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PAYING HEALTHCARE PROVIDERS: AN AGENCY-THEORETIC APPROACH FOR CHRONIC DISEASE MANAGEMENT

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ABSTRACT

The overall quality of healthcare delivered to Americans is suboptimal. The increasing prevalence of chronic disease exacerbates these problems representing a significant challenge for the healthcare system. Moreover there is a misalignment between healthcare provider's compensation and high quality care. The use of financial incentives varies according to whether providers receive their base compensation by fee-for-service, capitation or mixed payment. The purpose of this study is to develop a theoretical model to design an optimal payment system, linking base compensation and pay-for-performance to motivate provider's effort across the multiple tasks involved in successful chronic disease management.

Drawing from agency theory, we propose a simple multitasking model of provider choice of patient chronic care under different base compensation schemes. Specifically, a healthcare provider (agent) treats a patient and is reimbursed by the principal (the purchaser). High quality treatment increases patient's benefits, measured as controlled blood pressure for hypertensive care for example (downstream outcome). The purchaser also observes the provider's adherence to certain clinical processes, for example the frequency of monitoring tests or the provision of smoking cessation advice (intermediate outcomes). The question is to design the optimal pay-for-performance system, given the base compensation scheme, provider's characteristics and performance measurement systems.

This model is used to test the effects of alternative base payment mechanisms, provider's altruism and risk orientation, as well as the number and reliability of performance measures on the total welfare, measured as the sum of expected utility of the purchaser and the physician. Simulation analysis yields estimates of total welfare, patient's benefit, total spending, parameters of the payment system, provider's wage and percentage of provider's wage coming from pay-for-performance (i.e., size of incentives). The model further strengthens conventional arguments for mixed payment systems. Results show that the estimation of the purchaser's reward from increased quality should be made carefully to prevent overpayment. Moreover provider's altruism improves outcomes even though it may generate excessive spending on patient care. The more risk averse the provider is, the more important is the role played by pay-for-performance incentives. Therefore the incentive effects will vary substantially across providers. What is more, determining the number of performance measures and their reliability is a crucial decision for designing pay-for-performance programs. Finally, we identify perspectives for future research.

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DEDICATION

To my best friend, my soul mate and my husband-to-be,

Benjamin.

I want to thank him for giving me his unconditional support, always believing in me and continuously raising the bar. For all that, he has my everlasting love.

Chapter 1

INTRODUCTION

1.1 Motivation

The Institute of Medicine's (IOM, 2001) report "Crossing the Quality Chasm: A New Health System for the 21st Century" brought attention to the poor quality of healthcare in the United States. The Institute defined healthcare quality as "the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge" and identified six aims for healthcare: safety, effectiveness, patient-centered, timeliness, efficiency, and equity. While more than $2 trillion is spent annually on healthcare in the United States, American adults received on average just 55% of recommended care for the leading causes of death and disability (McGlynn et al., 2003). On average, children were receiving just 47% of recommended care overall (Mangione-Smith et al., 2007). And everyone is at risk for receiving poor quality care (Asch et al., 2006, Ma and Stafford, 2005). Solving these problems of rising healthcare costs and the problem of low quality is an important national priority, particularly with the increasing prevalence of chronic illnesses (AHRQ, 2008).

The World Health Organization (WHO) estimated in the 2005 report "Preventing chronic diseases : a vital investment" that chronic disease, such as heart disease, stroke, cancer, chronic respiratory diseases and diabetes, would account for 72% of the global disease burden, with 35 million deaths or approximately 60% of total deaths worldwide attributed to chronic disease. The increase in prevalence of chronic conditions is likely given the aging populations. The WHO defines chronic diseases as having one of the following characteristics: they are permanent, leave residual disability, are caused by pathological alteration, require special training of the patient for rehabilitation, or may be expected to require a long period of supervision, observation, or care.

In 2005, about 60 percent of the adult population age 18 and over had at least one chronic condition (Machlin, Cohen and Beauregard, 2008). Patients with one or more chronic diseases accounted for the major part of expenditures for most services. Overall, expenses for treatment of chronic conditions accounted for just over half of total expenses for medical care in 2005 for adults. These estimates are based on data collected in the Medical Expenditure Panel Survey Household Component and Medical Provider Component. Despite this vast expenditure and evidence of increasing prevalence of chronic conditions, it has been argued that healthcare system in the United States is geared first and foremost to acute medical care, failing to address chronic illnesses (Wagner et al., 2001)

We are particularly interested in two chronic conditions: diabetes and hypertension. In the United States alone, diabetes affects more than 17 million people and hypertension affects more than 50 million people. Despite clear evidence regarding the beneficial effects of quality treatment for diabetes and high blood pressure, McGlynn (2008) discussed some of the evidence about the problems with chronic care quality: 40% of persons with diabetes had not had their blood sugar measured in the past two years and 58% of persons with hypertension did not have their blood pressure adequately controlled. It is estimated that substandard care for diabetes is associated with 2600 cases annually of preventable blindness and 29,000 cases annually of preventable kidney failure, using models developed by the Diabetes Control and Complications Trial (McGlynn, 2008). In addition, it is assessed that suboptimal quality in treating hypertension contributes to 68,000 preventable deaths annually from stroke, heart attacks, and other causes (McGlynn, 2008).

Finally, as we will discussed in more details below, payment policies supporting healthcare delivery system are not aligned with the objective of a high quality system (IOM, 2001). As the current dysfunctional healthcare payment system is one of the factors contributing to poor quality, there is a need to restructure payment mechanisms to help close the quality gap and remove disincentives to improving quality. More recently, the FRESH-Thinking Project (www.fresh-thinking.org) identified that a sustainable healthcare reform should aim at creating "a payment system that encourages and rewards innovation in the efficient delivery of quality care" (Arrow et al., 2009).

1.2 Overview of Payment Mechanisms in Healthcare

There are many mechanisms for paying physicians; we propose to review these mechanisms and specifically how to design them to improve chronic care. Our analysis is summarized in Table 1.1.

1.2.1 Fee-for-service, Salary, Capitation

The predominant form of payment for health care services is called fee-for-service, under which the physician receives a fee for each intervention or service provided. In this framework, there is no limit on the number of services, payment is independent of quality or outcome and occurs after care has been provided. Fee schedules are prospectively determined, for example the Centers for Medicare & Medicaid Services (CMS) develop fee schedules used by Medicare for physicians. Depending on the level of the fee, there is the incentive to deliver more care in order to increase income, which may inflate prices, quantities and activity (Rosenthal, 2008). Providers can influence the demand for service leading to supplier induced demand (Watts and Segal, 2009) and overtreatment. Medicare uses a discounted fee schedule to reimburse physicians called the Resource-Based Relative Value Scale (RBRVS). The RBRVS is a payment method that classifies health services based on the cost of providing physician services in terms of effort, practice expenses, and malpractice insurance.

Salary payment implies that the physician receives a fixed amount of money for a certain period of time. This amount is likely to be decided by negotiation and may depend on provider's characteristics, such as experience, age and specialty. With this payment mechanism, providers bear no risk since their income is predictable and stable. However salary payment undermines productivity by giving incentives to under-treat, to shift costs to higher levels and to use excessively referrals. Consequently, salary is often combined with bonus payments. We won't study this payment mechanism in our model.

In episode-of-care payment, providers receive a single lump sum (often called "case rate") for all services they supply related to a condition or disease. Compared to fee-for-service, it provides the incentive to eliminate any unnecessary services within the episode. In capitation, the physician is paid a fixed amount of money per patient during a specific period of time regardless of the actual number of episodes. In other words, the actual number of services provided to each patient does not influence the payment level. Health maintenance organizations often use this payment mechanism. By limiting the number of episodes of care, capitation payment creates incentives to select healthier patient, to avoid patients with complex diseases and to under-treat, subject to retaining patients (Robinson, 2001).

1.2.2 Pay-for-performance

A pay-for-performance system is a compensation arrangement in which a fraction of the payments relies on performance assessed against a predefined measure, while another component of the compensation is determined by the base payment mechanisms discussed above. Pay-for-performance programs could help improve the quality of care and contain costs, as opposed to traditional payment systems that are usually independent of differences in quality. The Institute of Medicine (2006) issued a report "Rewarding Provider Performance*:* Aligning Incentives in Medicare" that brought attention to the need for quality improvement in healthcare and for a reformed payment system. Doran and Fullwood (2007) identified the common key elements of pay-for-performance programs: (1) defining quality of care, (2) setting targets, (3) measuring performance, (4) rewarding performance and (5) controlling unintended effects. Some of these key aspects are discussed below and throughout this thesis.

Table 1.1: Comparison of Base Payment Mechanisms

	Fee-for-service	**Salary**	**Capitation**
	Retrospective	Retrospective	Prospective
Description	A fee for each service provided	A fixed amount for a certain period of time	A fixed amount per patient for a given period of time
Incentive to over treat?	Yes	No	No
Selection risk?	No	Yes	Yes
Risk bearer?	Purchaser	Purchaser	Provider
Holistic approach for chronic care?	No	No	No

1.3 Overview of Incentive Models in Healthcare

1.3.1 Non-financial Incentive Models

Non-financial incentives refer to non-price or non-monetary mechanisms for improving quality, such as public reporting, recognition and performance profiling. Public reporting and transparency of performance data attempt to help providers understand and improve the quality of the care they deliver by affecting both professional peers and the public. There is some evidence that public reporting leads to performance improvement (Hibbard et al., 2003). Even though we will not consider these mechanisms in our model, we recognize the importance of public reporting in successfully designing payment systems. Indeed, Lindenauer et al. (2007) suggest that public reporting is more effective when combined with financial incentives, such as pay-for-performance. Moreover the sharing of performance data is likely to support consumer engagement, which is crucial for chronic disease management (Watts and Segal, 2009).

1.3.2 Financial Incentive Models: Penalty vs. Bonus

Purchasers may use a reward strategy to implement financial incentives, such as paying a bonus, or allowing higher updates to a provider's fee schedule. On the other hand, purchasers may cancel fee updates or withhold payments for penalizing lack of improvements. It is argued that people place more values on losses than equivalent gains (Stone and Ziebart, 1995).Therefore a system with penalties is likely to create stronger incentives for quality improvement, but it would also generate more resistance among providers. An intermediate strategy combining reward and risk was developed using self-financing scheme by Michigan Medicaid's Health Plan Bonus/Withhold system (Center for Health Care Strategies, 2007). In other words, purchasers finance payments for quality improvements out of demonstrated savings generated by providers.

1.3.3 Financial Incentive Models: Absolute vs. Relative Performance

Pay-for-performance programs can generally be structured to reward either improvement or excellence. Under a system that rewards excellence, providers would receive a reward if their performance meets or exceeds a specified threshold. In such a system, providers with the lowest baseline quality may be discouraged to attempt any improvements since they have little chance to reach the target. Yet, absolute thresholds could help prevent the caveats of trying to reach a moving target. Alternatively, targets can be based on relative improvement over baseline. This approach provides greater incentives for providers with the lowest baseline performance. It seems necessary to use both strategies for rewards to prevent the decline of the high performers, while acknowledging the progress of the improvers. In addition, pay-for-performance programs can be competitive or noncompetitive (Rosenthal, Fernandopulle, Song and Landon, 2004). In a competitive structure, providers may be rewarded bonuses if they achieve a predefined percentile ranking, as opposed to a predefined ranking subject to achieving a measured target.

1.3.4 Financial Incentive Models: Payout Algorithms

In this section, we present what the payout of a provider could be in greater details. Cromwell, Drozd, Smith and Trisolini (2007) defined several payout algorithms. They introduced a target rate, t, determined as an improvement over the local baseline rate, λ_{base}, such that: $t_i = \lambda_{base,i}(1 + \alpha_i)$, where α_i is the required rate of improvement over baseline for the i -th performance measure. For a single performance measure, the provider's expected percentage bonus $E(B_i)$ could be determined by one of four formulas depending on his own expected level of performance $E(\lambda_i)$:

(1) All or nothing:

$$E(B_i) = 0, \text{ if } \frac{E(\lambda_i)}{t_i} < 1$$

$E(B_i) = 1$, if $\frac{E(\lambda_i)}{t_i} \geq 1$

(2) Continuous unconstrained

$E(B_i) = \frac{E(\lambda_i)}{t_i}$, if $0 \leq \frac{E(\lambda_i)}{t_i} \leq 1$

(3) Continuous constrained

$E(B_i) = 0$, if $\frac{E(\lambda_i)}{t_i} < LL$ (lower limit)

$E(B_i) = \theta \frac{E(\lambda_i)}{t_i}$, if $LL \leq \frac{E(\lambda_i)}{t_i} \leq UL$ (upper limit) and $0 \leq \theta \leq 1$

$E(B_i) = 1$, if $\frac{E(\lambda_i)}{t_i} > UL$

(4) Composite score

$E(B_i) = \frac{E(\lambda_i)}{t_i}$, and overall percentage bonus $= E(B) = \sum_i \omega_i E(B_i)$

Different incentive model options can be considered. We will now focus on specific applications of such problem for chronic disease.

1.4 Overview of Incentive Models in Chronic Disease Management

1.4.1 Empirical Studies

In the United States, there are more than 180 pay-for-performance programs in use (Meddings and McMahon, 2008). Christianson, Leatherman and Sutherland (2008) and Petersen et al. (2006) provided a review of the literature on pay-for-performance initiatives, while Rosenthal et al. (2007) presented a comprehensive study on currently implemented pay-for-performance by analyzing 27 health plans. We propose to give an overview of the most recent literature on incentives models with a focus on chronic disease management, especially diabetes and hypertension care. This literature consists mostly of empirical studies seeking to determine the efficacy of financial incentives and most have produced positive results.

Curtin et al. (2006) determined the return on investment (ROI) for the implementation of a pay-for-performance program by a health maintenance organization. Quality, patient satisfaction, and provider efficiency for diabetes care were assessed by the program. The initiative was estimated to cost $1.15 million annually, while the ROI were 60% and 150% in the first 2 years of the program. Consequently, financial incentives for quality appeared to be cost-effective. Another study analyzing a pay-for-performance program for diabetes care was performed by Young et al. (2007) and included 4 diabetes performance measures: HbA1C testing, lipoprotein density screening, microalbumin and urinalysis, and eye examination. They tested for statistically significant changes in performance levels for each performance measure and found that the improvement of a single measure of diabetes care could be attributed to the program.

Levin-Scherz, DeVita and Timbie (2006) analyzed diabetes care and asthma control in a Massachusetts health care network with pay-for-performance. After the implementation of the incentive program, HbA1C testing levels improved by 7% (compared with 4.9% statewide) during 2 years and eye examinations improved by 18.7% (despite a statewide decline). In addition, Cutler, Palmieri, Khalsa and Stebbins (2007) analyzed the effects of a chronic disease care management (CDCM) program in a medical group operating under a small pay-for-performance financial incentive. They showed that following the establishment of the CDCM program, the LDL-C testing rate was 91.5%, and the goal attainment rate was 78.2%, as opposed to 67.8% and 55.7%, respectively, for patients not in the CDCM program.

Doran and Fullwood (2007) reviewed the evidence for the effectiveness of pay-for-performance schemes relating to hypertension. The authors noted that few incentive programs to date have targeted patients with hypertension. They also analyzed new data from a program in the United Kingdom that provides financial incentives for family practitioners treating 6 million hypertensive patients. For patients with such conditions, generous rewards are associated with high quality of care, even if other quality improvement initiatives may have contributed to this positive impact. Furthermore exception reporting rates were generally low and there was little evidence of widespread gaming of the reporting system.

Scott, Schurer, Jensen and Sivey (2009) showed that an Australian incentive program had a positive impact on quality of care in diabetes, as measured by the probability of ordering an HbA1c test. Since the reform was introduced, they evaluated that the probability of ordering an HbA1c test had increased by 20 percentage points. Similarly, Millet et al. (2009) found a positive impact of the Quality and Outcomes Framework, a major pay-for-performance incentive introduced in the United Kingdom during 2004, on diabetes management in patients with and without comorbidity. Finally, Shortell et al. (2009) examined the change in use of commonly recommended chronic illness care management processes (CMPs) in large medical groups between 2000 and 2006. They argued that public policies that promote quality improvement initiatives through the use of financial rewards for improving quality are likely to be associated with improved chronic illness care.

To sum up, pay-for-performance programs have the potential to lead to quality improvements in healthcare. In general, the literature confirms that theses incentive schemes are associated with better care quality, even though the improvements are usually modest (Rosenthal and Frank, 2006). There is some evidence (Crawley et al., 2009) that quality of chronic disease management remains broadly equitable after the introduction of a major pay-for-performance program. Frolich et al. (2007) described a conceptual model of the determinants of provider's responses to incentives, adapting the Behavioral Model developed by Andersen (1995) to providers. This model (along with Lee and Zenios, 2007 and Eggleston, 2005b) is one of the few examples of theoretical approaches to study the effect of pay-for-performance schemes on provider's behavior.

1.4.2 Bridges to Excellence

The motivation for our research problem is provided by an example of pay-for-performance program. Founded in 2002, Bridges to Excellence (BTE) is a not-for-profit organization created by employers, physicians, health care services, researchers, and other healthcare experts. It was one of the first pay-for-performance programs developed to reward physicians in solo or small practices for meeting quality benchmarks. The BTE initiative includes two physician recognition programs specifically related to chronic conditions: Diabetes Care Link (DCL) and Hypertension Care Link (HCL). To earn DCL or HCL recognition, providers voluntarily submit medical record data documenting their performance. Independent third parties Performance Assessment Organizations (PAOs) use multiple performance measures per condition to determine scoring, which emphasizes the need for a multidimensional approach to disease management. Once providers become recognized for high performance in diabetes care or hypertension care, BTE's programs provide fixed bonuses per covered patients.

BTE's programs provide condition-based rewards to providers to improve healthcare quality in 11 regions. BTE's diabetes program consists of a set of performance measures gathered in Table 1.2 associated with diabetes processes and outcomes, such as HbA1C levels and blood pressure. Physicians who provide high quality diabetes care can earn up to $100 per year per patient covered by a participating employer. BTE's hypertension program consists of a set of performance measures (gathered in Table 1.3), such as blood pressure and lipid testing, associated with improved outcomes in hypertensive patients. As it is a new program that has not been implemented yet, no reward size is known. Nevertheless for patients with cardiovascular disease, physicians who provide high quality cardiac care can earn up to $200 per year per covered patient. Towers Perrin has estimated annual costs savings for each performance measures with savings of $166 per diabetic patient maintaining blood pressure below 140/90 mmHg.

Table 1.2: Diabetes Care Link Measures (Bridges to Excellence, 2009)

Clinical Measures (Downstream Outcomes)	
Poor Control Measures	
HgBA1c Superior Control	> 9.0
Blood Pressure Control	≥ 140/90
LDL Control	≥ 130 mg/dl
Poor Control Composite Measures	
HgBA1c Control	> 9.0
Blood Pressure Control	≥ 140/90
LDL Control	≥ 130 mg/dl
Superior Control Measures	
HgBA1c Superior Control	< 7.0
HgBA1c Superior Control	< 8.0
Blood Pressure Superior Control	< 130/80
LDL Superior Control	< 100 mg/dl
Superior Control Composite Measures	
HgBA1c Superior Control	< 8.0
Blood Pressure Superior Control	< 130/80
LDL Superior Control	< 100 mg/dl
Process Measures (Intermediate Outcomes)	
Ophthalmologic Exam	
Nephropathy Assessment	
Podiatry Exam	

Table 1.3: Hypertension Care Link Measures (Bridges to Excellence, 2009)

Clinical Measures (Downstream Outcomes)	
Poor Control Measures	
Blood Pressure Control	≥160/100
LDL Control	≥ 160 mg/dl
Poor Control Composite Measures	
Blood Pressure Control	≥160/100
LDL Control	≥ 160 mg/dl
Superior Control Measures	
Blood Pressure Superior Control	<140/90
LDL Superior Control	< 130 mg/dl
Superior Control Composite Measures	
Blood Pressure Superior Control	<140/90
LDL Superior Control	< 130 mg/dl
Process Measures (Intermediate Outcomes)	
Complete Lipid Profile	
Use of Aspirin or Another Antithrombotic	
Urine Protein Test	
Annual Serum Creatinine Test	
Diabetes Documentation or Screening Test	
Documentation of Counseling for Diet and Physical Activity	
Smoking Status and Cessation Advice and Treatment	

1.5 Thesis Objective and Organization

There have been a growing number of empirical studies (e.g., cohort studies) to document the effects of pay-for-performance programs on quality. Despite the increasing use of such programs, we found in the literature no theoretical model of provider payment system linking base compensation, financial incentives and the multidimensional aspect of chronic care. To address these weaknesses of the literature, this thesis seeks to specify a simple economics model investigating the effect of financial incentives on the quality of provider services. Simulation is used to derive how payment environment, provider characteristics and measurement system affect the design of the optimal payment system. Finally, the multitask model is placed in the context of more general considerations for a reformed healthcare payment system.

Specifically the thesis is organized as follow: after reviewing the related economics literature, we develop our model in Chapter 2 building upon existing health economics models. Next we present and analyze results from the simulation study in Chapter 3. Chapter 4 contains a discussion of critical assumptions of our model. Finally, Chapter 5 offers summary and perspectives for future research. An appendix provides help to derive the model formulation.

Chapter 2

MODEL FORMULATION

2.1 Literature Review

In the healthcare system, the purchaser-provider relationship is omnipresent. In this relationship, a purchaser of health services (e.g., health plan or Medicare) and a provider enter a contractual agreement in which the provider agrees to treat patients and is reimbursed by the purchaser according to a predefined payment system. As the goals of the two parties are conflicting and as the provider is asymmetrically better informed (e.g., about the consequences of clinical decisions), the purchaser needs to give the provider incentives to induce appropriate behaviors (Arrow, 1963). The economics literature of contract theory, namely agency theory, offers a relevant framework to address the issues of compensation and incentives in healthcare. We now review the relevant literature focusing, first, on the fundamental underlying economic models and finally, on their applications in the healthcare sector.

Prendergast (1999) provides a review of the literature of the economics theory of incentives. Agency theory examines the agency relationship in which one party (the principal) delegates work to another (the agent). Agency relationships are plagued with incentive problems, which arise when (i) the principal cannot verify agent's decisions and (ii) the principal and the agent have different attitudes towards risk (Eisenhardt, 1989). Moral hazard arises in the case of hidden action, while adverse selection arises in the case of hidden information.

We begin with a simple model of the principal-agent paradigm, since it is an essential building block to understand our model. The principal pays to the agent a wage contingent on output, as specified in a contract. The agent's output depends not only on the effort exerted but also on a random component. The principal is assumed to be risk neutral, while the agent is risk-averse. The argument behind this assumption is that agents are usually unable to diversify their employment, whereas principals are capable of diversifying their investments. The agent would have full insurance but no incentive, if he receives a fixed salary, independent of the output realized. However, the agent would have full incentive, yet no insurance, if he receives a percentage of the output value obtained by the principal. The trade-off between incentives and insurance is explored by the classic agency model (Gibbons, 2005). The timing of events follows this sequence:

1. The principal and the agent sign a compensation contract $w(y)$, assumed to be linear: $w(y) = \alpha y + \beta$, where α is the bonus rate and β is the salary.

2. The agent chooses an effort level (e), but the principal cannot observe it.

3. Events beyond the agent's control occur (ε, normally distributed noise term with mean zero and variance σ^2).

4. The agent's output is determined: $y = e + \varepsilon$.

5. The agent receives $w(y)$.

The disutility of effort, $c(e) = \frac{ce^2}{2}, c > 0,$ represents the cost incurred by the agent. The agent's utility function is $U(x) = -\exp(-tx)$, where $t > 0$ is the agent's coefficient of absolute risk aversion and $x = w - c(e)$ is the agent's net pay-off. The agent's certainty equivalent is:

$CE(e) = \beta + \alpha e - c(e) - \frac{t}{2}\alpha^2\sigma^2$ (see Proof 1 in the Appendix). The principal trying to maximize his expected pay-off will solve:

$$\max_{e,\alpha,\beta} \; E(y - w(y))$$

subject to:

- The agent's incentive compatibility constraint: $\max_e CE(e)$.
- The agent's participation constraint: $CE(e) \geq U_0$.

The efficient contract is determined by solving the first-order condition, yielding to the optimal incentive parameter: $\alpha^* = \frac{1}{1+tc\sigma^2}$ (see Proof 2 in the Appendix). Since t, c and $\sigma^2$are positive, α^* is between zero (full insurance) and 1 (full incentives). This simple static model gives us a language for analyzing concepts such as reward, effort, and incentives in terms of model elements such as wage, payoffs, and output.

Holmstrom and Milgrom (1991) revisit the classic agency model to encompass the multitasking case in which the agent has to carry out multiple tasks that affect output while the desired outcomes for some tasks are more difficult to measure than others. Their model justifies linear contracts and constant salary even when output measures are not flawed. When there are multiple tasks, efforts can be distorted, thus incentive pay can serve to direct the distribution of the agent's effort among their various tasks. Effort distortion can be alleviated by using multiple performance measures in the design of contracts. Baker (1992) discusses parallels to this classic multitasking analysis and shows that even when agents are risk neutral, the constraint that the principal generally cannot pay for what she really cares about leads to effort distortion. Thiele (2009) analyzes the optimal aggregation of performance measures in a multitasking setting. He concludes that the number of informative performance measures should at least be equal to the number of tasks the agent has to perform. What is more, Thiele shows that the efficient aggregation of multiple performance measures depends on the agent's ability to execute relevant tasks. In our model, we will consider a multitasking environment.

In the classical principal-agent model (as well as in Holmstrom and Milgrom, 1991), the agent makes a single, once-for-all decision of how to allocate his efforts regardless of the information arriving over time. Holmstrom and Milgrom (1987) showed that in a continuous time model an efficient contract yields a linear agent's wage depending only on the final outcome. We will thus adopt a static approach in our model even though a dynamic principal-agent could be developed. Plambeck and Zenios (2000) combined the principal-agent approach with Markov decision processes to create a dynamic structure that could be applied to Operations Management problems. The authors showed that the model is analytically tractable and can be solved using dynamic programming.

We now review relevant articles applying these economic concepts to the healthcare sector and the payment of providers (Table 2.1). Newhouse (1996) provides a review of the health economics literature focusing on the tradeoff between efficiency in production and selection. Ellis and McGuire (1986) consider the physician as a utility-maximizing agent for both the hospital and the patient, but the patient is passive. They conclude that fully prospective payment is optimal only if the agent has a special utility function. They also examine a mixed reimbursement system, in which hospital reimbursements come from prospective and cost-based payments. Ellis and McGuire provide arguments for such a system and extend their model to take into account competition between hospitals for physicians. In our model, we will consider supply-cost sharing (Ellis and McGuire, 1993).

Chalkley and Malcomson (1998) analyze the optimal contract for health services when patient demand does not fully reflect quality. A purchaser (principal) hires a hospital to provide treatment to patients at a certain quality and cost of care level. They introduce the term benevolent to describe that providers (agents) care about patient benefits from treatment. The optimal contract depends on the benevolence level of the provider. Arguments for cost sharing and mixed reimbursement system are made if providers are partially benevolent. Jack (2005) relaxes the assumption that the purchaser knows the degree of altruism of the provider. Contracts need to be designed to make providers reveal their types. It results in an optimal contract that is a non-linear cost-sharing mechanism. Siciliani (2009) shows that providers with high or low altruism respond to changes in prices, whereas providers with intermediate altruism do not. Similarly to Eggleston (2005b), we will consider the provider's degree of altruism.

Ma (1994) analyzes the case in which patients are sensitive to quality provided by providers. After showing that fully prospective payments are optimal if all patients must be treated, he demonstrates that it is not the case when there is selection. In the case of dumping (in which costly patients are denied services by providers) or of quality discrimination among patient, the cost reimbursement contract can induce better results. In our model, we will not consider explicitly the selection of patients by the provider. Bardey, Canta and Lozachmeur (2008) extend the previous model in the case of two providers competing in quality for patients. Geographical location is considered as a strategic variable.

They conclude that a fully prospective reimbursement system may be not optimal in cases in which the level of specialization is not contractible.

Competition for patients can intensify quality distortion (Eggleston, 2005a). Also considering competition, Kwon (1997) investigates the existence of a variety of reimbursement mechanisms across health insurance markets. He analyzes the market for managed care plans by considering consumers' willingness to pay for quality. Kwon conducts an empirical analysis to predict the proportion of providers paid by fee-for-service (versus capitation) in health maintenance organization markets. In our model, we will not consider competition among providers.

The applications of the principal-agent paradigm are numerous. However, agency models are underrepresented in the health economic literature on pay-for-performance and chronic disease management. Lee and Zenios (2007) is, to the best of our knowledge, the only paper to present a multitask agency model for the management of a chronic disease (i.e, end-stage renal disease). In their model, the purchaser observes the downstream outcome and several other performance measures (intermediate outcomes). We adopt the same modeling approach, since management of hypertensive or diabetic patients call for the use of multiple performance measures (see Chapter 1). Lee and Zenios build a multitask principal-agent model to investigate the optimal mix of performance measures. They develop an empirical method to estimate the parameters of this model.

There are only a few empirical studies of multitask agency models and they generally examine if historical data can be explained by principal-agent models (see Dumont, Fortin, Jacquemet and Shearer, 2008 and Zweifel and Tai-Seale, 2009). Although we did not attempt to conduct an empirical study, due to the lack of relevant data, we will perform a numerical analysis of our model. Similarly to Danzon (1994), we will use simulation analysis to estimate the effect of alternative general payment systems, provider's characteristics and performance measurement system on the utility of the health plan and thus on patient's benefit results.

Table 2.1: Summary of Health Economics Models

	Specificities
Ellis & Mc Guire (1986)	Unidimensional, Competition, Benevolence, Mixed Reimbursement
Chalkley & Malcomson (1998)	Bidimensional, Benevolence, Patient demand (exogenous), Mixed Reimbursement
Jack (2005)	Unidimensional, Benevolence (private)
Siciliani (2009)	Unidimensional, Benevolence
Ma (1994)	Bidimensional, Patient demand, Dumping, Mixed Reimbursement
Bardey, Canta & Lozachmeur (2008)	Bidimensional, Competition for patients, Mixed Reimbursement
Eggleston (2005b)	Multidimensional, Competition, Benevolence, Mixed Reimbursement
Kwon (1997)	Unidimensional, Empirical, Patient choice, Mixed Reimbursement
Eggleston (2005a)	Multidimensional, Mixed Reimbursement, Benevolence
Lee & Zenios (2007)	Bidimensional, Empirical, Intermediate/Downstream Outcome
Our model: a combination of features found in no other models	Multidimesional, Numerical, Mixed Reimbursement, Benevolence, Intermediate/Downstream Outcome

Note: Although the list is not exhaustive, it includes many relevant studies using agency theory in the healthcare sector.

2.2 Multitask Model

We now consider the agent as a physician treating one patient and the principal as a health plan or insurer. The timing is as follow: at date 0, the plan hires a provider. They sign a compensation contract. At date 1, the provider chooses n actions that influence output, i.e., his choice of effort levels is represented by the vector $e^T = (e_1, \dots, e_n) \in \mathbb{R}^n$. However the plan cannot observe these choices, since the physician is asymmetrically better informed. Events beyond the provider's control $\varepsilon^T = (\varepsilon_1, \dots, \varepsilon_n) \in \mathbb{R}^n$ occur. Measured performance is observed by the plan and the physician. The provider receives the compensation specified by the contract at date 2.

We assume that the provider decides the level of spending, m_i, on task i. As in Eggleston (2005b), the agent's effort, e, is imperfectly correlated with the cost of care, $m^T = (m_1, \dots, m_n) \in \mathbb{R}^n$. Specifically, assume that $m_i = \mu_i(e_i + \varepsilon_i), i = 1, \dots, n,$ with $\mu = I_n \in \mathcal{M}_{n \times n}$.

At date 2, a vector of performance measures, $y^T = (y_1, \dots, y_n) \in \mathbb{R}^n$, is publicly reported. We assume that the provider's production function is linear and noisy. Similarly to Lee and Zenios (2007), we distinguish between intermediate and downstream outcomes. The first $n-1$ components of the provider's effort affect both intermediate outcomes y_i, $i = 1, \dots, n-1$, and the downstream outcome, y_n, whereas e_n characterizes additional effort that influences only y_n. We have:

$$y_i = e_i + \varepsilon_i, \qquad i = 1, \dots, n-1$$

$$y_n = \textstyle\sum_{i=1}^{n} e_i + \varepsilon_n,$$

where ε is a vector of normally distributed noise terms that are beyond the provider's control. The noise terms have mean zero and covariance matrix, $\Sigma \in \mathcal{M}_{n\times n}$.

The provider's compensation $w(e,\varepsilon)$, consists of three components:

- a fixed payment π_0 per patient. This amount represents either capitation or prospective payment.
- pay-for-performance incentives, $\pi_i y_i,\ i = 1, \dots, n$.
- reimbursement of a fraction $1 - s$ of the costs. Supply-side cost sharing is defined by s, with $0 \le s \le 1$. Pure cost reimbursement is described by $s = 0$, i.e. 100% of spending is reimbursed, while purely prospective payment, such as capitation is described by $s = \mathbb{1}$.

The plan pays the provider:

$w(e,\varepsilon) = \pi_0 + \sum_{i=1}^{n} \pi_i y_i + \sum_{i=1}^{n}(1 - s_i) m_i = \pi_0 + (J\pi)^T e + \pi^T \varepsilon + (\mathbb{1} - s)^T \mu(e + \varepsilon)$, where $s^T = (s, \dots, s) \in \mathbb{R}^n, \pi^T = (\pi_1, \dots, \pi_n) \in \mathbb{R}^n$.

$J = I_n + \begin{bmatrix} 0 & \dots & 1 \\ \vdots & \ddots & \vdots \\ 0 & \dots & 1 \end{bmatrix} \in \mathcal{M}_{n\times n}$, and $\mathbb{1}^T = (1, \dots, 1) \in \mathbb{R}^n$ are helper variables.

It is assumed that the provider is risk averse with a negative exponential utility function, $U(x) = -\exp(-tx)$, where t is the provider's risk aversion parameter and x is the provider's net payoff . Consider a provider who cares about patient benefit from treatment, y_N, as well as net revenue and disutility from effort :

$$U = \theta y_N + \left(w(e,\varepsilon) - \sum_{i=1}^{n} m_i \right) - c(e)$$

The provider bears a personal cost of effort assumed to be quadratic, $c(e) = \frac{1}{2}e^T Qe$, where $Q \in \mathcal{M}_{n\times n}$ is a symmetric, positive-definite matrix of effort cost parameters. Moreover, we assume that Q is sensitive to the payment environment. Indeed, simulation results from Eggleston (2005b) indicate that the cost of effort for treating chronically ill patients increases as cost-sharing increases. For example, when $n = 2$, we assume specifically that:

$$Q = \begin{bmatrix} Q_1 + Q_1{}' * s^2 & Q_3 * (1-s) \\ Q_3 * (1-s) & Q_2 + Q_2{}' * s^2 \end{bmatrix}, \text{ where } Q_1, Q_1{}', Q_2, Q_2{}' \text{and } Q_3 \in \mathbb{R}.$$

Figure 1.1 illustrates in three dimensions the fact that the cost of effort $c(e)$ increases when the provider increases his effort. What's more, it increases at a higher rate with downstream outcome effort than intermediary outcome effort.

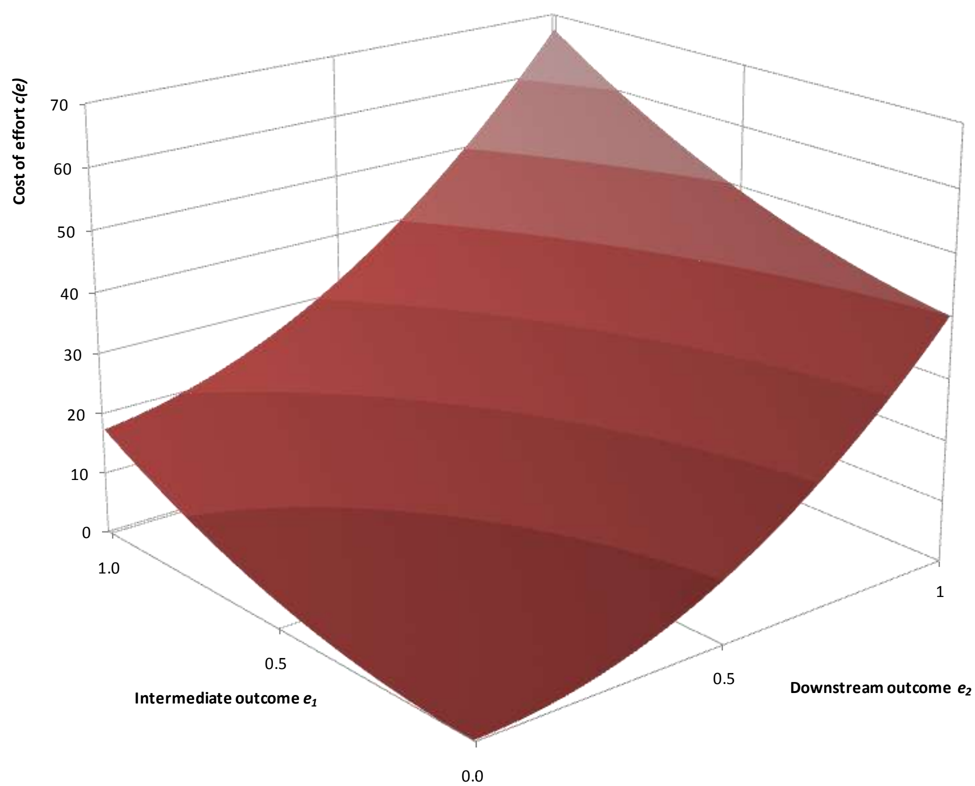

Figure 1.1: Three Dimensional Plot of the Provider's Disutility from Effort

The provider's utility becomes:

$$U = \pi_0 + (\theta - \mu s + J\pi)^T e - c(e) + (K\theta - \mu s + \pi)^T \varepsilon,$$

where $\theta^T = (\theta, \dots, \theta) \in \mathbb{R}^N, 0 \leq \theta \leq 1$, represents the level of benevolence of the provider and $K = \begin{bmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix} \in \mathcal{M}_{N\times N}$ is a helper variable.

Maximizing the expected utility is equivalent to maximizing the certainty equivalent which is characterized by:

$$CE(e) = \pi_0 + (\theta - \mu s + J\pi)^T e - c(e) - \frac{t}{2}(K\theta - \mu s + \pi)^T \Sigma (K\theta - \mu s + \pi),$$

where $(K\theta - \mu s + \pi)^T \Sigma (K\theta - \mu s + \pi)$ describes the provider's risk premium. Furthermore the provider will only participate if his contract is such that it provides him with his reservation certainty equivalent U_0, i.e., $CE(e) \geq U_0$. We assume as Joseph and Thevaranjan (1998) that the reservation certainty equivalent demanded by the provider is a function of his risk-aversion parameter t, such that: $U_0 = \frac{u_o}{t}$, where the parameter $u_o \in \mathbb{R}$ represents the premium paid for risk tolerance.

The risk-neutral principal receives a reward ν for each unit of downstream outcome, but not for the intermediate outcomes. We define the total amount of patient's benefit, $B = \nu^T e$. The purchaser's problem is to choose the parameters of the payment system (π_0, π) to maximize her expected utility:

$$E(P) = \nu^T e - E\big(w(e, \varepsilon)\big),$$

where $\nu^T = (\nu, \dots, \nu) \in \mathbb{R}^n$.

The maximization program is:

$$\max_{\pi} \ \nu^T e - E(w(e, \varepsilon))$$

s.t. $\max_e CE(e)$

$CE(e) \geq U_0$ (*)

To maximize his expected utility, the provider chooses $e^* = Q^{-1}(\theta - \mu s + J\pi^*)$ (see Proof 3 in the Appendix). Cost minimization requires that (*) binds, i.e., ${\pi_0}^* = U_0 - \frac{1}{2}(\theta - \mu s + J\pi)^T Q^{-1}(\theta - \mu s + J\pi) + \frac{1}{2}(K\theta - \mu s + \pi)^T t\Sigma(K\theta - \mu s + \pi)$. Substituting this expression and e^* in the purchaser's utility yields an unconstrained maximization problem.

$$\max_\pi \begin{array}{c} \left(\nu - J\pi - \mu(\mathbb{1} - s)\right)^T Q^{-1}(\theta - \mu s + J\pi) - U_0 + \\ \frac{1}{2}(\theta - \mu s + J\pi)^T Q^{-1}(\theta - \mu s + J\pi) - \frac{1}{2}(K\theta - \mu s + \pi)^T t\Sigma(K\theta - \mu s + \pi) \end{array}$$

The first-order condition with respect to π leads to:

$$\pi^* = (J^T Q^{-1} J + t\Sigma)^{-1}\left[J^T Q^{-1}\left(\nu - \mu(\mathbb{1} - s)\right) - \frac{t}{2}\Sigma(K\theta - \mu s)\right].$$

We now obtain closed-form solutions for the fixed payment (π_0), pay-for-performance rates $(J\pi)$, provider's wage (w), the percentage of provider's compensation coming from pay-for-performance ($P4P = E(\frac{\sum_{i=1}^n \pi_i y_i}{w(e,\varepsilon)})$), the total spending ($m = \sum_{i=1}^n m_i$), the total amount of patient's benefit ($B = \nu^T e$), plan's expected utility function value ($E(P)$), the provider's certainty equivalent ($CE = \frac{u_o}{t}$) and the total welfare ($T = E(P) + CE$).

2.3 Baseline Values for Simulation

We now propose to use this model to test the effects of alternative payment systems, provider's characteristics and performance measurement system on the utility of the health plan and thus on patient's benefit. Parameter values are selected to yield results that conform roughly to realistic mean empirical magnitudes for percentage bonus in provider's pay. Generally, percent of provider's pay eligible for bonus should represent at least 10% to motivate behavioral change in providers (Center for Health Care Strategies, 2007). Table 2.2 gathers base values for key parameters and references used notation. Unless otherwise specified, all parameters take base values.

Table 2.2: Notation and Base Values

Variable Name	***Description***
	Payment Environment
$\boldsymbol{\mu}$	Correlation Matrix between Cost of Care and Effort (I_n)
$\boldsymbol{s}$	Supply-side Cost Sharing ($0\ or\ [0,1]$)
$\boldsymbol{\nu}$	Reward received by the Purchaser in terms of Patient's Benefit ($10\ or\ [0,1]$)
	Provider's Characteristics
$\boldsymbol{t}$	Provider's degree of Risk Aversion ($1.10^{-5} or\ 2.10^{-5},\ 3.10^{-5},\ 4.10^{-5}$)
$\boldsymbol{\theta}$	Provider's degree of Benevolence ($0\ or\ [0,1]$)
$\boldsymbol{Q}$	Provider's Cost Effort Matrix ($Q_1 = Q_2 = 15,\ Q_1{}' = Q_3 = 10$ and $Q_2{}' = 100$)
$\boldsymbol{U_0} = \frac{u_o}{t}$	Provider's Reservation Certainty Equivalent ($u_o = 5.10^{-4}$)

Performance Measurement System	
ε_i	Noise Terms
$\boldsymbol{\Sigma}$	Covariance Matrix of Noise Terms (0.125* I_n)
$\boldsymbol{n}$	Number of Performance Indicators (2 or 5, 10)
Outcomes	
$\boldsymbol{e_i}$	Induced Effort on Task *i* (*)
$\boldsymbol{y_i}$	Performance Indicator for Intermediate Outcome *i* (*)
$\boldsymbol{y_n}$	Downstream Outcome (*)
$\boldsymbol{\pi_0}$	Fixed Payment (*)
$\boldsymbol{J\pi}$	Payment for each unit of Outcome *i* (*)
$\boldsymbol{w}$	Provider's Wage (*)
$\mathbf{P4P} = E(\frac{\sum_{i=1}^{n} \pi_i y_i}{w(e,\varepsilon)})$	Percentage of Provider's Wage coming from pay-for-performance (*)
$\boldsymbol{m} = \sum_{i=1}^{n} m_i$	Total Spending (*)
$\boldsymbol{B} = \nu^T e$	Patient's Benefit
$\boldsymbol{E}(\boldsymbol{P})$	Purchaser's Expected Utility (*)
$\boldsymbol{CE} = \frac{u_o}{t}$	Provider's Certainty Equivalent (*)
$\boldsymbol{T} = E(P) + CE$	Total Welfare (*)

Note: Base values are in parentheses.

* Variables determined by simulation

Chapter 3

ANALYSIS OF DIFFERENT PAYMENT SYSTEMS

3.1 Payment Environment

The payment environment is stylized using different parameters, namely: cost-sharing (s), purchaser's reward from downstream outcomes (v) and correlation matrix between cost of care and effort (μ). We propose to study the effects of varying the first two parameters, when there are two performance indicators ($n=2$).

3.1.1 Physician's Cost-Sharing Parameter s

Table 3.1 presents the effects of changing the reimbursement mechanism to decrease the percentage of reimbursement of costs from 100% $(s = 0)$ to 0% $(s = 1)$. The simulations confirm that a small amount of cost-sharing provides the greater total welfare (T), measured as the sum of expected utility of the purchaser and the physician. This is further illustrated on Figure 3.1, where total welfare reaches its maximum for $s = 0.1$, and $T = 3.30$. However, as the cost-sharing parameter s increases beyond this value, the total welfare diminishes, as well as the physician's wage (w), the patient's benefit (B) and the purchaser's utility (P). Physicians will also tend to spend less (i.e., m decreases), when the system approaches a capitation system $(s = 1)$.

The optimal pay-for-performance system that incorporates both intermediate and downstream outcomes pays the same amount for each unit of intermediate and downstream outcome ($\pi_1+\pi_2$, π_2), but rewards a greater fixed payment (π_0), as the system approaches a fee-for-service system ($s = 0$). The percentage of the physician's income that comes from pay-for-performance (*P4P*) is strictly decreasing in cost-sharing.

Table 3.1: Payment Environment: Cost-Sharing

Cost-sharing s	0.0	0.1	0.2	0.3	1.0
Fixed payment π_0	46.76	46.70	46.74	46.85	48.03
Payment for each unit of intermediary/downstream outcomes ($\pi_1+\pi_2$, π_2)	(9.0,9.0)	(9.1,9.1)	(9.2,9.2)	(9.3,9.3)	(10,10)
Agent's wage w	53.96	54.04	53.98	53.85	52.41
Bonus percentage *P4P*	12.01%	12.36%	12.35%	12.10%	8.36%
Total spending m	0.72	0.73	0.72	0.70	0.44
Patient's benefit B	7.20	7.34	7.24	7.01	4.38
Principal's utility P	-46.76	-46.70	-46.74	-46.85	-48.03
Agent's certainty equivalent *CE*	50.00	50.00	50.00	50.00	50.00
Total welfare T	3.24	3.30	3.26	3.15	1.97

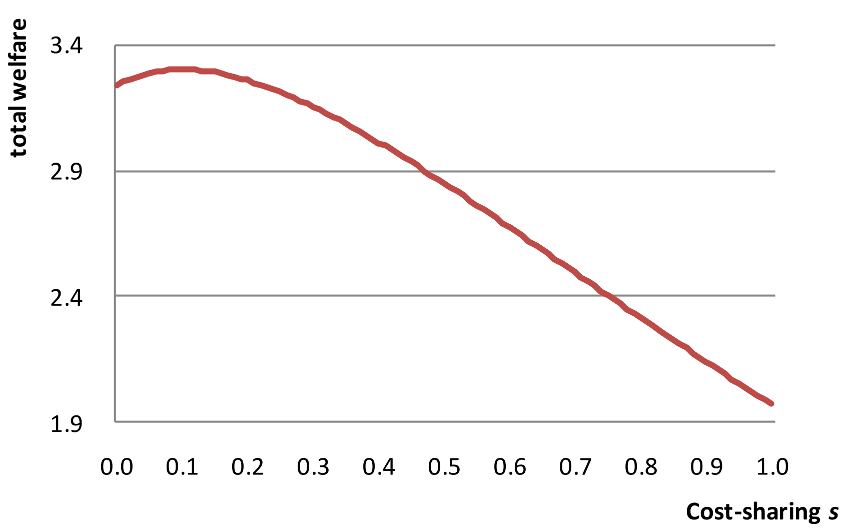

Figure 3.1: Effects of Cost-Sharing on Total Welfare

3.1.2 Purchaser's Reward ν

We now perform a sensitivity analysis to investigate the effect of varying the purchaser's reward for the downstream outcome ν. The results are gathered in Table 3.2. For a small range of variation of ν, total welfare (T) is strictly increasing in purchaser's reward, as shown in Figure 3.2. As the purchaser's reward ν increases, the physician's wage (w) increases, along with the patient's benefit (B), the purchaser's utility (P) and physician's spending (m). A higher purchaser's reward reinforces the optimal pay-for-performance system by paying more for each unit of intermediate and downstream outcomes ($\pi_1+\pi_2, \pi_2$) and a greater fixed payment (π_0). The percentage of the physician's income that comes from pay-for-performance ($P4P$) is strictly increasing in purchaser's reward. Therefore, there is a danger of overestimating the gains and thus overpaying, if the purchaser's reward is itself overestimated. We expect the gains generated from increasing purchaser's reward to decrease as ν increases beyond its current level.

Table 3.2: Payment Environment: Estimation of Purchaser's Reward

Purchaser's reward ν	9.0	9.5	10.0	10.5	11.0
Fixed payment π_0	47.44	47.11	46.76	46.39	46.00
Payment for each unit of intermediary/downstream outcomes ($\pi_1+\pi_2, \pi_2$)	(8.0,8.0)	(8.5,8.5)	(9.0,9.0)	(9.5,9.5)	(10.0,10.0)
Agent's wage w	53.20	53.57	53.96	54.37	54.80
Bonus percentage $P4P$	9.62%	10.79%	12.01%	13.28%	14.60%
Total spending m	0.64	0.68	0.72	0.76	0.80
Patient's benefit B	5.76	6.46	7.20	7.98	8.80
Principal's utility P	-47.44	-47.11	-46.76	-46.39	-46.00
Agent's certainty equivalent CE	50.00	50.00	50.00	50.00	50.00
Total welfare T	2.56	2.89	3.24	3.61	4.00

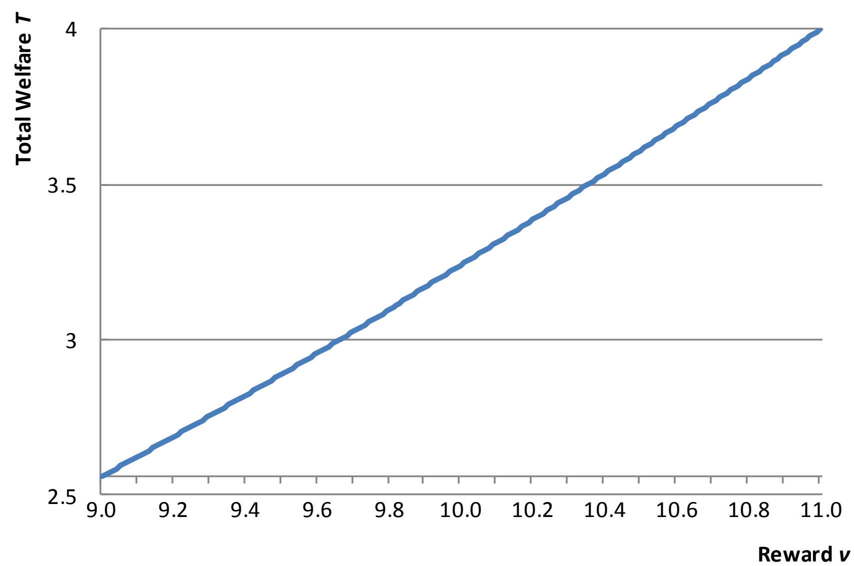

Figure 3.2: Effect of Estimation of Purchaser's Reward v on Total Welfare

3.2 Physician's Characteristics

The provider is described by different parameters, namely: his altruism level (θ), his risk-aversion parameter (t), his reservation certainty equivalent (U_0) and his cost function (Q). We propose to study the effects of varying the first two parameters, when there are two performance indicators ($n=2$) and the payment system is optimal ($s=0.1$).

3.2.1 Physician's Level of Benevolence θ

We now investigate the effects of the provider's level of altruism θ, results are gathered in Table 3.3. The main result is that total welfare (T) is strictly increasing in provider's level of benevolence, as shown in Figure 3.3. As the provider's level of altruism increases, the physician's wage (w) increases, along with the patient's benefit (B), the purchaser's utility (P) and physician's spending (m). The level of altruism of the provider does not influence the optimal pay-for-performance system, in the sense that the payment for each unit of intermediary and downstream outcomes ($\pi_1+\pi_2, \pi_2$) remains the same. The percentage of the physician's income that comes from pay-for-performance ($P4P$) is strictly increasing in physician's benevolence, while the fixed payment (π_0) is strictly decreasing.

As shown in Figure 3.4, results are qualitatively similar when the cost-sharing parameter (s) increases, given that the physician is selfish ($\theta = 0$) or altruistic ($\theta = 1$). We found that the level of welfare attained when the physician is altruistic remains well above the level obtained when the physician is selfish. With the same pay-for-performance system, altruism improves outcomes. However, a provider that cares about patient healthcare benefits may generate excessive spending on patient care. Indeed, such altruism reduces incentives to control costs.

Table 3.3: Physician's Characteristic: Benevolence Level

Benevolence level θ	0.00	0.25	0.50	0.75	1.00
Fixed payment π_0	46.70	46.51	46.32	46.12	45.92
Payment for each unit of intermediary/downstream outcomes ($\pi_1+\pi_2, \pi_2$)	(9.1,9.1)	(9.1,9.1)	(9.1,9.1)	(9.1,9.1)	(9.1,9.1)
Agent's wage w	54.04	54.06	54.07	54.08	54.08
Bonus percentage $P4P$	12.36%	12.70%	13.04%	13.38%	13.73%
Total spending m	0.73	0.75	0.77	0.80	0.82
Patient's benefit B	7.34	7.55	7.75	7.95	8.16
Principal's utility P	-46.70	-46.51	-46.32	-46.12	-45.92
Agent's certainty equivalent CE	50.00	50.00	50.00	50.00	50.00
Total welfare T	3.30	3.49	3.68	3.88	4.08

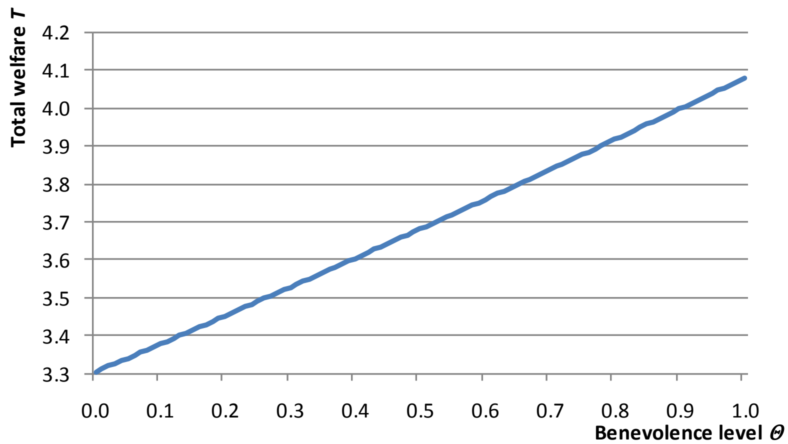

Figure 3.3: Effect of Provider's Benevolence Level on Total Welfare

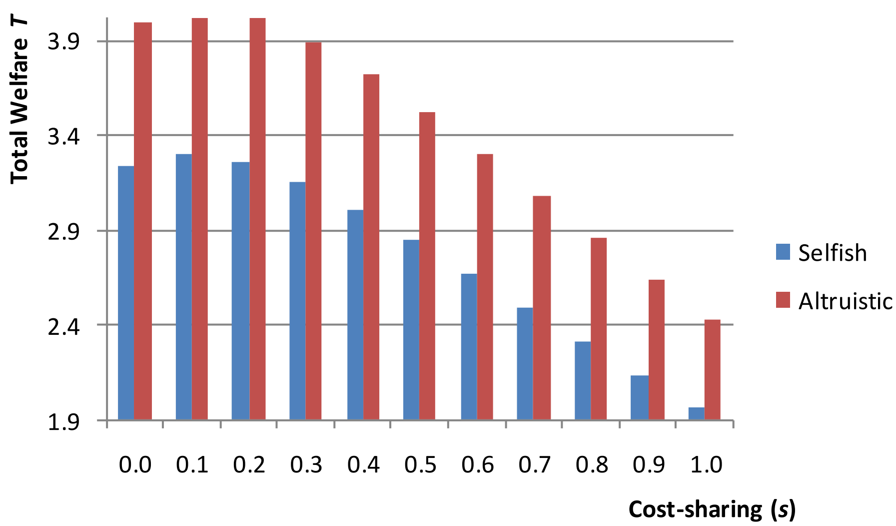

Figure 3.4: Effects of Cost-Sharing on Total Welfare Based on Benevolence Level

3.2.2 Provider's Risk Aversion *t*

We now investigate the effects of the provider's risk aversion t, results are gathered in Table 3.4. We will consider the following values: $t = 1.10^{-5}$, 2.10^{-5}, 3.10^{-5}, 4.10^{-5} and 5.10^{-5} per dollar respectively. The certainty equivalent will change according to the following formula: $U_0 = \frac{u_o}{t}$. Figure 3.5 shows that as the provider's risk aversion increases, the purchaser's utility (P) increases, the provider's certainty equivalent (CE) decreases and the total welfare (T) remains the same. As the provider's risk aversion increases, the patient's benefit (B), and physician's spending (m) remain the same, while the physician's wage decreases (w). Tolerance for risk (i.e., t is closer to 0) is a trait that is valued by the purchaser and leads to a monetary premium. The risk aversion of the provider does not influence the optimal pay-for-performance system, in the sense that the payment for each unit of intermediate and downstream outcomes ($\pi_1+\pi_2$, π_2) remains the same, while the fixed payment π_0 decreases to adjust to the provider's certainty equivalent. The percentage of the physician's income that comes from pay-for-performance ($P4P$) is strictly increasing in physician's risk aversion.

Table 3.4: Physician's Characteristic: Risk Aversion

Risk aversion t	1E-05	2E-05	3E-05	4E-05	5E-05
Fixed payment π_0	46.70	21.70	13.36	9.20	6.70
Payment for each unit of intermediary/downstream outcome ($\pi_1+\pi_2$, π_2)	(9.1,9.1)	(9.1,9.1)	(9.1,9.1)	(9.1,9.1)	(9.1,9.1)
Agent's wage w	54.04	29.04	20.70	16.54	14.04
Bonus percentage $P4P$	12.36%	23.01%	32.26%	40.39%	47.58%
Total spending m	0.73	0.73	0.73	0.73	0.73
Patient's benefit B	7.34	7.34	7.34	7.34	7.34
Principal's utility P	-46.70	-21.70	-13.36	-9.20	-6.70
Agent's certainty equivalent CE	50.00	25.00	16.67	12.50	10.00
Total welfare T	3.30	3.30	3.30	3.30	3.30

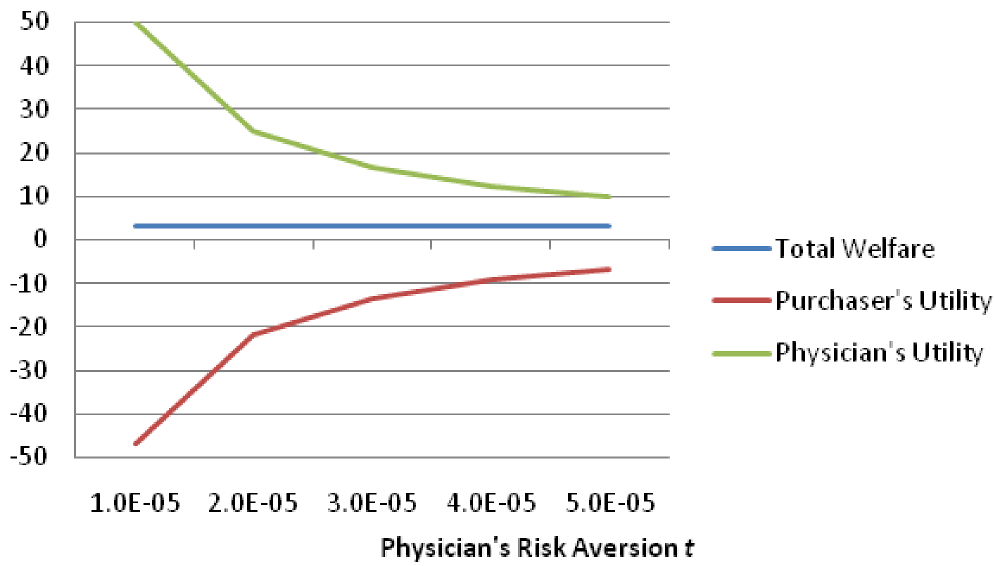

Figure 3.5: Effect of Provider's Risk Aversion on Total Welfare, Utility of Purchaser and Physician

3.3 Performance Measurement

Performance measurement is described by different parameters, namely: the number of performance measures (n) and the covariance matrix of the noise terms (Σ). We propose to study the effects of varying the first two parameters.

3.3.1 Number of Performance Measures

Determining the number of performance measures (n) to use is an important design decision in any pay-for-performance system. Table 3.5 and Table 3.6 present the effects of changing the reimbursement mechanism to decrease the percentage of reimbursement of costs from 100% $(s = 0)$ to 0% $(s = 1)$, when there are 5 and 10 quality indicators respectively. The results are qualitatively similar to the ones obtained when there are only two quality indicators, as illustrated by Figure 3.6. In other words, a small amount of cost-sharing provides the greater total welfare (T). Similarly to the case where $n = 2$, as the cost-sharing parameter s increases beyond the optimal value, the total welfare diminishes, as well as the physician's wage (w), the patient's benefit (B) and the purchaser's utility (P). Physicians will also tend to spend less (i.e., m decreases), when the system approaches a capitation system ($s = 1$). The notable difference is that the decrease is less brutal when there are more performance measures.

Table 3.5: Payment Environment: Cost-Sharing when *n=5*

Cost-sharing *s*	**0**	**0.1**	**0.2**	**0.3**	**1**
Fixed payment π_0	46.76	46.73	46.71	46.70	47.01
Agent's wage *w*	53.96	53.99	54.02	54.03	53.66
Bonus percentage *P4P*	12.01%	12.24%	12.45%	12.62%	12.40%
Total spending *m*	0.72	0.73	0.73	0.73	0.67
Patient's benefit *B*	7.20	7.26	7.31	7.33	6.65
Principal's utility *P*	-46.76	-46.73	-46.71	-46.70	-47.01
Agent's certainty equivalent *CE*	50.00	50.00	50.00	50.00	50.00
Total welfare *T*	3.24	3.27	3.29	3.30	2.99

Table 3.6: Payment Environment: Cost-Sharing when *n=10*

Cost-sharing *s*	**0**	**0.1**	**0.2**	**0.3**	**1**
Fixed payment π_0	46.760	46.748	46.738	46.730	46.790
Agent's wage *w*	53.960	53.974	53.987	53.997	53.924
Bonus percentage *P4P*	12.01%	12.18%	12.35%	12.52%	13.23%
Total spending *m*	0.720	0.723	0.725	0.727	0.713
Patient's benefit *B*	7.200	7.226	7.249	7.267	7.135
Principal's utility *P*	-46.760	-46.748	-46.738	-46.730	-46.789
Agent's certainty equivalent *CE*	50.00	50.00	50.00	50.00	50.00
Total welfare *T*	3.240	3.252	3.262	3.270	3.211

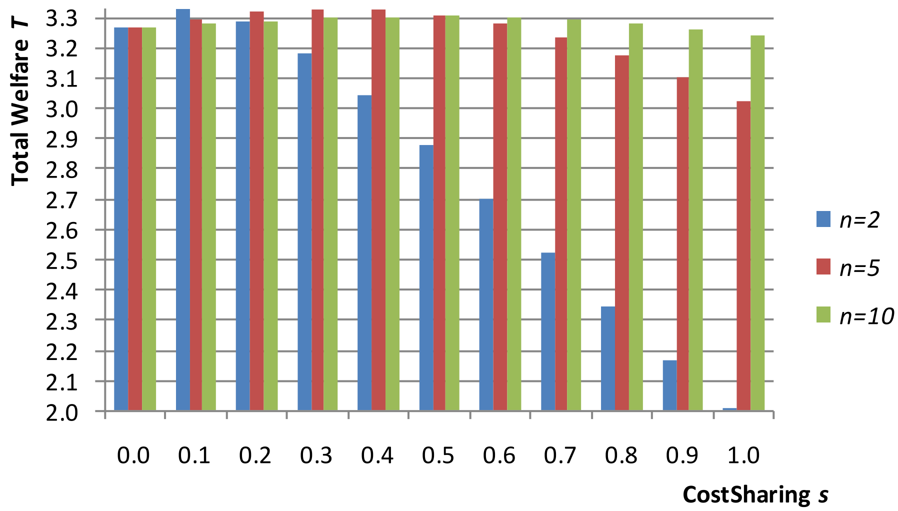

Figure 3.6: Effects of Cost-Sharing on Total Welfare (*n=2, 5 or 10*)

Using a large number of performance measures would support overall improvement in quality, but the incentive to improve in a particular area may be weak. On the other hand, using fewer quality indicators would allow the provider to focus his effort on areas where improvement is needed the most, but quality could decrease in areas not targeted by the incentive program.

3.3.2 Covariance Matrix of Noise Terms $\sum$

We do not present numerical results for the effect of varying the covariance matrix of noise terms $\sum$, since for reasonable increase of variance, there were no significant changes in outcomes with the values selected. However, we can give general comments on this parameter. As the variance and the absolute value of the covariance of the noise terms increase, i.e. the performance measure becomes less and less accurate, the total welfare would decrease.

Chapter 4

DISCUSSION

As we used a stylized model to analyze payment systems in healthcare, our results have several important limitations. We will discuss these limitations and review the literature related to them. Specifically, we will discuss general assumptions of principal-agent models, particular assumptions of our model (i.e., exponential utility, cost function, normal noises), and important features that we opted to leave out of our model (i.e., risk adjustment, performance measurement, group-based incentives).

4.1 Critical Assumptions

Our principal-agent framework relies on economic utilitarianism (Ross, 1973). Agency theory is built on a set of assumptions (see Table 4.1) worth stressing regarding the behavior of agents, organizations and information. First, people are assumed to seek to maximize their individual utility. Indeed, the principal and the agent are both fully rational maximizers. However with the increasing complexity of systems it may become necessary to model bounded rationality. Laffont and Martimort (2002) described two ways of modeling such a behavior. One of them is called the 'trembling hand' behavior in which the agent may make some small mistake in choosing a contract within the menu offered by the principal. This modeling approach could allow us to relax the assumption of complete rationality of all players.

Second, in the principal-agent framework, the players are assumed to exhibit self interest, in other words, in case of unanticipated events, they will behave in their best interests. Nonetheless, we assume that the provider's objective is not to maximize profit alone. Indeed, the agent's utility includes elements beyond the agent's profit, such as patient outcomes. This feature allows us to take into account the benevolence level of agents, since healthcare providers are driven by the principles of medical ethics and various ethical guidelines.

Third, in our model, we restrict ourselves to the simple form of linear contracts, to represent both cost sharing and pay-for-performance. Linear arrangements are often encounter in real world settings due to their simplicity. However in more general principal-agent models there is no limit on how complex feasible contracts can be, e.g. contracts can be quadratic. In addition, as discussed in Chapter 1, pay-for-performance algorithms can take several forms based on the type of reward, for example relative vs. absolute performance improvements. Our simple linear payment formula encompasses most common payment methods and allows us to perform tractable analyses. We leave for further research the exhaustive investigation of each particular type of payment contract.

Finally, the principal is assumed to be less informed than his agent. Information is viewed as a commodity that can be exchanged (Eisenhardt, 1989). The assumption of absence of private information for the principal is appropriate in our model since providers are better informed than purchasers about the consequences of clinical decisions. However, it is possible to relax this assumption (see Maskin and Tirole, 1990 and 1992). Moreover, information structures are assumed to be exogenously given to the agents. Models that represent information structures as endogenous can be developed (Laffont and Martimort, 2002).

In agency theory, the agent is assumed to be risk averse. The assumption of risk averseness is relaxed regarding the principal but not the agent. In the healthcare setting, it seems realistic that the provider is dependent on the purchaser concerning his security and income, while the purchaser has the opportunity to diversify his investments. The most stringent assumption here is that the agent's utility is exponential. Validating these assumptions or relaxing them is left for future research.

Table 4.1: Agency Assumptions applied to the Healthcare Setting

(adapted from Eisenhardt, 1989)

People	
Self-interest	Focus on maximizing utility
Rationality	
Risk orientation	Principal (Purchaser): risk neutral Agent (Provider): risk averse
Organization	
Goal conflict	
Information asymmetry	Better informed agent
Information	
	Viewed as a commodity Exogenous information structure

The optimal reimbursement system was derived from a key assumption about the provider's cost function. We assumed that the disutility from effort was sensitive to the payment environment. The relationship between the cost matrix and the cost sharing parameter could be modified. In addition, personal cost of effort could also be dependent on the number of treatments provided. A model capturing this relationship can be developed but analyses may become untractable. As in Lee and Zenios (2007), we could estimate the disutility from effort empirically to design evidence-based optimal incentive systems. This estimation would require a careful analysis of empirical evidence, such as cost reports from purchasers.

4.2 Risk Adjusment

We consider a physician who provides treatment to a single patient. However, if we want to generalize our model to take into account a population of patients, the patient outcomes need to be properly risk-adjusted by patient health factors that are beyond the control of the provider. Otherwise given the wide variance in health status there would be an incentive for physicians to "cream-skim" healthier patients, i.e. select those patients expected to be profitable. It is argued that deterring selection requires adequate risk adjustments: if providers are paid more for patients likely to be costly, the provider would not shun these patients. Indeed, with ideal risk adjustment, the risk-adjusted premium exactly compensate for the differences in the expected expenditures of the individual members. The same concept can be used for different purposes, either setting payments or adjusting patient case-mix in non-payment related measures.

Keenan, Buntin, McGuire and Newhouse (2001) defined formal risk adjustment as the adjustment of premium paid to health providers by purchasers based on a formula utilizing individual-level diagnostic or demographic information. They show that private purchasers have mechanisms other than formal risk adjustment to address selection risk, such as open enrollment provisions or premium negotiations. The conventional practice sets prices for patients proportional to their expected cost based on observable attributes. The risk-adjustment tools available to purchasers can be divided into three categories depending on the data they use: (i) demographic factors, such as age, sex, family status; (ii) administrative data; (iii) self-reported health status or (iv) any combination of the above.

There are four risk adjustment measures that can be used for outcomes assessment of chronically ill patients. The ACG (Adjusted Clinical Group) system was developed by Weiner, Tucker, Collins, Steinwachs and Mumford (1998) to estimate risk for health service use based on demographic factors and categories of diagnoses assigned over a defined time interval. The Diagnostic Cost Groups (DCG) Hierarchical Condition Category models are additive across condition categories using linear regression (Pope et al., 2004). In the CDPS (Chronic Illness and Disability Payment System), developed by Kronick, Gilmer, Dreyfus, and Lee (2000), the major chronic diagnostic categories are divided into 43 subcategories depending on severity. The same researchers have developed a pharmacy-based tool called Medicaid Rx, tailored to the Medicaid population (Gilmer et al., 2001).

There are other risk-adjustment tools called comorbidity measures. The CCI (Charlson Comorbidity Index) was designed by Charlson, Pompei, Ales et al. (1987) as a measure of the risk of 1-year mortality attributable to comorbidity in a longitudinal study of general hospitalized patients. The Seattle Index of Comorbidity (SIC) is a risk adjustment score that predicts resource utilization and mortality based on self-reported conditions (Fan, Au, Heagerty, Deyo, McDonell and Fihn, 2002). The Chronic Disease Score (Von Korff, Wagner and Saunders, 1992) is an aggregate comorbidity measure based on the patient's use of prescriptions during a 6-month period of current medication use.

Glazer and McGuire (2000) noted that risk adjustment can be a more powerful tool if purchasers not only pay in proportion to expected costs but also view risk adjustment as a tax subsidy scheme. Frank, Glazer and McGuire (2000) put forward a shadow price approach for managed care to empirically estimate the extent of distortion with many patient groups and many services. The primary objective of the purchaser should thus be to maximize consumer welfare instead of only being budget neutral or maximizing predictive power (i.e., statistical performance). After choosing the objective function to be optimized, modelers need to decide what risk adjusters are legitimate to be used for prediction and about the weights to attach to the included variables. An explicit approach that estimates a regression model with all empirically relevant variables is argued to provide a better explanatory model of healthcare expenditures (Schokkaert and Van de Voorde, 2006).

Finally, Eggleston, Ellis and Lu (2007) introduced dynamic risk adjustment to address the conflicting goals of conventional risk adjustment and health prevention by combining the conventional approach with pay-for-performance on prevention. They studied a simple model over two periods with two risk categories that can represent healthy and chronically ill patients. Indeed, providers should be paid the conventional risk adjustment amount plus a prevention bonus if performance is better than expected. Fixed payment is modeled as depending on the accuracy of currently available risk adjustment technology, β. This feature can be added in future research to refine our model.

4.3 Measuring Performance

We consider that we have a number of performance measures readily available. However, measuring performance is key to a successful payment system and represents a major hurdle in healthcare, in particular in chronic disease management. The most widely used performance measurement set is the Healthcare Effectiveness Data and Information Set (HEDIS). HEDIS was initiated by a few major employers and health maintenance organizations and is now refined regularly by the National Committee for Quality Assurance (NCQA). HEDIS now includes a larger breadth of measures, specifically a variety of measures related to care for chronic conditions. HEDIS measures can be used by purchasers to participate in NCQA's rigorous accreditation processes.

Many performance measures rely on administrative data generated by the billing process, i.e. claims submissions. While these data are inexpensive to obtain, they are subject to inaccuracy, as for example the coding of chronic diseases and comorbidities is highly variable (Iezzoni, Foley and Daley, 1992). The alternative to using claims-based data is using clinical data in medical records. However, the costs associated with obtaining such data may limit the use of these alternative data sources. As discussed in Chapter 1, there are several categories of performance measurement, including 'process' measures and 'outcome' measures. An 'outcome' measure (i.e. downstream outcome), such as the proportion of a physician's panel of patients with controlled blood pressure, is more influenced by patient characteristics than a 'process' measure (i.e., intermediate outcome) which estimates if a provider is consistent with guidelines of care (Kerr, Krein, Vijan et al., 2001).

Development of clinical practice guidelines (CPGs) is based on clinical evidence and expert consensus to help establish the standard of care. Adherence to specific guidelines is supposed to improve quality of care and reduce variability (Garber, 2005). Therefore CPGs are attractive to serve as foundations for process measures of quality. As most CPGs address single diseases, this approach may create disincentives to address the multiple dimensions of care for patients with several chronic diseases (Kiefe, Funkhouser, Fouad and May, 1998). Boyd et al. (2005) concluded that under a pay-for-performance system the guidelines for providing high quality care must address the management of complex patients who have comorbid diseases to prevent physicians from simply treating each condition. However, there is some evidence that physicians give more attention to sicker and more complex patients (Petersen, Woodard, Henderson, Urech and Pietz, 2009).

Petersen et al. (2009) studied the impact of 6 common comorbidities on quality of care for hypertension in the Veterans Affairs system. All the patients were hypertensive and were divided into 4 groups depending on their other medication conditions. Of this cohort, 49.5% had hypertension-concordant conditions (e.g., diabetes mellitus, ischemic heart disease, and dyslipidemia); 9% had only hypertension-discordant conditions (e.g., arthritis, depression, and chronic obstructive pulmonary disease); 26% had both; and 16% had neither. They found that patients with greater disease complexity received more medical attention than those without such conditions. The highest overall quality of care for hypertension was received by patients who had both types of comorbid conditions.

The Institute of Medicine (2006) proposed that performance measures for specific condition should be aggregated into a single composite per patient instead of existing provider-based measurement approaches. Moreover composite measures can be combined for complex patients who receive care from multiple providers. Data are not currently adequate to determine individual patient-level measurement. Lee (2008) developed composite measures for health maintenance organizations and examined from a statistical perspective alternative approaches used to combine HEDIS measures linearly. The number of performance measures required depends on the reliability of the performance measures: the better the performance measures are, the fewer you will need. A reliable and robust measurement system is crucial to implement a successful pay-for-performance program.

4.4 Group vs. Individual Rewards

In our model, we consider a single agent to represent an individual provider. Indeed, more than one-third of health maintenance organizations using pay-for-performance programs measure and reward quality at the individual provider level (Baker and Carter, 2005). Scholle et al. (2008) examined the validity and reliability of quality measures to assess physician performance. A quality indicator is said to be reliable when it allows us to distinguish an individual provider's performance from average performance. In this study, individual physicians are identified using the unique physician identifiers and are considered responsible for a quality event if the patient had to have a visit with the physician during a period when the physician could meet the quality indicator. The smaller the sample size of quality events is, the greater the risk for misclassification of the provider is. Composite scores can achieve a better reliability than individual items.

Further considerations of sufficient sample size and measurement reliability lead to generally prefer group-level incentives. Rewarding performance at the organization level addresses these issues by allowing providers to aggregate cases. Moreover, it would allow attaining a critical size of rewards that is meaningful to induce the desired change. Rewarding at the group level also presents the advantage to mitigate the stigmatism of individual poor performers as well as to support improvements in technology infrastructure, care processes and team coordination. Indeed, the organization would be responsible for allocating the rewards, and could invest a portion of the rewards in operational costs.

Coordination of care is proposed to improve patient care and outcomes particularly for those with chronic conditions and comorbidities, since those with such diseases see an average of 13 different physicians in a year (MedPAC, 2005). Patients often receive fragmented care in multiple care settings, such as specialist offices, hospitals, and long-term facilities. As a result, optimal collaboration and coordination between healthcare providers in the delivery of integrated care is now required to guarantee high-quality care (Glouberman and Mintzberg, 2001). Organization-level performance indicators that address specifically care coordination need to be developed and validated (Coleman and Boult, 2003). Incentives should prioritize holistic approaches and improved transitional care across settings and over time (Doran et al., 2006).

Group-based incentives were studied by Encinosa, Gaynor and Rebitzer (1997) using a behavioral microeconomic model combined with a survey of medical groups. They integrated the sociological concept of "group norms" and peer pressure to examine the empirical relationship with incentives. Gaynor, Rebitzer and Taylor (2004) analyzed the group-based incentives in health maintenance organizations. When multiple agents are involved in the decision-making process, it is argued that high-powered group incentives can improve outcomes and that the power of peer pressure is insufficient to overcome moral hazard. These issues are largely outside the scope of this thesis: a more refined principal-agent framework, such as the one developed by Itoh (1991), would be required to address the case of multiple agents.

Chapter 5

CONCLUSION AND FUTURE RESEARCH

5.1 Summary and Conclusion

The overall quality of healthcare delivered to Americans is suboptimal. The increasing prevalence of chronic disease exacerbates these problems representing a significant challenge for the healthcare system. Moreover there is a misalignment between healthcare provider's compensation and high quality care. The use of financial incentives varies according to whether providers receive their base compensation by fee-for-service, capitation or mixed payment. The purpose of this study is to develop a theoretical model to design an optimal payment system, linking base compensation and pay-for-performance to motivate provider's effort across the multiple tasks involved in successful chronic disease management.

Drawing from agency theory, we propose a simple multitasking model of provider choice of patient chronic care under different base compensation schemes. Specifically, a healthcare provider (agent) treats a patient and is reimbursed by the principal (the purchaser). High quality treatment increases patient's benefits, measured as controlled blood pressure for hypertensive care for example (downstream outcome). The purchaser also observes the provider's adherence to certain clinical processes, for example the frequency of monitoring tests or the provision of smoking cessation advice (intermediate outcomes). The question is to design the optimal pay-for-performance system, given the base compensation scheme, provider's characteristics and performance measurement system.

This model is used to test the effects of alternative base payment mechanisms, provider's altruism and risk orientation, as well as the number and reliability of performance measures on the total welfare, measured as the sum of expected utility of the purchaser and the physician. Simulation analysis yields estimates of total welfare, patient's benefit, total spending, parameters of the payment system, provider's wage and percentage of provider's wage coming from pay-for-performance (i.e., size of incentives). The model further strengthens conventional arguments for mixed payment systems. Results show that the estimation of the purchaser's reward from increased quality should be made carefully to prevent overpayment. Moreover provider's altruism improves outcomes even though it may generate excessive spending on patient care. The more risk averse the provider is, the more important is the role played by pay-for-performance incentives. Therefore the incentive effects will vary substantially across providers. What is more, determining the number of performance measures and their reliability is a crucial decision for designing pay-for-performance programs. Finally, we identify perspectives for future research.

5.2 Future Work

Future research could build upon our multitask principal-agent framework to estimate all the parameters from empirical data and develop an optimal payment system (Lee and Zenios, 2007) taking into account the general base compensation scheme. This model could also be combined with risk-adjustment tools, as described in Section 4.2. As our results depend on the functional forms and parameters values chosen, future work could relax and validate some of these assumptions (e.g., exponential utility). In addition, a richer payment formula could be used, incorporating more details about the reimbursement structure. As the increased adoption of Healthcare Information Technology will certainly lead to more and more available data, developing data-driven methods to design incentives systems has potential to help improve pay-for-performance programs.

Finally we studied pay-for-performance incentives directed to providers. Yet, giving financial rewards to patients who engage in healthy behaviors rather than providers represents a complementary strategy that may have greater benefit, the link being strong between lifetime healthcare costs and healthy behaviors (Volpp, Pauly, Loewenstein and Bangsberg, 2009). Indeed, patients with chronic conditions need to be involved as partner in their disease management (Watts and Segal, 2009). It is actually likely that chronically ill patients will develop considerable knowledge of their disease, given the continuing nature of chronic disease. From an economics modeling perspective, Chone and Ma (2009) consider the physician agency and model explicitly the physician-patient coalition under asymmetric information.

We believe that contract theory combined with simulation analysis based on empirical data provides a good framework to improve the design of optimal healthcare payment systems. Hopefully, reforming current payment systems to recognize and reward chronic care quality will lead to improved chronic disease management.

APPENDIX

In the appendix we present the proofs of the derivation of the classical one-dimensional principal-agent model in Proof 1 and 2. Finally, we give elements of matrix calculus to generalize the approach to the multidimensional model.

Proof 1

The certainty equivalent of lottery (L) is an outcome $CE(e)$ such that the agent is indifferent between (L) and the certain outcome $CE(e)$, i.e. $U(CE(e)) = E\big(U(x)\big)$. To find the certainty equivalent of the agent in the classical principal-agent model, we note that, as

$U(x) = -\exp(-tx)$ and $\varepsilon \sim \mathcal{N}(0, \sigma^2)$:

$\int_\varepsilon \exp(-t\big(\alpha(e+\varepsilon) - c(e)\big)\phi(\varepsilon)d\varepsilon =$

$-\exp(-t\big(\alpha e - c(e)\big)). \int_\varepsilon \exp(-t\alpha\varepsilon)\phi(\varepsilon)d\varepsilon,$

where $\phi(\varepsilon)$ is the normal density function and

$\int_\varepsilon \exp(-t\alpha\varepsilon)\phi(\varepsilon)d\varepsilon = \exp(-\frac{1}{2}t\alpha^2\sigma^2)$

Finally: $CE(e) = \beta + \alpha e - c(e) - \frac{t}{2}\alpha^2\sigma^2$

Proof 2

The problem is:

$$\max_{e,\alpha,\beta} \; E(y - w(y))$$

subject to

(1) $\max_e CE(e) = \beta + \alpha e - \frac{1}{2}ce^2 - \frac{t}{2}\alpha^2\sigma^2$

(2) $CE(e) = U_0$

The first-order condition of the agent's certainty equivalent with respect to e leads to:

$\frac{\partial CE(e)}{\partial e} = \alpha - c\mathrm{e} = 0$, i.e., $\mathrm{e}^* = \frac{\alpha}{c}$.

Replacing this expression in (2), we obtained: $\beta^* = U_0 - \frac{\alpha^2}{2c} + \frac{t}{2}\alpha^2\sigma^2$.

Now (1) becomes:

$E((y - w(y)) = e - \alpha e - \beta = \frac{\alpha}{c} - \frac{\alpha^2}{c} - U_0 + \frac{\alpha^2}{c} - \frac{t}{2}\alpha^2\sigma^2 = \frac{\alpha}{c} - \frac{\alpha^2}{2c} - U_0 - \frac{t}{2}\alpha^2\sigma^2$.

The first order condition with respect to α leads to:

$\frac{\partial E((y - w(y))}{\partial \alpha} = \frac{1}{c} - \frac{\alpha}{c} - t\alpha\sigma^2 = 0$, i.e., $\alpha^* = \frac{1}{1+tc\sigma^2}$.

Elements of Matrix Calculus

To generalize the previous approach to the multitask model we give basis of matrix calculus (table A.1), where $\boldsymbol{A}$ is a $\boldsymbol{nxn}$ matrix:

Table A.1: Matrix Calculus

$\boldsymbol{y}$	$\boldsymbol{\frac{\partial y}{\partial x}}$
Ax	A^T
$x^T A$	A
$x^T x$	$2x$
$x^T Ax$	$Ax + A^T x$

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