated.

The design of incentive systems is more difficult than it may seem at first glance. Although a main concern of economists, it can involve many parties: from managers and workers, to legislators and regulators as well as lawyers and judges. Moreover, it requires the consideration of all organizational complications and not just the principal features. Most complications are not straightforwardly visible and need thorough analysis to become fully apparent and transparent. One possible complication is for example the 'gaming' of the incentive system by agents (e.g. deliberate downgrading of quality in piece-rate systems). Therefore design of incentive systems requires an engineering approach and a combination of different techniques to be effective. Incentive management, which is the collective name for this approach to the design and maintenance of the organizational incentive mechanism as well as the associated protocols, serves as the important tool in creating efficient organizations. It directly addresses the issue of aligning workers' interest with those of the organization, and if efficiency is among them it aims to stimulate workers to operate more efficiently.

The design process of incentive management can typically be divided into three phases: theoretical design, empirical validation, and implementation. Figure 1.1 gives an overview of the different phases and the typical activities involved in each phase.

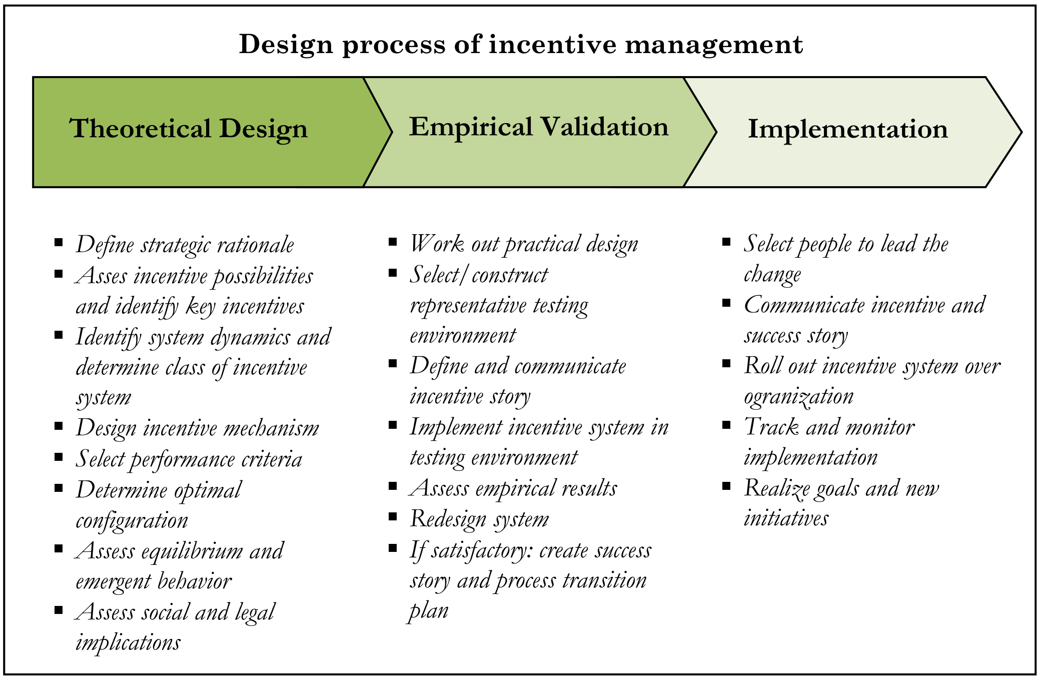

Figure 1.1: Phases in design process of incentive management and (non-exhaustive) list of activities per phase

In this research we will address part of the first phase, i.e. the theoretical design, of an innovative incentive system for university hospitals based on research facilities allocation. We will mainly address the economic issues involved, but will also give some non-economic considerations. We will explain the case in detail in the next section.

1.3 Research facilities based incentive management in university hospitals

The health care sector is no ordinary sector in terms of management purposes. The complex environment of hospitals with highly, but differently, trained professionals arguably places hospitals among the most challenging organizations to manage (e.g. Mintzberg, 1997). Mintzberg identifies four quadrants of influence: medical specialists, nurses, managers, and trustees. Each quadrant has its own objectives and its own approach to how it wants to achieve those objectives. The objectives are related to the goals of the hospital as a whole, but are generally not aligned.

The goals of a university hospital are generally threefold:

- providing the best possible patient care,
- the best possible research,
- and the best possible education.

As we have already argued, increasing hospital efficiency is currently of major importance for sustaining the level of patient care in the future. In particular physicians play an important role as their decisions do not only influence the health of patients but also the cost of care. In its aims to increase hospital efficiency, management can gain insight in the operation of the various departments under its control through performance evaluations. The level of direct authority of management over medical specialists and nurses is, however, very limited. Physicians require autonomy in their work and generally do not accept management's prescriptive efficiency-measures if these limit their freedom. Physicians are typically also more concerned with quality of care and can be afraid that efficiency-measures have a negative impact on quality. Yet, for the introduction of solutions to organizational inefficiencies taking the form of some kind of protocol (e.g. prescriptive 'rules' for surgery planning) it is essential to have the support of the physicians, who as decision making agents directly influence the underlying process. Getting hospitals to work more efficiently is therefore, although important, a difficult task.

Accordingly, it is imperative to identify the right incentives for targeting the individual physicians. In health care organizations incentives have traditionally been less present than in business. In typical non-profit university hospitals, as in the Netherlands, extensive financial incentives are not an option. Such incentives within the semi-public sector are hard to justify socially in the current political (and economical) climate.

After consideration, debate and discussion with involved health care professionals, we therefore proceed to the examination of another possibility: the allocation of research facilities. The reasoning behind this is as follows. Generally, physician payment levels in university hospitals are below those of regular hospitals. But university hospitals do offer the possibility to do research, achieve scientific status and operate at the frontier of what is medically possible. This likely is why many academic physicians choose to work in a university hospital over working in a regular hospital. Therefore financial incentives may be less powerful in this setting than incentives coupled to research performance, such as research facilities. Yet, it typically are (weak) financial incentives which (if at all) are used in the university hospital and often they are not based on the objectives of management. In the Netherlands for example, physicians in university hospitals receive:

a) a fixed wage only, and
b) a promotion to a higher wage level only on long term basis.

Now, by embedding the allocation of research budget and available operating room time for research in the right incentive-compatible protocol, departments and physicians may be induced in delivering more qualitative and more efficient performance.

What exactly can be labeled as 'research facilities'? Possibilities include research time – such as operating room time for clinical trials, lab time, time for congress visits, etc. – and research budget – in the form of monthly fees (expendable to for example research assistants), prizes, research grants, etc. – but also dedicated facilities – such as entry to restricted trainee programs. In this study we will leave the precise determination of research facilities open, thereby taking a high level approach. We only require that research facilities are the facilities (mostly already in existence) that contribute to the (individual) research performance. We can assume the facilities are such that no extra money is required to be put into the system (which leads to a budget balanced solution), but this assumption is not strictly necessary[2]. The total of

[2] We will give optimality conditions to determine the optimal level of research facilities should this be freely determinable

research facilities available in any period then may be represented as a pie of single unity which can be distributed over the different physicians.

Figure 1.2 gives a schematic overview of the typical organization of a university hospital in terms of different allocation levels of research facilities (grossly defined as above). It shows how research facilities are generally allocated from the hospital level to departments, and from departments to workgroups consisting of individual physicians. Typical allocations are in relation to research performance[3].

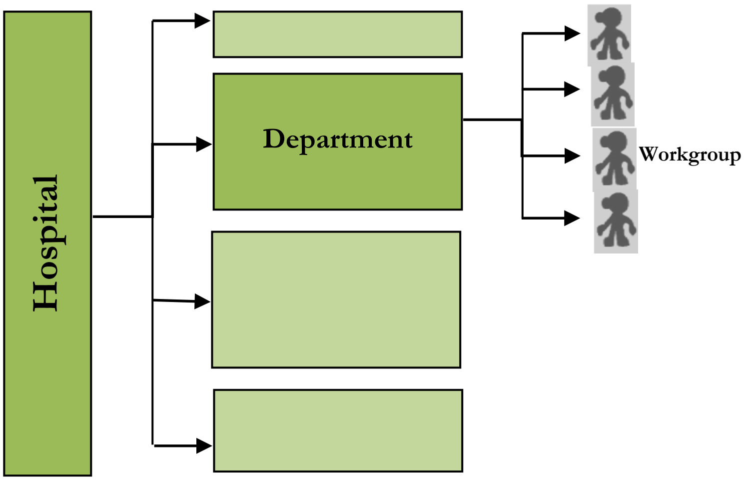

Figure 1.2: Typical organization of allocation levels for research facilities in a university hospital

Designing an optimal incentive system based on the allocation of research facilities is a non-trivial and challenging problem. We can view the problem as a distributed optimization problem with an objective function that depends on the private information of the workgroups/physicians. The central goal is twofold:

[3] For example, in the Erasmus Medical Center in the Netherlands departments are rewarded research budget based on research performance (the dependence has even been increased recently).

- to induce the physicians into delivering efforts that maximize hospital performance (in regular care and research), and
- to achieve an optimal allocation of research facilities that maximizes research performance.

In this problem the workgroups are characterized by their capabilities in research and in regular care. Moreover, they have different valuations regarding research facilities and they deliver individual care and research performance. In return for their performance they receive wage and research facilities as specified by the allocation mechanism. The two goals listed above now conflict in the sense that the allocation of research facilities in response to regular care performance may tend to award workgroups who perform well on regular care, while these workgroups may not be the best performers at research, and thus may not maximize research output.

An allocation mechanism should optimize the hospital performance for the equilibrium workgroup strategies, taking the above conflicts in account. The mechanism therefore requires sufficient structure to enable strong theoretical claims about the strategies that workgroups will select in equilibrium and the optimality properties of the final solutions. It should also carefully deal with negative effects that could arise due to the gaming of the incentive system. Moreover, feasibility considerations related to informational aspects, including communication properties such as message size and information processing complexity play a pivotal role. If for example, astronomical amounts of information must be transmitted, or if the strategy-determining problems to be solved by individual workgroups are tremendously complex, the practical feasibility of the mechanism is in question. Computation and agent self-interest may however also interact in non-obvious ways: agent-bounded rationality can for example also be used to design a mechanism that cannot be manipulated without solving an intractable problem (see Parkes, 2001). Final design-issues include trade-offs regarding 'fairness' or 'social desirability' of the mechanism.

1.4 Outline of this thesis

This thesis is organized as follows. Chapter 2 gives an overview of the relevant literature on incentive management and the techniques that are useful to our approach. Moreover, it discusses how our contributions relate to the literature base. In chapter 3 we present empirical findings from a survey held among medical specialists at Erasmus Medical Center in Rotterdam, the Netherlands. The survey gives empirical foundation for the usability of research facilities within an incentive system for physicians in university hospitals. Chapter 4 sets up a stylized model for the research facilities based incentive system. In chapters 5 and 6 we respectively analyze the scenarios of complete and incomplete contractibility and derive the optimal contracts for both scenarios. We do this for both homogeneous and heterogeneous physicians. We pay particular attention to the consequences of ignoring heterogeneity and we give a comparison of the optimal contracts with the 'current' contracts. In chapter 7 we construct an optimal contract that holds in the case of private information. Chapter 8 translates our theoretical results back to practice. Finally, chapter 9 contains our conclusions.

Chapter 2

Literature

Economics is all about incentives. The literature base regarding incentive management is therefore, not surprisingly, vast. It has reached into many areas of motivation and compensation and it has addressed a multitude of mechanisms that are available for inducing workers to act in the interest of their employers. In this chapter we discuss the relevant literature and some of the previous theoretical models that inspired our analysis. We order this chapter according to the various sub-disciplines in which the literature can be categorized.

2.1 Agency theory

The classical model of principal-agent relations and incentive contracts are studied in the field of agency theory. The canonical problem being the owner-manager situation, the earliest literature dates back to the 1950's and 60's and is from a.o. Baumol (1959), Simon (1959), Cyert and March (1963) and Williamson (1964). Arrow (1971) and Wilson (1968) explicitly explored risk sharing among individuals or groups. They described the risk-sharing problem as one that arises when cooperating parties have different attitudes toward risk.

Agency theory was later extended to include the so-called agency problem that occurs when cooperating parties have different goals and division of labor (Jensen and Meckling, 1976; Ross, 1973). Much of the later work has built on the early premises and centered around the issues that arise when (i) the desires or goals of the principal and agent conflict and (ii) it is difficult or expensive for the principal to verify what the agent is actually doing. Baker (1992) shows that in many empirically relevant cases agent payoff is not based on the principals objective. Influential work has further been from Perrow (1986) who reestablishes the importance of incentives and self-interest in organizational thinking. Although he asserts that agency theory is different from organization theory, agency theory is consistent with the nature of cooperative behavior (see the classical work of Barnard, 1938) and on the inducements and contributions of the employment relationship (e.g. March and Simon, 1958). Furthermore, the economic models of agent relations have contributed to organization theory and have yielded important insights into institutional systems, outcome uncertainty, incentives and risk. We further refer to Eisenhardt (1989) for a detailed overview of the field of agency theory. Throughout this thesis we will use methodology and techniques from several fields applicable to agency theory: contract theory, tournament theory, game theory and mechanism design.

2.2 Contract theory and the theory of the firm

Related to the field of agent theory is contract theory and the theory of the firm. The classical linear contract model which deals with a remunerable contract, can be specified as (see e.g. Baker, 1992):

$$w = a + b \cdot P(e, \varepsilon)$$

where w designates the total wage, a the base salary, b the performance related payments (or bonus), $P(\cdot,\cdot)$ a performance function resulting in a total performance measure, e the (unobserved) level of effort, and ε any exogenous effects on the outcome. Under the assumption that the principal's objective $V(e, \varepsilon)$ is not contractible, Baker shows that the optimal linear contract has a performance measure that is highly correlated with the principals objective. If correlation is low and the agent is risk-averse, he shows that it is best to dampen the performance related payments.

The theory also addresses the ownership of assets (e.g. Klein et al. (1978), Williamson (1985) and Grossman and Hart (1986)). Transfer of ownership is a special case of the linear contract where a is negative and b is such that the agent is a full residual claimant. Interesting is the work of Holmstrom and Milgrom (1994) who examine the differences between contracting and employment. They show how the effectiveness of low-powered incentives within the firm may be enhanced by simultaneously placing constraints on the employee's freedom to act. Their model is more complicated and also involves a configuration of ownership.

Baker, Gibbons and Murphy (1994) treat subjective performance measures as an alternative to the explicit contract to mitigate incentive distortions by imperfect objective measures. They show with benchmark analysis that a combination of objective and subjective performance measures can outperform both explicit and implicit contracts alone, if these would otherwise both result in a negative profit.

The payoff mechanisms for physicians in particular have also been widely investigated. Robinson (2001) offers a good overview. He argues that the three worst mechanisms are fee-for-service, capitation and salary. Fee-for-service would reward the provision of inappropriate services, capitation would reward the denial of appropriate services and harm the chronically ill, and salary would undermine productivity and foster a bureaucratic mentality. Robinson argues that better mechanisms are hybrids of these three mechanisms. Most of the situations in practice as well as the existing literature also involve a combination of these three mechanisms (see e.g. Pauly et al. (1990), Berwick (1996), Emery (1999) and Hanchak et al. (1996)). Pauly et al. provide a direct test between hospital ownership type and the effectiveness of primary care physician incentives. Their results indicate that for-profit ownership does enhance the power and need of management to offer effective rewards for parsimonious use of health resources. Hillman, Pauly and Kerstein (1989) use a regression model to test the hypothesis that financial incentives may change physician's behavior towards patients. Their conclusions are in favor of this hypothesis and they also confirm a positive relation between incentives and hospital profitability. Teleki et al. (2006) interview physicians about the application of financial incentives to stimulate quality of care and cost efficiency. Many supported incentives for high quality care but question measurement accuracy, bonus payment financing, and health plan involvement. Moreover, the interviewed physicians expressed the need for accurate and timely data, peer comparisons, and more patient time, staff support, and consultations with colleagues to successfully monitor and deliver quality care.

There have not been real field experiments for incentive systems for physicians, but there have been good comparisons and empirical evaluations. See Armour et al. (2001) and Petersen et al. (2006) for overviews. To the best of our knowledge, the allocation of research facilities as an incentive mechanism for university hospitals such as we suggest, has been left uncovered. However, in light of the existing literature this seems a fruitful direction for research.

2.3 Tournament theory

A useful analysis is also into the theory of tournaments and relative performance. This theory is applicable to many situations were multiple agents compete for (a share of) a resource. Tournaments are compensation schemes in which contestants' rewards are based on relative differences and not on marginal productivity. Examples include research tournaments (e.g. Taylor, 1995) and promotion systems (e.g. Lazear and Rosen, 1981). Relative performance extends the basic linear contract model to (see e.g. Nalebuff and Stiglitz, 1983):

$$w_i = a_i + b \cdot \frac{P_i(e_i, \varepsilon)}{1/n \sum_j P_j(e_j, \varepsilon)}$$

for a tournament with n agents, and for agent i total wage w_i, fixed salary a_i, performance bonus b and individual performance measure function $P_i(\cdot,\cdot)$ with e_i the unobserved effort and ε any exogenous effects that are common over agents.

Green and Stokey (1983) show that in the absence of a common shock, the use of optimal independent contracts dominates the use of the optimal tournament. If, however, a common shock is present with a sufficiently diffuse distribution, using the optimal tournament dominates using independent contracts.

Moldovanu and Sela (2001) study the optimal allocation of prizes in multi-prize contests under the objective of maximizing expected effort. They consider ability-dependent cost functions for effort – which is similar to our case – and they display the equilibria of contestants for linear, convex and concave cost functions. In particular they show that if the cost functions are linear or concave it is optimal to allocate the prize sum to a single 'first' prize, and that for sufficiently convex cost functions it is optimal to distribute the prize money over all agents except the last placed agent. Their framework is however different from ours, in that we do not consider ex ante fixed prizes and have multiple ability characteristics and a two-dimensional effort space. Also, our case involves adverse selection dilemmas.

2.4 Data envelopment analysis

Data envelopment analysis is a technique from management science which deals with the assessment of performance. The term was introduced by Charnes, Cooper and Rhodes (1978) who studied the efficiency of decision making units. Since then it has become the general heading under which many papers on the assessment of performance have been written. Unfortunately the term is somewhat non-intuitive. Nevertheless the technique is useful and is interestingly captured in the work of Norman and Stroker (1991). They argue that the analysis of performance should not be limited to a few isolated measures such as profit or cost. Instead a whole range of input and output factors should be considered to get a comprehensive insight in how well departments and individual agents are performing in comparison to each other. Useful performance measures for the public sector include staff utilization, productivity, throughput, accuracy, customer satisfaction, number of publications, client/staff ratio's etc. Moreover, they introduce the notion of relative efficiency, which corresponds to a individually weighted ratio of output and input measures which is individually maximized for each agent or department under consideration. By forcing the weighted sum of inputs to be equal to 1, it is possible to gain an objective measure of the relative efficiency of each agent or department.

Data envelopment analysis can be useful as a tool for measuring and calculating the performance differences between hospital departments and medical specialists. In this research we will not directly use the technique (we assume the performance evaluations to be performed external to our model), but it is important to know that good methods for performance assessment are available. Throughout this thesis we will assume the evaluations are performed correctly, as to reasonably reflect effort levels such as through data envelopment analysis, but do not impose explicit restrictions.

2.5 Game theory and mechanism design

Game theory and mechanism design are the fields we draw most from in this research. Game theory, which is a branch of applied mathematics, is used widely in economics to model situations in which decision makers interact. It is not, however, only of interest to analyze and understand such situations, but also to design the mechanisms that govern them (e.g. how to induce the physician to behave as desired). It is here that the field of mechanism design arises. By setting the right rules, mechanism design plays a major role in the engineering of important economic institutions and markets.

The general mechanism design problem is an implementation problem which can be described as follows (using notation consistent with Parkes (2001)). Consider a system with n agents, indexed $i = 1, \dots, n$ and a set of outcomes O. Each agent has private information about its utility for different outcomes, as characterized by its type $\theta_i \in \Theta_i$ where Θ_i is the set of all possible preferences to agent i. Let $u_i(o, \theta_i)$ denote the utility of outcome $o \in O$ to an agent with type θ_i, such that o_1 is preferred to o_2 by agent i if and only if $u_i(o_1, \theta_i) > u_i(o_2, \theta_i)$. Each agent has a strategy $s_i(\theta_i) \in \Sigma_i$ which is a complete contingent plan, or a decision rule, defining the action an agent will select in every possible state of the world, for a set Σ_i of all possible strategies to agent i. The problem is to compute the solution to a social choice function $f: \Theta_1 \times \dots \times \Theta_n \rightarrow O$ that selects an optimal outcome $o^* = f(\theta)$ based on the types $\theta = (\theta_1, \dots, \theta_n)$ of all agents, or alternatively to maximize an outcome function (e.g. profit). This is achieved by specifying a mechanism $M = (\Sigma_1, \dots, \Sigma_n, g(\cdot))$ where $g: \Sigma_1 \times \dots \times \Sigma_n \rightarrow O$ is an outcome rule such that $g(s)$ is the outcome implemented by the mechanism for strategy profile $s = (s_1, \dots, s_n)$.

There are several game-theoretical concepts to compute the strategies agents will select *in equilibrium*. The most well-known are the concepts of Nash equilibrium (Nash, 1950), Bayesian-Nash equilibrium (Harsanyi, 1967/68), and dominant strategy equilibrium (Gale, 1953), listed here in order of increasing strength. A mechanism implements a social choice function $f(\theta)$ if the outcome computed with equilibrium agent strategies is a solution to the social choice function for all possible agent preferences. The mechanism can have various properties depending on the outcomes it generates. These include, but are not limited to, Pareto optimality, allocative efficiency, (weak) budget balance, and individual rationality. For a full description of these properties we refer to Parkes (2001). Due to the revelation principle (see Myerson, 1981 and 1982) it may be possible to restrict attention to finding a direct mechanism in which each agent reports its type. Pathak and Sönmez (2009) introduce a method to asses and compare mechanisms on the degree of manipulability.

The problem of designing an allocation mechanism for research facilities in university hospitals is de facto also an implementation problem which can be modeled as above. In this case the strategies available to the physicians are a choice of effort levels as suggested in the principal agent formulation by Myerson (1982). Moreover, part of the rules of the game are already provided and have similarities to the class of coordination games, such as the n-person stag-hunt game (Ullmann-Margalit, 1977). Van Huyck, Battalio and Beil (1990) extend the n-person stag hunt such that each player faces an effort allocation problem and the profits are dependent on individual and collective effort. They show how strategic uncertainty and risk can lead to coordination failure. Crawford and Haller (1990) address strategies for learning how to cooperate in coordination games.

Lastly, of relevance is the analysis regarding credence goods and supplier-induced demand (see e.g. Pitchik and Schotter, 1987). This occurs in markets with strong information asymmetries between suppliers and buyers. Consider the physician who needs to diagnose a patient (who in the model of Pitchik and Schotter can either have a serious or a mild affection) and faces the choice to either propose a thorough (expensive) treatment or a simpler (less expensive) treatment. In a market situation (with revenues proportional to the treatment cost) the physician has an interest in selling his services, and therefore may advice a thorough treatment even in the case of a mild affection. Pitchik and Schotter show how the percentage of fraud depends on the occurrence of serious and mild affections. Further they show how quality control, price control and expert competence affect the equilibrium. Evans (1974) gave empirical evidence for the occurrence of self-induced demand in the health care sector. Although, supplier-induced demand is in direct relation with the physician reward mechanism, we do not further investigate this relation in this thesis.

Chapter 3

Empirical evidence: incentives in Erasmus Medical Center Rotterdam

In this chapter we display a survey held among medical specialists in the Erasmus Medical Center in Rotterdam, the Netherlands. The survey gives empirical foundation for our assertions on the usability of research facilities within an incentive system for physicians in university hospitals. We will first explain the set-up of the survey and then detail the outcomes.

3.1 A survey among medical specialists

Erasmus Medical Center is a large university hospital in the Netherlands employing over 600 medical specialists. According to the Times Higher Education (2009) ranking it is the number one European institution in clinical research. We conducted a survey among medical specialists at Erasmus Medical Center to empirically test our hypothesis of the usability of research facilities within an incentive system for physicians in university hospitals.

In particular we wanted to assess:

1. The key-factors for the choice of physicians to work in a university hospital instead of a regular hospital, and the distribution of those factors.

2. The key-factors that stimulate physicians in their work in a university hospital, and the distribution of those factors.

3. The current and desired distributions of physician time spent on patient care, research and education.

In order to obtain this assessment we send out an inquiry to all 613 medical specialists in the Erasmus Medical Center and asked them to answer three straightforward questions:

1. To what extent did the following factors play a role in your decision to work in a university hospital with respect to working in a regular hospital?

   Wage, network, (scientific) status, work level (diversity and specialization of treatments), research possibilities, education possibilities, expert-setting, other namely:…

   Each factor could be given a score from 1 to 5 depending on its impact (a 1 corresponding to little impact, a 5 corresponding to much impact).

2. To what extent do the following factors stimulate you in your work?

   Wage, network, (scientific) status, work level (diversity and specialization of treatments), research possibilities, education possibilities, expert-setting, other namely:…

   Again, each factor could be given a score from 1 to 5 depending on its impact.

3. What is your ideal and your current distribution in time spent between patient care, research, and education?

The questions were presented through an online inquiry in the period 7 July – 15 August 2009.

3.2 Results

Although the survey was held during a holiday period, we had 226 respondents out of 614 medical specialists (a response rate of 37 %), which is fairly decent. From the 226 questionnaires 11 were not filled in completely or appropriately and therefore are omitted from analysis. This leaves 215 questionnaires (35 % of the population) to analyze. Figures 3.1 through 3.5 give a graphical overview of the sample characteristics.

In figure 3.1 we can see the impact characteristics of valuation factors for the decision to work in a university hospital. The impact of the various factors differs considerably. The level of work, research possibilities and an expert-setting are the most important factors whereas wage

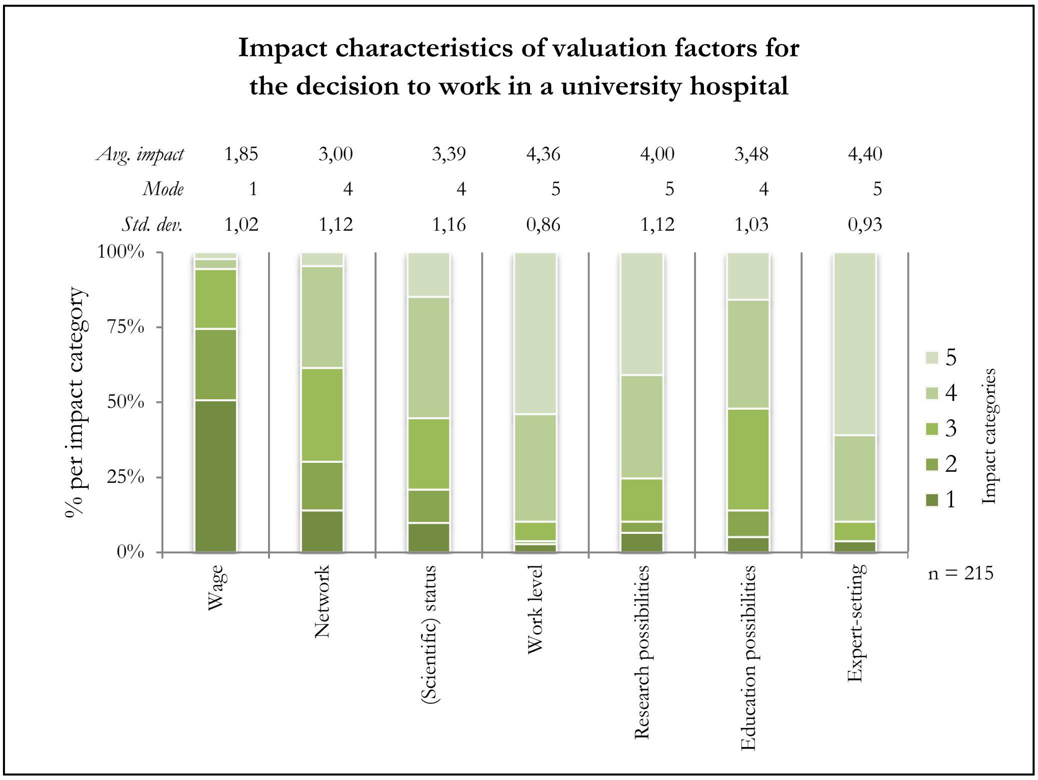

Figure 3.1: Impact characteristics of valuation factors for the decision to work in a university hospital

is found to be the least important factor. In fact, wage is significantly lower (P < 0.0001) than all the other factors. Because wage is typically lower in university hospitals than in regular hospitals, it is logical that wage has a lower impact here. Instead, physicians choose to work in a university hospital because of the high specialization level, the challenging patient groups, and the class leading techniques and equipment (as comprised in work level), as well as the possibility to do research and work with colleagues that are experts in their respective fields. Over 75 percent of the physicians assigned these factors an impact score of 4 or 5. Work level and expert setting also have the smallest standard deviations, which implies there is most consensus among physicians regarding these categories. Network, (scientific) status and education possibilities seem to have a more moderate impact. Some physicians mentioned better possibilities for self-development, less working pressure and flexible working times as additional factors for their decision to work in a university hospital. Furthermore, in some cases individual factors, such as geographical proximity to work of partner, played a role.

The decision to work in a university hospital is, however, not entirely relevant for all physicians because some medical disciplines are practiced only in university hospitals and not in regular

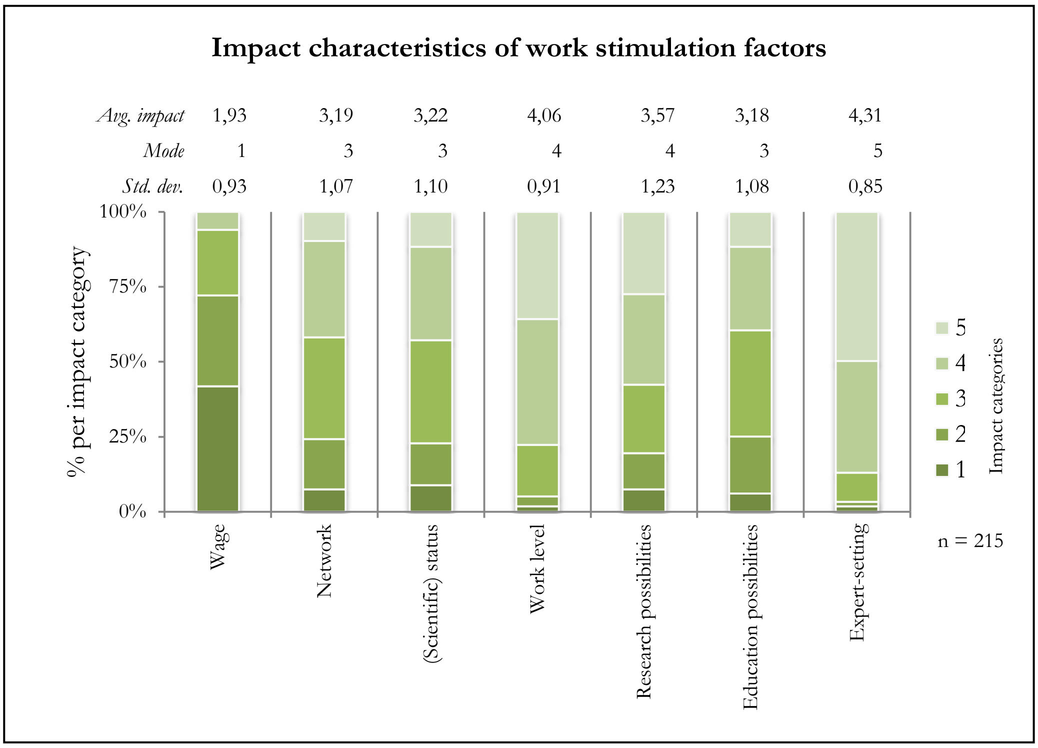

Figure 3.2: Impact characteristics of work stimulation factors

hospitals. The next question – about the impact of work stimulation factors – is relevant for all physicians. It also forms a validation for the outcome of the first question. The impact characteristics for this question are displayed in figure 3.2.

The results are fairly similar to those of the first question. Again, wage has significantly ($P < 0.0001$) the lowest impact among all factors. Interestingly, the standard deviation of wage is one of the lowest. Work level and expert setting give most stimulation and research possibilities again takes the third place. As before, there is most consensus among physicians regarding the impact of work level and an expert setting. Network, (scientific) status and education possibilities are again more moderate. Some physicians stated that reductions of research and education time lead to less stimulation, while they value congress visits. These results give reason to believe that incentive schemes in university hospitals should not focus on wage, but rather on one or more of the other stimulation factors. Over 95 percent of the physicians indicated they derive more work stimulus from research possibilities or scientific status than from wage. Research facilities therefore seem an appropriate incentive.

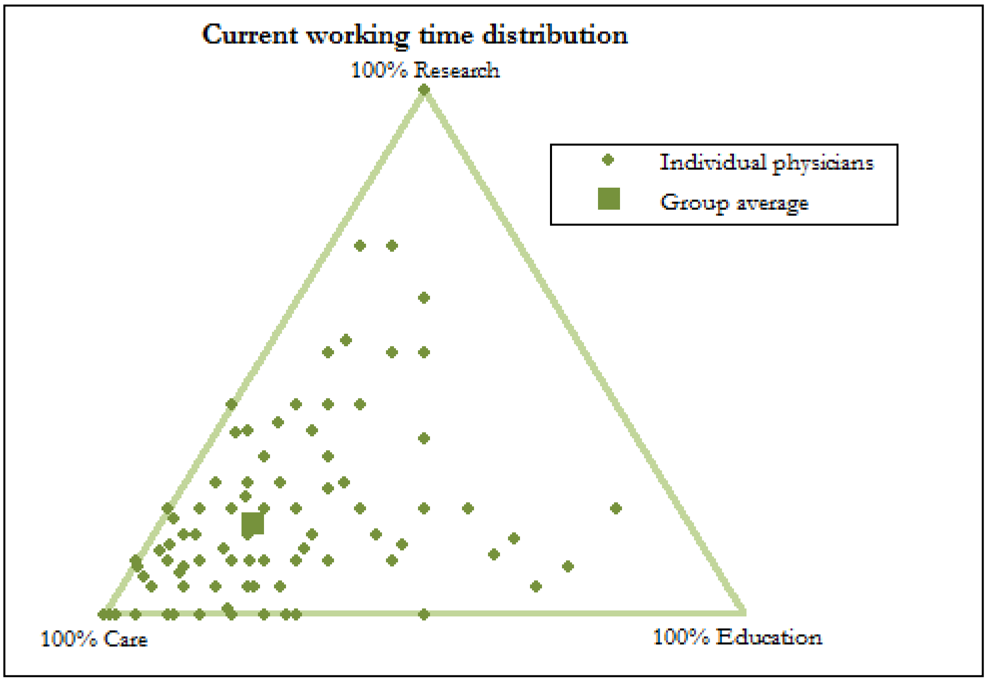

Figure 3.3: Current working time distribution over patient care, research and education

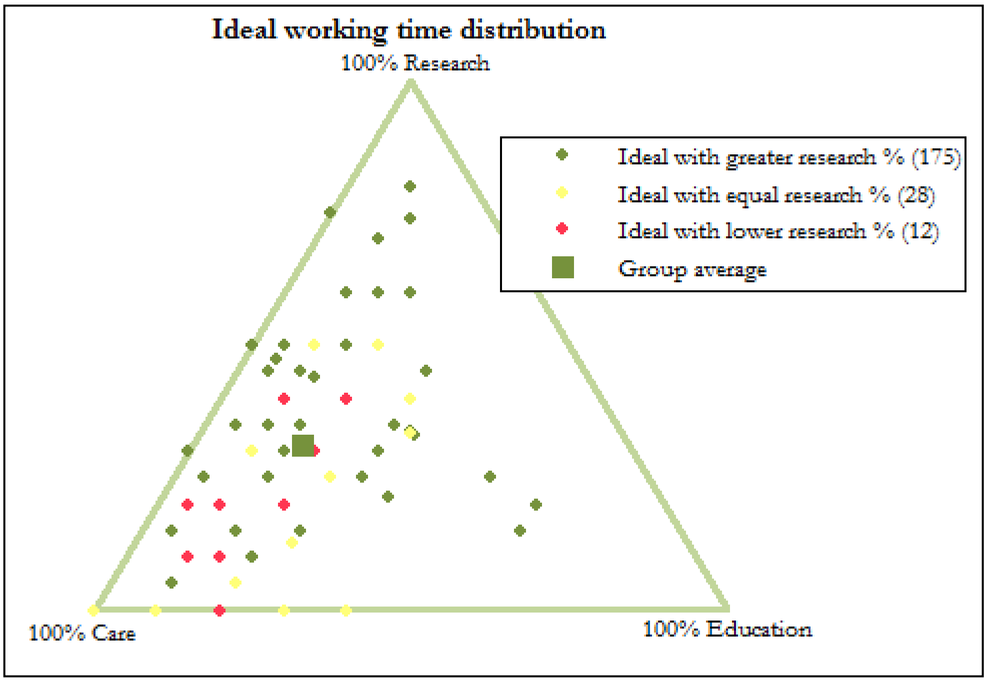

Figure 3.4: Ideal working time distribution over patient care, research and education

Figures 3.3 and 3.4 contain scatterplots of respectively the current and the ideal working time distributions over patient care, research and education.[4] The second plot (figure 3.4) displays in dark green the physicians who have an ideal distribution with more research time than in their current distribution, in yellow the physicians with an ideal containing an equal part of research, and in red the physicians with an ideal containing a smaller part of research. The demand for more research time is clearly visible. 175 physicians (81 %) have an ideal with more research time. Note also the shift in the group average.

The shift in the distribution of the group average has been decomposed in figure 3.5. Compared to the average current distribution the average ideal distribution sees a 3 percentage point increase in education and a 13 percentage point increase in research. Both shifts are significant ($P < 0.01$ and $P < 0.0001$ respectively) and at the dispense of time for patient care (which decreases with 16 percentage point). This suggests that research time – or more broadly: research facilities – can be used as an incentive for a considerable part of the medical specialists.

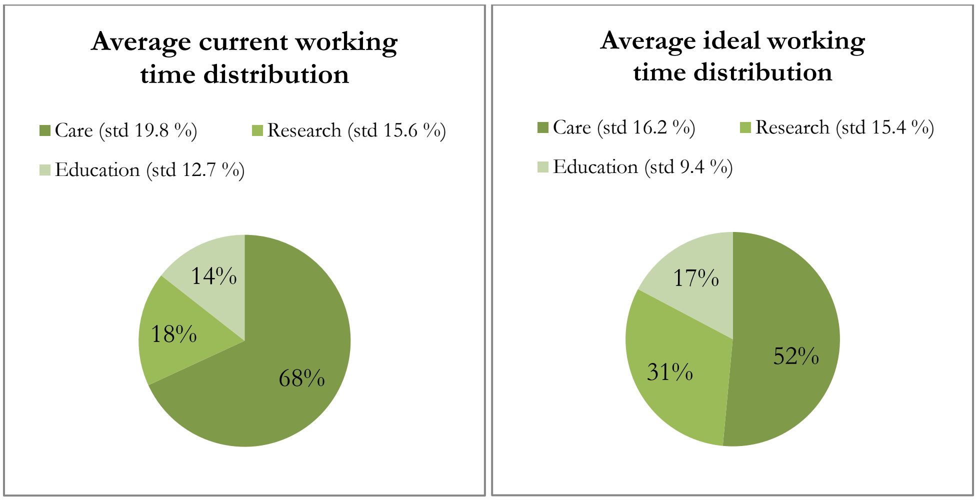

Figure 3.5: Average current and ideal working time distribution (bracketed values denote standard deviation)

[4] Some medical specialists mentioned that their role also holds a management part which is not contained strictly in any of the three areas of care, research and education. 27 had assigned percentages which did not total up to 100 %. Their answers have been rescaled to total up to 100 %.

Of course the ideal distribution displayed in figure 3.5 may not be directly desirable from the hospital's point of view, because less patient care is not in line with its mission statement and is not socially justifiable. Nevertheless, the allocation of research facilities can be used as a smart incentive if it improves the overall university hospital performance (composed of patient care, research and education), leading patients to be better off as well.

Chapter 4

A stylized model

Starting our analysis, this chapter presents a stylized principal-multi-agent model for the allocation of research facilities to physicians in university hospitals. We will first introduce the framework in which we will address this problem and then proceed with a mathematical representation.

4.1 The framework

Consider two physicians employed at a university hospital.[5] The hospital wants to perform in two areas: research and care[6]. In order to achieve performance the hospital needs input from its physicians. The input from the physicians is given as 'effort in research' and 'effort in care'.[7] Individual effort is not directly observed, but individual performance is. Performance on care is a function of effort in care and depends on a parameter for 'care-ability'. Performance on research is a function of effort in research and depends on parameters for 'research-ability' and 'available research facilities'. The ability parameters are private information to each physician. Each physician can set his effort levels independently.

[5] Our results generalize to the case of an arbitrary number $n > 2$ of physicians

[6] For simplicity education is omitted as a performance area, this does not affect our results qualitatively

[7] Instead of interpreting the effort levels as 'total' levels, we may also interpret them as levels of 'extra' effort which is given beyond a required base level

The hospital first offers the physicians a contract, which they can accept or reject. Next, the physicians decide simultaneously how much effort they exert. After all physicians have set their effort levels the physicians are rewarded with a financial compensation (a wage) and with research facilities. In equilibrium it holds that initially available research facilities are equal to those awarded at the end of the game. The mechanism by which wage and research facilities are awarded is known to all physicians. Physicians have a valuation for wage and research facilities[8]. Physicians may differ in their valuations depending on their individual 'preference'. The valuation function, parameterized on physician preference for research facilities, is common over all physicians but a physician's preference is private information to each physician. All physicians further incur a cost (or 'disutility') that is increasing with their effort.

We refer to the combined 'preference' and 'ability' parameters of a physician as a physician's 'type'. The valuation and cost functions can then be captured in a single utility function parameterized on this type. Each physician chooses his effort levels in order to maximize expected utility. A physician's choice of effort levels is called a physician's 'strategy'. Each physician also has an outside utility, i.e. the utility he could obtain if he would not work for this hospital.

The objective of the university hospital is to maximize the weighted sum of (i) total care performance and (ii) total research performance over physicians. Our goal is to specify an allocation mechanism that will maximize this objective based on the physicians' strategies in equilibrium. The strategies that physicians select in equilibrium are computed by a game theoretic equilibrium concept (see e.g. Osborne, 2004).

Based on this framework we can proceed to the mathematical model presented in the next section.

4.2 Formal model definition

Consider a university hospital with two physicians indexed $i = 1, 2$. There are two performance categories: care and research, and two reward categories: wage and research facilities. Each

[8] Changing the framework to incorporate a valuation for research performance instead of research facilities does not change our results qualitatively.

physician i is characterized by a type $\theta_i = (a1_i, a2_i, r_i)$ where $a1_i \in [0,1]$ and $a2_i \in [0,1]$ are ability-parameters for respectively care and research, and $r_i \in [0,1]$ is a valuation parameter for research facilities. Valuation parameters are scaled such that $P(r_i = 0) = P(r_i = 1) = 0$. The type of physician i is private information to physician i. Let Θ denote the set of possible types to each physician. By delivering effort each physician i can obtain a wage $\omega_i \in \mathbb{R}_+$ and a share of research facilities $\rho_i \in [0,1]$. By normalization it holds that $\sum_i \rho_i \leq 1$.

First, the hospital offers each physician i a contract which it can accept or reject. Next, each physician i simultaneously selects a level for care-effort $e1_i \in \mathbb{R}_+$ and research-effort $e2_i \in \mathbb{R}_+$. Denote the effort tuple $(e1_i, e2_i)$ as the strategy $s_i \in \Sigma$ of physician i, where $\Sigma = \mathbb{R}_+^2$. With strategy s_i each physician i realizes a performance level $p1(e1_i; a1_i) \in \mathbb{R}_+$ for care [9] (parameterized on his care ability $a1_i$) and a performance level $p2(e2_i; a2_i, \rho_i) \in \mathbb{R}_+$ for research[10] (parameterized on his research ability $a2_i$ and his available research facilities ρ_i). The levels of effort are not directly observable and measurable, but the performance levels are. The performance functions are concave in effort and strictly increasing. We denote the set of all observable performance characteristics of all physicians under strategy profile $s = (s_1, s_2)$ by $P_s = \{p1_1, p1_2, p2_1, p2_2\}$.

Then each physician i receives a wage ω_i and a share of research facilities ρ_i according to an allocation mechanism $g(\cdot)$. Because of equilibrium, initially available research facilities are equal to research facilities awarded at the end of the game. If we denote with O the possible set of allocation outcomes such that each outcome $o \in O$ contains the wage ω_i and research facilities ρ_i obtained by each physician i for delivering efforts $e1_i$ and $e2_i$, the allocation mechanism $g: \mathbb{R}^{m+n} \to O$ is such that $g(P_s)$ is the allocation outcome for strategy profile $s = (s_1, s_2)$. The allocation mechanism $g(\cdot)$ is known ex ante to all physicians.

Each physician i has a valuation $v(\omega_i, \rho_i; r_i)$ for the wage ω_i and the research facilities ρ_i he obtains (parameterized on his research facilities valuation parameter r_i). The valuation function is strictly concave and satisfies the conditions $v_\omega(\cdot) > 0$ and $v_\rho(\cdot) > 0$, and $\frac{\delta v_\rho}{\delta \omega_i} = 0$, where subscripts to functions denote partial derivatives. Each physician also incurs a cost for the efforts $e1_i$ and $e2_i$ he delivers. Combining valuation and cost we let

9 In the remainder we will occasionally use $p1_i$ as shorthand notation for the care performance $p1(e1_i; a1_i)$ of agent i

10 $p2_i$ is shorthand notation for the research performance $p2(e2_i; a2_i, \rho_i)$ of agent i

$$u_i(\sigma;\theta_i) = v(\omega_i, \rho_i; w_i, r_i) - e1_i - e2_i \tag{4.1}$$

denote the quasi-linear utility of outcome $\sigma \epsilon \mathcal{O}$ to physician i with type θ_i. This utility is such that outcome σ_1 is preferred to outcome σ_2 if and only if $u_i(\sigma_1;\theta_i) > u_i(\sigma_2;\theta_i)$. Each physician has an outside utility $\bar{U}(a1_i, a2_i)$ which is increasing with ability.

The objective of the university hospital is to maximize hospital performance $\mathcal{H}(\sigma;\theta)$ defined as

$$\mathcal{H}(\sigma;\theta) = \alpha \sum_i p1(e1_i, a1_i) + \beta \sum_i p2(e2_i; a2_i, \rho_i) - \sum_i \omega_i \tag{4.2}$$

where α and β are weights the hospital assigns to respectively care performance and research performance, and $\theta = (\theta_1, \theta_2)$ are the types of all physicians. Our goal is to specify an allocation mechanism $g(\cdot)$ that implements the optimal outcome based on the physicians' strategies in equilibrium.

4.3 Solution approach

We will use the following solution approach to analyze and solve the hospital's problem within the context of the mathematical model described above.

As a benchmark we start in chapter 5 by analyzing the hospital's optimal decision when all information (including effort) is perfectly observable and can be contracted upon. Because of the complete contractibility the resulting contract is called a *complete contract*. In particular, this first step gives us what is called the first-best contract in principal-agent theory. We also do this for the case that the current wage system is left intact. For ease of analysis we separately consider homogeneous physicians before proceeding to heterogeneous physicians.

The derived complete contracts constitute the mechanism design concept of a *social choice function*. A social choice function $f: \Theta^2 \rightarrow \mathcal{O}$, where Θ is the set of possible physician types, and $\mathcal{O}$ the set of possible outcomes, is a representation of the desirable outcome for every set of physician types. The social choice function is important because once we have a social choice function we can look for a mechanism that implements it. That is, for a group equilibrium strategy concept σ which associates with type set $\theta \in \Theta^2$, the set of strategies $\sigma(\theta)$, that are equilibrium or stationary strategies for all physicians, we can look for an outcome function g which translates strategies into outcomes such that for all $\theta \in \Theta^2$ the outcome $g(\sigma(\theta))$ is identical to the outcome $f(\theta)$ of the social choice function. This relation is represented graphically in figure 4.1.

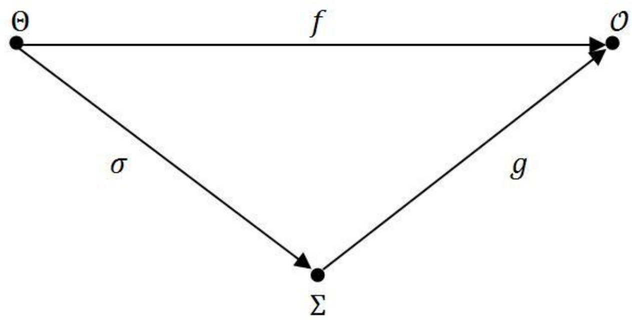

Figure 4.1: Relation social choice function and mechanism

The derivation of the optimal mechanism that implements the complete contracts is given in chapter 6. Because in this chapter the complete observability of effort is dropped, the resulting contracts are called *incomplete contracts*. Physician types are still considered to be perfectly observable. We pay particular attention to the consequences of ignoring heterogeneity and we give a comparison of the optimal contracts with the 'current' contracts.

In chapter 7 we extent to the case that information on physician types is not observable, but instead must be revealed through physicians. This requires the formulation of specific conditions for truthful revelation and the derivation of a new complete contract. The conditions on the optimal incentive system follow.

Chapter 5

Complete contracts

We first analyze a benchmark scenario where complete contractibility is possible. Complete contractibility implies a complete and exact agreement can be made on the delivered effort and on the rewarded wage and research facilities. The pool of workers is considered fixed. Under a complete contract a physician's wage consists only of a base salary and his available research facilities consist only of a base endowment. A physician's effort levels are precisely specified; there is no variability. In order to clearly examine the relevant aspects of the contracts, we distinguish two situations: (i) homogeneous physicians and (ii) heterogeneous physicians.

5.1 Homogeneous physicians

Consider a hospital with two homogeneous physicians. As now $\theta_1 = \theta_2$ we omit the type parameterization in the functions below for ease of exposition. The hospital's optimization problem is:

$$\max \ \mathcal{H}(\sigma) = \alpha \cdot \sum_i p1(e1_i) + \beta \cdot \sum_i p2(e2_i; \rho_i) - \sum_i \omega_i \tag{5.1}$$

subject to the individual rationality (or *participation*) constraints:

$$u_i(\sigma) = v(\omega_i, \rho_i) - e1_i - e2_i \geq \bar{U} \qquad i = 1,2 \tag{5.2}$$

and the research facilities constraint:

$$\sum_i \rho_i \leq 1 \tag{5.3}$$

For $e1_i, e2_i, \omega_i \in \mathbb{R}_+$ and $\rho_i \in [0,1]$.

The first-best levels of effort, wage and research facilities are described in Proposition 5.1.

PROPOSITION 5.1 [Complete contract with homogeneous physicians]

A complete contract for homogeneous physician's is optimal if and only if it has the following properties:

1. Effort levels of each physician are strictly positive and equal over physicians. The optimal effort levels equate the marginal benefit to the hospital in both performance categories to the marginal cost of effort relative to the marginal physician valuation for extra wage:

$$\alpha \cdot p1_{e1}(e1_i) = \beta \cdot p2_{e2}(e2_i) = \frac{1}{v_\omega(\omega_i, \rho_i)}$$

2. All research facilities are allocated and each physician holds an equal share of research facilities:

$$\rho_i = \frac{1}{2} \qquad\qquad i = 1,2$$

3. The wage makes each physician indifferent between accepting and rejecting the contract, given the optimal levels of effort and research facilities:

$$\omega_i = v^{-1}(\bar{U} + e1_i + e2_i; \rho_i) \qquad\qquad i = 1,2$$

The proof is given in the appendix.

The complete contract sets effort levels that maximize the joint surplus. Utility is equal for all physicians. Through the allocation of research facilities the hospital boosts research performance, and is able to pay a lower wage to the physicians than without the allocation of research facilities. This is the basic situation in university hospitals, where a lower wage is paid than in regular hospitals.

It is interesting to see what happens if the current wage system is left intact and only the research facilities allocation system can be changed. This situation has more practical relevance as changing wages is likely to encounter resistance from physicians (if wage is lowered) or from society (if substantial financial stimulation is introduced). Moreover, from chapter 3 we have learned that research facilities are likely to have more impact than wage as an incentive within university hospitals.

We therefore take the current wage levels as given. We suppose they are predetermined at separate levels $\omega_1 \neq \omega_2$. We assume theses wages are feasible in the sense that they allow at least one possible allocation of research facilities in which none of the participation constraints is violated. The properties of the optimal contract now change. In particular, the optimal allocation of research facilities is not equal over physicians, as can be seen from Proposition 5.2.

PROPOSITION 5.2 [Complete contract with homogeneous physicians and predetermined wage]

If wages are predetermined at different – but feasible – levels, a complete contract for homogeneous physicians is optimal if and only if it has the following properties:

1. Effort levels of each physician are strictly positive. For each physician the optimal effort levels equate the marginal benefit to the hospital in both performance categories:

$$\alpha \cdot p1_{e1}(e1_i) = \beta \cdot p2_{e2}(e2_i)$$

2. The total of contracted effort makes each physician indifferent between accepting and rejecting the contract, given the optimal levels of research facilities and the predetermined wage:

$$e1_i + e2_i = v(\omega_i, \rho_i) - \bar{U} \qquad i = 1,2$$

3. All research facilities are allocated and the allocation is such that the net marginal benefit of allocating research facilities to a physician is equal over all physicians:

$$MA_1 = MA_2$$

where

$$MA_i = \beta \cdot p2_\rho(e2_i; \rho_i) + v_\rho(\omega_i, \rho_i) \cdot \beta \cdot p2_{e2}(e2_i; \rho_i) \tag{5.4}$$

Again, the proof is given in the appendix.

In this case effort levels are only equal for all physicians if there are sufficient research facilities to offset the utility differences caused by the wage differences. Otherwise, physicians with a higher wage are contracted to deliver more effort. The distribution of effort over care and research is such that the marginal benefits to the hospital for care and research are equal. Moreover, research facilities are allocated so as to create most benefit, which means the marginal allocation benefit must be equal over all physicians. This marginal allocation benefit is composed of a direct component resulting from the 'use' of research facilities (the first term in (5.4)), and an indirect component resulting from the effort that can be induced with research facilities (the second term in (5.4)).

Note that the marginal allocation benefit also represents the shadow price of research facilities, i.e. the marginal increase in performance if more research facilities are made available. This gives the optimality condition when the total of available research facilities is freely determinable (e.g. the budget for research facilities is not predetermined): the marginal cost of providing research facilities should then be equated to the marginal allocation benefit.

5.2 Heterogeneous physicians

Consider next the heterogeneous case in which the physicians differ in ability. We have two heterogeneous physicians, with each physician i having type θ_i. The full form hospital optimization problem is now given by:

$$\max\ \mathcal{H}(\sigma;\theta) = \alpha \cdot \sum_i p1(e1_i; a1_i) + \beta \cdot \sum_i p2(e2_i; a2_i, \rho_i) - \sum_i \omega_i \tag{5.5}$$

subject to the individual rationality constraints:

$$u_i(\sigma;\theta) = v(\omega_i, \rho_i; r_i) - e1_i - e2_i \geq \overline{\overline{U}}(a1_i, a2_i) \qquad i = 1,2 \tag{5.6}$$

and the research facilities constraint:

$$\sum_i \rho_i \leq 1 \tag{5.7}$$

For $e1_i, e2_i, \omega_i \in \mathbb{R}_+$ and $\rho_i \in [0,1]$.

We omit the case where wage is undetermined and consider immediately the interesting case where the current wage system is left unaffected and only the research facilities allocation system is introduced. The wages are fixed at predetermined – possibly separate – levels. The optimal levels of effort and research facilities are then described in Proposition 5.3 which is similar to Proposition 5.2.

PROPOSITION 5.3 [Complete contract with heterogeneous physicians and predetermined wage]

If wages are predetermined at different – but feasible – levels, a complete contract for heterogeneous physicians is optimal if and only if it has the following properties:

1. Effort levels of each physician are strictly positive. For each physician the optimal effort levels equate the marginal benefit to the hospital in both performance categories:

$$\alpha \cdot p1_{e1}(\, e1_i \,; a1_i) = \beta \cdot p2_{e2}(\, e2_i \,; a2_i, \rho_i)$$

2. The total of contracted effort makes each physician indifferent between accepting and rejecting the contract, given the optimal levels of research facilities and the predetermined wage:

$$e1_i + e2_i = v(\omega_i, \rho_i; r_i) - \bar{\bar{U}}(a1_i, a2_i) \qquad i = 1,2$$

3. All research facilities are allocated and the allocation is such that the net marginal benefit of allocating research facilities to a physician is equal over all physicians:

$$MA_1(\theta_1) = MA_2(\theta_2)$$

where

$$MA_i(\theta_i) = \beta \cdot p2_\rho(e2_i; a2_i, \rho_i) + v_\rho(\omega_i, \rho_i; r_i) \cdot \beta \cdot p2_{e2}(e2_i; a1_i, \rho_i) \qquad (5.8)$$

The proof is identical to the proof of Proposition 5.2, except for parameterization in the functions.

The dependency of the optimal complete contract on physician ability is that physicians who are better in care than in research, are contracted to do relatively more care than research, and vice versa (property 1 of Proposition 5.3). Furthermore, the higher a physician's abilities, the more research facilities he receives. An experienced professor therefore optimally obtains more research facilities than a starting physician. Research facilities allocation is also influenced by research facilities valuation, with physicians with a higher valuation receiving more facilities. The inducement effect is larger for these physicians, i.e. they are willing to work harder for the same amount of research facilities. Finally, when a physician receives more research facilities, he will also be contracted to deliver more effort.

Note that even if the wage system was not predetermined, the allocation of research facilities would still be related to care performance – the expression for the marginal allocation benefit of research facilities remains unchanged. The only real difference between the two scenario's is the marginal benefit to the hospital in each performance category (property 1). If the wage system is not predetermined these marginal benefits are equated to the marginal cost of effort relative to the marginal physician valuation for extra wage (just as we have seen in Proposition 5.1).

The contract described by Proposition 5.3 holds some perverse incentives if physicians would have to reveal to reveal their type in order to implement the contract (recall that physician types are actually private information to the physicians). By pretending to have a lower research facilities valuation, physicians could obtain a higher utility. To see why this holds, note that the contract wants to equate the utility of all physicians to their outside utility $\bar{U}$. If physicians report their true types their utility will indeed be equated to $\bar{U}$. However, if a physician lies about his type, and claims he has a higher valuation than he actually has, he will be contracted to deliver more effort and receive more research facilities. However, as the amount of extra research facilities is computed based on his revealed (higher) type, and not on his true (lower) type, the extra research facilities will not be enough to offset the costs of extra effort. Hence, the physician will obtain a utility level below $\bar{U}$. The reverse holds if a physician claims to have a lower valuation than he actually has, he will then obtain a utility level above $\bar{U}$. Should physicians also have to reveal their ability, they will be inclined to pretend to have a higher ability. Therefore the contract will induce physicians to lie about their type.

It becomes evident now that – under private information – contracts need to satisfy another condition: incentive compatibility. Indeed, it is not at all trivial how to implement contracts with this condition. We will treat this matter in chapter 7. In the next chapter we will first extend the contracts to the more realistic scenario in which effort is not contractible.

Chapter 6

Incomplete contracts

We now proceed to the scenario where physician effort is not completely contracted upon. Instead, the physicians receive a reward proportional to their performance and they choose their effort levels strategically as in a game. Now incentives begin to play a role. We again distinguish the situations that physician types are equal, and that physician types are unequal.

6.1 Homogeneous physicians

As before we have two homogeneous physicians. And as $\theta_1 = \theta_2$ we omit the type parameterization in the functions below for ease of exposition. We consider again the case that wage is predetermined (the original wage system is left intact), so that ω_i is a constant for each physician i.

We need the following definition.

DEFINITION 6.1 [(Strictly) concave allocation mechanism]

An allocation mechanism $g(\cdot)$ through which the research facilities ρ_i of physician i are determined by $\rho_i = g^{\rho_i}(\cdot)$ with $g^{\rho_i}(\cdot)$ a concave function is called a concave allocation mechanism. It is called a strictly concave allocation mechanism if the function $g^{\rho_i}(\cdot)$ is strictly concave.

Recall that in the first stage of the game the hospital offers the physicians a contract which they can accept or reject. In the next stage the physicians decide on the level of effort they exert. We solve the contract design problem of the hospital by backward induction, starting with the physician's choice of effort levels.

Physician's problem

Given the strategy s_j of physician $j \neq i$, and given a concave allocation mechanism $g(\cdot)$ through which the research facilities ρ_i of physician i are determined by $\rho_i = g^{\rho_i}(P_s)$, P_s being the set of all performance characteristics of all physicians under strategy profile $s = (s_i, s_j)$, every physician i faces the problem:

$$\max \ u_i(\sigma) = v(\omega_i, \rho_i) - e1_i - e2_i \tag{6.1}$$

subject to the allocation constraint:

$$\rho_i - g^{\rho_i}(P_s) = 0 \tag{6.2}$$

For $e1_i, e2_i \in \mathbb{R}_+$ and $\rho_i \in [0,1]$.

Solving the above problem yields the conditions for the best response of physician i to the strategy of the other physician. This leads to the following Lemma.

LEMMA 6.1 [Best response function for homogeneous physicians and predetermined wage]

In the case of homogeneous physicians and predetermined wage, the best response function $b^{BR}{}_i(s_j)$ of a physician i under a concave allocation mechanism $\rho_i = g^{\rho_i}(P_s)$ to the strategy s_j of the other physician, is given by:

$$b^{BR}{}_i(s_j) = s_i^*$$

where $s_i^* = (e1_i^*, e2_i^*)$ is such that the marginal reward (in terms of utility) to care effort, as well as the marginal reward to research effort, multiplied with a performance boost from extra research facilities, is equal to the marginal cost of effort. I.e. s_i^* satisfies:

$$MC_i \cdot MP_i = MR_i \cdot MP_i = 1 \tag{6.3}$$

where

$$MC_i = v_\rho(\omega_i, \rho_i) \cdot g^{\rho_i}_{p1_i}(P_s) \cdot p1_{e1}(e1_i)$$

$$MR_i = v_\rho(\omega_i, \rho_i) \cdot g^{\rho_i}_{p2_i}(P_s) \cdot p2_{e2}(e2_i; \rho_i)$$

$$MP_i = \frac{1}{1 - g_{p2_i}^{\rho_i}(\cdot) \cdot p2_\rho(e2_i; \rho_i)}$$

For proof, see the appendix.

In Lemma 6.1 MC_i and MR_i denote the marginal valuation for extra research facilities multiplied with the marginal return (in terms of research facilities) to respectively care effort and research effort. MP_i denotes a self-multiplication factor for research facilities. Note that this self-multiplication factor $\left(1 - g_{p2_i}^{\rho_i}(\cdot) \cdot p2_\rho(\cdot)\right)^{-1}$, represents the snowball effect in the allocation of research facilities (because of their contribution to research performance). In determining their effort levels the physicians take this performance boost in account.

If the hospital has installed individual incentives, the physician's research facilities increase with his effort. However, if the hospital gives team or relative incentives, the efforts of the other physician affect physician i's outcome. Therefore the best response function will depend on the strategy of the other physician. If the allocation mechanism is strictly concave, the best response function is injective, i.e. for every strategy of the other physician each physician has one unique best response strategy. Besides the benefits of extra research facilities, there is also a cost of providing effort. The optimal effort levels equate these benefits and costs at the margin. Note that wage plays no role in the physicians problem, as we have assumed that research facilities valuation is independent of wage.

We now proceed to the hospital's maximization problem.

Hospital's problem

The hospital's optimization problem is:

$$\max \ \mathcal{H}(g(\cdot)) = \alpha \cdot \sum_i p1(e1_i) \ + \beta \cdot \sum_i p2(e2_i; g^{\rho_i}(\cdot)) - \sum_i \omega_i \qquad (6.4)$$

subject to the individual rationality constraints which are required for the physicians to accept the contract:

$$v(\omega_i, g^{\rho_i}(\cdot)) - e1_i - e2_i \geq \bar{U} \qquad i = 1,2 \tag{6.5}$$

the research facilities constraint:

$$\sum_i g^{\rho_i}(\cdot) \leq 1 \tag{6.6}$$

and the four equilibrium constraints from the best response function described by (6.3).

It turns out that the hospital can achieve the effort and profit levels of the optimal complete contract described by Proposition 5.2. The required incentive scheme is described by Proposition 6.1.

PROPOSITION 6.1 [Incomplete contract with homogeneous physicians and predetermined wage]

When effort cannot be contracted, but performance can, and when wages are predetermined at different – but feasible – levels, the optimal incomplete contract for homogeneous physicians consists of relative incentives and a base allocation of research facilities.

Optimal relative incentives for research performance are described by:

$$g_{p2_i}^{\rho_i}(P_s) = \frac{\beta}{MA_j} \tag{6.7}$$

and optimal relative incentives for care performance are described by:

$$g_{p1_i}^{\rho_i}(P_s) = \frac{\alpha}{MP_i \cdot MA_j}(1 - \frac{\beta}{MA_j} \cdot \frac{\delta p2_j}{\delta \rho_j}) \tag{6.8}$$

where MA_i is as described by (5.4) and MP_i is as described by (6.3).

The level of the base allocation follows from the participation constraints (6.5).

The proof is in the appendix.

The hospital can obtain maximum profits by including relative incentives in the contract. In the optimum, the incentives are chosen such that every physician delivers optimal effort, given that the other physicians deliver optimal effort (Nash equilibrium). The contract is ex ante budget balanced, i.e. in expectation the research facilities allocation constraint (6.6) is satisfied.

The incentives for research performance are increasing with the research performance of the other physician. The reason is that we want to equate the marginal allocation benefit of research facilities over physicians, as we have seen in the complete contract (Proposition 5.2). If one physician delivers more effort and earns more research facilities this decreases his marginal allocation benefit. Hence, as the other physician now has a relatively higher marginal allocation benefit, his research facilities incentives should be increased. This incentive structure has the advantage that it encourages the support of co-workers. The same holds for incentives for care performance. Care incentives, however, also decrease with the physician's own research efforts. This makes the allocation rule strictly concave in performance. This concavity was required for solving the physician's choice of effort problem.

The non-linear shape of the allocation rule has two disadvantages. First, deriving the closed form of the allocation rule is difficult (if not impossible). Second, the non-intuitivity of the rule makes selling the contract to physicians difficult. However, the contract can easily be turned into a linear contract with individual incentives by evaluating the relevant terms at the optimal levels described in Proposition 5.2. This linear contract with individual incentives will lead to the same profits and is also ex ante budget balanced. It is of the form:

$$g^{\rho_i}(P_s) = g^{\rho_i}_{p1_i}(P_s^*) \cdot p1_i + g^{\rho_i}_{p2_i}(P_s^*) \cdot p2_i + A_i^* \tag{6.9}$$

where $g^{\rho_i}_{p1_i}(P_s^*)$ and $g^{\rho_i}_{p2_i}(P_s^*)$ are as described in Proposition 6.1 but evaluated in the optimum characteristics derived from Proposition 5.2, and where A_i^* is the base allocation following from the participation constraints (6.5). Note that a physician's wage plays no role beyond the determination of the base allocation.

The linear contract with individual incentives has the added benefit that it constitutes a dominant strategy equilibrium, which is stronger than Nash equilibrium. Moreover, it eliminates the concern about multiplicativity of equilibria (multiple Nash equilibria might exist; there is only one dominant strategy equilibrium).

6.2 Heterogeneous physicians

In the case of heterogeneous physicians the derivation of the optimal incomplete contract is analogous to the homogeneous case. Therefore we omit the rigorous presentation of the heterogeneous problems and proceed directly to the results. As we will see the general concepts of the contract remain the same. There are however several particular effects of heterogeneity that we will discuss. In addition to the optimal incomplete contract under the current wage system we present two other scenarios. The first scenario examines the consequences of ignoring heterogeneity. The second scenario examines the situation in which research facilities allocation is only based on research performance and there is no coupling with care performance (which reflects the current situation).

First, the best response function for heterogeneous physicians is described in Lemma 6.2.

LEMMA 6.2 [Best response function for heterogeneous physicians and predetermined wage]

In the case of heterogeneous physicians and predetermined wage, the best response function ${b^{BR}}_i(s_j)$ of a physician i under a concave allocation mechanism $\rho_i = g^{\rho_i}(P_s)$ to the strategy s_j of the other physician, is given by:

$$ {b^{BR}}_i(s_j) = s_i^* $$

where $s_i^* = (e1_i^*, e2_i^*)$ is such that the marginal reward (in terms of utility) to care effort, as well as the marginal reward to research effort, multiplied with a performance boost from extra research facilities, is equal to the marginal cost of effort. I.e. s_i^* satisfies:

$$ MC_i(\theta_i) \cdot MP_i(\theta_i) = MR_i(\theta_i) \cdot MP_i(\theta_i) = 1 \qquad (6.10) $$

where

$$ MC_i(\theta_i) = v_\rho(\omega_i, \rho_i; r_i) \cdot g^{\rho_i}_{p1_i}(P_s) \cdot p1_{e1}(e1_i; a1_i) $$

$$ MR_i(\theta_i) = v_\rho(\omega_i, \rho_i; r_i) \cdot g^{\rho_i}_{p2_i}(P_s) \cdot p2_{e2}(e2_i; \rho_i, a2_i) $$

$$ MP_i(\theta_i) = \frac{1}{1 - g^{\rho_i}_{p2_i}(P_s) \cdot p2_\rho(e2_i; \rho_i, a2_i)} $$

Heterogeneity has three effects on a physician's optimal effort levels. First, when a physician's ability in either care or research increases he finds it optimal to exert more effort in that category. Second, when a physician's ability in research increases the performance boost from research facilities MP_i increases and hence the physician will find it optimal to exert more effort in general (in both effort categories). Third, the optimal effort levels increase with valuation for research facilities. This last effect represents the fact that physicians who have more valuation for research facilities are willing to work harder to obtain them.

In the previous stage of the game the hospital optimally offers the physicians the contract described by Proposition 6.2.

PROPOSITION 6.2 [Incomplete contract with heterogeneous physicians and predetermined wage]

When effort cannot be contracted, but performance can, and when wages are predetermined at different – but feasible – levels, the optimal incomplete contract for heterogeneous physicians consists of relative incentives and a base allocation of research facilities.

Optimal relative incentives for research performance are described by:

$$g_{p2_i}^{\rho_i}(P_s) = \frac{\beta}{MA_j(\theta_j)} \tag{6.11}$$

and optimal relative incentives for care performance are described by:

$$g_{p1_i}^{\rho_i}(P_s) = \frac{\alpha}{MP_i(\theta_i) \cdot MA_j(\theta_j)}(1 - \frac{\beta}{MA_j(\theta_j)} \cdot \frac{\delta p2_j}{\delta \rho_j}) \tag{6.12}$$

where $MA_i(\theta_i)$ is as described by (5.8) and $MP_i(\theta_i)$ is as described by (6.10).

The level of the base allocation follows from the participation constraints (6.5).

Heterogeneity affects the optimal incomplete contract as follows. Care ability has no effect on incentives, it only increases the base allocation. Research ability affects care incentives and the base allocation, which both increase with ability. The research ability of the other physician, however, has a negative effect on both care and research incentives. Hence, it pays to be better in research than the other physician. Both care and research incentives are further influenced negatively by research facilities valuation of the other physician.

Just as in the homogeneous case, the contract can be turned into a linear contract with individual incentives. The form is identical to (6.9).

Incentive compatibility still is an issue, should the contract be extended to the case of private information. Physicians can obtain higher utilities by pretending to have higher ability or higher valuation[11]. If they do, they will deliver less than optimal effort.

Ignoring heterogeneity

It is interesting to examine the consequences of ignoring heterogeneity. This will allow us to identify the real impact of heterogeneity on the optimal contracts.

If heterogeneity is ignored, all physicians are offered the same contract, which is specified in Proposition 6.1. Let us assume the standardized homogeneous type is an average of the heterogeneous types. Physicians, however, will set their effort levels according to condition (6.10) which is based on their type. As a result the following equilibrium conditions hold:

$$MA_i(\theta_i) = MA_j \qquad i = 1,2 \qquad j \neq i$$

These conditions correspond to the third property of Proposition 5.3 (marginal allocation benefit), but in contrast to the optimal conditions they do *not* equate marginal allocation benefit over physicians. Instead they equate the marginal allocation benefit of a physician to the *computed* marginal allocation benefit of the standardized homogenous type under the optimal complete contract for homogeneous physicians. It is clear that the optimality conditions are not satisfied and the hospital performance is suboptimal.

Further comparison with the optimum reveals that the participation constraint will no longer be binding. In the optimum the utility of physicians is equal to their outside utility, but if heterogeneity is not taken in account physicians with lower abilities than the standardized

[11] This is a difference with the optimal complete contract, where physicians could do better by pretending to have a lower valuation. This difference arises because physicians can now choose their effort levels themselves.

homogeneous type will make a rent – they profit from a higher base allocation and higher incentives – whereas physicians with higher abilities will obtain a lower utility – they have a lower base allocation and lower incentives than they should have. The same holds with respect to research facilities valuation.

Therefore, if heterogeneity is ignored, retention of physicians – especially higher talented physicians – becomes a problem. If ability is verifiable, e.g. through tests and exams or just over time in practice, but research facilities valuation is ignored, the hospital will have difficulty retaining physicians with higher valuations. Over time this will reduce the power of research facilities incentives. Hence, ignoring heterogeneity erodes hospital performance both directly (through setting suboptimal incentives) and indirectly (as the most talented and the most keen to work physicians may be lost).

The 'current' situation

In the 'current' situation there is no coupling between research facilities allocation and care performance. We will examine the differences between the optimal incentive system in this current situation and the optimal incentive system we have derived earlier. We demonstrate that not coupling research facilities allocation to care performance is not optimal.

In case research facilities are only allocated in response to research performance, the optimal allocation rule is of the form:

$$g^{\rho_i}(P_s) = g^{\rho_i}_{p2_i}(P_s^*) \cdot p2_i + A_i^*$$

where

$$g^{\rho_i}_{p2_i}(P_s) = \frac{\beta}{MA_j(\theta_j)}$$

As we have implied, there are no incentives for care performance through research facilities allocation. Therefore, in the absence of other incentives for care, hospital care performance will be suboptimal. In fact, without incentives, economic theory predicts that the effort levels in care are zero.

This means, however, that due to the participation constraint (which binds in the optimum):

$$v(\omega_i, \rho_i; r_i) - e1_i - e2_i = \bar{U}(a1_i, a2_i) \qquad i = 1,2$$

the efforts delivered in research are higher than under the optimal incentive system we have derived. Also, because research facilities are only allocated in response to research performance, more research facilities will be allocated to the physicians who have high research ability. This means that the boost in research performance that can be achieved through research facilities, is maximal in the 'current' situation. Yet, the impact of this extra research performance does not outweigh the impact of inducement of care efforts which we see in the optimal incentive system. Hospital performance is highest under the optimal incentive system we have derived.

Naturally, because the optimal incentive system we have derived rewards care performance more than in the current situation, physicians with higher care ability will benefit under our optimal incentive system (in terms or research facilities). However, these physicians will also have to work harder. Physicians who are better in research will be allowed to take it easier. As a result all physicians will be equally well off under our optimal incentive system as they are in the current situation.

Chapter 7

Contracts under private information

In the previous chapters we had assumed the hospital has perfect information. The hospital could verify how able each physician was in care and in research, and identify each physician's valuation for research facilities. Although it is likely that ability scores may be obtained through tests and exams or over time through examination on the work floor, this is not so likely for research facilities valuation. Therefore, in this chapter, we step away from the assumption of perfect information and impose that research facilities valuation must be revealed through physicians. We derive the conditions which the optimal incentive system should satisfy in this case.

7.1 Incentive compatibility

When information is private and physicians need to reveal how competent they are and how much valuation for research facilities they possess, it is only natural that they will try to reveal their characteristics in such a way that they will be best off. If, for example, physicians could obtain a higher payoff if their abilities are higher, they will try to claim to have a high ability. Now, because of tests, exams and observation in practice, it is generally not possible for a physician to pretend to have a higher ability than he really has. However, he could pretend to be worse. Of course no physician would do so unless pretending to have a worse ability would result in a higher payoff. Therefore, when the contract includes payoffs that are increasing with ability, the physicians have no incentive to *lie* about their type. The contract is called *incentive compatible*.

Although incentive compatibility is relatively straightforward for information on physician ability, it is not so for information on physician valuation for research facilities. In an inquiry or in a negotiation procedure, a physician could claim to have either a higher or lower valuation than he really has. Therefore, if the contract includes payoffs that are increasing with physician valuation for research facilities, all physicians will pretend to have a high valuation. Achieving incentive compatibility for research facilities valuation therefore requires specific constraints on the contract.

The incentive compatibility (IC) constraints imply that a physician's utility is maximized when he reveals his true type *and* given that the other physicians reveal their true type (Bayesian-Nash equilibrium). Their derivation is as follows. Consider the utility function of a physician i:

$$u_i(\sigma;\theta) = v(\omega_i, \rho_i; r_i) - e1_i - e2_i$$

The hospital offers the physician a contract in which his research facilities and his effort levels are determined by the valuation parameters revealed by all physicians, as well as their ability scores. In this case, where we have two physicians, we denote the revealed type parameters with $\widehat{\theta_i}$ and $\widehat{\theta_j}$ and obtain:

$$u_i\big(\sigma(\hat{\theta});\theta\big) = v\big(\omega_i, \rho_i(\widehat{\theta_i}, \widehat{\theta_j}); r_i\big) - e1_i(\widehat{\theta_i}, \widehat{\theta_j}) - e2_i(\widehat{\theta_i}, \widehat{\theta_j}) \qquad (7.1)$$

The hospital should offer a contract $\{\rho_i\big(\widehat{\theta_i}, \widehat{\theta_j}\big), e1_i\big(\widehat{\theta_i}, \widehat{\theta_j}\big), e2_i(\widehat{\theta_i}, \widehat{\theta_j})\}$ that maximizes (7.1) for $\widehat{\theta_i} = \theta_i$ and given that $\widehat{\theta_j} = \theta_j$. Differentiating (7.1) with respect to $\widehat{r_i}$ and evaluating in θ_i we obtain the first order condition for a utility function that is maximized when the physician reveals his true type:

$$v_\rho\big(\omega_i, \rho_i(\theta_i, \theta_j); r_i\big) \cdot \frac{\delta\rho_i(\theta_i, \theta_j)}{\delta r_i} - \frac{\delta e1_i(\theta_i, \theta_j)}{\delta r_i} - \frac{\delta e2_i(\theta_i, \theta_j)}{\delta r_i} = 0 \qquad (7.2)$$

This is the incentive compatibility constraint for physician i.

By including the incentive compatibility constraints in our problem, we may restrict attention to the case where physician's truthfully report their type. This is known as the revelation principle (Myerson, 1981 and 1982). It eliminates the need to consider strategic behavior and lying. We can now maximize the expected hospital performance over all possible physician types.

We present the full problem in the next section.

7.2 Contract design with private information

As before, we have two heterogeneous physicians, with each physician i having type $\theta_i = \{a1_i, a2_i, r_i\}$ and a predetermined wage ω_i. We assume the ability scores for care $a1_i$ and for research $a2_i$ are known, but research facilities valuation r_i is not. We further assume the hospital can derive the probability distribution function $f(r)$ of the valuation parameters. The full form hospital optimization problem is now given by:

$$\max \ \mathrm{E}_\theta[\mathcal{H}(\sigma;\theta)]$$
$$= \iint_0^1 \left(\alpha \cdot \sum_i p1(e1_i(\theta_i,\theta_j);a1_i) + \beta \cdot \sum_i p2\big(e2_i(\theta_i,\theta_j);a2_i,\rho_i(\theta_i,\theta_j)\big)\right) \cdot f(r_i) \cdot f(r_j)\, dr_i dr_j \tag{7.3}$$

subject to the individual rationality constraints:

$$v\big(\omega_i,\rho_i(\theta_i,\theta_j);r_i\big) - e1_i(\theta_i,\theta_j) - e2_i(\theta_i,\theta_j) \geq \overline{\overline{U}}(a1_i,a2_i) \qquad \begin{matrix} i = 1,2 \\ r_i \in [0,1] \end{matrix} \tag{7.4}$$

the incentive compatibility constraints:

$$v_\rho\big(\omega_i,\rho_i(\theta_i,\theta_j);r_i\big) \cdot \frac{\delta\rho_i(\theta_i,\theta_j)}{\delta r_i} - \frac{\delta e1_i(\theta_i,\theta_j)}{\delta r_i} - \frac{\delta e2_i(\theta_i,\theta_j)}{\delta r_i} = 0 \qquad \begin{matrix} i = 1,2 \\ j \neq i \\ r_i, r_j \in [0,1] \end{matrix} \tag{7.5}$$

and the research facilities constraint:

$$\sum_i \rho_i(\theta_i,\theta_j) \leq 1 \qquad \begin{matrix} j \neq i \\ r_i, r_j \in [0,1] \end{matrix} \tag{7.6}$$

For $e1_i(\cdot), e2_i(\cdot) \in \mathbb{R}_+^n$ and $\rho_i(\cdot) \in [0,1]^n$.

This problem is substantially more difficult than the problems in chapters 5 and 6. It can be solved however, by using the calculus of variations. The resulting conditions on the optimal contract are described by Proposition 7.1.

PROPOSITION 7.1 [Optimal contract under private information]

If research facilities valuation is private information and if wages are predetermined, the optimal contract for heterogeneous physicians has the following properties:

1. Effort levels of each physician are strictly positive. For each physician the effort levels equate the marginal benefit to the hospital in both performance categories:

$$\alpha \cdot p1_{e1}(\, e1_i(\theta_i, \theta_j)\,; a1_i) = \beta \cdot p2_{e2}\big(\, e2_i(\theta_i, \theta_j)\,; a2_i, \rho_i\big)$$

2. Physicians are allowed to make a rent so that their utility is higher than their outside utility:

$$v\big(\omega_i, \rho_i(\theta_i, \theta_j); r_i\big) - e1_i(\theta_i, \theta_j) - e2_i(\theta_i, \theta_j) > \bar{U}(a1_i, a2_i) \qquad i = 1,2 \quad r_i, r_j \in (0,1]$$

3. All research facilities are allocated and the allocation is such that the net marginal benefit of allocating research facilities to a physician is equal over all physicians:

$$MA_1(\theta_1) = MA_2(\theta_2) \qquad r_i, r_j \in [0,1]$$

where

$$\begin{aligned} MA_i(\theta_i) = \quad & \beta \cdot f(r_i) \cdot f(r_j) \cdot p2_\rho\big(e2_i(\theta_i, \theta_j), \rho_i(\theta_i, \theta_j); a2_i\big) \\ & + \alpha \cdot v_{\rho\rho}\big(\omega_i, \rho_i(\theta_i, \theta_j); r_i\big) \cdot \frac{\delta \rho_i(\theta_i, \theta_j)}{\delta r_i} \cdot E_{r_i}[p1_{e1}\big(e1_i(\theta_i, \theta_j); a1_i\big)] \\ & - \alpha \cdot \frac{\delta}{\delta r_i}\big(v_\rho(\omega_i, \rho_i(\theta_i, \theta_j); r_i) \cdot E_{r_i}[p1_{e1}\big(e1_i(\theta_i, \theta_j); a1_i\big)]\big) \end{aligned}$$

The proof is in the appendix.

In the optimum the hospital offers the physicians a contract based on the valuation for research facilities the physicians reveal. The offered contracts are such that it is optimal for physicians to reveal their true valuation provided that the other physicians reveal their true valuation. As usual, the revelation of information is costly. Therefore the hospital can no longer obtain effort levels that are as high as the contracts in chapters 5 and 6. In order for the hospital to achieve optimal profits, the hospital must now not claim all surplus and allow the physicians to obtain a higher utility than they could elsewhere. As before, the contracted levels of effort balance the marginal profits to the hospital in care and research. The allocation rule for research facilities is such that all research facilities are allocated (at least in expectation), no matter what types the physicians reveal. Furthermore, research facilities are allocated such that they equate the marginal allocation benefit over physicians. This is similar to the optimal contracts from chapter 5, only the marginal allocation benefit is now computed differently due to the incentive compatibility constraint. The first term represents the direct increase in research performance that results from efficient resource utilization (increases with research ability). The second term represents the increase in inducement effect if physician valuation increases. The last term dampens this inducement benefit in the final allocation, so that it is not profitable for physicians to deviate from their true type.

Although we could now proceed to give a formula for the incomplete version of the contract, it is not very meaningful. The functions that relate contracted effort and allocated research facilities to the revealed valuation are dependent on the performance and valuation functions through a system of differential equations. Hence, they are not explicit and neither is any incentive mechanism that depends on them. If, however, the performance functions and valuation functions are known, the explicit functions for contracted effort and allocated research facilities can be derived, and so can a meaningful formula for the incomplete contract. This is powerful as it allows to construct the optimal incentive system for given valuation and performance functions.

In the next chapter we will discuss how our theoretical results obtained in this chapter and in the previous two chapters extend to practice.

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Chapter 8

Incentive management: from theory to practice

The theoretical contracts designed in this thesis describe the optimal incentive system within a fairly generally modeled setting of university hospitals. In this chapter we discuss how the theoretical contracts extend to practice. We first present a brief summary of our most important results. We then formulate the steps involved towards implementation. We also discuss the conditions under which it is profitable for a university hospital to implement a research facilities based incentive system.

8.1 Overview of main theoretical results

Table 8.1 summarizes the main theoretical results achieved in this thesis.

Summary of main results of chapters 5, 6 and 7	
Complete contracts	▪ *Compared to regular hospitals, research facilities allocation allows university hospitals to pay lower wages* ▪ *Optimal contracts balance, for each physician, his effort distribution over care and research such that the marginal benefit of effort to the hospital in both categories is equal* ▪ *The hospital optimally allocates all research facilities* ▪ *Research facilities are optimally allocated such that they equate the marginal allocation benefit over physicians: this is a balance between resource utilization and inducement effects* ▪ *The optimal level of available research facilities equates the marginal cost of research facilities to the marginal allocation benefit.* ▪ *Contracted effort levels increase with ability and with valuation* ▪ *Allocated research facilities also increase with ability and valuation*
Incomplete	▪ *Physicians like to deliver most effort in the category they are best at*

contracts	▪ *Physicians with higher valuations are willing to work harder* ▪ *If effort cannot be contracted, but performance can, the hospital can achieve optimal effort levels by offering contracts composed of a base allocation and relative incentives →Nash equilibrium* ▪ *The optimal incomplete contract can be linearized and turned into a contract with individual incentives →Dominant strategy equilibrium* ▪ *Expected budget balance holds* ▪ *The base allocation is increasing with ability* ▪ *Incentives are increasing with research ability* ▪ *Incentives are decreasing in valuation of the other physicians* ▪ *Incentives are increasing in the performance of the other physicians* ▪ *Ignoring heterogeneity leads to suboptimal performance and compromises retention of physicians* ▪ *The current situation does not provide sufficient inducement of care performance, but could foster a higher research performance if incentives are set optimally* ▪ *Optimal incentive system gives higher total hospital performance than in the current situation*
Contracts under private information	▪ *Holds when valuation is private, but abilities can be observed* ▪ *If rewards are increasing in valuation, physicians are inclined to lie* ▪ *Incentive compatibility ensures truthful implementation of contracts → Bayesian-Nash equilibrium* ▪ *Optimal contracts balance, for each physician, his effort distribution over care and research such that the marginal benefit of effort to the hospital in both categories is equal* ▪ *Physicians are allowed to make a rent compared to their outside utility* ▪ *Marginal allocation benefit is equated over physicians* ▪ *Expected budget balance holds* ▪ *Revelation of information is costly →lower total performance* ▪ *Optimal incentive system can be constructed for given production and valuation functions*

Table 8.1: Summary of main results of chapters 5, 6 and 7

In our analysis we have deliberately imposed that the current wage system remains intact. This brings our results closer to short term implementability. Also the model is deliberately kept as simple as possible, whilst including the most practically relevant aspects. The basic dependencies revealed through the models are recognizable and realistic. Most of the results are also intuitive. Only the exact formulas required for optimal contracts become quite complex as we introduce more realism. This is an obstacle for practical implementation. Yet, there are ways to overcome at least some of these obstacles. We will come back to this in the next section.

8.2 Extensions to practice

In chapter 1 we presented an overview of the phases in the design process of incentive management and the various steps per phase (figure 1.1). We will now reflect on how this thesis has dealt with these activities. We describe what has been done, and what is still left open. Furthermore, we examine the steps involved towards implementation and discuss how some of the problems in extending the theoretical results to practice can be overcome.

Strategic rationale
In this thesis we have defined the strategic rationale behind incentives for university hospitals (as captured in the hospital performance function). For extensions to practice it is, however, important that clear strategic, tactical and practical goals are set immediately. Our results leave room for a precise definition of such goals.

Assess incentive possibilities
Through discussions with involved health care professionals and an inquiry held at a large regional university hospital, we have identified that significant support for research facilities incentives exist. There is significantly more support for such incentives than for financial incentives. We have specified several potential concepts for research facilities – including OR time for clinical trials, research budgets, time for congress visits, traineeships and seminars – but a more precise identification of which research facilities are desired has to be done in order to extend our results to practice.

Identify system dynamics and determine class of incentive system
We presented a principal-multi-agent model that captures the most important system dynamics. Physicians need to perform in both care and research, are heterogeneous in ability and valuation, and have private information regarding their type. We showed how the tradeoff between resource utilization of research facilities and inducement effects is captured within an optimal incentive system. There are, however, also dynamics that we did not consider. Coordination between physicians for example, also plays a role, as does altruism (i.e. the extend to which physicians care about the utility of other physicians or of patients). Dur and Sol (2008) show how team and relative incentives can stimulate social interaction when altruism is present. Social interaction in turn can help solve coordination problems. Because these issues have been examined in other literature, we have chosen to pay particular focus to the unique effects of the two performance categories and the resource utilization versus inducement tradeoff.

Design incentive mechanism
We have designed an incentive system that is optimal with respect to our framework. The results have been summarized in table 8.1. The results give good insight in the rules by which an incentive system should be ideally designed. The framework is of course an abstraction from reality designed to examine the effects of research facilities allocation on hospital

performance. In reality, factors that were not included in our framework play a role. We have mentioned coordination and altruism. Uncertainty is another factor. Combining our new results with results from existing work on coordination, altruism and uncertainty therefore is an important next step towards implementation.

Assess equilibrium and emergent behavior

The conditions for optimal contracts we have specified constitute either a Nash equilibrium (incomplete contracts with relative incentives), a Bayesian-Nash equilibrium (contracts under private information) or a dominant strategy equilibrium (linearized incomplete contract with individual incentives). A dominant strategy equilibrium is the strongest game theoretical equilibrium concept, and, importantly, is unique. A (Bayesian-)Nash equilibrium is, however, no weird notion in an environment in which physicians have a general idea or expectation of the actions of the other physicians, and can learn of and examine each other's actions dynamically. Clear communication can help coordinate to the desired (Bayesian-)Nash equilibrium. Further patterns on emergent behavior can be evaluated in a field experiment.

Remaining steps

Remaining steps towards implementation include obtaining more information on the desired research facilities and estimation of the valuation functions. This can be achieved by setting up a larger questionnaire and by using, for example, non-linear regression. Relevant performance criteria need to be identified based on the strategic, tactical and practical goals, and the 'right' physicians – those responsible for the performance measures – need to be selected for inclusion in the incentive scheme. Care is required in selecting performance criteria because of negative externalities, in particular because of the effects of self-induced demand. Performance measures can be quantifiable or subjective and may differ over physicians. An important technique for processing and comparing performance levels is data envelopment analysis. Dependent on the contract the hospital wants to construct, (parts of) the performance functions need to be estimated. This is again possible through, for example, non linear regression. Finally, social and legal implications need to be assessed and a field experiment may be set up and evaluated.

Complications and practical alternatives

Although the optimal contracts are theoretically valuable, their complexity may, as mentioned, be a complication for practical implementation. In particular a contract that accounts for incentive compatibility may become complex as the valuation functions and performance functions turn out to be complex. An incentive compatible contract sets up a sustainable environment with respect to the retention of physicians and the working of incentives. A practical alternative may, however, be found in the linearized incomplete contract with individual incentives for heterogeneous physicians. Physicians should then periodically reveal their valuation (e.g. through periodical negotiation or evaluation interviews) and are offered the incentive scheme based on their revealed valuation. If, however, their performance levels in the subsequent period deviate too much from the optimal performance levels computed with their revealed valuation, their incentive contract is adjusted accordingly. Parkes (2001) presents an approach in this direction for iterative auction design. By dynamically solving simpler problems he shows that optimal one shot solutions (in our case the optimal incentive compatible contract) can be approached.

Conditions for implementation

Introducing a research facilities based incentive system in a university hospital requires the combined and committed efforts from managers, medical specialists, trustees, and implementation- and design professionals. As a result, introducing such a system implies costs, requires time, and may introduce tensions. It is therefore only worthwhile if sufficient impact on hospital performance can be achieved. In any case, sufficient support should exist for research facilities based incentives. We have given empirical indications that sufficient support exists in typical non-profit university hospitals. The inquiry we held at the Erasmus Medical Center in the Netherlands revealed that over 80 percent of the physicians in that hospital would prefer to do more research, and over 95 percent of the physicians indicated they derive more work stimulus from research possibilities or scientific status than from wage. Erasmus Medical Center is a large non-profit university hospital. This is a representative setting for many university hospitals, both national and foreign. Hence, we expect that our findings are applicable to many university hospitals. The potential impact on hospital performance and the potential efficiency improvements necessary to offset the various costs seem present in the Erasmus Medical Center. More in-depth analysis of the desired research facilities and the underlying support is however recommended. As is a case by case analysis for other hospitals.

8.3 Worked examples

As a final step we present a practical illustration of the effects of the incentive contracts through three worked examples.

Suppose the performance and valuation functions are given by:

$$p1(e1_i; a1_i) = a1_i\sqrt{e1_i}$$

$$p2(e2_i, \rho_i; a2_i) = a2_i\sqrt{e2_i(1+\rho_i)}$$

$$v(\omega_i, \rho_i; r_i) = \sqrt{\omega_i} + 5r_i\sqrt{\rho_i}$$

outside utility is given by:

$$\overline{U}(a1_i, a2_i) = 1.25 \cdot (a1_i + a2_i)$$

and the hospital has specified a weight $\alpha = 0.6$ for care performance, and a weight $\beta = 0.4$ for research performance.

Example 1: different abilities
Suppose the information on ideal working time distribution derived in the inquiry presented in chapter 3 (figure 3.4) can be interpreted as an indication for physician ability. (It is natural for physicians to want to spend more time on the area they are best at.) Next, neglecting education scores, we can identify two relatively common, but yet distinct, physician types: physicians with an ideal research percentage around three times as large as their ideal care percentage, and physicians with an ideal research percentage around three times as small as their ideal care percentage. This leads us to formulate a physician type 1 and 2 with ability scores as given in table 8.2 below (with arbitrary values for the valuation parameter and wage):

	$a1_i$	$a2_i$	r_i	ω_i
Physician 1:	0.75	0.25	0.5	1
Physician 2:	0.25	0.75	0.5	1

Table 8.2: Physician characteristics in example 1

The optimal levels of effort, research facilities, utility, and performance described by the complete contract are given in table 8.3. Also included (bracketed) are the optimal levels in the 'current' situation as formulated in chapter 6.

	$e1_i$	$e2_i$	ρ_i	u_i
Physician 1:	1.27 (0)	0.09 (0.5)	0.42 (0.09)	1.25 (1.25)
Physician 2:	0.23 (0)	1.44 (2.14)	0.59 (0.91)	1.25 (1.25)

	$\mathcal{H}$	care	research
Hospital:	1.07 (0.68)	0.58 (0)	0.49 (0.68)

Table 8.3: Optimal levels of effort, research facilities, utility and performance in example 1 (bracketed values denote levels in the 'current' situation)

Compared to the current situation, there is an increase in hospital performance $\mathcal{H}$ of 57 percent. Care performance is higher, and research performance is slightly lower. Also, research facilities are more equally distributed. Physician utility levels are the same in both situations, and hence Physicians are equally well off in the optimum as in the current situation.

The hospital optimally offers the physicians the following contracts:

$$\rho_1 = 0.71 \cdot p1_1 + 0.86 \cdot p2_1 - 1.81$$

$$\rho_2 = 0.71 \cdot p1_2 + 1.02 \cdot p2_2 - 2.54$$

The optimal base allocation is negative. Because a negative amount of research facilities cannot be allocated, the contracts are transformed to:

$$\rho_1 = \begin{cases} 0 & if\ 0.71 \cdot p1_1 + 0.86 \cdot p2_1 < 1.81 \\ 0.71 \cdot p1_1 + 0.86 \cdot p2_1 - 1.81 & otherwise \end{cases}$$

$$\rho_2 = \begin{cases} 0 & if\ 0.71 \cdot p1_2 + 1.02 \cdot p2_2 < 2.54 \\ 0.71 \cdot p1_2 + 1.02 \cdot p2_2 - 2.54 & otherwise \end{cases}$$

The second physician has a higher powered incentive scheme than the first physician. This is due to research incentives and the base allocation; incentives for care are the same for both physicians (which is coincidence).

Example 2: extension with different preferences

Consider the same physicians as in example 1, but now with a different valuation parameter. These parameters can for example be obtained from the impact characteristics of work stimulation factors, as we have presented in chapter 3. For contrast, we take parameters of 0.25 and 0.75 (which implies a valuation for research facilities that is respectively 1.25 and 3.75 times as high as wage valuation). The physician characteristics are then given by table 8.4:

	$a1_i$	$a2_i$	r_i	ω_i
Physician 1:	0.75	0.25	0.25	1
Physician 2:	0.25	0.75	0.75	1

Table 8.4: Physician characteristics in example 2

The optimal levels of effort, research facilities, utility, and performance described by the complete contract are given in table 8.5.

	$e1_i$	$e2_i$	ρ_i	u_i
Physician 1:	0.37 (0)	0.02 (0.09)	0.27 (0.07)	1.25 (1.25)
Physician 2:	0.37 (0)	2.59 (3.36)	0.73 (0.93)	1.25 (1.25)

	$\mathcal{H}$	care	research
Hospital:	1.02 (0.79)	0.37 (0)	0.65 (0.79)

Table 8.5: Optimal levels of effort, research facilities, utility and performance in example 2 (bracketed values denote levels in the 'current' situation)

Because physician 1 is now willing to work less hard to obtain research facilities than physician 2, he is contracted to deliver less effort and obtains less research facilities than before. The difference in hospital performance compared to the current situation has decreased somewhat, but is still 29 percent. The utility of both physicians is unaffected.

The optimal contracts are as follows:

$$\rho_1 = \begin{cases} 0 & if\ 0.58 \cdot p1_1 + 0.76 \cdot p2_1 < 0.43 \\ 0.58 \cdot p1_1 + 0.76 \cdot p2_1 - 0.43 & otherwise \end{cases}$$

$$\rho_2 = \begin{cases} 0 & if\ 0.57 \cdot p1_2 + 0.89 \cdot p2_2 < 4.34 \\ 0.57 \cdot p1_2 + 0.89 \cdot p2_2 - 4.34 & otherwise \end{cases}$$

Physician 1 (who has a lower valuation) has a lower powered incentive scheme than before, whereas physician 2 has a higher powdered incentive scheme than before. For both physicians care incentives are lower than before.

Example 3: extension with an increase in wage

Consider again the same physicians, but now the wage of physician 1 is increased by 25 percent. The physician characteristics are given by table 8.6:

	$a1_i$	$a2_i$	r_i	ω_i
Physician 1:	0.75	0.25	0.25	1.25
Physician 2:	0.25	0.75	0.75	1

Table 8.6: Physician characteristics in example 3

The optimal levels of effort, research facilities, utility, and performance described by the complete contract are given in table 8.7.

	$e1_i$	$e2_i$	ρ_i	u_i
Physician 1:	0.44 (0)	0.03 (0.14)	0.23 (0.05)	1.25 (1.25)
Physician 2:	0.38 (0)	2.66 (3.41)	0.77 (0.95)	1.25 (1.25)

	$\mathcal{H}$	care	research
Hospital:	1.06 (0.81)	0.39 (0)	0.67 (0.81)

Table 8.7: Optimal levels of effort, research facilities, utility and performance in example 3 (bracketed values denote levels in the 'current' situation)

Due to the wage increase, physician 1 is now contracted to do deliver more effort but receives less research facilities than before. These research facilities are allocated to physician 2 who is also contracted to deliver more effort. Again, utility of physicians is unaffected. The difference in hospital performance compared to the current situation is 31 percent.

The optimal contracts are:

$$\rho_1 = \begin{cases} 0 & if\ 0.58 \cdot p1_1 + 0.77 \cdot p2_1 < 0.58 \\ 0.58 \cdot p1_1 + 0.77 \cdot p2_1 - 0.58 & otherwise \end{cases}$$

$$\rho_2 = \begin{cases} 0 & if\ 0.57 \cdot p1_2 + 0.91 \cdot p2_2 < 4.44 \\ 0.57 \cdot p1_2 + 0.91 \cdot p2_2 - 4.44 & otherwise \end{cases}$$

The increase in wage has only a small effect on incentives (research incentives have increased somewhat). The true effect is seen in the base allocation, which has been lowered for both physicians.

Chapter 9

Conclusions

9.1 Concluding remarks

In this work, we have studied the possibility of introducing incentives in university hospitals through the allocation of research facilities. Our aim was to construct an allocation mechanism for research facilities that would maximize hospital performance. We have presented a mathematical approach for constructing such an allocation mechanism.

Through an inquiry held at a large regional university hospital we have obtained empirical evidence that physicians in university hospitals are more interested in, and susceptible to, research facilities based incentives than financial incentives. This is promising as extensive financial incentives in typical non-profit university hospitals are hard to justify socially in the current political and economical climate.

However, basing an incentive system on research facilities introduces complications. Availability of research facilities is often limited. It is simply not possible to allow all physicians to do more research as this compromises time spend on care. Also, operating room time is limited, and so is time for clinical trials. As we are considering the semi-public sector it is even common practice to have an annually fixed research budget. Therefore, the main tradeoff in using research facilities within an incentive system is between efficient resource utilization and inducement effects.

We have developed a principal-multi-agent model to study the influence of research facilities based incentives on hospital performance. The physicians in the model engage in both care and research. The model allows for heterogeneity in physician abilities and physician valuation for research facilities. Moreover, physicians can receive different wages and hold private information.

We have succeeded in constructing an optimal allocation mechanism for research facilities within the context of our model. We have shown that university hospitals can increase their performance by offering physicians incentive contracts for research facilities consisting of a base allocation and relative or individual incentives. That is, provided that the hospital can obtain truthful information on the physicians valuation for research facilities. We have derived optimality conditions for an incentive compatible contract in case truthful information on physician valuation cannot be directly derived. Although we have assumed the total of available research facilities is predetermined, we have given optimality conditions for when the hospital wants to set this total optimally and for when there are costs associated to the provision of research facilities.

Compared to the current situation, our contracts lead to a slight decrease in research performance, but increase overall hospital performance. As care efforts are improved, patients will be better off. Optimally, the hospital takes heterogeneity of physicians in account. Ignoring heterogeneity may lead to problems with the retention of physicians with high abilities and of physicians willing to work hardest. An important consideration in our analysis is to keep the current wage system intact. This allows for short term practical extensions of our results.

The optimal incentive compatible contracts are complicated. We have argued that a practical alternative may be found in a contract with linear individual incentives. Physicians then periodically reveal their valuation through negotiation or evaluation interviews. They are offered incentives corresponding to their revealed valuations. If, however, their performance levels deviate too much from the optimal performance levels computed with their revealed valuation, their incentive contract is adjusted accordingly.

Our findings are applicable to university hospital where sufficient support for research facilities incentives exist. Considering the representative setting of the university hospital in which we obtained empirical evidence for such support, we expect our results can impact many university hospitals, both national and foreign.

9.3 Future work

We have deliberately kept our model as simple as possible whilst incorporating the most practically relevant – and previously uninvestigated – aspects. Issues we have not dealt with in our model are uncertainty, altruism and coordination. Interesting next steps would be to integrate existing results on these areas into our findings. Expanding our work to include the concept of time – for example as an additional cost, and limitation, for delivering care and research – would be another interesting option. Additional interdependencies between care performance and research performance may also be considered. For example, internalizing the effects of research status on the treatments the hospital can do. Situations where only team output can be contracted also form a point of interest. In practice, it often occurs that multiple physicians are involved with the treatment of a patient or the research of a medicine. The outcomes then depend on the combined efforts of the physicians.

On a practical note, there are direct research interests with regard to the precise determination of desired research facilities, as well as the estimation of valuation and performance functions. Setting up a larger, more in-depth, inquiry, possibly over multiple cross-national university hospitals, would be a useful venture in this direction. Further, the selection of the right performance criteria that are in line with hospital goals should be another focal point. Important considerations in selecting performance criteria are availability of data, measurement accuracy, externalities, and in particular the effects of self-induced demand. We imagine a field experiment being set up to investigate the working of research facilities based incentives in practice.

Lastly, the generality of our model allows the results to be extended beyond the health care sector. For instance, budget allocation in the governmental and semi-public sector, or organizations in general, when budget allocation has inducement effects on business units. We view our work as the first step towards even more nuanced and varied models balancing resource utilization versus inducement effects.

Appendix

PROOF OF PROPOSITION 5.1 [Complete contract with homogeneous physicians]

Consider the equivalent problem:

$$\min \sum_i \omega_i - \alpha \cdot \sum_i p1(e1_i) - \beta \cdot \sum_i p2(e2_i; \rho_i) \tag{A1}$$

subject to

$$\bar{U} + e1_i + e2_i - v(\omega_i, \rho_i) \leq 0 \qquad i = 1,2 \tag{A2}$$

$$\sum_i \rho_i - 1 \leq 0 \tag{A3}$$

For $e1_i, e2_i, \omega_i \in \mathbb{R}_+$ and $\rho_i \in [0,1]$, $i = 1,2$.

This problem is convex and therefore the KKT conditions are sufficient for optimality.

The Lagrange function is given by:

$$\mathcal{L} = \lambda_0 \left(\sum_i \omega_i - \alpha \cdot \sum_i p1(e1_i) - \beta \cdot \sum_i p2(e2_i; \rho_i) \right) + \sum_i \lambda_i \big(\bar{U} - u_i(\sigma) \big)$$
$$+ \lambda_3 \left(\sum_i \rho_i - 1 \right) - \sum_i (\lambda_{3+i} e1_i + \lambda_{3+2i} e2_i + \lambda_{3+3i} \omega_i + \lambda_{3+4i} \rho_i + \lambda_{3+5i} (\rho_i - 1)) \tag{A4}$$

where λ_k denotes the Lagrange multiplier for the k-th constraint.

The KKT first order conditions are given by $\mathcal{L}_\sigma = \mathbf{0} \Rightarrow$

$$\frac{\delta \mathcal{L}}{\delta e1_i} = -\lambda_0 \alpha \cdot p1_{e1}(e1_i) + \lambda_i - \lambda_{3+i} = 0 \qquad i = 1,2 \tag{A2}$$

$$\frac{\delta \mathcal{L}}{\delta e2_i} = -\lambda_0 \beta \cdot p2_{e2}(e2_i; \rho_i) + \lambda_i - \lambda_{3+2i} = 0 \qquad i = 1,2 \tag{A3}$$

$$\frac{\delta\mathcal{L}}{\delta\rho_i} = -\lambda_0\beta \cdot p2_\rho(e2_i;\rho_i) - \lambda_i v_\rho(\omega_i,\rho_i) + \lambda_3 + \lambda_{3+4i} - \lambda_{3+5i} = 0 \qquad i = 1,2 \qquad \text{(A4)}$$

$$\frac{\delta\mathcal{L}}{\delta\omega_i} = \lambda_0 - \lambda_i v_\omega(\omega_i,\rho_i) - \lambda_{3+3i} = 0 \qquad i = 1,2 \qquad \text{(A5)}$$

and the conditions on the individual rationality constraints given by (A2):

$$\lambda_i \cdot \left(\bar{U} + e1_i + e2_i - v(\omega_i,\rho_i)\right) = 0 \qquad i = 1,2 \qquad \text{(A6)}$$

plus the condition on the research facilities constraint (A3):

$$\lambda_3 \cdot \left(\sum_i \rho_i - 1\right) = 0 \qquad \text{(A7)}$$

and lastly:

$$\lambda_{3+i}e1_i = 0, \qquad \lambda_{3+2i}e2_i = 0, \qquad \lambda_{3+3i}\omega_i = 0,$$

$$\lambda_{3+4i}\rho_i = 0, \qquad \lambda_{3+5i}(\rho_i - 1) = 0$$

$$i = 1,2 \quad \text{(A8)}$$

Any point σ with $e1_i = e2_i = \rho_i = 0$ and $\omega_i > v^{-1}(\bar{U};\rho_i = 0)$ for all i is a Slater point ∴ we put $\lambda_0 = 1$. Consider the case that all $\lambda_{3+ki} = 0$ for $k = 1,\dots,5$: all basic constraints on the individual variables are satisfied. From (A8) and $v_\omega(\cdot) > 0$ (as we have assumed) it follows that $\lambda_i > 0$ for $i = 1,2$ ∴ the individual rationality constraints (5.2) bind for all physicians. Eliminating λ_i for $i = 1,2$ in (A5), (A6) and (A8) the first part of Proposition 5.1 follows.

From $\lambda_i > 0$ for $i = 1,2$ and $v_\omega(\cdot) > 0$ it follows that $\lambda_3 > 0$ and hence the research facility constraint (5.3) binds. Eliminating λ_3 in (A7) and using (A5), (A6), and (A8) it follows that $\lambda_1 = \lambda_2$ and subsequently that all ρ_i are equal for $i = 1,2$ which gives the second part of Proposition 5.1.

The third part follows from $\lambda_i > 0$ for $i = 1,2$, which makes the individual rationality constraints (5.2) binding.

■■■

PROOF OF PROPOSITION 5.2 [Complete contract with equal types and predetermined wage]

Determination of the sufficiency of the KKT conditions for global optimality is analogous to the proof of Proposition 5.1.

The Lagrange function is now given by:

$$\mathcal{L} = \lambda_0 \left(\sum_i \omega_i - \alpha \cdot \sum_j p1(e1_i) - \beta \cdot \sum_i p2(e2_i; \rho_i) \right) + \sum_i \lambda_i \big(\overline{U} - u_i(\sigma) \big)$$
$$+ \lambda_3 \left(\sum_i \rho_i - 1 \right) - \sum_i (\lambda_{3+i} e1_i + \lambda_{3+2i} e2_i + \lambda_{3+3i} \rho_i + \lambda_{3+4i} (\rho_i - 1)) \tag{B1}$$

The KKT first order conditions correspond to (A5), (A6), and (A7), the 2 conditions on the individual rationality constraints (A9), and the condition on the research facilities constraint (A10), plus the 8 conditions on the individual variables (A11).

Again, because a Slater point exists (we assumed the feasible space is not empty), we put $\lambda_0 = 1$. We also put $\lambda_{3+ki} = 0$ for $k = 1, \dots, 4$ as we may. From (A6) and $p2_{e2}(\cdot) > 0$ we obtain that $\lambda_i > 0$ for $i = 1,2$ ∴ the individual rationality constraints (5.2) bind for all physicians. After eliminating λ_i for $k = 1,2$ the first part of Proposition 5.2 follows from (A5) and (A6).

The second part follows from $\lambda_i > 0$ for $i = 1,2$, (A7) and observing that $v_\rho(\cdot) > 0$, which gives $\lambda_3 > 0$ and hence both the research facilities constraint (5.3) and the individual rationality constraints (5.2) bind.

The third part is directly derived from (A5) and (A7) after the elimination of λ_k for $k = 1, \dots, 3$.

■■■

PROOF OF PROPOSITION 5.3 [Complete contract with equal types and predetermined wage]

Take the parameterized functions given in chapter 4 and proceed according to the proof of Proposition 5.2. Proposition 5.3 follows.

■■■

PROOF OF LEMMA 6.1 [Best response function for homogeneous physicians and predetermined wage]

Consider the equivalent problem:

$$\min -u_i(\sigma) = e1_i + e2_i - v(\omega_i, \rho_i) \tag{C1}$$

subject to

$$\rho_i - g^{\rho_i}(P_s) = 0 \tag{C2}$$

For $e1_i, e2_i \in \mathbb{R}_+$ and $\rho_i \in [0,1]$.

Since $g^{\rho_i}(P_s)$ is concave it is a convex problem and the KKT conditions are sufficient for optimality.

The Lagrange function is given by:

$$\mathcal{L} = \lambda_0\big(e1_i + e2_i - v(\omega_i, \rho_i)\big) + \lambda_1\big(\rho_i - g^{\rho_i}(P_s)\big) - \lambda_2 e1_i - \lambda_3 e2_i - \lambda_4 \rho_i + \lambda_5(\rho_i - 1) \tag{C3}$$

where λ_k denotes the Lagrange multiplier for the k-th constraint.

The KKT first order conditions are $\mathcal{L}_\sigma = \mathbf{0} \Rightarrow$

$$\frac{\delta \mathcal{L}}{\delta e1_i} = \lambda_0 - \lambda_1 g^{\rho_i}_{p1_i}(P_s) \cdot p1_{e1}(e1_i) - \lambda_2 = 0 \qquad i = 1,2 \tag{C4}$$

$$\frac{\delta \mathcal{L}}{\delta e2_i} = \lambda_0 - \lambda_1 g^{\rho_i}_{p2_i}(P_s) \cdot p2_{e2}(e2_i; \rho_i) - \lambda_3 = 0 \qquad i = 1,2 \tag{C5}$$

$$\frac{\delta \mathcal{L}}{\delta \rho_i} = -\lambda_0 \cdot v_\rho(\omega_i, \rho_i) + \lambda_1(1 - g^{\rho_i}_{p2_i}(P_s) \cdot p2_\rho(e2_i; \rho_i) - \lambda_4 + \lambda_5 = 0 \qquad i = 1,2 \tag{C6}$$

and the condition on the allocation constraint (C2):

$$\lambda_1\big(\rho_i - g^{\rho_i}(P_s)\big) = 0 \tag{C7}$$

and:

$$\lambda_2 e1_i = 0, \qquad \lambda_3 e2_i = 0, \qquad \lambda_4 \rho_i = 0, \qquad \lambda_5(\rho_i - 1) = 0$$

We put $\lambda_0 = 1$ and $\lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$ as we may. Eliminating λ_1 and rearranging terms the condition follows from combining (C4), (C5) and (C6). If $g^{\rho_i}(P_s)$ is concave, the point $(e1_i, e2_i, \rho_i)$ satisfying these conditions is the global optimum.

■■■

PROOF OF PROPOSITION 6.1 [Incomplete contract with homogeneous physicians and predetermined wage]

From Proposition 5.2 we have that

$$\alpha \cdot p1_{e1}(e1_i) = \beta \cdot p2_{e2}(e2_i) \tag{D1}$$

for physician i, and

$$\alpha \cdot p1_{e1}(e1_j) = \beta \cdot p2_{e2}(e2_j) \tag{D2}$$

for physician j. Combining with condition (5.4) this leads to three independent conditions. Given that the efforts of physician j are optimal and satisfy (D2), for physician i's efforts to be optimal as well, it should hold that:

$$\begin{aligned} \beta \cdot p2_\rho(e2_i;\rho_i) + v_\rho(\omega_i,\rho_i) \cdot \alpha \cdot p1_{e1}(e1_i) \\ = \beta \cdot p2_\rho(e2_j;\rho_j) + v_\rho(\omega_j,\rho_j) \cdot \alpha \cdot p1_{e1}(e1_j) \end{aligned} \tag{D3}$$

and

$$\begin{aligned} \beta \cdot p2_\rho(e2_i;\rho_i) + v_\rho(\omega_i,\rho_i) \cdot \beta \cdot p2_{e2}(e2_i) \\ = \beta \cdot p2_\rho(e2_j;\rho_j) + v_\rho(\omega_j,\rho_j) \cdot \beta \cdot p2_{e2}(e2_j) \end{aligned} \tag{D4}$$

The physician's choice of effort is determined by first-order conditions (6.3). Comparing with (D3) and (D4), solving for $g^{\rho_i}_{p2_i}(P_s)$ and $g^{\rho_i}_{p1_i}(P_s)$ and rewriting, the results follow.

■■■

PROOF OF PROPOSITION 7.1 [Optimal contract under private information]

We solve the problem using the calculus of variations. Let the vector functions $\pi_k: [0,1]^2 \to (\mathbb{R}^n)'$ for $k = 1,2,3$ denote Lagrange multipliers (as the two multipliers for the individual rationality constraints will be set to 0 (as we may), we omit them for ease of exposition), and let $h(\cdot): [0,1]^2 \to (\mathbb{R}^n)'$ denote an arbitrary vector function. The first order conditions are given by

$$\iint_0^1 \left(\alpha \cdot p1_e\left(e1_i(\theta_i,\theta_j); a1_i\right) \cdot h(\theta_i,\theta_j) - \pi_i \cdot h_{\theta_i}(\theta_i,\theta_j)\right) \cdot f(r_i) \cdot f(r_j) dr_i dr_j = 0 \qquad \forall r_i, r_j \quad \forall h(\cdot) \quad i = 1,2 \quad j \neq i \tag{E1}$$

$$\iint_0^1 \left(\beta \cdot p2_e\left(e2_i(\theta_i,\theta_j), \rho_i(\theta_i,\theta_j); a2_i\right) \cdot h(\theta_i,\theta_j) - \pi_i \cdot h_{\theta_i}(\theta_i,\theta_j)\right) \cdot f(r_i) \cdot f(r_j) dr_i dr_j = 0 \qquad \forall r_i, r_j \quad \forall h(\cdot) \quad i = 1,2 \quad j \neq i \tag{E2}$$

$$\iint_0^1 \left(\beta \cdot p2_\rho\left(e2_i(\theta_i,\theta_j), \rho_i(\theta_i,\theta_j); a2_i\right) \cdot h(\theta_i,\theta_j) + \pi_i(v_{\rho\rho}(\omega_i, \rho_i(\theta_i,\theta_j); r_i) \cdot \frac{\delta \rho_i(\theta_i,\theta_j)}{\delta r_i} \cdot h(\theta_i,\theta_j) + v_\rho(\omega_i, \rho_i(\theta_i,\theta_j); r_i) \cdot h_{\theta_i}(\theta_i,\theta_j)) + \pi_3 \cdot h(\theta_i,\theta_j)\right) \cdot f(r_i) \cdot f(r_j) dr_i dr_j = 0 \qquad \forall r_i, r_j \quad \forall h(\cdot) \quad i = 1,2 \quad j \neq i \tag{E3}$$

After an integration by parts, and by observing that $f(0) = f(1) = 0$, this system reduces to:

$$\iint_0^1 \left(\alpha \cdot p1_e\left(e1_i(\theta_i,\theta_j); a1_i\right) \cdot f(r_i) - \frac{\delta(\pi_i \cdot f(r_i))}{\delta r_i}\right) \cdot h(\theta_i,\theta_j) \cdot f(r_j) dr_i dr_j = 0 \qquad \forall r_i, r_j \quad \forall h(\cdot) \quad i = 1,2 \quad j \neq i \tag{E4}$$

$$\iint_0^1 \left(\beta \cdot p2_e\left(e2_i(\theta_i,\theta_j),\rho_i(\theta_i,\theta_j);a2_i\right)\cdot f(r_i) - \frac{\delta(\pi_i \cdot f(r_i))}{\delta r_i}\right)\cdot h(\theta_i,\theta_j)\cdot f(r_j)dr_i dr_j = 0 \quad \text{(E5)}$$
$$\forall r_i, r_j \quad \forall h(\cdot) \quad i = 1{,}2 \quad j \neq i$$

$$\iint_0^1 \left(\beta \cdot p2_\rho\left(e2_i(\theta_i,\theta_j),\rho_i(\theta_i,\theta_j);a2_i\right)\cdot f(r_i) + \pi_i(v_{\rho\rho}(\omega_i,\rho_i(\theta_i,\theta_j);r_i)\cdot \frac{\delta\rho_i(\theta_i,\theta_j)}{\delta r_i} \cdot f(r_i) - \frac{\delta v_\rho(\omega_i,\rho_i(\theta_i,\theta_j);r_i)}{\delta r_i}) + \pi_3 \cdot f(r_i)\right)\cdot h(\theta_i,\theta_j)\cdot f(r_j)dr_i dr_j = 0 \quad \text{(E6)}$$
$$\forall r_i, r_j \quad \forall h(\cdot) \quad i = 1{,}2 \quad j \neq i$$

Now, applying the main theorem of the calculus of variations, it follows that for the above integrals to be zero, it must hold that:

$$\left(\alpha \cdot p1_e\left(e1_i(\theta_i,\theta_j);a1_i\right)\cdot f(r_i) - \frac{\delta(\pi_i \cdot f(r_i))}{\delta r_i}\right)\cdot f(r_j) = 0 \quad \text{(E7)}$$
$$\forall r_i, r_j \quad i = 1{,}2 \quad j \neq i$$

$$\left(\beta \cdot p2_e\left(e2_i(\theta_i,\theta_j),\rho_i(\theta_i,\theta_j);a2_i\right)\cdot f(r_i) - \frac{\delta(\pi_i \cdot f(r_i))}{\delta r_i}\right)\cdot f(r_j) = 0 \quad \text{(E8)}$$
$$\forall r_i, r_j \quad i = 1{,}2 \quad j \neq i$$

$$\left(\beta \cdot p2_\rho\left(e2_i(\theta_i,\theta_j),\rho_i(\theta_i,\theta_j);a2_i\right)\cdot f(r_i) + \pi_i(v_{\rho\rho}(\omega_i,\rho_i(\theta_i,\theta_j);r_i)\cdot \frac{\delta\rho_i(\theta_i,\theta_j)}{\delta r_i} \cdot f(r_i) - \frac{\delta v_\rho(\omega_i,\rho_i(\theta_i,\theta_j);r_i)}{\delta r_i}) + \pi_3 \cdot f(r_i)\right)\cdot f(r_j) = 0 \quad \text{(E9)}$$
$$\forall r_i, r_j \quad i = 1{,}2 \quad j \neq i$$

Integrating and solving the differential equations (E7) and (E8) for π_i leads to the first part of Proposition 7.1 (after elimination of π_i). The second part holds because the Lagrange multipliers for the individual rationality constraint are zero. The third part follows from substituting π_i in (E9) and eliminating π_3.

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References

ARROW, K. Essays in the Theory of Risk Bearing. Chicago: Markham. (1971).

ARMOUR, B. The Effect of Explicit Financial Incentives on Physician Behavior. *Arch Intern Med. 161*, (2001), 1261-1266.

BAKER, G. Incentive Contracts and Performance Measurement. *Journal of Political Economy 100*, 3 (1992), 598-614.

BAKER, G., GIBBONS, R., AND MURPHY, K.. Subjective Performance Measures in Optimal Incentive Contracts. *Quarterly Journal of Economics 109*, 4 (1994): 1125-1156.

BARNARD, C. The Functions of the Executive. Cambridge, MA: Harvard University Press. (1938).

BAUMOL, W. Business Behavior, Value and Growth. New-York: Macmillan. (1959).

BERWICK, D. Payment by Capitation and the Quality of Care. *New England Journal of Medicine 335*, 16 (1996), 1227-1231.

CHARNES, A., COOPER, W., AND RHODES, E. Measuring the Efficiency of Decision Making Units. *European Journal of Operational Research 2*, (1978), 429-444.

CRAWFORD, V., AND HALLER, H. Learning How to Cooperate: Optimal Play in Repeated Coordination Games. *Econometrica 58*, 3 (1990), 571-595.

CYERT, R. AND MARCH, J. A Behavorial Theory of the Firm. Englewood Cliffs, NJ: Prentice-Hall. (1963).

DUR, R., AND SOL, J. Social Interaciton, Co-Worker Altruism, and Incentives. *CESifo Working Paper No. 2476*, (2008).

EISENHARDT, K. Agency Theory: An Assessment and Review. *Academy of Management Review 14*, 1 (1989), 57-74.

EMERY, D. Global Fees for Episodes of Care: A New Approach to Healthcare Financing. New York: HEMA Educational Foundation and McGraw-Hill. (1999).

EVANS, R. Supplier-Induced Demand: Some Empirical Evidence and Implications. In: Perlman, M. (Ed.), The Economics of Health Care and Mental Care. London: Macmillan. (1974), 162-201.

FREUND, D., AND SMEEDING, T. The Future Costs of Health Care in Ageing Societies: Is the Glass Half Full or Half Empty? *Seminar paper* (2002).

GALE, D. A Theory of N-Person Games with Perfect Information. *Proceedings of the National Academy of Sciences of the United States of America 39*, (1953), 496-501.

GLANNON, W. AND ROSS, L.F. Are Doctors Altruistic? *Journal of Medical Ethics 28*, (2002), 68-69.

GROSSMAN, S., AND HART, O. The Costs and Benefits of Ownership: A Theory of Vertical and Lateral Integration. *The Journal of Political Economy 94*, 4 (1986), 691-719.

GREEN, J., AND STOKEY, N. A Comparison of Tournaments and Contracts. *Journal of Political Economy 91*, 3 (1983), 349 - 364.

HAGIST, C., AND KOTLIKOFF, L. Who's Going Broke? Comparing Growth in Healthcare Costs in Ten OECD Countries. *NBER Working Paper No. 11833* (2005).

HANCHAK, N., SCHLACKMAN, N., AND HARMON-WEISS, S. Healthcare's Quality-Based Compensation Model. *Health Care Financing Review 17*, 3 (1996), 143-158.

HARSANYI, J. Games with Incomplete Information Played by 'Bayesian' Players, Parts I, II and III. *Management Science 14*, (1967/68), 159-182, 320-334, and 486-502.

HILLMAN, A., PAULY, M., AND KERSTEIN, J. How Do Financial Incentives Affect Physician's Clinical Decisions and the Financial Performance of Health Maintenance Organizations? *The New England Journal of Medicine 321*, 2 (1989), 86-92.

HOLMSTROM, B., AND MILGROM, P. The Firm as an Incentive System. *The American Economic Review 84*, 4 (1994), 972-991.

JENKINS, G., MITRA, A., GUPTA, N., AND SHAW, J. Are Financial Incentives Related to Performance? A Meta-Analytic Review of Empirical Research. *Journal of Applied Psychology 5*, 83 (1998), 777-787.

JENSEN, M., AND MECKLING, W. Theory of the Firm: Managerial Behavior, Agency Costs, and Ownership Structure. *Journal of Financial Economics 3*, 4 (1976), 305-360.

KLEIN, B., CRAWFORD, R, AND ALCHIAN, A. Vertical Integration, Appropriable Rents, and the Competitive Contracting Process. *Journal of Law and Economics 21*, 2 (1978), 297-326.

LAZEAR, E.P., AND ROSEN, S. Rank-Order Tournaments as Optimum Labor Contracts. *Journal of Political Economy 89*, 5 (1981), 841-864.

LIAO, C. The Evidence of Physician (Supplier) Induced Demand. *Job Market Paper,* (2008).

MARCH, J. AND SIMON, H. Organizations. New York: Wiley. (1958).

MINTZBERG, H. Toward Healthier Hospitals. *Health Care Management Review 22,* 4 (1997), 9-18.

MOLDOVANU, B., AND SELA, A. The optimal Allocation of Prizes in Contests. *American Economic Review 91*, 3 (2001), 542-558.

MYERSON, R. Optimal Auction Design. *Mathematics of Operations Research 6*, 1 (1981), 58-73.

MYERSON, R. Optimal Coordination Mechanisms in Generalized Principal Agent Problems. *Journal of Mathematical Economics 10*, (1982), 67-81.

NALEBUFF, B., AND STIGLITZ, J. Prices and Incentives: Towards a General Theory of Compensation and Competition. *Bell Journal of Economics 14*, 1 (1983), 21 - 43.

NASH, J. Equilibrium Points in n-Person Games. *Proceedings of the National Academy of Sciences of the United States of America 36*, 1 (1950), 48-49.

NORMAN, M., AND STOKER, B. Data Envelopment Analysis: The Assessment of Performance. Chisester: John Wiley & Sons. (1991).

OECD. OECD Health Data 2008: Statistics and Indicators for 30 Countries, December 2008.

OSBORNE, M. An Introduction to Game Theory. New York: Oxford University Press. (2004).

PARKES, D. Iterative Combinatorial Auctions: Achieving Economic and Computational Efficiency. *PhD dissertation* (2001).

PATHAK, P., AND SÖNMEZ, T. Comparing Mechanisms by their Vulnerability to Manipulation. *Working paper*. (2009).

PAULY, M., HILLMAN, A., AND KERSTEIN, J. Managing Physician Incentives in Managed Care: The Role of For-Profit Ownership. *Medical Care 28*, 11 (1990), 1013-1024.

PERROW, C. Complex Organizations. New York: Random House. (1986).

PITCHIK, C., AND SCHOTTER, A. Honesty in a Model of Strategic Information Transmission. *The American Economic Review 77*, 5 (1987), 1032-1036.

ROBINSON, J. Theory and Practice in the Design of Physician Payment Incentives. *The Milbank Quarterly 79*, 2 (2001), 149-177.

ROSS, S. The Economic Theory of Agency: The Principal's Problem. *American Economic Review 49*, 3 (1959), 134-139.

SIMON, H. Theories of Decision-Making in Economics and Behavioral Science. *The American Economic Review*, 63 (1973), 253-283.

TAYLOR, C. Digging for Golden Carrots: An Analysis of Research Tournaments. *The American Economic Review 85*, 4 (1995), 872-890.

TELEKI, S., DAMBERG, C., PHAM, C., AND BERRY, S. Will Financial Incentives Stimulate Quality Improvement? Reactions From Frontline Physicians. *American Journal of American Quality 21*, (2006), 367-374.

TIMES HIGHER EDUCATION. Top European Institutions in Clinical Medicine. (2009). Available online at: http://www.timeshighereducation.co.uk/story_attachment.asp?storycode=406694&seq=2&type=T&c=1.

ULLMANN-MARGALIT, E. The Emergence of Norms. Oxford: Clarendon Press. (1977).

VAN HUYCK, J., BATTALIO, R., AND BEIL, R. Tacit Coordination Games, Strategic Uncertainty, and Coordination Failure. *American Economic Review 80*, (1990), 234-248.

WILLIAMSON, O. The Economics of Discretionary Behavior: Managerial Objectives in a Theory of the Firm. Englewood Cliffs, NJ: Prentice-Hall. (1964).

WILLIAMSON, O. The Economic Institutions of Capitalism. New York: Free Press. (1985).

WILSON, R. The Theory of Syndicates. *Econometrica 36*, 1 (1968), 119-132.