Universidade do Minho
Escola de Economia e Gestão

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Quality Competition in Regulated Markets

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Quality Competition in Regulated Markets

Tese de Doutoramento
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Trabalho realizado sob a orientação do
Professor Odd Rune Straume

September 2021

DECLARATION

STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration. I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

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"This thesis is dedicated in memory of my mother"

ABSTRACT

This doctoral thesis studies quality competition in regulated markets, such as health care and education. The three essays are based on theoretical contributions using a spatial competition framework. The first essay analyses the effect of competition on quality provision in mixed markets, where public and private providers coexist. We make two key assumptions about the public provider in such markets, namely that it faces a regulated price and is (partly) motivated. We find that increased competition has an *a priori ambiguous* effect on quality provided by the public provider, while the scope for a quality reduction by the private provider is larger. We also derive the first-best solution and show how it coincides with the Nash equilibrium of a private (symmetric) duopoly. The second essay extends the analysis to more than two competitors to study quality competition in a mixed oligopoly. We consider a welfare-maximising public provider competing with two profit-maximising private providers that differ with respect to the regulatory regime they face, with only one of the private providers being included in the public funding scheme. We find that changes in the funding scheme or in the degree of competition have differential effects on quality provision across the different types of providers and thus generally ambiguous effects on average quality provision. In terms of social welfare, we find that the two policy instruments in the funding scheme, price and copayment, are policy complements (substitutes) for sufficiently low (high) levels of the copayment rate. We also identify a welfare trade-off between the public funding scheme's generosity (price level) and its extent (number of private providers included). The third essay studies the strategic relationship between hospital investment in health technologies and provision of service quality. We assume providers are altruistic and allow for hospital investment and quality provision to be either complements or substitutes in the patient health benefit and provider cost functions. We assume that each hospital commits to a certain investment level before deciding on the provision of service quality. We show that, compared to a simultaneous-move benchmark, providers' lack of ability to commit to a particular quality level generally leads to either under- or overinvestment. Underinvestment arises when the price-cost margin is positive and when quality and investments are strategic complements. In turn, this has implications for the optimal design of hospital payment contracts. We show that, differently from the simultaneous-move case, the first-best solution is generally not attainable by setting the fixed price at the appropriate level, but the regulator must complement the payment contract with at least one more instrument to address under- or overinvestment. We also analyse the welfare effects of different policy options (separate payment for investment, through a higher per-treatment price, or refinement of pricing) to reimburse hospitals for their investments.

Index terms— Quality competition, Mixed oligopoly, Regulation, Altruism, Welfare, Investment

RESUMO

Esta tese de doutoramento estuda a concorrência pela qualidade em mercados regulados, tais como os mercados de cuidados de saúde ou de ensino. Os três ensaios que a constituem baseiam-se em contributos teóricos do âmbito da concorrência espacial. O primeiro ensaio analisa o efeito da concorrência na qualidade oferecida em mercados mistos, aqueles em que prestadores públicos e privados coexistem. Adotamos dois pressupostos fundamentais acerca do prestador público nestes mercados; nomeadamente, que é alvo de um preço regulado e que é (parcialmente) ”motivado”. Concluímos que maior intensidade da concorrência tem um efeito *a priori* ambíguo na qualidade oferecida pelo prestador público, enquanto existe maior margem para um efeito negativo na qualidade oferecida pelo prestador privado. Também calculamos a solução ótima e demonstramos que esta coincide com o Equilíbrio de Nash num oligopólio privado (e simétrico). O segundo ensaio estende a análise a mais de dois prestadores para analisar a concorrência pela qualidade em oligopólios mistos. Analisamos a concorrência entre um prestador público cujo objetivo é maximizar o bem-estar social e dois prestadores privados cujo objetivo é maximizar o maximizar o lucro. Estes distinguem-se entre si pela regulação de que são alvo: apenas um deles é incluído no esquema de financiamento público. Demonstramos que alterações neste esquema ou na intensidade da concorrência afetam a qualidade oferecida pelos três prestadores diferentemente, resultando em efeitos geralmente ambíguos na qualidade média do mercado. Relativamente ao bem-estar social, demonstramos que os dois instrumentos regulatórios, o preço e o copagamento, são complementos (substitutos) de política pública se o nível da taxa de copagamento for suficientemente baixo (alto). Também identificamos um compromisso entre a prodigalidade do esquema de financiamento público (o preço) e a extensão da sua aplicação (o número de prestadores privados nele incluídos). O terceiro ensaio estuda a relação estratégica entre investimentos hospitalares em tecnologias de saúde e a qualidade do serviço prestado. Assumimos que os prestadores (hospitais) são ”altruístas” e consideramos simultaneamente a possibilidade de o investimento e a qualidade serem complementos ou substitutos na função-benefício dos utentes e na função-custo dos prestadores. Assumimos também que os hospitais comprometem-se a realizar um determinado nível de investimento antes de escolher a qualidade oferecida. Mostramos que, em comparação com um jogo simultâneo, a ausência de compromisso sobre a qualidade resulta geralmente em sub- ou sobreinvestimento. Subinvestimento ocorre quando a diferença preço-custo é positiva e quando qualidade e investimento são complementos estratégicos. Isto tem implicações para o desenho ótimo dos contratos de financiamento hospitalar. Ao contrário do que acontece num jogo simultâneo, a solução ótima não é geralmente atingida pela fixação do preço no valor adequado, devendo o regulador complementar o contrato de financiamento com pelo menos mais um instrumento para lidar com o sub- ou o sobreinvestimento. Também analisamos o efeito no bem-estar de duas políticas públicas de reembolso do investimento hospitalar, o financiamento independente do investimento através um preço por tratamento mais elevado ou um esquema de preços mais sofisticado.

Index terms— Competição de qualidade, Oligopólio misto, Regulação, Altruísmo, Bem-estar, Investimento

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LIST OF ACRONYMS

DRG: Diagnosis-Related Group

OECD: Organisation for Economic Co-operation and Development

EU: European Union

GDP: Gross Domestic Product

MRI: Magnetic Resonance Imaging

TAVI: Transcatheter Aortic Valve Implantation.

CHAPTER 1

INTRODUCTION

Over the last decades, governments have shown a keen interest in introducing pro-competitive reforms in regulated markets - such as health care and education - as a means of relaxing constraints on consumer choice, improving quality, and increasing efficiency. There are two major features in these sectors. First, the government is the main funder of these services and enact a variety of policy interventions, among others, the regulated price and copayment share.[1] Second, simultaneous provision of these services by a mix of public and private providers is common, but the relative share of these types of providers varies considerably across different countries.[2] Furthermore, the coexistence of public and private providers means that the objective function of at least one of the providers differs from that of the others. This calls for an understanding of how public and private providers strategically interact, and how they respond to different funding schemes.

In regulated markets, quality is a key concern, and designing a concrete set of tools and regulations to ensure a satisfactory provision of quality is therefore of great policy relevance. Furthermore, policies that trigger competition can potentially play a useful role in stimulating quality provision. Ideally, they should be assessed alongside other competitive forces to deliver these services more efficiently,[3] and with a focus on what fosters consumer welfare, meanwhile ensuring providers' market participation and encouraging them to compete on quality. This raises several policy issues. For example, how should providers be regulated? How do private providers respond to changes in the funding scheme? How a change in policy levers affect quality provision? What are the optimal payment schemes? How does competition between public and private providers affect quality provision? Should private providers be included in or excluded from the public funding scheme? These policy questions are highly topical and of key importance.

This thesis is comprised of three independent chapters, each of which studies a policy-motivated question related to the role of provider competition, and investigates how the strategic interaction between providers can yield different implications depending on the dimension on which providers compete, market structure, altruistic preferences, and diversity of providers.[4] The analyses presented in chapters 2-4 are based on spatial competition frameworks where

[1] Public expenditure in OECD countries for healthcare and education markets account for around 18 percent, and these markets account for around 13 percent of GDP (Biggar & Fels, 2017).

[2] For instance, 82 percent attend public schools in OECD countries in 2018. Only 2 out of 10 students attended a private school (either dependent or independent) but in Chile, Hong Kong, Lebanon, Netherlands, UK, and UAE more than one in two students attended a private school (OECD, 2020b, ch. 7). A similar variability resembles in health care markets (Herrera, Rada, Kuhn-Barrientos, & Barrios, 2014).

[3] For instance, in the framework of the EuroDRG project "Diagnosis-Related Groups in Europe: Towards Efficiency and Quality", policies pursue to achieve the right balance between improving access to medical innovation and restricting market forces to contain costs (Schreyögg, Bäumler, & Busse, 2009).

[4] See Brekke, Gravelle, Siciliani, and Straume (2018) for a review of theoretical models of hospital competition under price regulation to explain how the effect of competition on quality is sensitive to specific dimensions.

the unit demand assumption is particularly appropriate, since each consumer demand one unit of service (medical treatment or school admission) from the preferred provider. In addition, consumer choice is crucially based, among other relevant attributes in each chapter, on quality and travel distance (Brekke, Siciliani, & Straume, 2020). As is common in the spatial competition literature, we analyse the relationship between competition and quality provision by using the marginal cost of traveling as an inverse measure of competition intensity. In this regard, we explore whether more competition induces providers to produce higher quality goods or services.

Chapter 2 and 3 focus on mixed markets in regulated markets where public and private providers coexist. In addition, both chapters consider consumers facing a regulated copayment fee if they access a funded provider. Furthermore, a funded provider will face a regulatory price while a non-funded provider will decide its price given the rivals' regulatory prices. The main contribution is to uncover key mechanisms to explain the quality ranking among providers in mixed markets, and pursue a general intent to broadly characterize the effects of public policy, in terms of funding levels and price-setting, on the quality of services provided.

Chapter 2 considers a spatial mixed duopoly model to investigate the effect of competition between public and private providers on quality provision. It also characterises how the providers' equilibrium choices would change in response to a change in the policy levers, namely the regulated price, copayment fee, and copayment share. The model is based on a two-stage game where the key assumptions are that both providers compete on quality in the first-stage, but the private provider also chooses price endogenously in the second-stage, while the public provider faces a regulated price. Moreover, we explore how a departure from profit-maximising behaviour by the public provider can alter and potentially reverse the scope of a positive effect of competition on the quality of the private provider.

Chapter 3 extends the previous chapter and incorporates a Salop circular model to examine competition among three providers, where the providers differ in both their objectives and the regulatory measures they face. More specifically, the novelty of the triopoly specification is an important extension to the existing literature of mixed oligopoly. We assume the public provider is publicly funded, provides services at a regulated price, and chooses quality to maximise social welfare. However, the private providers' decisions about price and quality are entirely profit-driven. Furthermore, the publicly funded private provider accepts price regulation and receives public funds just as a public provider does, but its choice of the quality of service is profit-driven. This chapter's main contribution is to characterize the quality ranking among the three providers, where we reveal that any ranking can emerge depending on the policy instruments under the funding scheme and the degree of competition. We also investigate how heterogeneity of regulation among private firms can have different policy implications which also complements the existing theoretical contributions that discuss the welfare implications of asymmetry among private firms (Haraguchi & Matsumura, 2020a, 2020b; Kim, Lee, & Matsumura, 2019; Liu, Wang, & Zeng, 2020).

Chapter 4 is tailor-made to fit one particular industry, namely the health care market, and the analysis is based on a duopolistic model where hospitals are reimbursed with a per-treatment price and a lump-sum transfer, where each of the policy instruments might depend on the level of investment in health technologies. A further motivation to investigate this issue comes from the variety of solutions adopted in different health care systems for the reimbursement of capital costs. We consider an objective function where hospitals are partly altruistic and care about the health benefit of the average patient. In addition, we assume hospital investment and quality to be either complements or substitutes in the patient health benefit and provider cost functions. The main contribution of this chapter is to study the interaction between investment and service quality. In particular, we investigate how hospitals make investment decisions, and the circumstances under which they lead to under- or overinvestment, and how these investment decisions affect the provision of service quality under a range of payment arrangements. In real-world health care markets, however, hospital payment contracts tend to be based on historic cost patterns and are often unlikely to coincide with the ones that maximise social welfare. Acknowledging this, we analyse the welfare effects of several realistic policy reforms, where the starting point is a simple two-part contract with a DRG tariff and a lump-sum transfer, neither of which depends directly on investment.

Finally, chapter 5 summarises the main findings of each study, distills its policy implications, and discusses some limitations that can be carried as possible extensions for further research.

CHAPTER 2

PUBLIC-PRIVATE COMPETITION IN REGULATED MARKETS[1]

2.1 Introduction

According to a recent OECD report, "[c]ompetition in public markets is often neglected or, in some cases, actively suppressed" (Biggar & Fels, 2017, p. 3). The report seeks to design pro-competitive reforms to derive quality improvements in the health-care and education market sectors. Despite the goal of public provision to offer affordable access to merit goods, quality is a central concern for policymakers. The theoretical literature shows a limited scope in exploring quality effects of competition in mixed markets. Furthermore, the empirical evidence suggests mixed results for quality differentiation whenever public and private providers coexist (Bemo, 2013; Cellini & Goldin, 2014; Friedman, Avila, Friedman, & Meltzer, 2019; Moscelli, Gravelle, Siciliani, & Gutacker, 2018; Moscone, Siciliani, Tosetti, & Vittadini, 2020; Pavel, Chakrabarty, & Gow, 2015). One of the key policy challenges is how to ensure that providers have sufficient incentives for quality provision in mixed markets.

Regulated markets have one important feature in common: the government plays the central role of the major funder of the services to public providers.[2] In practice, governments tie the payment of subsidy to the provision of a particular service. Another important feature in several public-sector areas is a regulated copay.[3] Both policy levers, regulated price and copayment fee, act as competitive forces and affect the outcome of strategic competition with private providers. Therefore, market mechanisms with these tools regulate the flow of services by the public provider in ways that are mainly not available to private rivals, perhaps in selecting the range of quality standards. In return, the private provider's incentive for quality investment depends on the total funds received by the public provider.

In many countries, private and public providers of goods and services compete against each other. This is quite common in health-care services, education, long-term care, nursing homes, and child-care markets. In these sectors, the private sector has experienced a rapid growth in the last two decades. According to Henry KFF, from 1999 to 2018,

[1] This chapter was published in the *Journal of Institutional and Theoretical Economics* as Ghandour, Z. (2021) Public-private competition in regulated markets. *Journal of Institutional and Theoretical Economics*, 177(3), 299–336. https://doi.org/10.1628/jite-2021-0007.

[2] Historically, governments have contributed to public firms financial subsidies that result in an overall growth of the public sector. For instance, in 2015, education and health-care markets accounted for around 13 percent of the GDP and around 18 percent of public expenditure in OECD countries (Biggar & Fels, 2017).

[3] This was suggested by policymakers as a potential way to control costs. For example, Sabik and Gandhi (2016) suggest that copayments might be an effective tool for reducing the use of emergency department for nonurgent care.

the U.S. share of for-profit private hospitals surged from 15.1 to 24.9 percent.[4] Although most European markets in higher education and health care are dominated by public providers (where prices are typically regulated), the private market is very active. Jeurissen, Duran, and Saltman (2016) report that for-profit hospital beds in eight European countries increased from about 15.6 percent in 2005 to 18.4 percent in 2013. In addition, the private-sector facilities account for 74 percent of nursing-home care in England (Barron & West, 2017). In most countries, private providers compete in quality and price to attract consumers. A prime example is the market for education, where private schools are allowed to set their own tuition fees while students have free access (in some cases the voucher covers the full cost) to public schools (Del Rey & Estevan, 2019; Eigbiremolen, 2020).

In this paper, we develop a useful framework to address quality competition given asymmetric pricing between a public and a private provider, where the former faces an exogenous (regulated) price and the latter is free to choose its price. If the goal is to increase quality provision, should the regulator increase the fixed price per consumer to the public provider, or decrease the copay? How does the private provider respond to changes in the funding scheme? How does the degree of competition affect quality provision, and what are the welfare implications? These questions are highly topical and of key importance. The paper sheds light on some of the mechanisms that lead to the widespread phenomenon of variations in quality in mixed markets, where many effects of this coexistence have not been established yet, either theoretically or empirically.

We use a spatial competition framework, as it is well suited to studying competition in markets where consumers display a preference for the closest provider unless more distant providers offer better quality and/or lower prices. We explore how different assumptions on the behaviour of public providers affect the equilibrium outcomes. To this end, we consider in the benchmark pure profit maximisation before we introduce heterogeneous objective functions. We assume the public provider is semialtruistic in the sense that it cares, to some extent, about the gross utility of its consumers. The providers act as follows. The private provider chooses the price in the second stage given the two quality levels chosen in the first stage under an exogenously given funding scheme.

We develop four sets of results. First, we characterise the incentives for the private provider to supply higher quality than the public provider. When providers are close to each other in the services they offer, competition becomes fierce and this induces the private provider to offer the highest quality in the market if the regulated price of the public provider is sufficiently low. The presence of altruism reduces the scope for the private firm to have higher quality than the public firm in equilibrium. The reason stems from the fact that a high level of altruism increases the marginal revenue of quality, which, in turn, lowers the quality of the private provider's service due to strategic substitutability.

[4] See the Henry Kaiser Family Foundation, Hospitals by Ownership (2018), at https://www.kff.org/other/state-indicator/hospitals-by-ownership.

Second, we explore the effect of competition on quality provision. Under pure profit maximisation, more competition unambiguously increases the quality of the public provider. However, we find that the relationship between competition and quality of the private provider is generally ambiguous. More interestingly, the private provider increases quality in response to more competition if the marginal willingness to pay for quality is sufficiently high and the regulated price is sufficiently low. In this case, there is a positive relationship between average quality and competition. The result is reversed if the willingness to pay for quality is low. This is because the public provider has weak incentives for quality provision and an increase in competition has a smaller effect on the private provider's incentive to increase the quality. If the public provider is motivated, we find that the scope for a positive relationship between average quality and competition is larger.

Third, we investigate how a change in policy levers affects quality provision. We find that the average quality is increasing in the regulated price. On the other hand, a higher copayment fee might lead to lower quality provision for the public provider and therefore also to lower average quality provision. Our analysis also highlights the effect of the co-payment share on the quality provision. This is of particular relevance and worth exploring given the everlasting financing constraint most governments face. To do so, we examine the change in the composition of the funding scheme while keeping the total level of expenditure fixed by the government. We show that the average quality decreases (increases) in response to a higher copayment share for a sufficiently large (small) regulated price of the public provider. Moreover, the presence of altruism reduces the scope for a positive relationship between average quality and the copayment share.

Finally, we find that the first-best solution can be implemented either by privatizing the public provider or by regulating it in a way that makes it mimic a private profit-maximising provider, which implies a copayment fee equal to the price of the private provider. We also consider the case where a policy maker seeks to set the copayment rate at a relatively low level to satisfy considerations that are not explicitly modeled in our framework. We find that the welfare-maximising price is decreasing in the copayment fee if the public provider is sufficiently profit-oriented. Given the optimal price, our results also reveal that the public provider always offers the highest quality in the market, and more competition leads to a higher average quality if the public provider is sufficiently profit oriented.

The rest of the paper is organised as follows. In the next section, we present a brief overview of related literature. In Section 2.3, we outline the model, and in the subsequent section, we derive the equilibrium price and quality under the assumption of sequential choices. In Section 2.5, we analyse the effect of competition on quality provision. In Section 2.6, we discuss the effects of a change in policy levers (regulated price and copay) on quality. Section 2.7 is devoted to welfare analysis. The paper is concluded in Section 2.8.

2.2 Related literature

Our paper contributes to the theoretical literature on the relationship between competition and quality provision. All the articles in this literature that we are aware of deal either with price competition or with price regulation. Under price regulation and profit-maximising providers, there is a direct positive relationship between competition and quality (Brekke, Nuscheler, & Straume, 2006; Gravelle, 1999; Wolinsky, 1997). In the presence of altruism, the relationship between competition and quality is generally ambiguous (Brekke, Siciliani, & Straume, 2011).

Standard spatial competition models, where providers compete in prices and quality, reveal mixed results. Ma and Burgess (1993) and Economides (1989) find no effect of more competition on quality provision. However, Brekke, Siciliani, and Straume (2010) find that more competition tends to increase quality when consumers have decreasing marginal utility of income. Conversely, Brekke, Siciliani, and Straume (2018) find an unambiguously negative relationship between competition and quality if providers are (partly) motivated and utility is strictly concave in income.

In the literature applying a Hotelling-type spatial competition framework (Hotelling, 1929), our paper relates partly to Herr (2011) and Amin, Badruddoza, and Rosenman (2018), who study quality competition in mixed duopoly. Both papers consider price regulation. Our model differs from theirs in that the public firm cannot choose the price, and therefore there is asymmetric pricing between providers. In addition, Herr (2011) assumes two hospitals differ in their marginal costs and considers that public hospitals wish to maximise the sum of profit and market share. In our framework, we do not highlight cost efficiency, and we assume the public provider is altruistic in the sense that it cares, to some extent, about the gross utility its consumers derive from the service, as in (L. Levaggi & Levaggi, 2020).

For a vertical differentiation framework, where consumers are heterogeneous with respect to their willingness-to-pay for quality, there is an extensive literature studying quality and price competition (Klumpp & Su, 2019; Laine & Ma, 2017). In a recent study, Stenbacka and Tombak (2018) find that the socially optimal reimbursement policy is invariant to the introduction of for-profit competition with a premium quality directed towards high-quality-preference consumers. The present analysis uses horizontal (rather than vertical) differentiation for two reasons. First, we avoid heterogeneity in consumers' preferences to make our analysis more tractable.[5] Second, there is strong empirical evidence that the travelling distance is one of the main predictors of a consumer's choice of education or health-care provider (Brekke et al., 2011; De Fraja & Iossa, 2002; Kessler & McClellan, 2000; Moscone et al., 2020; Tay, 2003).

Both quality differentiation and market equilibria may differ greatly, depending on the assumptions made and the country one looks at. Using a theoretical model, Epple and Romano (1998) study the competition between public and private schools in the U.S. and obtain that the quality for the former is lower than that for the latter in equilibrium. On

[5](Hirth, 1997, p. 417) states "with heterogeneous quality preferences, [...] there would be several submarkets for different quality/cost combinations".

the contrary, Romero and Del Rey (2004), focused on a mixed duopoly market in European higher education market where public universities set higher admission standards and set almost zero tuition fees to maintain the quality of enrollments, in contrast with commercially run institutions having a price policy only.[6]

Empirically, there is strong evidence that competition has a positive effect on quality in education markets (Dee, 1998; Deming, Goldin, & Katz, 2012; Hoxby, 1994; Thapa, 2013). A recent empirical work on U.S. public postsecondary institutions concludes that tuition cuts are less effective per dollar than increases in spending on college attainment, in terms of degree completion and enrollment (Deming & Walters, 2017). When the price is a choice variable, the results are mixed. Some studies find a positive relation between competition and quality in the healthcare market (Cooper, Gibbons, Jones, & McGuire, 2011; Gaynor, Moreno-Serra, & Propper, 2013). However, a negative relationship between competition and quality is suggested by Grabowski (2004) for nursing homes in the U.S. In England, Forder and Allan (2014) find that competition reduces the quality of care in homes for the elderly. Propper, Burgess, and Gossage (2008) find a positive relation between competition and mortality rates for patients with heart attacks in England.[7]

2.3 Model

Consider a duopoly market for a particular service (e.g., healthcare or education) offered by two providers, denoted by $j = \{1, 2\}$, located at opposite endpoints of a Hotelling line of length one. Provider 1 is a public (or publicly funded private) provider located at the left, whereas provider 2 is a private provider located at the right. Provider 1 receives a regulated price p_1 per unit of the good supplied. An amount T (part of p_1) is paid by the consumers as co-payment fees, whereas the remaining amount, denoted λ, is subsidised by a public funder. However, the private provider without public funding (Provider 2) has to raise revenues in the market by charging a price p_2 per unit of the good supplied. In contrast to the standard assumption in the mixed-duopoly literature that providers compete either on quality (for a given regulated price) or along two different dimensions, price and quality, we consider asymmetric pricing. The public provider (or publicly-funded private provider) faces an exogenous (regulated) price, while the private provider is free to choose its price.

A prime example of the situation analysed in this paper is the education market.[8] The public university or school, financed by governmental funds, charges no fees or tuition fees that play a negligible role. In contrast, the private universities or schools receive no public funding and charge tuition fees to maximise profits (Del Rey & Estevan, 2019; Epple, Romano, Sarpça, & Sieg, 2017). Another relevant example is the market for health care. Unlike the private

[6]Cremer and Maldonado (2013) study mixed-oligopoly equilibria with private and public schools. They examine how the equilibrium allocation (quality, tuition fees and welfare) is affected by the presence of public schools and by their relative position in the quality range.

[7]For a comprehensive survey on competition and quality in healthcare markets, see (Gaynor & Town, 2011).

[8]The private sector holds a third (32.9%) of the world's total higher education enrollment (Levy, 2018).

hospital sector in European countries, which treats publicly funded patients and in which money follows the patient Barros and Siciliani (2011), most patients in the U.S. and in emerging countries buy private health insurance when they choose a private provider. Those with private insurance are footing the bill for higher prices through higher insurance premiums and rising deductibles.[9] In a recent study, Cooper, Craig, Gaynor, and Van Reenen (2019) focus on analyzing the drivers of hospital price variation across regions and within hospitals, and demonstrate that greater hospital market concentration leads to higher costs for patients.

Demand comes from a unit mass of patients who are uniformly distributed on the line. Each patient demands one unit from the most preferred provider. The utility of a consumer who is located at z and buys the good from Provider j is given by[10]

$$U_j(z) = \begin{cases} v + \beta q_1 - T - tz^2 & \text{if public,} \\ v + \beta q_2 - p_2 - t(1-z)^2 & \text{if private,} \end{cases} \tag{2.3.1}$$

where q_j is the quality offered by Provider j and the parameters $\beta > 0$ and $t > 0$ measure, respectively, the marginal willingness to pay for quality and the marginal transportation cost.[11] An alternative interpretation for the latter is the degree of horizontal product differentiation, as in the heterogeneity of services. In line with our previously stated assumptions, T is the copayment fee and p_2 is the price chosen by Provider 2. We assume v is large enough so that no consumer is excluded from the market. The location z of the consumer who is indifferent between buying the service from either provider is determined by solving $\beta q_1 - T - tz^2 = \beta q_2 - p_2 - t(1-z)^2$. With a uniform distribution of consumers, the demand faced by the public provider and that faced by the private provider are $D_1 = z$ and $D_2 = 1 - z$, respectively. Hence, the market share for Provider 1 is given by

$$D_1(q_1, q_2, p_2) = \frac{t + p_2 - T + \beta(q_1 - q_2)}{2t}, \tag{2.3.2}$$

while the total demand for Provider 2 is $D_2(q_1, q_2, p_2) = 1 - D_1$.

We assume that output (denoted D_j) and quality (denoted q_j) are separable in costs.[12] The cost function is given by

[9] In the U.S., commercial insurers are estimated to pay about twice what Medicare does for hospital care (see https://www.americanprogress.org/issues/healthcare/reports/2019/06/26/471464/high-price-hospital-care/).

[10] If each provider chooses a location $x_j \in L$ where we assume $\Delta = x_2 - x_1$ and $x_2 \geq x_1$, then [$t\Delta$] appears as a multiplicative term in all equilibrium functions. Accordingly, we used fixed locations to avoid redundancy ($\Delta = 1$), as both parameters t and Δ have exactly the same effect.

[11] We use quadratic consumer transportation costs as in D'Aspremont, Gabszewicz, and Thisse (1979) to avoid discontinuities in the providers' profit functions.

[12] This is a widely used assumption in the literature (Brekke et al., 2006; Economides, 1989).

$$C(D_j, q_j) = cD_j + \frac{k}{2}q_j^2. \tag{2.3.3}$$

The costs are linear in the output and convex in quality: $C_q > 0$, $C_{qq} > 0$ and $C_{q=0} \equiv cD_j$. Accordingly, we assume that the marginal cost of production, c, is constant. In addition, $k > 0$ is a cost parameter related to quality investments.

Provider 1 is prospectively financed by a third-party payer offering a regulated price of the service, denoted λ. More specifically, λ can be interpreted as a fixed price per treatment in health care or per service or student in education markets. In addition, a consumer pays a copayment fee, T, if she demands one unit from Provider 1. We make the following parameter assumptions: $T \leq c$ and $T+\lambda > c$. The former asserts that consumers pay at most a fee equal to the marginal cost of production. The latter asserts that the total price received by the public provider ($p_1 = \lambda + T$) is strictly higher than the marginal cost.

In order to ensure nonnegative profits for Provider 1, we assume it receives a possible lump-sum transfer from the public payer, denoted B. The profits of Provider j are thus given by

$$\pi_j = \begin{cases} B + (p_1 - c)D_1 - \frac{k}{2}q_1^2 & \text{if public,} \\ (p_2 - c)D_2 - \frac{k}{2}q_2^2 & \text{if private.} \end{cases} \tag{2.3.4}$$

In our benchmark model, we assume that both providers are profit maximisers. This assumption is fairly standard in the health economics literature.[13] One might argue that it does not fully capture the objectives of public or publicly-funded private providers. Thus, we take into account heterogeneous objective functions. On one hand, the private provider maximises profits given by (2.3.4). On the other hand, the public provider seeks to maximise the weighted sum of its profit and the gross utilities of consumers who purchase its product - in line with recent studies (L. Levaggi & Levaggi, 2020; Lisi, Siciliani, & Straume, 2020). The objective function of Provider 1 is assumed to be given by

$$\Omega(q_1, q_2, p_2) = \pi_1 + \alpha D_1(v + \beta q_1). \tag{2.3.5}$$

Public providers are able to attract more motivated workers who have a stronger preference for quality. This assumption has been recognised within the health and education economics literature (Besley & Ghatak, 2005; Eggleston, 2005; Makris & Siciliani, 2013). The parameter α measures the degree of public-provider altruism. This allows us to understand how the different assumptions on the behaviour of public providers (profit maximisation and altruism) affect the equilibrium outcomes while the private provider always seeks profit maximisation.

[13] Brekke et al. (2006) assume that the public firm maximises only profits, and Dranove and White (1994) find that not-for-profit hospitals behave ultimately as profit maximisers.

We use a spatial competition framework to study the effect of more competition (a reduction in t) on quality provision in a two-stage game. In addition, we explore how quality provision depends on policy levers. For the main part of the analysis, we allow for sequential choices where quality is treated more as a long term variable.[14] We consider the following two-stage game:

Stage 1 Both providers simultaneously choose q_1 and q_2.

Stage 2 The private provider (Provider 2) chooses its price, p_2.

This sequence of moves is widely used in the literature. The existing theoretical models consider price choice in the second stage where both providers obtain the price set for a given pair of quality levels (q_1,q_2) respectively. This kind of Bertrand competition differs from our model in that the price of provider 1 is exogenously given.

Finally, in order to ensure equilibrium existence in the quality subgame and in the welfare maximisation problem, we assume that the quality cost parameter k is bounded below.[15]

2.4 Analysis

Suppose the regulator is able to precommit to a particular design of the funding scheme. In other words, Provider 1 faces an exogenous regulated price, λ, and an exogenously given copayment fee, T. The game is solved by backward induction, so we start out by considering the optimal price chosen by Provider 2.

2.4.1 Optimal private price

The private provider chooses a price that maximises the provider's profits. For a given pair of quality levels, we find that the profit-maximising price is given by[16]

$$p_2(q_1, q_2; T) = \frac{T + c + t + \beta(q_2 - q_1)}{2}. \tag{2.4.1}$$

We see that the optimal price of the private provider is increasing in the co-payment fee, T. This is due to prices being *strategic complements* for given quality levels. If we consider t as the product-space interpretation of horizontal differentiation, then, all else equal, the private provider responds to an increase in p_2 if the market faces a higher level of heterogeneity in the services offered. Moreover, the optimal price of Provider 2 depends on the quality difference,

[14] Our results hold if both quality and price decisions are made simultaneously.

[15] See appendix section 2.A for a derivation of the lower bound $\underline{k}$.

[16] The second-order condition satisfies the global maximum criterion: $\partial^2\pi_2/\partial p_2^2 = -1/t < 0$.

$q_2 - q_1$. All else equal, the higher q_2 is relative to q_1, the higher is the price p_2. Notice that higher quality by a rival provider leads to a drop in demand, which makes demand more price-elastic, all else equal. This reduces in turn the profit-maximising price. Therefore, the price of the private provider is a *strategic substitute* to the quality of a rival provider and a *strategic complement* to its own quality.

2.4.2 Quality competition

We consider the equilibrium in the first stage of the game. Both providers choose simultaneously the quality levels in anticipation of the optimal price for Provider 1. Substituting (2.4.1) into (2.3.4) and maximizing (2.3.4)-(2.3.5) with respect to q_j yields the first-order conditions for Provider 1 and 2. The best-response-functions $q_1(q_2)$ and $q_2(q_1)$ in the general model are given by[17]

$$q_1(q_2) = \beta \frac{(T + \lambda - c) + \alpha(3t + c + v - T - \beta q_2)}{2(2kt - \alpha\beta^2)}, \tag{2.4.2}$$

$$q_2(q_1) = \beta \frac{(T - c + t - \beta q_1)}{4kt - \beta^2}. \tag{2.4.3}$$

The quality choice is optimal when the marginal benefit from increased demand equals the marginal cost of quality provision. Consider first the public provider. Using (2.3.5), the marginal benefit of quality for Provider 1 is given by

$$(p_1 - c)\left(\frac{\partial D_1}{\partial q_1} + \frac{\partial D_1}{\partial p_2}\frac{\partial p_2}{\partial q_1}\right) + \alpha\left(\beta D_1 + (v + \beta q_1)\frac{\partial D_1}{\partial q_1}\right). \tag{2.4.4}$$

If the public provider seeks profit maximisation ($\alpha = 0$), the profitability of quality provision depends on the size of the price-cost margin and on the quality responsiveness of demand.[18] In particular, neither marginal revenue nor marginal cost for provider 1 depends on the rival's quality, q_2. Thus, q_1 is strategically independent of q_2. In the presence of altruism ($\alpha > 0$), the public provider has marginal nonfinancial benefit from aggregate consumer utility as an additional term. In this case, the marginal payoff is increasing in the degree of altruism, α. Besides, the expression multiplied by α in (2.4.4) captures two effects. The first effect is related to the existing consumers who get higher utility; this is known as the *"inframarginal"* utility increase (first term in the parenthesis). The second effect is the *marginal* utility increase, which captures the utility of new consumers. Nevertheless, the *inframarginal* utility increase is affected by q_2. The demand of the public provider, D_1, is decreasing in q_2. A higher q_2 leads to lower D_1, which means fewer consumers benefit from an increase in q_1. When the public provider is altruistic, this reduces the marginal benefit of

[17] For the second-order and stability conditions, see the appendix 2.A.

[18] If $\alpha = 0$, the marginal revenue is given by $(T + \lambda - c)\,(\beta/(2t) - \beta/(4t))$.

quality investments. Thus, all else equal, higher q_2 leads to lower q_1. This explains why the public provider depends on the rival's quality ($\partial q_1(q_2)/\partial q_2 < 0$) if and only if $\alpha > 0$.

Consider next the private provider. Using (2.3.4), the marginal revenue of quality of this provider is given by

$$(p_2 - c)\left(\frac{\partial D_2}{\partial q_2} + \frac{\partial D_2}{\partial p_2}\frac{\partial p_2}{\partial q_2}\right) + \frac{\partial p_2}{\partial q_2}D_2 = (p_2 - c)\left(\frac{\beta}{2t} - \frac{\beta}{4t}\right) + \frac{\beta}{2}D_2. \tag{2.4.5}$$

The marginal revenue of quality for the private provider depends on D_2, which is decreasing in the quality of the public provider. A higher q_1 leads to lower D_2, which, in turn, makes demand more price elastic. The provider will therefore respond by reducing both price and quality (p_2 and q_2 are complementary strategies). This explains why the best response function $q_2(q_1)$ has an inverse relation with rival's quality and why the nature of this strategic interaction holds at any degree of altruism. Notice that only the best response of the public provider in (2.4.2) is increasing in the regulated price λ, all else equal.

If the subgame-perfect Nash equilibrium is an interior solution, the equilibrium outcome is given by

$$q_1^* = \beta\frac{(T + \lambda - c)(4kt - \beta^2) + \alpha\left(v(4kt - \beta^2) + 4t(3kt - \beta^2 + k(c - T))\right)}{4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)}, \tag{2.4.6}$$

$$q_2^* = \beta\frac{(T - c)(4kt - \beta^2) + 4kt^2 - \beta^2\lambda - \alpha\beta^2(T + 5t + v - c)}{4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)}, \tag{2.4.7}$$

$$p_2^* = \frac{2kt\left((4kt - \beta^2)(T + c) + 4kt^2 - \lambda\beta^2\right) - \alpha\beta^2\left(2kt(T + v + 5t) + c(6kt - \beta^2)\right)}{4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)}. \tag{2.4.8}$$

In order to ensure the existence of an equilibrium, we assume that the regulated price has an upper and a lower bound ($\underline{\lambda} < \lambda < \bar{\lambda}$) and the degree of altruism is bounded below and above: $0 \leq \alpha < \overline{\alpha}$. [19]

2.4.3 Equilibrium quality ranking

We proceed to identify the characteristics of the market that can explain the equilibrium quality ranking between providers. What are the incentives for the private provider to supply higher quality than the public provider? Given the equilibrium outcomes, the quality difference is given by[20]

[19] See appendix section 2.A for further details.

[20] The proofs of this and all subsequent propositions are given in the appendix section 2.B.

$$q_2^* - q_1^* = \beta \frac{4kt[t-\lambda] - \alpha[12kt^2(c-T)(4kt-\beta^2) + t(4kv+\beta^2)]}{4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)}. \tag{2.4.9}$$

Proposition 2.1. *(i) If the public provider is a profit-maximiser, the private provider offers higher (lower) quality than the public if the degree of product differentiation t is sufficiently large (small) relative to the regulated price λ. (ii) The presence of altruism reduces the scope for the private provider to have higher quality than the public provider.*

The first part of Proposition 2.1 shows that if providers are profit oriented, Provider 1 is the high-quality provider if $t < \lambda$. A higher regulated price λ increases the marginal revenue of quality for the public provider (higher q_1). Due to strategic substitutability ($\partial q_2/\partial q_1 < 0$), this leads to lower q_2. Therefore, the incentive for the private provider to supply higher quality than the public provider is reinforced if the latter is subsidised with a sufficiently small amount of state subsidy. In the presence of altruism, the intuition is straightforward. A high level of motivation towards the quality ($\alpha > 0$) increases the marginal revenue of quality (higher q_1) for the public provider, which, in turn, lowers q_2 due to strategic substitutability. Therefore, if $\alpha > 0$, the quality of the public provider dominates for a larger set of parameters.

2.5 Quality effects of competition

The impact of more competition (lower t) on quality is clear when prices are regulated. Competition leads to higher quality if price is above marginal cost. In our framework, provider 1 only chooses the quality for a given regulated price. On the contrary, Provider 2 chooses both quality and price. Hence, more competition makes demand more responsive to changes in qualities and prices. This generates two effects on the incentives for quality provision: one direct and one indirect. For a given price, the provider has an incentive to increase its quality provision in order to attract more consumers, who are now more responsive to such a quality increase. This is the direct effect. On the other hand, since more competition also makes consumers more responsive to price changes, the private provider has an incentive to reduce the price. However, a price reduction reduces the private provider's profit margin, and therefore reduces the provider's incentive to attract more demand by increasing quality. In other words, a lower price reduces the provider's return to quality investments. This indirect effect counteracts the aforementioned direct effect and makes the relationship between competition and quality provision *a priori ambiguous* for the private provider. In our framework, if the public provider cannot choose prices, does more competition induce providers to offer higher-quality services?

Using transportation costs as an inverse measure of the degree of competition, we analyse the effect of competition on the equilibrium outcome. In the first part of our analysis, we assume that providers seek profit maximisation ($\alpha = 0$). We are able to state the following:[21]

[21] The table in the appendix section 2.C summarises all subsequent results under pure profit maximisation, and in the presence of altruism for the public provider.

Proposition 2.2. *Suppose that both providers are profit maximisers. Then more competition (lower t) leads to*

(i) Higher quality for the public provider;

(ii) Lower (higher) quality for the private provider if the regulated price λ is sufficiently high (low) or (and) the willingness to pay for quality β is sufficiently low (high).

More competition makes demand more quality- and price-elastic. For the public provider, the effect of more competition is unambiguously positive and this confirms the standard result in the literature. For a positive price-cost margin, increased competition gives the public provider incentives to supply more quality ($\partial q_1^*/\partial t < 0$). For the private provider, the direct effect dominates the indirect effect if β is sufficiently high and the regulated price λ is sufficiently low. If β is high, an increase in competition has a larger effect on the private provider's incentive to increase the quality. In addition, the role of λ is through strategic interaction. A lower λ reduces the public provider's incentive for quality provision, which in turn reduces the negative feedback effect on the private provider's incentives for quality provision. Thus, if β is large and λ is small, the direct effect of competition dominates ($\partial q_2^*/\partial t < 0$) and leads to higher quality in equilibrium. This result can be reversed if β is low *or* λ is high, and this is sufficient to make the indirect effect dominate ($\partial q_2^*/\partial t > 0$), implying a reduction in quality for the private provider as a response to more competition.

Given the results in Proposition 2.2, the relationship between competition and quality for the public provider is positive, while it has an ambiguous sign for the private provider. If the indirect effect dominates the direct effect, there are two counteracting forces ($\partial q_1^*/\partial t < 0$ and $\partial q_2^*/\partial t > 0$). Thus, it is important to assess the overall effect on the average quality $\overline{q}$, which is defined as[22]

$$\overline{q} := \sum_{j=1}^{2} D_j^* q_j^* \tag{2.5.1}$$

Considering the equilibrium outcome and differentiating (2.5.1) with respect to t, we can highlight the effect of competition on $\overline{q}$ as follows:

Proposition 2.3. *Suppose that both providers are profit maximisers. If the regulated price λ is sufficiently large, more competition leads to a higher average quality $\overline{q}$. Otherwise, for a sufficiently low λ, more competition leads to higher (lower) average quality if the willingness to pay for quality, β, is sufficiently high (low).*

The intuition is simple. The intensity of quality competition is strong when consumers' marginal willingness to pay for quality, β, is high. Both providers will have a strong incentive to increase quality as a response to more competition. In sum, this leads to higher average quality if the regulated price is sufficiently small. On the contrary, if β is low, the

[22] See the appendix section 2.B for further details.

private provider will reduce quality in response to increased competition (cf. Proposition 2.2). Moreover, the role of the regulated price λ is essential to the price-cost margin for the public provider. If λ is low, provider 1 has weak incentives for quality provision, because the profit margin is tight. This means that increased competition has only a small positive effect on the public provider's quality. Thus, a reduction in quality for the private provider outweighs weak incentives for quality of the public provider. The overall effect is a decrease in the equilibrium average quality in response to increased competition.

Considering the case of $\alpha > 0$, we seek to explain how the results in Propositions 2.2 and 2.3 change if the public provider is motivated. We can summarise the results as follows:

Proposition 2.4. *If the public provider is motivated ($\alpha > 0$) instead of being a pure profit maximiser ($\alpha = 0$), increased competition has an a priori ambiguous effect on quality provision by the public provider, while the scope for a quality reduction by the private provider is larger.*

The effect of competition on the quality of the public provider is ambiguous in the presence of altruism. We find, under some conditions, that more competition reduces the quality for the public provider. The larger β is, the larger is the effect of a reduction of t on the demand responsiveness to quality. When β is sufficiently large, the private provider has a strong incentive to increase quality as a response to more competition. When λ is sufficiently small, the public provider has weak incentives to increase quality because the profit margin is low. If $\alpha > 0$, then the strategic response from the public provider ($\partial q_1/\partial q_2 < 0$) is large enough to dominate, implying that the public provider will respond to increased competition by reducing quality. Lower t makes demand more quality-elastic, and the incentive to increase quality depends on the marginal payoff of quality, which is increasing in α. For the private provider, a higher α increases the public provider's marginal payoff of quality provision and reinforces Provider 1 to offer higher quality in response to more competition. Due to strategic substitutability ($\partial q_2/\partial q_1 < 0$), this will increase the scope for the private provider to reduce its quality.

In sum, the relationship between competition and quality provision for each provider is a *priori ambiguous*, and it depends, among other things, on the degree of altruism. While it is not possible to determine the sign of the effect of competition on average quality analytically, numerical simulations suggest, for a sufficiently high β and low λ, that the effect of more competition on average quality provision is positive (negative) if the degree of altruism is sufficiently small (large), implying that an increase (decrease) in quality provision by the private provider is always sufficient to outweigh the quality reduction (increase) by the public provider.

2.6 Policy levers

In this section, we analyze the role of the social planner who controls the public provider's payments through the regulated price and copayment fee. First, we study the effects of a change in each of these measures on the quality provision and the price of the private provider. Second, we examine the change in the composition of policy levers while keeping the price per unit of the good supplied to the public provider at a fixed level.

2.6.1 Regulated price

The effects of a change in the regulated price λ are given as follows:

Proposition 2.5. *Whether the public provider is motivated or not, an increase in the regulated price λ leads to higher quality for the public provider and lower quality (and price) for the private provider.*

The marginal effect of an increase in the regulated price on equilibrium levels will not depend whether the public provider is motivated or not. Recall that $q_1(q_2)$ is increasing in the regulated price λ. This is intuitive with the constant marginal costs. The public provider benefits from an increase in the price-cost margin, which increases its incentives to invest more in quality improvements. Thus, a higher λ translates into a higher q_1, which in turn leads to lower q_2 due to strategic substitutability. This leads the private provider to reduce the price, p_2, due to complementary strategic interaction with q_2. In sum, a higher regulated price has a heterogeneous effect on the quality provision of the two providers, $\partial q_1^*/\partial\lambda > 0$ and $\partial q_2^*/\partial\lambda < 0$.

The effect of a marginal increase in the regulated price on average quality is summarised by:

Proposition 2.6. *Average quality is increasing in the regulated price λ regardless of the degree of altruism α.*

The level of the regulated price determines the market share of the two providers. A high λ increases the profitability of the public provider's incentives to offer higher quality, which in turn leads to an inflow of consumers toward Provider 1. On the contrary, due to strategic interaction ($\partial q_2/\partial q_1 < 0$), there is a negative effect on the private provider. An increase in λ will cause the reduction in q_2 to be low in comparison with the increase in q_1. In sum, this leads to higher average quality as a response to a higher regulated price. Notice that the marginal revenue of quality for the public provider increases in the presence of altruism. Thus, for $\alpha > 0$, the positive effect (due to an increase in q_1) is sufficiently strong to dominate the negative effect (due to a reduction in q_2), implying a higher average quality in response to λ.

2.6.2 Co-payment fee

In our model, one potentially interesting role of the copayment fee, T, is as a policy instrument to stimulate quality provision in the market. The effects of a change in the copayment fee are summarised below:

Proposition 2.7. *A higher copayment fee T leads to*

(i) Higher quality and price for the private provider.

(ii) Higher (lower) quality for the public provider if the degree of altruism α is sufficiently small (large).

If both providers are profit maximisers, the regulator can induce providers to increase quality provision through an increase in the co-payment fee. Price regulation for the public provider is equivalent to regulating markups. Thus, a higher T has a direct positive impact on the profit margin of the public provider which leads to higher q_1. Furthermore, all else equal, higher T increases the demand for the private provider D_2, which makes the demand for this provider less price-elastic. Thus, the provider optimally responds by increasing the price p_2. Due to price and quality being complementary strategies, this leads to higher quality q_2. The presence of altruism entails a trade-off regarding the public provider's incentive for quality provision in response to a higher co-payment fee. If $\alpha > 0$, there is an additional strategic response ($\partial q_1(q_2)/\partial q_2 < 0$). A higher quality for the private provider as a response to higher T leads to lower quality for the public provider, and this effect is sufficiently strong only if α is large enough.

If the public provider is sufficiently profit oriented, an increase in T has unambiguously positive effect on the quality of each provider. In this case, can we draw a conclusion that a higher copayment fee leads to a higher average quality? In addition, each provider responds differently to a higher copayment fee if the public provider is highly motivated. Thus, it is important to assess the effect of the copayment fee on the average quality $\overline{q}$, which can be summarised as follows:

Proposition 2.8. *(i) If $\alpha = 0$, the average quality is increasing in the copayment fee if the regulated price λ is sufficiently low. However, for a sufficiently large λ, a higher copayment fee leads to a higher (lower) average quality provision if the willingness to pay for quality , β, is sufficiently large (small). (ii) The presence of public-provider altruism increases the scope for a negative relationship between co-payment and average quality.*

The first part of Proposition 2.8 shows that average quality might go down for a sufficiently low β and sufficiently large λ, although both quality levels will increase in response to higher T. The reason is that a higher co-payment fee leads to reallocation of consumers from the public to the private provider. If λ is sufficiently high, we know that $q_1 > q_2$ (cf. Proposition 2.1) and the public provider is the high-quality provider in the market. If β is small, a larger share of consumers choose the low-quality provider. Thus, a reallocation of consumers from the public to the private provider can cause average quality to drop even if quality increases for both providers. The intuition for the second part is as follows. If $\alpha > 0$, that will increase the scope for the public provider to reduce quality in response to a higher T (cf. Proposition 2.7). Thus, in the presence of altruism, the scope for a negative relationship between T and $\overline{q}$ is larger.

2.6.3 Copayment share

In previous subsections, we considered the effect on quality provision when the co-payment or regulated price varies. An increase in one of these policy levers will definitely lead to an increase in the total price, p_1, facing the public provider. However, a more useful policy could be to fix the price for the public provider but change the share of costs paid by the consumers relative to the share paid by the regulator. Based on (2.3.1), we assume $T = sp_1$, where s is the copayment rate. In such a scenario, the regulated price is given by $\lambda = (1-s)p_1$, and the total price, $p_1 = T + \lambda$, is fixed. The effects of a change in the copayment rate s are given as follows:

Proposition 2.9. *A higher copayment rate s leads to*

(i) higher quality (and price) for the private provider

(ii) lower (no change in the) quality of the public provider if $\alpha > (=) 0.$

The second part of Proposition 2.9 shows that if consumers face a higher copayment fee (increasing the proportion that is paid out of pocket by the consumer) relative to the share paid by the regulator in the case of a regulated price λ, this has no effect on the quality for a profit-maximising public provider. An increase in s does not increase the profit margin of the public provider, as the total price is fixed. However, all else equal, a higher s increases the demand for the private provider, which makes the demand for this provider less price-elastic. This, in turn, gives the private provider an incentive to increase the price and offer higher quality (because p_2 and q_2 are complementary strategies). In the presence of altruism, there is an additional strategic response ($\partial q_1^s / \partial q_2^s < 0$). A higher quality for the private provider in response to a higher s leads to a lower quality for the public provider, and this effect holds regardless of the motivation level α, in contrast to Proposition 7. With fixed expenditure, if the policymaker reduces the regulated price (i.e., increases s), how does this affect the average quality? We examine the effect of a higher s on the average quality $\overline{q}^s$, which can be summarised:

Proposition 2.10. *(i) If $\alpha = 0$, the average quality decreases (increases) in response to a higher copayment share if the regulated price λ is sufficiently high (low). (ii) The presence of altruism reduces the scope for a positive relationship between average quality and copayment share.*

If the regulated price λ is sufficiently low, the private provider is the high-quality provider. An increase in the share of co-payment gives an incentive for the private provider to increase quality investments (cf. Proposition 2.9). This leads to higher overall average quality in equilibrium. The reverse result ($\partial \overline{q}^s / \partial s < 0$) requires λ to be sufficiently high. In this case, the public provider is the high-quality provider. The demand reallocation from the public to the private provider as a response to a higher share of co-payment can cause the average quality to drop. If $\alpha > 0$, the public provider reduces the quality (cf. Proposition 2.9), and, due to the strategic response ($\partial q_1^s / \partial q_2^s < 0$), the scope for a positive relationship between average quality and co-payment share is smaller.

2.7 Welfare

The above analysis is based on the assumption that the public payer is able to precommit to a particular regulatory policy, which is exogenously given. In this section, we complement our framework with a welfare analysis such as is common in the literature of mixed duopoly. In the first part, we derive the first-best solution and subsequently show how this solution can be implemented by optimal choices of the regulated price and the copayment fee. In the second part, we derive a welfare-maximising price for a given copayment fee for the public provider, and analyse how some of the results in the benchmark model are affected given the optimal price.

We define social welfare as the difference between gross consumer surplus and provider costs. To define W more precisely, consider the aggregate consumer utility, denoted U, plus total profits, net of public funding:

$$W = U + \sum_{j=1}^{2} \pi_j - \lambda D_1 - B, \tag{2.7.1}$$

where the aggregate consumer utility is given by

$$U = \int_0^{D_1} \left(v + \beta q_1 - T - tx^2\right) dx + \int_{D_1}^{1} \left(v + \beta q_2 - p_2 - t\left(1-x\right)^2\right) dx. \tag{2.7.2}$$

Since the total demand is fixed, we can more conveniently reformulate the welfare expression as

$$W = v + \beta \overline{q} - \delta - c - \frac{k}{2} \sum_{j=1}^{2} q_j^2, \tag{2.7.3}$$

where $\overline{q}$ is defined in (2.5.1) and aggregate transportation costs are given by

$$\delta = \frac{t}{12} + \frac{\left(T - p_2 - \beta\left(q_1 - q_2\right)\right)^2}{4t}. \tag{2.7.4}$$

Imposing symmetry and easing notation by writing $q_j = q$, which implies that aggregate transportation costs are minimised (at $\delta = t/12$), the social welfare is given by

$$W = v + \beta q - \frac{t}{12} - c - kq^2. \tag{2.7.5}$$

2.7.1 The first-best solution

Suppose the regulator is able to control quality and demand directly. We start out by considering the socially optimal first-best solution. Maximising (2.7.5) with respect to the quality, the first-best quality level, equal for each provider, is given by[23]

$$q^{FB} = \frac{\beta}{2k}. \tag{2.7.6}$$

It follows immediately that the first-best quality is increasing in consumers' marginal willingness-to-pay for quality, β, and decreasing in the quality cost parameter, k.

2.7.2 Implementation of the first-best solution

Suppose that the regulator cannot set quality directly, but is able to commit to a particular funding scheme as a long term decision. The solution can be implemented by optimal choices of the regulated price and the copayment fee, as stated in the next proposition.

Proposition 2.11. *If the public payer can commit to a regulatory regime, the first-best solution is implemented by setting the regulated price*

$$\lambda^{FB} = t - \frac{\alpha\left(\beta^2 + 4kt + 2kv\right)}{2k} \tag{2.7.7}$$

and the copayment fee

$$T^{FB} = c + t. \tag{2.7.8}$$

We find that it is not possible to implement the first-best solution by setting the copayment fee below marginal cost. This is in contrast to our assumption that consumers pay at most a fee equal to the marginal cost in the main analysis. In this case, the first-best solution coincides with the Nash equilibrium under a private duopoly.[24] Thus, privatization of the public provider would be an alternative way to achieve the first-best solution. Furthermore, a higher degree of

[23] The second order condition is satisfied: $\partial^2 W/\partial q^2 = -2k < 0$.

[24] Social welfare is maximised by minimising total transportation costs and maintaining the quality level where the marginal benefit is equal to the marginal cost.

altruism leads to a lower first-best price (λ^{FB} is decreasing in α). This is intuitive, since the social planner needs to incentivise the public provider less in order to achieve the first-best level of quality in the presence of altruism.

2.7.3 Optimal price for a given copayment fee

Our main model is based on the observation that public and private providers do coexist in regulated markets. In the following we will therefore take the existence of a public provider with low copayment fee as given. We assume that the public payer seeks to set the copayment rate at a sufficiently low level to satisfy considerations that are not explicitly modeled in our framework. One relevant example in health-care or education markets is that a policy maker seeks to ensure broad access to the services offered by the public provider for disadvantaged patients/students. That being the case, we derive the welfare-maximising price level for the public provider and we assess how it depends on the copayment fee. Later, we analyse the effect of competition on quality provision and derive the equilibrium quality ranking when the price is optimally chosen.

Suppose that the copayment fee T is exogenously given. We maximize (2.7.3) with respect to the regulated price λ to find the optimal price level, given by

$$\widehat{\lambda} = \frac{2k\left(\left(3kt-\beta^2\right)\left(4kt-\beta^2\right)(c-T)+2t\left(5kt-\beta^2\right)\left(2kt-\beta^2\right)\right)+\alpha\Upsilon}{2k\left(\beta^4+kt\left(8kt-7\beta^2\right)\right)}, \tag{2.7.9}$$

where

$$\Upsilon := -2kv\left(\beta^4+kt\left(8kt-7\beta^2\right)\right)+kt\left(8kt-3\beta^2\right)\left(\beta^2-6kt+2k\left(T-c\right)\right)-\beta^4\left(\beta^2-6kt\right). \tag{2.7.10}$$

The social welfare is maximised at a price level where the marginal social benefit of improved quality equals the marginal costs. From a social-welfare perspective, this implies that quality can be either over-provided or under-provided.

First, we explore the relationship between the optimal price and the copayment fee, which can be stated as follows:

Proposition 2.12. *There exists a threshold value $\widehat{\alpha} \in (0, \overline{\alpha})$ such that a marginal increase in the copayment fee T leads to a decrease (increase) in the optimal price $\widehat{\lambda}$, i.e., $\partial\widehat{\lambda}/\partial T < (>) 0$ if $\alpha < (>) \widehat{\alpha}$.*

In other words, there is an unambiguously negative relationship between the optimal price and the copayment fee if the public provider is sufficiently profit oriented. This indicates that these two funding instruments are *policy substitutes*: a higher copayment fee leads to a lower optimal price level. We can easily verify that the optimal price $\widehat{\lambda}$ is decreasing in the degree of altruism, α. In this case, the regulator would like to *dampen* incentives for quality provision, as the public provider has more incentives to provide higher quality due to marginal benefit from nonfinancial gain.

Notice that the optimal price, $\widehat{\lambda}$, is higher than the one used in the implementation of the first-best solution, λ^{FB}, if the public is sufficiently profit oriented.

The intuition behind the result in Proposition 2.12 can be explained by considering how a marginal increase in the copayment fee affects average quality when the regulated price is at the welfare-optimal level. It can be shown that this effect is positive if α is sufficiently low and negative otherwise (which is consistent with the result in Proposition 2.8). Thus, if the public provider is sufficiently profit oriented, a higher copayment fee increases average quality and the regulator would therefore like to *dampen* quality provision, which can be done by decreasing the price $\widehat{\lambda}$. The opposite logic applies if the public provider is sufficiently altruistic.

Second, we analyse the effect of competition on quality provision, which can be described as follows:

Proposition 2.13. *At the welfare maximising price $\widehat{\lambda}$, if the public provider is sufficiently profit oriented, increased competition (lower t) leads to*

(i) higher quality for the public provider and lower quality for the private provider.

(ii) higher average quality.

In the first part of Proposition 2.13, we find that increased competition has a heterogeneous effect on quality between two providers at the optimal price, with a positive effect for the public provider and a negative effect for the private provider. The intuition follows directly from Proposition 2.2, which shows that the private provider responds to more competition by decreasing quality (where the indirect effect dominates the direct effect) if the price is sufficiently high. The regulator sets a sufficiently high price $\widehat{\lambda}$ in order to incentivize a certain equilibrium. In this scenario, a decrease in quality by the private provider is *counteracted* by an increase in the quality of the public provider, leading to higher average quality. Therefore, more competition leads to higher average quality at the optimal price if the public provider is sufficiently profit oriented, which is in contrast to the ambiguous result in Proposition 2.3. While it is not possible to determine the sign of the relationship for all degree of altruism, numerical simulations suggest that more competition has a positive effect on average quality if the degree of altruism is not very high.

Finally, as in Section 2.4.3, we compare the equilibrium quality levels between providers given the welfare-maximising price level $\widehat{\lambda}$, which produces the following ranking:

Proposition 2.14. *The public provider always offers the highest quality in the market when the price is optimally chosen at $\widehat{\lambda}$,*

$$(q_1^* - q_2^*)_{|\lambda=\widehat{\lambda}} = \beta\left(3kt - \beta^2\right)\frac{t + c - T}{\beta^4 + kt\left(8kt - 7\beta^2\right)} > 0. \tag{2.7.11}$$

Notice that the quality difference in (2.7.11) does not depend on the degree of altruism and is decreasing in the copayment fee, T. For a given copayment fee, the highest quality in the market is always offered by a public provider.

The intuition behind this quality ranking is directly linked to the case discussed in Proposition 2.1, which shows that the public provider is the high-quality provider if the regulated price is sufficiently high. The regulator sets a sufficiently high price in order to maintain a dominant position for the public provider, which in turn offers the highest quality as shown in (2.7.11).

2.8 Policy implications and concluding remarks

In this paper, we investigate the widespread observation that, whenever public and private providers coexist, quality differentiation varies. We have set up a model with an institutional context relevant to health-care and education markets, where the public provider (or publicly funded private provider) faces an exogenous regulated price, while the private provider is free to choose its price. Within the framework, we have explored the effect of competition on quality provision and highlighted how the change in the funding policy affects the outcome of strategic competition between providers. In our benchmark model, we consider pure profit-maximisation before we consider heterogeneous objective functions in the presence of altruism for the public provider.

Our results are mainly explained by the nature of strategic interaction between the public and the private provider. In the profit-maximising duopoly, the public provider's best response is strategically independent of the quality offered by the private provider. The picture is reversed in the presence of altruism. Our theoretical analysis produces four main results. First, we find that the private firm is the high-quality provider if the market entails a high-level horizontal differentiation (diversity in services) and the regulated price of the public provider is sufficiently small. This finding is in line with observation in most developing countries (Alumran, Almutawa, Alzain, Althumairi, & Khalid, 2020; Berendes, Heywood, Oliver, & Garner, 2011).[25] On the contrary, when the price is fixed for public and private hospitals, the picture is mixed in European countries (Kruse, Stadhouders, Adang, Groenewoud, & Jeurissen, 2018).

Second, we explore the effect of competition on quality provision. Under pure profit maximisation, we find that increased competition leads to lower average quality if the willingness-to-pay for quality is low and the regulated price of the service provided is sufficiently small. If the willingness-to-pay for quality is low, the indirect effect dominates the direct effect, leading to lower quality for the private provider. If the regulated price is small, the public provider has weak incentives for quality provision due to a tight profit margin. In the presence of altruism, we find that increased competition has an *a priori ambiguous* effect on the quality offered by the public provider, while the scope for a quality reduction by the private provider is larger. Thus, the evidence that increased competition improves quality is less clear-cut reflects the fact that the economic theory of quality competition can produce different outcomes (Sivey & Chen,

[25] Only eight of the 50 best-ranked U.S. universities are public (Times Higher Education, 2019) at https://www.timeshighereducation.com/world-university-rankings/2019/world-ranking#!/page/0/length/50/locations/US/sort_by/rank/sort_order/asc/cols/stats.

2019).

Third, we show that a higher copayment fee leads to lower quality for the public provider if it is sufficiently motivated. Provider motivation also increases the scope for a negative relationship between the copayment fee and average quality. We also examine the change in the composition of policy levers while keeping the price per unit of the good supplied to the public provider fixed. This has been a recurrent concern and has triggered a heated policy and scholarly debate. We show that average quality decreases (increases) in response to higher co-payment share for a sufficiently large (small) regulated price.

Finally, we derive the first-best solution and show how it coincides with the Nash equilibrium of a private (symmetric) duopoly. Given the existence of a public provider, the first-best solution can be implemented either by privatizing the public provider or by regulating it in a way that makes it act like a private profit-maximising provider, which implies a copayment fee equal to the price of the private provider. The interest in other-than-governmental revenue has greatly increased within European public universities (Jacobs & Van Der Ploeg, 2006). Besides, such revenue is common, for instance, in low-income countries where governments face financial constraints (Pedró, Leroux, & Watanabe, 2015).

We extend our welfare analysis with an underlying assumption that a policy maker wants to keep the copayment fee at a low level that is exogenously determined by out-of-the-model considerations. If providers are sufficiently profit oriented, we find that the welfare maximising price depends negatively on the copayment fee. This implies that that these two funding instruments are *policy substitutes*: a higher copayment fee leads to a lower optimal price level. Our results also suggest that the public provider offers the highest quality in the market when the price is optimally chosen. De Fraja (2009) explains that large state subsidies to state-owned educational institutions are justified by the training externality rather than a redistributive concern. We also show that the welfare maximising price stimulates higher quality provision in response to more competition if the public provider is sufficiently profit oriented.

In our model, one limitation is that consumer preferences are not vertically differentiated. Equity considerations play an important role in policy decisions in healthcare and education markets (Salti, Chaaban, & Raad, 2010; Siciliani & Straume, 2019). Further possible generalizations of this model include the introduction of location choice[26] and of endogenous costs, and the extension to more than two competitors. We will leave these for future research.

[26] If the location of the private hospital is determined endogenously, Hehenkamp and Kaarbøe (2020) find that it locates toward the corner of the market to avoid costly quality competition if the regulator offers low reimbursement prices. However, that study considers price regulation instead of asymmetric pricing.

APPENDIX

Appendix 2.A Equilibrium existence

In the quality subgame, the second-order conditions are given by

$$\frac{\partial^2 \Omega}{\partial q_1^2} = -\frac{(2kt - \alpha\beta^2)}{2t} < 0, \tag{2.A.1}$$

$$\frac{\partial^2 \pi_2}{\partial q_2^2} = -\frac{(4kt - \beta^2)}{4t} < 0, \tag{2.A.2}$$

which are satisfied if

$$2kt > \alpha\beta^2, \tag{2.A.3}$$

and

$$\beta^2 < 4kt. \tag{2.A.4}$$

The stability condition requires that the Jacobian matrix be positive definite:

$$\frac{\partial^2 \Omega}{\partial q_1^2}\frac{\partial^2 \pi_2}{\partial q_2^2} - \frac{\partial^2 \Omega}{\partial q_1 \partial q_2}\frac{\partial^2 \pi_2}{\partial q_1 \partial q_2} = \frac{(\beta^2 - 4kt)(\alpha\beta^2 - 2kt)}{8t^2} - \frac{\alpha\beta^4}{16t^2} > 0, \tag{2.A.5}$$

which requires

$$\alpha < \overline{\alpha} := \frac{4kt(4kt - \beta^2)}{\beta^2(8kt - \beta^2)}. \tag{2.A.6}$$

Thus, the condition in (2.A.1) always holds if (2.A.6) holds.

Furthermore, the second-order condition in the welfare maximisation problem is given by

$$\frac{\partial^2 W}{\partial \lambda^2} = -2k\beta^2 \frac{kt\,(8kt - 7\beta^2) + \beta^4}{(\alpha\beta^4 + 16k^2t^2 - 4kt\beta^2 - 8kt\alpha\beta^2)^2} < 0. \tag{2.A.7}$$

The condition in (2.A.7) holds if $kt\,(8kt - 7\beta^2) + \beta^4 > 0$, or

$$k > \underline{k} := \frac{7\beta^2}{8t}. \tag{2.A.8}$$

The condition in (2.A.4) always holds if (2.A.8) holds. In order to ensure the existence of equilibrium in all versions of the game (before and after endogenizing the regulated price), the condition in (2.A.8) is sufficient to ensure that the condition in the quality game subgame, (2.A.2), is satisfied.

In order to ensure the existence of equilibrium for quality, the optimal quality for Provider 1 has to be always positive. As the numerator in (2.4.6) is monotonically increasing in the regulated price λ, this implies that $q_1 \geq 0$ if

$$\lambda \geq \underline{\lambda} := c - T + \alpha \frac{v(\beta^2 - 4kt) + 4t(\beta^2 - 3kt + k(T-c))}{(4kt - \beta^2)}. \tag{2.A.9}$$

The optimal quality for the private provider has to be strictly positive. As the numerator in (2.4.7) is monotonically decreasing in the regulated price, this implies that $q_2^* \geq 0$ if

$$\lambda \leq \bar{\lambda} := \frac{(T-c)(4kt - \beta^2) + 4kt^2 - \alpha\beta^2(5t + T + v - c)}{\beta^2}. \tag{2.A.10}$$

For $\alpha = 0$, we have $\bar{\lambda} > \underline{\lambda}$ if

$$t > c - T. \tag{2.A.11}$$

When $\alpha \neq 0$, we require the previous condition in addition to the necessary level of altruism such that $\alpha < \overline{\alpha}$. Thus, α is bounded below and above: $0 \leq \alpha < \overline{\alpha}$.

An interior solution for the optimal price $\widehat{\lambda}$ requires $\underline{\lambda} < \widehat{\lambda} < \bar{\lambda}$, which in turn imposes that the following two inequalities hold:

$$\widehat{\lambda} - \underline{\lambda} = \frac{1}{2}\left(4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)\right) \frac{\beta^4 + kt\left(10kt - 7\beta^2\right) + 2k^2t\left(c - T\right)}{k\left(4kt - \beta^2\right)\left(\beta^4 + kt\left(8kt - 7\beta^2\right)\right)} > 0. \tag{2.A.12}$$

This condition holds for all $T < c$. The second inequality is

$$\bar{\lambda} - \widehat{\lambda} = \frac{1}{2}\left(4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)\right) \frac{\beta^4 + kt\left(4kt - 5\beta^2\right) + 2k\left(2kt - \beta^2\right)\left(T - c\right)}{k\beta^2\left(\beta^4 + kt\left(8kt - 7\beta^2\right)\right)} > 0. \tag{2.A.13}$$

This condition holds if

$$T > c - \left(\frac{\beta^4 + kt\left(4kt - 5\beta^2\right)}{2k\left(2kt - \beta^2\right)}\right). \tag{2.A.14}$$

This condition is compatible with $T < c$, including $T = 0$, as long as k is sufficiently high.

Appendix 2.B Proofs

Proof of Proposition 2.1

(i) If $\alpha = 0$, the numerator in (2.4.9) reduces to $\beta(t - \lambda)$, which is positive if $t > \lambda$. Thus, if $\alpha = 0$, we have $q_2^* > q_1^*$ if $t > \lambda$. (ii) In the presence of altruism, the statement is true if the second square bracket is positive, which follows immediately from (2.4.9). To put it differently, there exists a threshold $\hat{t}$ where $\hat{t} > \lambda$ such that $q_2^* > q_1^*$ if $t > \hat{t}$. Conversely, $q_2^* < q_1^*$ if $t < \hat{t}$. *Q.E.D.*

Proof of Proposition 2.2

The effect of competition on the quality of the public provider is given by

$$\frac{\partial q_1^*}{\partial t} = -4\beta \frac{k(T + \lambda - c)\left(4kt - \beta^2\right)^2 + \alpha\kappa}{\left(4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)\right)^2} \lesseqgtr 0, \tag{2.B.1}$$

$$\frac{\partial q_2^*}{\partial t} = \beta \frac{4k[\beta^2(8kt - \beta^2)(T + \lambda - c) + 4kt^2(4k(c - T) - \beta^2)] - \alpha\Theta}{[4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)]^2} \lesseqgtr 0, \tag{2.B.2}$$

where

$$\kappa = \left[\begin{array}{c} \alpha\beta^6 + k\beta^4(\lambda + v(1 + \alpha)) + 6kt\alpha\beta^2(4kt - \beta^2) \\ +k(c - T)\left(16k^2t^2 - \beta^4(1 + \alpha)\right) + 4k^2t(2v(2kt - \beta^2) - t\beta^2) \end{array} \right], \tag{2.B.3}$$

and

$$\Theta := \beta^2 \left[\begin{array}{c} 5\alpha\beta^4 - 48k^2t^2 + 4vk\beta^2 - 32k^2t(T + v - c) \\ +8k\beta^2(\alpha v + \lambda - t - (\alpha + 1)(c - T)) \end{array} \right]. \tag{2.B.4}$$

(i) If $\alpha = 0$, the numerator in (2.B.1) reduces to $-\beta(T + \lambda - c)$, which is negative because $p_1 > c$.

(ii) If $\alpha = 0$, the numerator in (2.B.2) is monotonically increasing in λ. Setting $\lambda = \overline{\lambda}$ yields $4kt(4kt - \beta^2)(T - c + 2t)$, which is positive because $t > c - T$. Therefore, $\partial q_2^*/\partial t > 0$ if λ is sufficiently high. However, setting $\lambda = \underline{\lambda}$ yields $4kt^2\left(4k\lambda - \beta^2\right)$ which has an ambiguous sign. It is positive if β is sufficiently low. Thus, $\partial q_2^*/\partial t > 0$ if β is sufficiently low for all $\lambda \in (\underline{\lambda}, \overline{\lambda})$. On the other hand, for a sufficiently high β - in particular, at the highest level compatible with existence of equilibrium, $\beta^2 = 8kt/7$ - it reduces to $-\frac{16}{7}k^2t^2\left(2t - 7\lambda\right)$, which is negative if t is sufficiently high relative to λ (recall that $t > \underline{\lambda} := c - T$). Thus, if $\alpha = 0$, we have $\partial q_2^*/\partial t < 0$ if β is sufficiently high and λ is sufficiently small. *Q.E.D.*

Proof of Proposition 2.3

Given the equilibrium levels, we compute (2.5.1) and differentiate it with respect to t:

$$\frac{\partial \overline{q}}{\partial t}|_{\alpha=0} = \beta \frac{-\beta^2\lambda(12kt-\beta^2)(\beta^2+k\lambda) - 4k^2t^2(2t\beta^2+3\lambda(4kt-5\beta^2)) + \varphi}{4kt^2\left(4kt-\beta^2\right)^3}, \tag{2.B.5}$$

where

$$\varphi = (c-T)(4kt-\beta^2)\left(20k^2t^2 - \left(\beta^2+k\lambda\right)\left(8kt-\beta^2\right)\right). \tag{2.B.6}$$

The sign of (2.B.5) is determined by the sign of the numerator. If β is sufficiently high - in particular, on setting $\beta^2 = 8kt/7$, the numerator reduces to

$$-\frac{16}{343}k^3t^2\left(t\left(196t-137\lambda\right) + 266\lambda^2 + 20k^2t^2\left(149t-84\lambda\right)(c-T)\right),$$

which is negative if λ is sufficiently low. Thus, $\partial\overline{q}/\partial t < 0$ if β is sufficiently high and λ is sufficiently low. Denote the numerator by G. The partial derivative of G with respect to λ yields

$$\frac{\partial G}{\partial \lambda} = \left(\begin{array}{c} -\beta^4\left(12kt-\beta^2\right) - 12k^2t^2\left(4kt-5\beta^2\right) - 2k\beta^2\lambda\left(12kt-\beta^2\right) \\ -k\left(c-T\right)\left(4kt-\beta^2\right)\left(8kt-\beta^2\right) \end{array}\right). \tag{2.B.7}$$

$\partial G/\partial\lambda < 0$ if β is sufficiently low. In this case, the numerator is monotonically decreasing in λ. Otherwise, for sufficiently high β - in particular, if we set $\beta^2 = 8kt/7$ - then $\partial G/\partial\lambda$ reduces to

$$\frac{16}{343}k^3t^2\left(420(T-c) + 137t - 532\lambda\right),$$

which has an ambiguous sign. Setting $\lambda = \overline{\lambda}$ in the numerator of (2.B.5) yields $\frac{4kt}{\beta^2}(4kt-\beta^2)^2(T-c+t)(\beta^2+k(c-T-6t)) < 0$ regardless of whether β is high or low. On the other hand, setting $\lambda = \underline{\lambda}$ yields $8k^2t^2\left(T-c+t\right)\left(4k(c-T)-\beta^2\right) \lesseqgtr 0$. It is positive if β is sufficiently low. Thus, $\partial\overline{q}/\partial t > 0$ if β and λ are sufficiently small. *Q.E.D.*

Proof of Proposition 2.4

(i) The statement in the proposition is true if the sign of the numerator in (2.B.1) is ambiguous.
Define $M = -\left(k(T+\lambda-c)\left(4kt-\beta^2\right)^2 + \alpha\kappa\right)$

Notice that M is monotonically decreasing in λ. On one hand, setting $\lambda = \underline{\lambda}$, then M reduces to

$$[M]_{\lambda=\underline{\lambda}} = \alpha\left(4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)\right)\frac{\beta^4 - k\beta^2\left(c-T\right) + 6kt\left(2kt-\beta^2\right)}{4kt-\beta^2} > 0. \tag{2.B.8}$$

The numerator in (2.B.8) is increasing in k and positive for all $k > \underline{k}$. Therefore, if λ is sufficiently small, this implies $\partial q_1^*/\partial t > 0$. On the other hand, setting $\lambda = \overline{\lambda}$, then M reduces to

$$[M]_{\lambda=\overline{\lambda}} = \left[4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)\right]\frac{\alpha\beta^2\left(3kt-\beta^2\right) - k\left(4kt-\beta^2\right)\left(T-c+t\right)}{\beta^2}. \tag{2.B.9}$$

The left square bracket is positive, while the numerator has an ambiguous sign and depends on α. For a sufficiently high β, setting $\beta^2 = 8kt/7$, the numerator in (2.B.9) reduces to $-\frac{4}{49}k^2t\left(35\left(T-c+t\right) - 26t\alpha\right)$. It is negative (positive) if α is sufficiently small (large). Therefore, for a sufficiently high β and λ, $\partial q_1^*/\partial t < 0$ if α is sufficiently small. Otherwise, for a sufficiently large α, $\partial q_1^*/\partial t > 0$ for all $\lambda \in (\underline{\lambda}, \overline{\lambda})$.

(ii) The statement is true if (2.B.4) is negative, $\Theta < 0$. Notice that Θ is monotonically increasing in λ. Setting $\lambda = \overline{\lambda}$ in Θ yields

$$\Theta = -\beta^2[8kt(2kt+\beta^2) + 4kv(8kt-\beta^2) + 5\alpha\beta^2(8kt-1)] < 0. \tag{2.B.10}$$

Thus, $\Theta < 0$ for all $\lambda \in (\underline{\lambda}, \overline{\lambda})$. *Q.E.D.*

Proof of Proposition 2.5

The effect of the regulated price on the equilibrium outcome is given by

$$\frac{\partial q_1^*}{\partial \lambda} = \beta\frac{(4kt-\beta^2)}{4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)} > 0, \tag{2.B.11}$$

$$\frac{\partial q_2^*}{\partial \lambda} = -\frac{\beta^3}{4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)} < 0, \tag{2.B.12}$$

$$\frac{\partial p_2^*}{\partial \lambda} = -2kt\frac{\beta^2}{4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)} < 0. \tag{2.B.13}$$

Proof of Proposition 2.6

The marginal effect of the regulated price on average quality (if $\alpha > 0$) is given by

$$\frac{\partial \overline{q}}{\partial \lambda} = \beta \frac{4kt[3kt(4kt - 3\beta^2) + \beta^2(\beta^2 + 2k\lambda) + k(c - T)(4kt - \beta^2)] + \alpha\xi}{[4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)]^2}, \tag{2.B.14}$$

where $\xi = \beta^2[\beta^2(13kt - \beta^2) + 8k^2tv - (c - T)k\beta^2]$.

Denote the numerator in (2.B.14) by A. We derive

$$\frac{\partial^3 A}{\partial k^3} = 96t^2 (c - T + 3t) > 0. \tag{2.B.15}$$

This implies that $\partial^2 A/\partial k^2$ is monotonically increasing in k. Evaluating at the lower bound of k, we derive

$$\frac{\partial^2 A}{\partial k^2}|_{k=\underline{k}} = 4t\beta^2 (19(c - T) + 45t + 4(\lambda + v\alpha)) > 0. \tag{2.B.16}$$

Thus, A is strictly convex for all parameter configurations. Furthermore,

$$\frac{\partial A}{\partial k}|_{k=\underline{k}} = \frac{1}{4}\beta^4 (119(c - T) + 205t + 56(\lambda + v\alpha) + 4\alpha (T - c + 13t)) > 0. \tag{2.B.17}$$

and

$$[A]_{k=\underline{k}} = \frac{1}{32}\beta^6 \frac{245(c - T) + 259t + 196(\lambda + v\alpha) + 4\alpha (7(t + T - c) + 76t)}{t} > 0. \tag{2.B.18}$$

A is positive and increasing in k and positive at $k = \underline{k}$. It follows that $\partial\overline{q}/\partial\lambda > 0$ for all $k > \underline{k}$. *Q.E.D.*

Proof of Proposition 2.7

The marginal effects of an increase in the copayment fee T on the equilibrium values are given by

$$\frac{\partial q_1^*}{\partial T} = \beta \frac{4kt(1 - \alpha) - \beta^2}{4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)} \gtrless 0, \tag{2.B.19}$$

$$\frac{\partial q_2^*}{\partial T} = \beta \frac{4kt - \beta^2(1 + \alpha)}{4kt(4kt - \beta^2) - \alpha\beta^2(8kt - \beta^2)} > 0, \tag{2.B.20}$$

$$\frac{\partial p_2^*}{\partial T} = 2kt\frac{4kt-\beta^2(1+\alpha)}{4kt(4kt-\beta^2)-\alpha\beta^2(8kt-\beta^2)} > 0. \tag{2.B.21}$$

(i) If $\alpha = 0$, it is trivial that all effects are positive. In the presence of altruism, (ii) the numerator in (2.B.19) is monotonically decreasing in α. Setting the highest level of altruism ($\alpha = \overline{\alpha}$) reduces the numerator in (2.B.19) to $-\frac{(4kt-\beta^2)^3}{\beta^2(8kt-\beta^2)}$, which is negative. Hence, $\partial q_1^*/\partial T < 0$ if α is sufficiently high. However, $\partial q_1^*/\partial T > 0$ if α is sufficiently small. Thus, the sign is ambiguous and depends on the degree of altruism. Both equations (2.B.20) and (2.B.21) share the same numerator. Setting the highest level of altruism ($\alpha = \overline{\alpha}$) reduces the numerator in (2.B.20) to $\frac{(4kt-\beta^2)^2}{(8kt-\beta^2)}$, which is positive. Thus, $\partial q_2^*/\partial T > 0$ and $\partial p_2^*/\partial T > 0$ for all $\alpha \in (0, \overline{\alpha})$. *Q.E.D.*

Proof of Proposition 2.8

We examine the effect of the copayment fee on the average quality, which is given by

$$\frac{\partial \overline{q}}{\partial T} = \beta\frac{4kt(4kt-\beta^2)(5kt-\beta^2-k\lambda)+\alpha\Xi}{[4kt(4kt-\beta^2)-\alpha\beta^2(8kt-\beta^2)]^2}, \tag{2.B.22}$$

where

$$\Xi = \left[\begin{array}{c} 2k(4kt-\beta^2)(4kt-\beta^2(1+\alpha))(T-c)-4k^2tv(4kt-\beta^2) \\ +\beta^4(13kt-\beta^2)-16k^2t^2(6kt+\beta^2)+k\beta^4\lambda+k\alpha\beta^2(24kt^2+v\beta^2+2t\beta^2) \end{array}\right]. \tag{2.B.23}$$

(i) If $\alpha = 0$, the numerator in (2.B.22) reduces to $5kt-\beta^2-k\lambda$, which is monotonically decreasing in λ. Setting $\lambda = \underline{\lambda}$ yields $k(4t+t-(c-T))-\beta^2$, which is positive. Thus, $\partial\overline{q}/\partial T > 0$ if λ is sufficiently low. On the other hand, setting $\lambda = \overline{\lambda}$ yields $(4kt-\beta^2)\dfrac{\beta^2-k(T-c+t)}{\beta^2}$, which has an ambiguous sign. It is positive (negative) if β is sufficiently high (low). Thus, for sufficiently high λ, $\partial\overline{q}/\partial T > (<) 0$ if β is sufficiently high (low). (ii) The statement is true if (2.B.23) is negative, $\Xi < 0$. Notice that Ξ is monotonically increasing in λ. Setting $\lambda = \overline{\lambda}$ in Ξ yields H which is given by

$$H = \left[\begin{array}{c} \beta^4(13kt-\beta^2)+3kt\alpha\beta^2(8kt-\beta^2)+k\alpha\beta^2(8kt-\beta^2)(c-T) \\ -12k^2t^2(8kt-\beta^2)-4k^2tv(4kt-\beta^2)-k(8kt-\beta^2)(4kt-\beta^2)(c-T) \end{array}\right]. \tag{2.B.24}$$

We derive

$$\frac{\partial^3 H}{\partial k^3} = -96t^2(2(c-T)+6t+v) < 0, \tag{2.B.25}$$

which implies that $\partial^2 H/\partial k^2$ is decreasing in k. Then

$$\frac{\partial^2 H}{\partial k^2}|_{k=\underline{k}} = -4t\beta^2 \left(36(c-T) + 132t + 19v - 4\alpha\left(c - T + 3t\right)\right). \tag{2.B.26}$$

$$\frac{\partial H}{\partial k}|_{k=\underline{k}} = -\frac{1}{4}\beta^4 \left(214(c-T) + 914t + 119v - 52\alpha\left(c - T + 3t\right)\right). \tag{2.B.27}$$

$$[H]_{k=\underline{k}} = -\frac{1}{32}\beta^6 \frac{420(c-T) + 2020t + 245v - 168\alpha\left(c - T + 3t\right)}{t}. \tag{2.B.28}$$

H is strictly concave and decreasing in k if the expressions (2.B.26), (2.B.27) and (2.B.28) are negative, which is true for all $\alpha < \overline{\alpha}$. This implies that $H < 0$ for all $k > \underline{k}$. Therefore, $\Xi < 0$ for all $\lambda \in (\underline{\lambda}, \overline{\lambda})$. *Q.E.D.*

Proof of Proposition 2.9

We solve the model in the same way as in the main analysis, using a two-stage game. The Subgame Perfect Nash Equilibrium (q_1^s, q_2^s, p_2^s) is equivalent to (2.4.6)-(2.4.8) except that $T = sp_1$.

The effects of the copayment share on the quality levels and the price of the private provider are given by

$$\frac{\partial q_1^s}{\partial s} = -4kt\alpha\beta \frac{p_1}{4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)} \leq 0, \tag{2.B.29}$$

$$\frac{\partial q_2^s}{\partial s} = \beta \frac{p_1\left(4kt - \alpha\beta^2\right)}{4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)} > 0, \tag{2.B.30}$$

$$\frac{\partial p_2^s}{\partial s} = \frac{2ktp_1\left(4kt - \alpha\beta^2\right)}{4kt(4kt-\beta^2) - \alpha\beta^2(8kt-\beta^2)} > 0. \tag{2.B.31}$$

Proof of Proposition 2.10

The effect of the copayment rate on average quality is given by

$$\frac{\partial \overline{q}}{\partial s} = \beta k p_1 \frac{4kt\left(8kt\left(t + sp_1\right) + \beta^2\left(c - p_1\right) - 4kt\left(c + p_1\right)\right) - \alpha\Psi}{\left(\alpha\beta^4 + 16k^2t^2 - 4kt\beta^2 - 8kt\alpha\beta^2\right)^2} \lesseqgtr 0, \tag{2.B.32}$$

where

$$\Psi = \left[\begin{array}{c} \beta^4 (c - p_1) + 16kt^2 (\beta^2 + 6kt) + 16kt (2kt - \beta^2) (c - sp_1) + 4ktv (\beta^2 + 4kt) \\ -\alpha\beta^2 (24kt^2 + v\beta^2 + 2\beta^2 (t + sp_1 - c) + 8kt (c - sp_1)) \end{array} \right]. \tag{2.B.33}$$

(i) If $\alpha = 0$, (2.B.32) reduces to

$$\frac{\partial \overline{q}^s}{\partial s} = \beta p_1 \frac{8kt(t + sp_1) + \beta^2(c - \lambda - sp_1) - 4kt(c + \lambda + sp_1)}{4t (4kt - \beta^2)^2}, \tag{2.B.34}$$

where $\lambda = (1-s)p_1$. The numerator in (2.B.34) is decreasing in λ. Setting $\lambda = \underline{\lambda}$ (where $\underline{\lambda} = c - sp_1$), reduces the expression to $8kt(t + sp_1 - c) > 0$ (recall $t > c - sp_1$). Thus, if λ is sufficiently small, $\partial \overline{q}^s / \partial s > 0$. However, setting $\lambda = \overline{\lambda}$ (where $\overline{\lambda} = \frac{(4kt-\beta^2)(sp_1-c)+4kt^2}{\beta^2}$), the expression reduces to $4kt(4kt - \beta^2)\frac{c-t-sp_1}{\beta^2}$, which is negative. Therefore, $\partial \overline{q}^s / \partial s < 0$ if λ is sufficiently high. (ii) If $\alpha > 0$, the statement in the proposition is true if (2.B.33) is positive, $\Psi > 0$. Notice that Ψ is decreasing in λ (recall $p_1 = \lambda + sp_1$). Setting $\lambda = \overline{\lambda}$ (where $\overline{\lambda} := \frac{(sp_1-c)(4kt-\beta^2)+4kt^2-\alpha\beta^2(5t+sp_1+v-c)}{\beta^2}$), then Ψ reduces to

$$[\Psi]_{\lambda=\overline{\lambda}} = \left(\begin{array}{c} 4kt (3t (\beta^2 + 8kt) + v (\beta^2 + 4kt) + (8kt - 3\beta^2) (c - sp_1)) \\ -\alpha\beta^2 (8kt - \beta^2) (c + 3t - sp_1) \end{array} \right). \tag{2.B.35}$$

Denote the expression in (2.B.35) by R. We derive

$$\frac{\partial^2 R}{\partial k^2} = 32t^2 (2(c - sp_1) + 6t + v) > 0, \tag{2.B.36}$$

which implies that R is convex in k. Evaluating at the lower bound of k, we derive

$$\frac{\partial R}{\partial k}|_{k=\underline{k}} = 4t\beta^2 (45t + 8v + 11 (c - sp_1) - 2\alpha (c + 3t - sp_1)). \tag{2.B.37}$$

$$[R]_{k=\underline{k}} = \frac{1}{4}\beta^4 (336t + 63v + 56 (c - sp_1) - 24\alpha (c + 3t - sp_1)). \tag{2.B.38}$$

R is strictly convex and increasing in k if expressions (2.B.37) and (2.B.38) are positive, which is true for all $\alpha < \overline{\alpha}$. Therefore, $\Psi > 0$ for all $\lambda \in (\underline{\lambda}, \overline{\lambda})$. *Q.E.D.*

Proof of Proposition 2.11

Regarding the implementation of the first-best solution, the equilibrium demand taken into consideration the equilibrium outcomes in (2.4.6)-(2.4.8) is given by

$$D_1^* = \frac{k\left(4t\left(3kt-\beta^2\right)+\beta^2\lambda+\left(4kt-\beta^2\right)(c-T)\right)+\alpha\beta^2\left(\beta^2-3kt+k\left(T-c+v\right)\right)}{4kt(4kt-\beta^2)-\alpha\beta^2(8kt-\beta^2)}. \tag{2.B.39}$$

Equating (2.B.39) with $D^* = 1/2$, we compute the optimal copayment fee

$$T = c + \frac{2k\beta^2\lambda + 4kt\left(2kt-\beta^2\right)+\alpha\beta^2\left(\beta^2+2kt+2kv\right)}{2k\left(4kt-\beta^2\right)-2k\alpha\beta^2}. \tag{2.B.40}$$

Replacing (2.B.40) in the quality levels at equilibrium yield the following:

$$q_1^{FB} = \beta\frac{2k\lambda-\beta^2+2kt+2k\alpha\left(2t+v\right)}{2k\left(4kt-\beta^2\right)-2k\alpha\beta^2}, \tag{2.B.41}$$

$$q_2^{FB} = \frac{\beta}{2k}. \tag{2.B.42}$$

The quality difference is given by

$$q_1^{FB} - q_2^{FB} = \beta\frac{2k\left(\lambda-t\right)+\alpha\left(\beta^2+4kt+2kv\right)}{2k\left(\left(4kt-\beta^2\right)-\alpha\beta^2\right)}. \tag{2.B.43}$$

We deduce that $q_1^{FB} = q_2^{FB}$ if and only if

$$\lambda^{FB} = t - \frac{\alpha\left(\beta^2+4kt+2kv\right)}{2k}. \tag{2.B.44}$$

Replacing (2.B.44) in (2.B.40) will give us

$$T^{FB} = c + t. \tag{2.B.45}$$

Proof of Proposition 2.12

The relationship between the optimal price and the copayment fee is given by

$$\frac{\partial\widehat{\lambda}}{\partial T} = \frac{-\left(3kt-\beta^2\right)\left(4kt-\beta^2\right)+\alpha kt\left(8kt-3\beta^2\right)}{kt\left(8kt-7\beta^2\right)+\beta^4} \gtrless 0. \tag{2.B.46}$$

The numerator in (2.B.46) is monotonically increasing in α. Evaluating (2.B.46) at the upper bound of α, given by

$\overline{\alpha} = \frac{4kt(4kt-\beta^2)}{\beta^2(8kt-\beta^2)}$, we derive $\left[\frac{\partial\widehat{\lambda}}{\partial T}\right]_{\alpha=\overline{\alpha}} = \frac{\left(4kt-\beta^2\right)^2}{\beta^2(8kt-\beta^2)} > 0$. Since $\left[\frac{\partial\widehat{\lambda}}{\partial T}\right]_{\alpha=0} < 0$, this implies that $\partial\widehat{\lambda}/\partial T < (>)0$ if $\alpha < (>)\widehat{\alpha}$, where $\widehat{\alpha} = \frac{\left(3kt-\beta^2\right)\left(4kt-\beta^2\right)}{kt(8kt-3\beta^2)}$. *Q.E.D.*

Proof of Proposition 2.13

(i) If $\alpha = 0$, the effects of competition on the quality of the public and private provider at the welfare-maximising price are given by

$$\frac{\partial q_1^*}{\partial t}|_{\lambda=\widehat{\lambda}} = -\beta\frac{\beta^4 + kt\left(10kt - 7\beta^2\right) + 2k^2t\left(c - T\right)}{2kt\left(\beta^4 + kt\left(8kt - 7\beta^2\right)\right)} < 0, \tag{2.B.47}$$

$$\frac{\partial q_2^*}{\partial t}|_{\lambda=\widehat{\lambda}} = \beta\frac{\beta^2\left(\beta^4 + kt\left(16kt - 9\beta^2\right)\right) + 2k^2t\left(8kt - 3\beta^2\right)\left(c - T\right)}{2kt\left(-\beta^2 + 4kt\right)\left(\beta^4 + kt\left(8kt - 7\beta^2\right)\right)} > 0. \tag{2.B.48}$$

By continuity, this result holds also for α sufficiently close to zero.

(ii) If $\alpha = 0$, the effect of competition on the average quality at the optimal price is

$$\frac{\partial\overline{q}}{\partial t}|_{\lambda=\widehat{\lambda}} = -\frac{1}{2}\beta\left(3kt - \beta^2\right)\frac{\beta^8 + kt\left(\beta^4\left(56kt - 13\beta^2\right) + 8k^2t^2\left(10kt - 13\beta^2\right)\right) - \ell}{kt\left(4kt - \beta^2\right)\left(\beta^4 + kt\left(8kt - 7\beta^2\right)\right)^2}, \tag{2.B.49}$$

where

$$\ell := k\left(c - T\right)\left(\beta^4\left(9kt - \beta^2\right) - 6k^2t^2\left(8kt - \beta^2\right) + 2k^2t\left(16kt - 7\beta^2\right)\left(T - c\right)\right). \tag{2.B.50}$$

The sign of (2.B.49) depends on the sign of the numerator. Denote the numerator in (2.B.46) by F, from which we derive

$$\frac{\partial^4 F}{\partial k^4} = 384t^2\left(2\left(T - c\right)^2 + 3t\left(c - T\right) + 5t^2\right) > 0, \tag{2.B.51}$$

which implies that $\partial^3 F/\partial k^3$ is monotonically increasing in k. Evaluating at the lower bound $\underline{k}$, we derive

$$\frac{\partial^3 F}{\partial k^3}|_{k=\underline{k}} = 12t\beta^2\left(49\left(T - c\right)^2 + 81t\left(c - T\right) + 88t^2\right) > 0, \tag{2.B.52}$$

which implies that $\partial^2 F/\partial k^2$ is monotonically increasing in k. Furthermore:

$$\frac{\partial^2 F}{\partial k^2}|_{k=\underline{k}} = \frac{1}{2}\beta^4\left(441\left(T - c\right)^2 + 783t\left(c - T\right) + 602t^2\right) > 0, \tag{2.B.53}$$

$$\frac{\partial F}{\partial k}|_{k=\underline{k}} = \frac{1}{32t}\beta^6 \left(1715\left(T-c\right)^2 + 3203t\left(c-T\right) + 1936t^2\right) > 0, \tag{2.B.54}$$

$$[F]_{k=\underline{k}} = \frac{1}{256}\beta^8 \frac{2401\left(T-c\right)^2 + t\left(2489t + 4634\left(c-T\right)\right)}{t^2} > 0. \tag{2.B.55}$$

Thus, F is positive and increasing in k at $k = \underline{k}$. Since F is strictly convex for all $k > \underline{k}$, it follows that F is positive for all $k > \underline{k}$. The overall sign in (2.B.49) is negative for all $k > \underline{k}$., and thus $\frac{\partial \overline{q}}{\partial t}|_{\lambda=\widehat{\lambda}} < 0$ if $\alpha = 0.$ By continuity, this result holds also for α sufficiently close to zero. *Q.E.D.*

Appendix 2.C Summary table

The table summarises the main results under two scenarios: pure profit maximisation, and the presence of altruism for the public provider.

Pure profit maximisation ($\alpha = 0$ **)**	**In the presence of altruism (** $\alpha > 0$ **)**
Effect of competition (lower t **)**	
Propositions 2.2 and 2.3	Proposition 2.4
$\partial q_1^*/\partial t$<0	$\partial q_1^*/\partial t$>0 if λ is small and β is high
$\partial q_2^*/\partial t$>0 if β is low or λ is large	$\partial q_1^*/\partial t$<0 if α is small and λ is large
$\partial q_2^*/\partial t$<0 if β is high and λ is small	The scope for $\partial q_2^*/\partial t$>0 is larger
$\partial \overline{q}/\partial t$<(>)0 if β is high(low) and λ is small	The scope for $\partial \overline{q}/\partial t$<0 is larger
Effect of the regulated price λ	
$\partial q_1^*/\partial \lambda$>0; $\partial q_2^*/\partial \lambda$<0 (Proposition 2.5)	
$\partial \overline{q}/\partial \lambda$>0 (Proposition 2.6)	
Effect of the copayment fee T	
Propositions 2.7(i) and 2.8(i)	Propositions 2.7(ii) and 2.8(ii)
$\partial q_1^*/\partial T$>0; $\partial q_2^*/\partial T$>0	$\partial q_1^*/\partial T$>(<)0 if α is small(large); $\partial q_2^*/\partial T$>0
$\partial \overline{q}/\partial T$>(<)0 if λ is large and β is high(low)	The scope for $\partial \overline{q}/\partial T$<0 is larger
Effect of the copayment share s	
Propositions 2.9(i) and 2.10(i)	Propositions 2.9(ii) and 2.10(ii)
$\partial q_1^s/\partial s = 0$; $\partial q_2^s/\partial s > 0$	$\partial q_1^s/\partial s < 0$; $\partial q_2^s/\partial s > 0$
$\partial \overline{q}/\partial s > (<) 0$ if λ is small (large)	The scope for $\partial \overline{q}/\partial s$>0 is smaller

Table 2.C.1: Summary table

CHAPTER 3

QUALITY COMPETITION IN MIXED OLIGOPOLY[1]

3.1 Introduction

There are many services, among them health and education, which are provided by a mix of public and private providers, but where the relative share of these types of providers varies considerably across different countries. In such mixed markets, where public and private providers coexist, competition typically takes place among providers with different objectives and which are subject to different regulatory schemes. This raises several policy issues. For example, should private providers be included in public funding schemes? And if so, should such providers be allowed to distribute profits? In education markets, for example, many countries do not give public funding to for-profit private schools, while others, including several US states, permit publicly funded charter schools to be operated by for-profit providers (Boeskens, 2016; Lee, 2018). Furthermore, in health and education markets quality is a key concern, and designing policies to ensure a satisfactory provision of quality requires an understanding of how public and private providers strategically interact, and how they respond to different funding schemes.

In this paper we analyse the effects of mixed oligopolistic competition on quality provision in regulated markets where three different types of providers interact: (1) public providers, (2) publicly funded private providers, and (3) private providers without public funding. Providers of type 1 and 2 both face a regulated price (paid by the public funder) and a copayment rate (paid by the providers' consumers), but are assumed to differ in their objectives, with private providers being more profit-oriented than their public counterparts. On the other hand, providers of type 2 and 3 are similar in terms of objectives, but differ in terms of the regulatory environment in which they operate. Whereas publicly funded providers receive (part of) their revenues from the public funder, private providers without public funding must raise all their revenues from the market by charging a price for their services. Thus, while providers of type 1 and 2 only choose the quality of the service they provide, type 3 providers choose both quality and price.

Within this framework, we study three different (but related) set of issues. First, we study the nature of strategic interaction among these three different types of providers and how their quality provision depends on the characteristics of the funding scheme, which in turn determines the ranking of equilibrium quality provision across the three types of providers. Second, we analyse the effect of (intensified) competition on the quality provision of each type of provider and on the average quality provision in the market. Finally, we include a welfare analysis where we characterise the normative relationship between the regulated price and the copayment rate as policy instruments, and where we also

[1] This chapter is co-authored with Odd Rune Straume.

study the optimal degree of public funding coverage in the market.

Although our model is not tailor-made to fit one particular industry, our analysis applies in particular to regulated markets such as health care and education. In the health care markets of many European countries, patients can choose between public and private providers within the national health system, where prices and copayments are regulated, or alternatively choose a private provider outside the national health system and pay the expenses either out-of-pocket or via private health insurance.[2]

A similar mix of provider options is present in education markets, where tuition fees in publicly funded schools tend to be either absent or regulated, while independent private schools rely on the fees charged to their students. In such markets, publicly funded private schools have become a prominent feature across OECD countries (Boeskens, 2016).[3] Average OECD figures for 2012 show that 14.2% of 15-year-old students attended government-dependent private schools, 81.7% attended public schools, while 4.1% attended independent private schools (OECD, 2013).

Both in health care and education markets, the extent of public funding coverage for private providers is a contentious issue in many countries. In education markets, for example, proponents of extending funding to private providers argue that this stimulates inter-school competition and offers incentives for innovation and quality improvements. On the contrary, opponents argue that funding private education might lead to public sector resource depletion and ultimately result in a reduction in educational quality (Boeskens, 2016).

In order to analyse competition among three different types of providers, as explained above, we use a spatial competition framework with three providers – one of each type – equidistantly located on a Salop circle. We consider a two-stage game where all three providers choose quality in the first stage, followed by the price choice of the unregulated private provider in the second stage. Within this game-theoretic framework we derive three sets of results: two sets of positive results and one set of normative results. First, regarding the relationship between the characteristics of the funding scheme and the equilibrium quality provision in the market, we find that a higher regulated price or a higher copayment rate will reduce the quality provision of the public provider while increasing the quality provision of at least one of the private providers. The resulting effect on average quality is generally ambiguous. Furthermore, the highest quality in the market is provided by one of the publicly funded providers, unless the copayment rate is very high. Second, regarding the effect of competition on quality provision, we find that stronger competition stimulates the quality provision of the publicly funded private provider but has a generally ambiguous effect on the quality provision of the other two

[2] See for example Siciliani, Chalkley, and Gravelle (2017) for an overview of the scope for competition between health care providers in five different European countries

[3] One specific example is Chile, where the educational system is based on three types of schools; municipal, subsidised private and entirely private schools. The first two types are mainly funded by government subsidies per student and may also receive small contributions as school charges. However, the entirely private schools do not receive any public funding and raise their revenues from charging student fees (Chumacero, Gómez, & Paredes, 2011). According to official 2010 data from the Chilean Ministry of Education, 40.4% of students were enrolled in municipal schools, 50.8% in government-funded private schools, and 8.8% in independent private schools (OECD, 2012)

providers. However, numerical simulations suggest that the relationship between competition intensity and average quality provision is positive. Finally, regarding the welfare effects of different funding policies, we find that the regulated price and the copayment rate are policy complements (substitutes) for sufficiently low (high) levels of the copayment rate. Furthermore, when extending the analysis to consider the optimal degree of public funding coverage, we find that this depends on the level of the regulated price, where welfare is maximised when both, one and no private providers are funded for low, intermediate and high values, respectively, of the regulated price. Thus, there exists a welfare trade-off between funding generosity and funding coverage.

The rest of the paper is organised as follows. In the next section we present a relatively brief summary and discussion of related literature, before presenting the model in detail in Section 3.3. The main analysis, both positive and normative, is conducted in Section 3.4 for a given market structure in terms of public funding. In Section 3.5 we extend the analysis to consider the welfare effects of either removing public funding from the private provider or extending public funding to both private providers. Some concluding remarks are offered in Section 3.6.

3.2 Related literature

Our paper is related to the literature on mixed oligopoly in general and on quality competition between public and private providers in health care and education markets in particular. In the theory of mixed oligopolies, a sizeable literature has grown out of the seminal contributions by De Fraja and Delbono (1989) and Cremer, Marchand, and Thisse (1989). Later contributions include Cremer, Marchand, and Thisse (1991), Matsumura (1998), Bennett and La Manna (2012), and Haraguchi and Matsumura (2016). A main message from this literature is that the presence of public firms might yield welfare improving effects in oligopolistic industries, and a key issue has been to determine the optimal degree of public ownership (Matsumura, 1998).[4] A common assumption in this literature is that firms compete either in prices or quantities, and quality is generally not an issue.

There is however a smaller and more specialised literature dealing with quality competition in mixed oligopolies. Grilo (1994) produced what is probably the earliest contribution in this literature, studying quality and price competition in a vertically differentiated mixed duopoly. A later contribution building on this work is Lutz and Pezzino (2014), who find that a mixed duopoly is generally welfare superior to a private duopoly. Laine and Ma (2017) also study quality and price competition in a vertically differentiation framework and show the existence of multiple equilibria that differ with respect to the identity of the high-quality firm (public or private). The latter result has some parallels to the present paper, where

[4]There is also a recent strand of this literature analysing the policy implications of asymmetries between private firms in mixed oligopolies (e.g., Haraguchi and Matsumura (2020a, 2020b)), which has parallels to our study where there are regulatory asymmetries between the private providers.

we show that the public provider may or may not produce the highest quality in the market, depending on the details of the funding scheme. However, one of several important differences between our paper and all of the above mentioned papers on quality competition in mixed oligopolies is that the latter papers apply a vertical differentiation framework, whereas our study is conducted in a setting of horizontal differentiation. Our paper is therefore more closely related to the type of analysis conducted by Ishibashi and Kaneko (2008), who study quality and price competition between a welfare-maximising state-owned firm and a profit-maximising private firm in a Hotelling model. They find that, absent of any cost efficiency differences, the public firm chooses a lower quality than the private firm in equilibrium, which is similar to the quality ranking result in our paper for a sufficiently high regulated price. Furthermore, they show that social welfare is maximised if the public firm's objective is a weighted average of welfare and profits, thus indicating that partial privatisation of the state-owned firm would be welfare improving.

Common for all the above mentioned papers is that competition takes place in an unregulated setting, which is another key difference from the present paper, in which two of the three competing providers face regulated prices. In this respect, our paper is more closely related to papers that study quality competition in *regulated* mixed oligopolies, often applied to health care markets. An early study is Barros and Martinez-Giralt (2002) who analyse quality and price competition between a public and a private health care provider under different reimbursement rules. Sanjo (2009) and Herr (2011) also study quality competition between a public and a private health care provider, but under the assumption that prices for both providers are regulated. These studies are all conducted within a horizontal differentiation (Hotelling) framework.[5] More recent studies of mixed duopoly quality competition with fixed prices have addressed issues such as soft budgets (R. Levaggi & Montefiori, 2013), partial privatization policies (Chang, Wu, & Lin, 2018) and location choices (Hehenkamp & Kaarbøe, 2020). A broader review of the merits of mixed markets in health care, presented in a unified framework, is given by (L. Levaggi & Levaggi, 2020).

A similar type of study, using a Hotelling-type framework, but applied to the education sector, is Brunello and Rocco (2008), who analyse a mixed duopoly game between a public school choosing quality ('educational standard') and a private school choosing quality and price (tuition fee). As in the present paper, they find that the public agent can provide either the highest or the lowest quality in equilibrium. Overall, our paper can be seen as an extension of the above described literature on quality competition in regulated mixed oligopolies, where we include a richer set of provider types that differ not only in their objectives but also in terms of regulatory constraints.[6]

Finally, our paper is related to the literature on the relationship between competition and quality provision, which has become an increasingly prominent strand of the health economics literature in particular. The empirical evidence of this

[5] A similar study using instead a vertical differentiation framework is (Stenbacka & Tombak, 2018).

[6] Our paper is more directly an extension of Ghandour (2021) who studies quality competition in a mixed duopoly where the public provider is subject to price regulation while the private provider is not.

relationship in hospital markets with regulated prices is somewhat mixed, with both positive (e.g., Cooper et al. (2011), Gaynor et al. (2013)) and negative (e.g., (Moscelli, Gravelle, & Siciliani, 2021; Skellern, 2017)) effects being reported. This should probably not come as a surprise, though, given the ambiguous nature of the theoretical predictions (Brekke et al., 2011).

3.3 Model

Consider a market for a good (e.g., health care or education) that is supplied by three different providers that are equidistantly located on a circle with circumference equal to 1. Each of the three providers is of a different kind. Provider 1 is publicly owned, Provider 2 is a publicly funded private provider, whereas Provider 3 is a private provider without public funding. The two providers that are either publicly owned or publicly funded receive a fixed price $p_1 = p_2 = \overline{p}$ per unit of the good supplied. A fraction s of this price is paid by the consumers as copayment, whereas the remaining share is paid by a public funder. However, these two providers are assumed to differ with respect to their objectives. We follow the standard assumption in the mixed oligopoly literature that the public provider maximises social welfare while the private provider is a profit maximiser. The third provider also maximises profits, but has to raise revenues in the market by charging a price p_3 per unit of the good supplied.

Consumers are uniformly distributed on the same circle. Each consumer demands one unit of the good from the most preferred provider and the total mass of consumers is normalised to 1. The utility of a consumer located at x who buys the good from Provider i, located at z_i, is given by

$$u(x, z_i) = v + \beta q_i - r_i - t\,|x - z_i|\,;\; i = 1, 2, 3, \tag{3.3.1}$$

where q_i is the quality offered by Provider i and r_i is the price paid by Provider i's consumers. In line with our previously stated assumptions, $r_1 = r_2 = s\overline{p}$ and $r_3 = p_3$. The parameters $\beta > 0$ and $t > 0$ measure, respectively, the marginal willingness to pay for quality and the marginal transportation cost. The latter can be interpreted either as the marginal cost of travelling in geographical space or the marginal mismatch cost in product space. We also assume that the utility parameter $v > 0$ is sufficiently large to ensure full market coverage for all quality and price configurations.

Suppose that every consumer in the market makes a utility-maximising choice of provider. Let $\widehat{x}_i^{i+1}$ denote the distance between the location of Provider i and the location of the consumer who is indifferent between Provider i and the neighbouring Provider $i+1$. When each consumer maximises utility, this distance is given by

$$\widehat{x}_i^{i+1}\left(q_i, q_{i+1}; r_i, r_{i+1}\right) = \frac{1}{6} + \frac{\beta\left(q_i - q_{i+1}\right) - \left(r_i - r_{i+1}\right)}{2t}. \tag{3.3.2}$$

Since each provider has two neighbours, the demand for Provider i is given by

$$D_i\left(q_i, q_{i-1}, q_{i+1}; r_i, r_{i-1}, r_{i+1}\right) = \widehat{x}_i^{i+1}\left(q_i, q_{i+1}; r_i, r_{i+1}\right) + \widehat{x}_i^{i-1}\left(q_i, q_{i-1}; r_i, r_{i-1}\right). \qquad (3.3.3)$$

Substituting from (3.3.2), this yields

$$D_i\left(q_i, q_{i-1}, q_{i+1}; r_i, r_{i-1}, r_{i+1}\right) = \frac{1}{3} + \frac{\beta\left(2q_i - q_{i-1} - q_{i+1}\right) - \left(2r_i - r_{i-1} - r_{i+1}\right)}{2t} \qquad (3.3.4)$$

The Salop model is generally characterised by localised competition, implying that the demand of each provider only depends on the prices and qualities of that provider and its two neighbours. However, with only three providers, each provider has all the remaining providers in the market as neighbours. Thus, all providers compete directly with each other.

We assume that the cost of provision is separable in quantity and quality, with the cost function of Provider i given by

$$C\left(D_i, q_i\right) = cD_i + \frac{k}{2}q_i^2. \qquad (3.3.5)$$

The profits of Provider i are thus given by

$$\pi_i = \left(p_i - c\right)D_i - \frac{k}{2}q_i^2. \qquad (3.3.6)$$

Whereas the private providers (2 and 3) are assumed to maximise profits, the publicly owned provider is assumed to maximise social welfare, denoted W, which is given by aggregate consumer utility, denoted U, plus total profits, net of public funding:

$$W = U + \sum_{i=1}^{3}\pi_i - (1-s)\,\overline{p}\sum_{i=1}^{2}D_i. \qquad (3.3.7)$$

With a slight abuse of notation, aggregate consumer utility is given by[7]

$$U = \sum_{i=1}^{3}\left(\int_0^{\widehat{x}_i^{i+1}}\left(v + \beta q_i - r_i - tx\right)dx + \int_0^{\widehat{x}_i^{i-1}}\left(v + \beta q_i - r_i - tx\right)dx\right). \qquad (3.3.8)$$

Since total demand is fixed, which implies that social welfare does not depend directly on prices and other monetary

[7] Notice that, if $i = 1$, then $i - 1 = 3$, and if $i = 3$, then $i + 1 = 1$.

transfers, we can more conveniently reformulate the welfare expression as

$$W = v + \beta\overline{q} - T - c - \frac{k}{2}\sum_{i=1}^{3} q_i^2, \tag{3.3.9}$$

where

$$\overline{q} := \sum_{i=1}^{3} D_i q_i \tag{3.3.10}$$

is average quality and

$$T := \frac{t}{12} + \frac{\sum_{i=1}^{3} r_i (r_i - r_{i+1}) + \beta \left(\beta \sum_{i=1}^{3} q_i (q_i - q_{i+1}) + \sum_{i=1}^{3} q_i (r_{i-1} + r_{i+1}) - 2\sum_{i=1}^{3} q_i r_i\right)}{2t} \tag{3.3.11}$$

is aggregate transportation costs.[8] The last two terms in (3.3.9) represent the total cost of provision in the market. It is immediately obvious from (3.3.11) that aggregate transportation costs are minimised (at $T = t/12$) for a symmetric outcome, where $r_i = r_j$ and $q_i = q_j$, for all i and j, $i \neq j$.

Our subsequent analysis is based on different versions (or subgames) of the following three-stage game:

Stage 1 A welfare-maximising regulator chooses its policy parameter(s), either $\overline{p}$ (s) or both $\overline{p}$ and s.

Stage 2 Each of the three providers chooses its level of quality provision, q_i.

Stage 3 The private Provider 3 chooses its price, p_3.

The separation of Stage 2 from Stage 3 is motivated by the implicit assumption that the level of quality provision is more of a long-term decision than the price choice. Furthermore, in versions of the game where we include Stage 1, we implicitly assume that the regulator is able to precommit to a particular regulatory policy as a long-term decision. Finally, in order to ensure equilibrium existence in all versions of the game considered, we assume that the quality cost parameter k is bounded from below:[9]

$$k \geq \underline{k} := \frac{3\beta^2}{2t}. \tag{3.3.12}$$

In order to rule out a negative price-cost margin for the publicly funded private provider, we also assume that $\overline{p} \geq c$.

[8] Notice that subscripts $i+1$ and $i-1$ refer to the two neighours of Provider i located in the clockwise and anticlockwise direction, respectively. Keep also in mind that $r_1 = r_2 = s\overline{p}$ and $r_3 = p_3$.

[9] See appendix section 3.A for further details.

3.4 Analysis

In this section we derive and characterise the subgame-perfect Nash equilibrium. In particular, we are interested in comparing the equilibrium quality provision across the three different providers, and how this quality provision depends on the design of the funding scheme and on the degree of competition in the market. We start out by considering the subgame that starts at Stage 2 of the above described game, which allows us to analyse optimal provider behaviour under an exogenously given regulatory regime. This is arguably the most realistic scenario, given that prices and copayment rates might be based on considerations that lie outside the scope of the present model. However, we will subsequently introduce Stage 1 to the game and analyse the optimal choice of regulated price for a given copayment rate, before endogenising both policy variables ($\overline{p}$ and s) and derive the subgame-perfect Nash equilibrium of the full game.

3.4.1 Fixed price and copayment

Suppose that the publicly funded providers face an exogenous price, $\overline{p}$, and an exogenously given copayment rate, s. The game is solved by backwards induction, so we start out by considering the optimal price chosen by Provider 3.

3.4.1.1 Optimal private price

At the third stage, the private provider without public funding chooses a price that maximises the provider's profits. By maximising π_3, as given by (3.3.6), with respect to p_3, we find that the profit-maximising price is given by[10]

$$p_3\left(q_1, q_2, q_3; s, \overline{p}\right) = \frac{t}{6} + \frac{c + s\overline{p}}{2} - \beta\left(\frac{q_1 + q_2}{4}\right) + \frac{\beta q_3}{2}. \tag{3.4.1}$$

We see that the optimal price of the private provider is decreasing in the quality levels of each of the two rival providers (q_1 and q_2). A higher quality by a rival provider leads to a drop in demand, which makes demand more price elastic, all else equal. This reduces in turn the profit-maximising price. Thus, the price of the private provider is a *strategic substitute* to the quality of a rival provider.

On the other hand, the optimal price of the private provider is increasing in the provider's own quality (q_3). All else equal, a higher quality provision leads to higher demand, which makes demand less price elastic. Consequently, the profit-maximising price increases. In other words, price and quality are *complementary strategies* for the private provider.

[10] The second-order condition is trivially satisfied, since $\partial^2\pi_3/\partial p_3^2 = -2/t < 0$.

Finally, notice that Provider 3's optimal price is increasing in both the regulated price ($\overline{p}$) and the copayment rate (s). This is due to prices being *strategic complements* for given quality levels. A higher $\overline{p}$ or a higher s implies, all else equal, that the good supplied by either of the publicly funded providers becomes more expensive for consumers. This leads to higher, and thus less price-elastic, demand for Provider 3, who optimally responds by increasing the price.

3.4.1.2 Quality competition

Anticipating the price choice of Provider 3, all providers simultaneously and independently choose qualities in order to maximise their objective functions. It is instructive to carefully study the nature of the strategic interaction between the different providers. Maximising (3.3.6)-(3.3.7) with respect to q_i, the best response functions are given by[11]

$$q_1(q_2, q_3) = \beta \frac{2(c - s\overline{p}) + 6t - 3\beta(3q_2 + 2q_3)}{16kt - 15\beta^2}, \tag{3.4.2}$$

$$q_2 = \frac{7\beta(\overline{p} - c)}{8kt}, \tag{3.4.3}$$

$$q_3(q_1, q_2) = \beta \frac{2t + 6(s\overline{p} - c) - 3\beta(q_1 + q_2)}{6(2kt - \beta^2)}. \tag{3.4.4}$$

For each provider, the optimal quality level balances marginal benefits against marginal costs. Whereas the marginal cost of quality provision is by assumption equal for all providers, and given by kq_i, the marginal benefits are not.

Consider first the two profit-maximising providers. The marginal revenue of quality provision for the publicly funded provider (Provider 2) is given by

$$(\overline{p} - c)\left(\frac{\partial D_2}{\partial q_2} + \frac{\partial D_2}{\partial p_3}\frac{\partial p_3}{\partial q_2}\right) = (\overline{p} - c)\left(\frac{\beta}{t} - \frac{\beta}{8t}\right). \tag{3.4.5}$$

The profitability of quality provision depends on the size of the price-cost margin ($\overline{p} - c$) and on the quality responsiveness of demand. All else equal, a higher price-cost margin and/or a more quality responsive demand will increase the incentives for quality provision. However, notice that a quality increase by Provider 2 has a direct and an indirect effect on the provider's demand. The positive direct effect is counteracted by the fact that a quality increase triggers a price reduction by the competing private provider (Provider 3) in the subsequent stage. This indirect effect dampens the incentives for quality provision by Provider 2, all else equal. However, because of the linearity of the demand function, neither the direct nor the indirect effect of quality on demand depends on the quality levels chosen by the competing

[11] The second-order and stabilitiy conditions are satisfied, as shown in appendix section 3.A.

providers. Thus, q_2 is strategically independent of the rivals' qualities.

Consider next the private Provider 3. The marginal revenue of quality for this provider is given by

$$(p_3 - c)\left(\frac{\partial D_3}{\partial q_3} + \frac{\partial D_3}{\partial p_3}\frac{\partial p_3}{\partial q_3}\right) + \frac{\partial p_3}{\partial q_3}D_3 = (p_3 - c)\left(\frac{\beta}{t} - \frac{\beta}{2t}\right) + \frac{\beta}{2}D_3. \tag{3.4.6}$$

The difference between the two private providers is that Provider 3 chooses its price, p_3. The resulting effect on the incentives for quality provision is captured by the last term in (3.4.6). Since price and quality are complementary strategies for the provider, a higher quality level will have an additional positive effect on revenues through a higher price. Notice, however, that the magnitude of this effect depends on Provider 3's demand (D_3), which is decreasing in the quality levels of the provider's rivals (q_1 and q_2). All else equal, a higher quality level by Provider 1 or Provider 2 will reduce the demand of Provider 3, which in turn reduces the latter provider's revenue gain of a higher price, with a corresponding reduction in the provider's incentives for quality provision. Thus, the quality decision of Provider 3 is a *strategic substitute* to the qualities chosen by the provider's rivals. Notice also that the optimal quality level chosen by Provider 3 is increasing in the regulated price $\overline{p}$. The reason is that a higher regulated price increases the optimal price chosen by Provider 3 in the last stage of the game, all else equal, which in turn increases the profitability of quality provision for this provider at the previous stage.

Finally, consider the public provider, which by assumption maximises social welfare. Using (3.3.9), the marginal benefit of quality for the public provider is given by

$$\beta\left(\frac{\partial \overline{q}}{\partial q_1} + \frac{\partial \overline{q}}{\partial p_3}\frac{\partial p_3}{\partial q_1}\right) - \left(\frac{\partial T}{\partial q_1} + \frac{\partial T}{\partial p_3}\frac{\partial p_3}{\partial q_1}\right). \tag{3.4.7}$$

Once more, the marginal benefit is a sum of direct and indirect effects. Consider first the *direct* effect of higher quality provision by the public provider, which is given by

$$\beta\frac{\partial \overline{q}}{\partial q_1} - \frac{\partial T}{\partial q_1}. \tag{3.4.8}$$

The first term is unambiguously positive, since a unilateral increase in the quality provision of the public provider increases average quality in the market. However, the sign of the second term is *a priori* indeterminate and depends on relative market shares, which in turn depend on the distribution of qualities and consumer prices across the three providers. Generally, a higher quality provision by the public provider increases (reduces) aggregate transportation costs if it leads to a more (less) asymmetric distribution of market shares.

Using the definitions of $\overline{q}$ and T, we derive

$$\frac{\partial \overline{q}}{\partial q_1} = D_1 + \frac{\beta}{2t}(2q_1 - q_2 - q_3) > 0 \tag{3.4.9}$$

and

$$\frac{\partial T}{\partial q_1} = \beta \frac{p_3 - s\overline{p} + \beta(2q_1 - q_2 - q_3)}{2t} \gtrless 0, \tag{3.4.10}$$

where p_3 is given by (3.4.1). A higher quality by rival providers (i.e, an increase in q_2 or q_3) implies that the public provider has a lower market share, which in turn reduces the effect of q_1 on average quality. On the other hand, a lower market share for the public provider increases the scope for a negative sign of $\partial T/\partial q_1$, which implies that aggregate transportation costs can be reduced by an increase in q_1. A similar ambiguity applies to the regulated price, $\overline{p}$. As long as $s > 0$, a lower price $\overline{p}$ increases the market share of the public provider, thus making q_1 a more effective instrument to increase average quality provision. On the other hand, the scope for a detrimental effect of a quality increase on aggregate transportation costs also increases. Summing these two potentially counteracting effects, we obtain

$$\beta\frac{\partial \overline{q}}{\partial q_1} - \frac{\partial T}{\partial q_1} = \beta\left(\frac{1}{3} + \frac{\beta(2q_1 - q_2 - q_3)}{2t}\right). \tag{3.4.11}$$

We see that the sum of the two effects does not depend on the regulated price, which implies that the two counteracting effects of a price change exactly cancel each other. On the other hand, the direct marginal benefit of quality depends negatively on rivals' qualities, implying that the above described effect related to average quality dominates.

In order to explain how the public provider's quality provision depends on the regulated price $\overline{p}$, we need to turn to the effects that work through subsequent changes in the private price p_3. The effects of p_3 on average quality and aggregate transportation costs are given by, respectively,

$$\frac{\partial \overline{q}}{\partial p_3} = \frac{q_1 + q_2 - 2q_3}{2t} \tag{3.4.12}$$

and

$$\frac{\partial T}{\partial p_3} = \frac{2(p_3 - s\overline{p}) + \beta(q_1 + q_2 - 2q_3)}{2t}. \tag{3.4.13}$$

The *indirect* marginal benefit of quality provision by the public provider is thus given by

$$\left(\beta\frac{\partial \overline{q}}{\partial p_3} - \frac{\partial T}{\partial p_3}\right)\frac{\partial p_3}{\partial q_1} = \left(\frac{s\overline{p} - p_3}{t}\right)\frac{\partial p_3}{\partial q_1}, \tag{3.4.14}$$

where p_3 is given by (3.4.1), and where $\partial p_3/\partial q_1 = -\beta/4$. Thus, the public provider's incentive for quality provision in order to induce a desired change in p_3 depends *negatively* on $s\overline{p}$, and the intuition for this follows directly from (3.4.13).[12] A lower value of $s\overline{p}$ reduces the market share of Provider 3, which turn increases the scope for a reduction in aggregate transportation costs as a result of a decrease in p_3. And a reduction in p_3 can be induced by higher public quality provision.

The above decomposition of direct and indirect effects explains why the public provider's optimal choice of quality depends negatively on q_2, q_3 and $s\overline{p}$. A higher quality by any of the rival providers leads to a reduction in the market share of the public provider, which implies that q_1 becomes a less effective instrument to increase average quality. Consequently, the optimal quality level of the public provider goes down. A quality reduction by the public provider also results from an increase in $s\overline{p}$, but for a different reason, which is related to the objective of reducing aggregate transportation costs by inducing a change in the price set by the private Provider 3, as explained above.

If the subgame perfect Nash Equilibrium is an interior solution, the equilibrium outcome is given by

$$q_1^* = \beta \frac{\beta^2 \left(42\beta^2 \left(\overline{p} - c\right) + kt \left(79c - 63\overline{p}\right)\right) + 16kt \left(kt \left(c + 3t - s\overline{p}\right) - \beta^2 \left(2t + s\overline{p}\right)\right)}{8kt \left(kt \left(16kt - 23\beta^2\right) + 6\beta^4\right)}, \quad (3.4.15)$$

$$q_2^* = \frac{7\beta \left(\overline{p} - c\right)}{8kt}, \quad (3.4.16)$$

$$q_3^* = \beta \frac{21\beta^2 \left(3\beta^2 \left(\overline{p} - c\right) + 2kt \left(3c - \overline{p}\right)\right) + 4kt \left(8kt \left(t - 3c + 3s\overline{p}\right) - 3\beta^2 \left(4t + 7s\overline{p}\right)\right)}{12kt \left(kt \left(16kt - 23\beta^2\right) + 6\beta^4\right)}, \quad (3.4.17)$$

$$p_3^* = \frac{\left(2kt - 3\beta^2\right)\left(16kt^2 + 3c\left(16kt - \beta^2\right) - 21\beta^2\overline{p}\right) + 12ks\overline{p}t\left(8kt - 7\beta^2\right)}{12\left(kt\left(16kt - 23\beta^2\right) + 6\beta^4\right)}. \quad (3.4.18)$$

In the following, we perform a thorough characterisation of the equilibrium and show how the equilibrium quality provision depends on the characteristics of the funding scheme and on the intensity of competition, as inversely measured by the parameter t.

3.4.1.3 The relationship between the funding scheme and equilibrium quality provision

In our model, the funding scheme consists of two elements: the regulated price ($\overline{p}$) and the copayment rate (s). In the following, we analyse the effects of a change in each of these instruments on the equilibrium quality provision.

[12] Although p_3 depends positively on $s\overline{p}$, it is straightforward to verify, by using (3.4.1), that $s\overline{p} - p_3$ is monotonically increasing in $s\overline{p}$.

The effects of a change in the regulated price $\overline{p}$ are given as follows:[13]

Proposition 3.1. *A higher regulated price $\overline{p}$ leads to*

(i) lower quality for the public provider,

(ii) higher quality for the publicly funded private provider,

(iii) lower (higher) quality for the private provider without public funding if the copayment rate s is sufficiently low (high).

The intuition for these results is directly linked to the nature of the strategic interaction in the quality game. Notice that the two publicly funded providers respond to changes in the regulated price in a completely opposite fashion, which is caused by the assumed differences in the objective functions. The profit-maximising provider (Provider 2) responds to a higher price by increasing quality, because a higher price-cost margin makes it more profitable to attract demand by providing a higher quality level. For the publicly owned provider, on the other hand, such a concern is irrelevant because of the assumption that the provider is a welfare maximiser. On the contrary, a higher regulated price gives this provider an incentive to *reduce* its quality in order to induce a price increase by the private Provider 3, with the objective of reducing aggregate transportation costs through a more equal distribution of market shares.[14]

Finally, for the private provider without public funding, the effect of a higher regulated price on quality provision depends crucially on the magnitude of the copayment rate that applies to the publicly funded providers. If the copayment rate is sufficiently low (high), the provider will respond to a higher regulated price by reducing (increasing) quality provision. In order to understand this result, notice that the mechanisms through which a change in the regulated price affects quality provision are very different for the two private providers. Whereas the regulated price directly determines the price-cost margin of Provider 2, the effect on Provider 3 goes through demand. If the copayment rate is sufficiently low, a higher regulated price will shift demand from Provider 3 to Provider 2 because of the increase in quality offered by the latter provider.[15] This makes Provider 3's demand more price elastic and the provider will therefore respond by reducing both price and quality. However, a higher copayment rate will dampen (and might ultimately reverse) the demand shift from Provider 3 to Provider 2 due to a higher regulated price, because of a larger increase in the consumer copayment. Thus, if the copayment rate is sufficiently high, a higher regulated price will *increase* the demand of Provider 3 and therefore lead to a higher price and quality offered by this provider.

[13] The proof of this an all subsequent propositions (apart from those that are trivially proved) are given in appendix section 3.B.

[14] More precisely, a higher regulated price will either *dampen* the public provider's incentive to reduce aggregate transportation costs by offering *higher* quality, or it will *reinforce* the provider's incentive to reduce aggregate transportation costs by *lowering* its quality provision. In either case, a higher regulated price results in lower public quality provision, all else equal.

[15] A higher price will also reduce the quality provision of Provider 1, but this effect is not large enough to prevent a demand loss for Provider 3.

In sum, a higher regulated price has a strongly heterogeneous effect on quality provision across the different providers, with a negative effect for the publicly owned provider, a positive effect for the publicly funded private provider, and an *a priori* ambiguous effect for the private provider without public funding. It might therefore be useful to consider the effect on *average* quality, $\overline{q}$, as defined by (3.3.10). On general form, the effect of a marginal increase in the regulated price on average quality is given by

$$\frac{\partial \overline{q}}{\partial \overline{p}} = \sum_{i=1}^{3} \left(\frac{\partial q_i^*}{\partial \overline{p}} D_i + q_i^* \frac{\partial D_i}{\partial \overline{p}} \right). \tag{3.4.19}$$

Proposition 3.2. *(i) Suppose that s is sufficiently close to either zero or one. In this case, $\partial \overline{q} / \partial \overline{p} > 0$ for all $k > \underline{k}$ if $(\overline{p} - c)$ is sufficiently high relative to t. (ii) Suppose that k is sufficiently close to $\underline{k}$. In this case, $\partial \overline{q} / \partial \overline{p} < 0$ for all $s \in [0, 1]$ if $(\overline{p} - c)$ is sufficiently small or if t is sufficiently high.*

Unsurprisingly, given the heterogeneous results presented in Proposition 3.1, the relationship between the size of the regulated price and average quality provision is *a priori* ambiguous. In Proposition 3.2 we have identified different parameter sets for which this relationship is either positive or negative. The characteristics of these parameter sets suggest that the scope for a *positive* effect of a price increase on average quality provision is larger if the regulated price is relatively high to begin with, and if the intensity of competition is also relatively high (i.e, if t is relatively low), which magnifies the demand responses to changes in prices and qualities. In such a scenario, if the copayment rate is sufficiently small, a higher regulated price leads to a higher average quality because of the quality increase by Provider 2, whereas, if the copayment rate is sufficiently large, a similar effect is enabled by the quality increase by Provider 3.

The effects of a change in the copayment rate s are summarised below:

Proposition 3.3. *A higher copayment rate s leads to*

(i) lower quality for the public provider,

(ii) no change in the quality of the publicly funded private provider,

(iii) higher quality for the private provider without public funding.

A higher copayment rate implies that the good supplied by either of the publicly funded providers become more expensive for consumers. But this has no effect on the quality offered by the publicly funded private provider. Notice that Provider 2 maximises profits and a higher copayment rate does not influence the profit margin, nor does it influence the demand responsiveness to quality. In other words, both the marginal benefit and the marginal cost of quality provision for Provider 2 are unaffected by the copayment rate.

The incentives are different for the welfare-maximising public provider. Since a higher copayment rate reduces the market share of the public provider, this reduces the effect of the public provider's quality on average quality (cf. (3.4.9)), which all else equal gives Provider 1 an incentive to reduce its quality provision.

Since a higher s leads to lower quality of the public provider, the private provider without public funding experiences higher, and thus less price-elastic, demand. This, in turn, gives the private Provider 3 an incentive to increase the price and therefore also leads to higher quality (because price and quality are complementary strategies).

Therefore, in our model, each provider responds differently to a higher copayment rate, with a negative effect for the publicly owned provider, a positive effect for the private provider without public funding, and no effect for the publicly funded private provider. Thus, it is important to assess the effect of the copayment rate s on *average* quality $\overline{q}$, which is generally given by

$$\frac{\partial \overline{q}}{\partial s} = \sum_{i=1}^{3} \left(\frac{\partial q_i^*}{\partial s} D_i + q_i^* \frac{\partial D_i}{\partial s} \right). \tag{3.4.20}$$

Proposition 3.4. *Suppose that the regulated price is not very high nor very low. In this case, there exists a threshold value* $\widehat{s} \in (0,1)$ *such that* $\partial \overline{q}/\partial s < (>) 0$ *if* $s < (>) \, \widehat{s}$.

Not surprisingly, given the results in Proposition 3.3, the relationship between the copayment rate and average quality provision is *a priori* ambiguous. However, for a large set of parameter values, we are able to establish a convex relationship between the copayment rate and average quality, where a marginal increase in the copayment rate leads to a reduction (increase) in average quality if the initial level of the copayment rate is sufficiently low (high). In other words, average quality is minimised for an intermediate degree of consumer copayment.

This convex relationship has a relatively intuitive explanation. Notice first that a change in the copayment rate affects average quality directly through an increase (decrease) in the quality of Provider 1 (Provider 3). In addition, there is an indirect effect through demand reallocation from Provider 1 to Provider 3. Since a higher copayment rate leads to lower (higher) quality for Provider 1 (Provider 3), this demand reallocation is more likely to contribute to higher average quality the higher the copayment rate is to begin with.

3.4.1.4 Equilibrium quality ranking

We proceed to identify the characteristics of the market that can explain the distribution of the quality provision across the different providers. For this purpose, it is convenient to define three different threshold values of the regulated price:

$$p^* := \frac{32t\,(2kt - 3\beta^2) + 3c\,(48kt - 77\beta^2)}{21\,(16kt - 19\beta^2) + 24s\,(7\beta^2 - 8kt)}, \tag{3.4.21}$$

$$p^{**} := \frac{8t\left(3kt - 2\beta^2\right) + c\left(64kt - 41\beta^2\right)}{7\left(8kt - 7\beta^2\right) + 8s\left(\beta^2 + kt\right)}, \tag{3.4.22}$$

$$p^{***} := \frac{16kt^2 + 3c\left(16kt - \beta^2\right)}{3\left(7\beta^2 + 8s\left(2kt - \beta^2\right)\right)}. \tag{3.4.23}$$

Using these definitions, we are able to state the following:[16]

Proposition 3.5. *(i) Suppose that* $s < \frac{21c+7t}{21c+8t}$*, which implies* $p^* < p^{**} < p^{***}$*. The equilibrium quality ranking is then given by*

$$\begin{aligned}
q_1^* > q_3^* > q_2^* \quad if \quad \overline{p} < p^*, \\
q_1^* > q_2^* > q_3^* \quad if \quad p^* < \overline{p} < p^{**}, \\
q_2^* > q_1^* > q_3^* \quad if \quad p^{**} < \overline{p} < p^{***}, \\
q_2^* > q_3^* > q_1^* \quad if \quad \overline{p} > p^{***}.
\end{aligned}$$

(ii) Suppose that $s > \frac{21c+7t}{21c+8t}$*, which implies* $p^{***} < p^{**} < p^*$*. The equilibrium quality ranking is then given by*

$$\begin{aligned}
q_1^* > q_3^* > q_2^* \quad if \quad \overline{p} < p^{***}, \\
q_3^* > q_1^* > q_2^* \quad if \quad p^{***} < \overline{p} < p^{**}, \\
q_3^* > q_2^* > q_1^* \quad if \quad p^{**} < \overline{p} < p^*, \\
q_2^* > q_3^* > q_1^* \quad if \quad \overline{p} > p^*.
\end{aligned}$$

(iii) If $s = \frac{21c+7t}{21c+8t}$*, which implies* $p^{***} = p^{**} = p^*$*, then* $q_1^* = q_2^* = q_3^*$*.*

Although any possible ranking of quality levels across the three providers can arise in equilibrium, the above proposition nevertheless reveals some clear patterns, which can be described as follows:

Corollary 3.1. *(i) If the regulated price* $\overline{p}$ *is sufficiently low (high), the publicly funded private provider offers the lowest (highest) quality and the publicly owned provider offers the highest (lowest) quality. (ii) The private provider without public funding offers the highest quality in the market only if the copayment rate* (s) *is sufficiently close to 1.*

These patterns are explained by looking at the results derived in Propositions 3.1 and 3.3. The quality of the public provider is decreasing in the regulated price and copayment rate while the quality of the publicly funded private

[16]The proof of this proposition relies on a straightforward comparison of equilibrium expressions and is therefore omitted.

provider is only increasing in $\overline{p}$. This explains why Provider 1 offers higher quality than Provider 2 if the regulated price is sufficiently low, and *vice versa* if the regulated price is sufficiently high.

For the private provider without public funding, we have seen from Proposition 3.1 that the relationship between the regulated price and equilibrium quality provision for this provider depends crucially on the size of the copayment rate s. The quality provision of Provider 3 is increasing in $\overline{p}$ only if s is sufficiently high, which explains why the private provider without public funding might offer the highest quality in the market only if both $\overline{p}$ and s are sufficiently high.

3.4.1.5 Competition intensity and quality provision

In spatial competition models, a standard competition measure is the (inverse of) transportation costs. Lower transportation costs increase the degree of substitutability between the goods offered by different providers, which intensifies competition. In our model, the publicly funded providers only choose their qualities for a given regulated price. On the contrary, the private provider without public funding chooses both quality and price. Hence, more competition makes demand more responsive to changes in qualities and prices.

Generally, more competition has two countering effects on quality. The direct effect is that increased competition makes demand more responsive to a marginal increase in quality for given prices. However, if prices are endogenous there is also an indirect effect due to the fact that increased competition makes consumers more responsive to price changes, which all else equal leads to lower prices and thus reduces providers' marginal return to quality investments. This indirect effect counteracts the aforementioned direct effect and makes the relationship between competition and quality provision *a priori ambiguous* for the private provider without public funding.

Proposition 3.6. *More competition (lower t) has the following effects on the quality provision of each provider:*

(i) The public provider increases (decreases) quality if $\overline{p}$ is sufficiently low (high).

(ii) The publicly funded private provider increases quality.

(iii) If the regulated price is not very high nor very low, there exists a threshold value $\widetilde{s} \in (0, 1)$ such that the private provider without public funding reduces (increases) quality if $s < (>)\, \widetilde{s}$.

For the private provider with public funding, the effect of more competition is unambiguous and standard. Lower transportation costs make the provider's demand more responsive to quality changes and, given a positive price-cost margin, the provider increases its quality provision in order to attract more demand.

For the two other providers, though, increased competition has an ambiguous effect on the incentives for quality provision. We find that the public provider has an incentive to increase (decrease) its quality provision in response to more competition if the regulated price is sufficiently low (high). In order to explain the intuition behind this result, we focus on the public provider's incentive to use its quality provision as an instrument to increase average quality in the market. The effectiveness of this instrument depends on relative market shares. More specifically, the larger the market share of the public provider, the larger is the effect of an increase in the provider's quality on average quality in the market. More competition (lower t) makes demand more quality and price elastic. In an asymmetric equilibrium (with quality and price differences), more competition therefore leads to a reallocation of demand towards providers with higher quality and/or lower price. If $\overline{p}$ is sufficiently low (high), the public provider is the high (low) quality provider in the market (cf. Proposition 3.5). Therefore, for a sufficiently low $\overline{p}$, increased competition leads to an inflow of consumers towards the public provider, which, in turn, expands its market share (higher D_1). This makes q_1 a more effective instrument to increase average quality, resulting in stronger incentives for quality provision by the public provider. The reverse result (i.e., $\partial q_1/\partial t > 0$) requires that $\overline{p}$ is sufficiently high.

For the private provider without public funding, there are two main channels through which more competition affects the provider's incentives for quality investments. The first channel is a strategic response to the other private provider. A reduction in t triggers a quality increase by Provider 2, which in turn leads to lower, and thus more price-elastic, demand for Provider 3, who optimally responds by decreasing the price. This reduces the profitability of quality provision for Provider 3 and leads to lower quality (because p_3 and q_3 are complementary strategies). On the other hand, competition leads to a demand reallocation, which depends on relative quality levels, as previously explained. The higher s is, the higher is the equilibrium quality provision of Provider 3 relative to the other providers (cf. Proposition 3.3). Thus, for a sufficiently high s, increased competition leads to a demand reallocation towards Provider 3, who experiences higher, and thus less price-elastic, demand. This gives Provider 3 an incentive to increase the price and in turn quality, thus counteracting the effect of the aforementioned strategic response to the other private provider. If s is sufficiently high, the effect working through demand reallocation is the dominating effect, leading to an overall increase in quality provision by Provider 3. On the other hand, if s is sufficiently low, the effect of demand reallocation reinforces the strategic response effect, leading to a reduction in q_3.

In sum, the relationship between competition and quality provision for Provider 2 is positive, while it has an indeterminate sign for the two other providers. Therefore, it is *a priori* not clear whether the effect of more competition on *average* quality, $\overline{q}$, is positive or negative. While it is not possible to determine the sign of this effect analytically, numerical simulations suggest that the effect of more competition (a reduction in t) on average quality provision is unambiguously positive, implying that the increase in quality provision by the publicly funded private provider is always sufficient to outweigh any quality reduction by the other providers.

3.4.2 Optimal price for a given copayment rate

We now turn to the normative part of our analysis. Suppose that the copayment rate is exogenously given, but that the public payer, at an initial stage of the game, chooses a welfare-maximising price for the two publicly funded providers.[17] Given the equilibrium outcomes in (3.4.15)-(3.4.18), we maximise the welfare function in (3.3.7) with respect to $\overline{p}$ for a given copayment rate to find the optimal price level, given by[18]

$$\overline{p}(s) = \frac{8kst(\beta^2 + 16kt)(kt - \beta^2)(16kt^2 + 3c(16kt - \beta^2)) + \Lambda}{3\Delta}, \tag{3.4.24}$$

where

$$\begin{aligned}\Lambda := {} & 56t\beta^2\left(12\beta^4\left(17kt - 3\beta^2\right) + k^2t^2\left(144kt - 311\beta^2\right)\right) \\ & + 21c\beta^2\left(\beta^4\left(1427kt - 252\beta^2\right) + 16k^2t^2\left(64kt - 137\beta^2\right)\right)\end{aligned} \tag{3.4.25}$$

and

$$\begin{aligned}\Delta := {} & 16kst\left(kt - \beta^2\right)\left(\beta^2 + 16kt\right)\left(7\beta^2 + 4s\left(2kt - \beta^2\right)\right) \\ & + 49\beta^2\left(8k^2t^2\left(16kt - 37\beta^2\right) + \beta^4\left(205kt - 36\beta^2\right)\right).\end{aligned} \tag{3.4.26}$$

The relationship between the copayment rate and the welfare-maximising price can be described as follows:

Proposition 3.7. *A marginal increase in the copayment rate, s, leads to an increase (decrease) in the optimal price, $\overline{p}(s)$, if the copayment rate is initially sufficiently low (high).*

In other words, there is a positive relationship between the price and the copayment rate if the copayment rate is sufficiently low, while this relationship is negative for sufficiently high values of the copayment rate. In order to trace the intuition behind this result, notice that social welfare is maximised at a price which balances marginal social (net) benefit of improved quality against marginal costs, which implies that quality can be either underprovided or overprovided from a social welfare perspective. Whereas the marginal cost of quality is by assumption equal for all providers, the marginal benefits are not. On the one hand, if s is relatively low to begin with, we know that average quality decreases in response to a higher copayment rate due to the convex relationship established by Proposition 3.4. Thus, if s increases from a

[17] We can think of this scenario as the level of the copayment rate being set to satisfy considerations that are not explicitly modelled in our framework. For example, the copayment rate might be set at a relatively low level to ensure broad access to the good offered by the two publicly funded providers.

[18] The assumption in (3.3.12) ensures that the second-order condition of the welfare-maximising problem is satisfied (see appendix section 3.A for details).

sufficiently low initial value, the regulator would like to *stimulate* quality provision, and this can be done by increasing the price, as indicated by the first part of Proposition 3.2. On the other hand, for a sufficiently high initial value of s, the effect of a further increase in the copayment rate on average quality is positive (cf. Proposition 3.4). In this case, the regulator would like to *dampen* incentives for quality provision, which can be achieved by lowering the price (once more, given the result in the first part of Proposition 3.2).

As in the previous section, we proceed by ranking the equilibrium quality levels across the three providers, but now setting the regulated price at the welfare-maximising level. In other words, we compare the equilibrium quality across providers given the welfare-maximising price level, $\overline{p}(s)$, which produces the following ranking:[19]

Proposition 3.8. *Suppose that the regulated price is set at the welfare-maximising level, given by (3.4.24). In this case,*

(i) if $s < \frac{21c+7t}{21c+8t}$*, the equilibrium quality ranking is given by*

$$q_2^*(s) > q_1^*(s) > q_3^*(s);$$

(ii) if $s > \frac{21c+7t}{21c+8t}$*, the equilibrium quality ranking is given by*

$$q_3^*(s) > q_1^*(s) > q_2^*(s).$$

For any given copayment rate, the quality offered by the public provider always lies between the qualities offered by the high-quality and low-quality providers, respectively. The highest and lowest quality in the market is always offered by a private provider. Unless the copayment rate is very close to one, the publicly funded private provider has the highest quality, whereas the private provider without public funding has the lowest quality in the market, but these roles are reversed if the copayment rate is sufficiently close to one. Notice that the two regimes detailed in Proposition 3.8 correspond to two of the several regimes detailed in Proposition 3.5 and the intuition behind this quality ranking mirrors the one discussed in relation to Proposition 3.5.

3.4.3 Optimal price and copayment rate

Finally, suppose that, at an initial stage of the game, the public payer chooses both the copayment rate and the price (applying to the publicly funded providers) in order to maximise social welfare. We start out by deriving the first-best solution and subsequently show how this solution can be implemented by optimal choices of the price and the

[19]The proof of this proposition relies on a straightforward comparison of equilibrium expressions and is therefore omitted.

copayment rate.

3.4.3.1 The first-best solution

Suppose that the regulator is able to control quality and demand directly. Given the symmetry of the model, transportation costs are clearly minimised if each consumer attends the nearest provider, implying equal market shares for all providers. Maximising (3.3.9) with respect to the quality of each provider under this symmetry assumption, the first-best quality level – equal for each provider – is found to be given by

$$q_i^{FB} = \frac{\beta}{3k}. \tag{3.4.27}$$

Intuitively, the first-best quality level is increasing in the consumers' marginal willingness to pay for quality (β) and decreasing in the marginal cost of quality provision (captured by k).

3.4.3.2 Implementation of the first-best solution

Suppose that the regulator cannot set quality directly, but is able to commit to a particular funding scheme as a long term decision. In other words, we let the regulator set both the price and the copayment rate at the first stage of the game. Formally, the regulator maximises (3.3.9) with respect to $\overline{p}$ and s. The unique solution to this problem is stated in the next proposition:

Proposition 3.9. *If the regulator can commit to a funding scheme before the providers make their decisions, the first-best solution is implemented by setting the price*

$$\overline{p}^* = c + \frac{8}{21}t \tag{3.4.28}$$

and the copayment rate

$$s^* = \frac{21c + 7t}{21c + 8t}. \tag{3.4.29}$$

The proof of this proposition is left to the interested reader, who can easily verify that the first-best solution is implemented by plugging (3.4.28)-(3.4.29) into (3.4.15)-(3.4.18).

Social welfare is maximised by considering two different dimensions: minimising total transportation costs and ensuring quality provision at a level where the marginal benefit is equal to the marginal cost. Because of the two-dimensionality of the problem, two different instruments are needed to implement the first-best solution. More specifically, the reguator needs one instrument to ensure symmetric quality provision across the three providers, and another instrument to ensure that this quality provision is at the first-best level.[20] Consequently, the implementation of the first-best solution implies some degree of cost-sharing between consumers and the public funder (i.e., $s^* < 1$).

3.5 Extension: Public funding coverage

In this section we extend our analysis by introducing another policy variable, namely the degree of public funding coverage among the providers in the market. Taking the above analysis as a benchmark, we consider the effects (on quality provision and welfare) of (i) extending public funding to include the third (private) provider, or (ii) restricting public funding only to the publicly owned provider.

3.5.1 Public funding of all private providers

Suppose that all providers in the market, whether they are public or private, are subject to the same funding scheme. This amounts to setting $p_3 = \overline{p}$ and $r_3 = s\overline{p}$, which implies complete symmetry between the two private providers (2 and 3). It also implies that all providers now only compete along the quality dimension. The Nash equilibrium at the second stage of the game (described in Section 2) is in this case given by[21]

$$q_1^{PF} = \frac{\beta \left(kt^2 - 3\beta^2 \left(\overline{p} - c\right)\right)}{3kt \left(kt - \beta^2\right)}, \tag{3.5.1}$$

$$q_2^{PF} = q_3^{PF} = \frac{\beta \left(\overline{p} - c\right)}{kt}. \tag{3.5.2}$$

The quality of the public provider is decreasing in the regulated price $\overline{p}$ whereas the quality of publicly funded private providers is increasing in $\overline{p}$. In addition, it follows immediately that more competition (lower t) leads unambiguously to higher quality for the private providers, whereas the relationship between the degree of competition and quality of the public provider is *a priori* indeterminate and depends on the size of the regulated price. In particular, if $\overline{p} - c$ is sufficiently high (low) relative to t, more competition leads to lower (higher) quality. All these results mirror the previously derived results for Provider 1 and Provider 2 in the benchmark model.

What are the effects on equilibrium quality provision of extending the public funding coverage? If copayment rates are relatively low, which is arguably the most relevant case, we are able to state the following results:

[20] The result in Proposition 3.9 relies on the assumption that the cost of quality provision is equal across the three providers. With cost asymmetries, a richer set of instruments would be needed to implement the first-best solution.

[21] The second-order conditions are reported in appendix section 3.A.

Proposition 3.10. *Suppose that s is sufficiently low and that $\overline{p}-c$ is sufficiently high relative to t. In this case, an extension of public funding to all private providers leads to lower quality provision by the public provider ($q_1^{PF} < q_1^*$) and higher quality provision by both private providers ($q_2^{PF} > q_2^*$ and $q_3^{PF} > q_3^*$).*

Thus, within the range of parameters considered, a public funding extension tends to stimulate quality provision for both private providers while lowering quality provision for the public provider. As long as the incentives for quality provision among the private providers are sufficiently strong (i.e., as long as $\overline{p}-c$ is sufficiently large relative to t), a public funding extension induces higher quality for these providers. However, since the quality choice of the public provider is a strategic substitute to the quality choices made by the private providers (see analysis and discussion in Section 3.1.3), the former provider will respond by reducing its quality provision.

Since public and private providers respond differently to a public funding extension, the implication for average quality provision is *a priori* indeterminate. Numerical simulations suggest that average quality tends to increase if the regulated price is sufficiently high and decrease otherwise. This is quite intuitive, since the level of the regulated price determines the market shares of the providers. If $\overline{p}$ is relatively high, the market share of the public provider is relatively low (cf. Proposition 3.1), implying that the effect on average quality is dominated by the quality increase of the private providers. The opposite logic applies if $\overline{p}$ is relatively low.

3.5.2 No public funding of private providers

An alternative policy option is to abstain from funding private providers. Suppose instead that only the public provider faces a regulated price and copayment rate, whereas each of the two private providers must raise funds in the market by charging a price for the good provided. Thus, we assume a two-stage game similar to the one considered in the main analysis, but where the two private providers simultaneously choose price at the second stage of the game. As before, we solve the game by backwards induction.

If the subgame perfect Nash Equilibrium is an interior solution, the equilibrium outcome is given by[22]

$$q_1^{NPF} = \beta\frac{t\left(55kt-42\beta^2\right)+2\left(14\beta^2+15kt\right)\left(c-s\overline{p}\right)}{27kt\left(5kt-6\beta^2\right)}. \tag{3.5.3}$$

$$q_2^{NPF} = q_3^{NPF} = 14\beta\frac{t\left(2kt-3\beta^2\right)+\left(3kt-2\beta^2\right)\left(s\overline{p}-c\right)}{27kt\left(5kt-6\beta^2\right)}. \tag{3.5.4}$$

[22]The second-order conditions are reported in appendix section 3.A.

$$p_2^{NPF} = p_3^{NPF} = \frac{5t\left(2kt - 3\beta^2\right) + 2c\left(15kt - 22\beta^2\right) + 5s\overline{p}\left(3kt - 2\beta^2\right)}{9\left(5kt - 6\beta^2\right)}. \tag{3.5.5}$$

Both private providers offer the same quality and price in equilibrium, both of which react positively to an increase in the regulated price $\overline{p}$ or in the copayment rate s. We proceed to compare the quality levels in (3.5.3)-(3.5.4) with our benchmark in (3.4.15)-(3.4.17). Once more we restrict attention to the case of a relatively low copayment rate.

Proposition 3.11. *Suppose that s is sufficiently low and that $\overline{p} - c$ is sufficiently high relative to t. In this case, a removal of public funding for private providers leads to higher quality provision for the public provider ($q_1^{NPF} > q_1^*$) and the private provider without previous public funding ($q_3^{NPF} > q_3^*$), and lower quality provision by the private provider with previous public funding ($q_2^{NPF} < q_2^*$).*

The effects on quality provision of a funding removal are to a large extent the opposite of the effects of a funding extension. Given that the private providers have sufficiently strong incentives to compete for demand (i.e., given that $\overline{p} - c$ is sufficiently high relative to t), a removal of funding reduces the incentives for quality provision for the private provider that loses its public funding. However, because of strategic substitutability, the two other providers respond by increasing their quality provision. Once more, the effect on average quality provision is *a priori* ambiguous, but numerical simulations suggest that average quality will increase if the regulated price is sufficiently low and decrease otherwise. In qualitative terms, this is the opposite of the effect of a funding extension. Intuitively, this is once more related to the relationship between the regulated price and the market shares of the three providers. If the regulated price is low, the public provider has a high market share and the average quality effect is driven by the quality increase of the public provider. On the other hand, if the regulated price is sufficiently high, the average quality effect is driven by the quality reduction of the previously funded private provider, which has a high market share in the pre-reform equilibrium.

3.5.3 Optimal degree of funding coverage

A natural extension of the above analysis is to consider the optimal degree of funding coverage. Suppose that the price and copayment rate are exogenously determined by out-of-the-model considerations. For a given price and copayment rate, is welfare maximised by funding one or both private providers, or by funding none of them?

For analytical tractability reasons, our analysis is performed numerically. In Figure 3.5.1 we indicate the optimal degree of funding coverage in $(s, \overline{p})$-space when the other parameters are given by $\beta = 3$, $k = 10$, $t = 2$, $c = 0.5$ and $v = 1$. Although the figure is drawn for a particular set of parameters, a similar picture emerges for

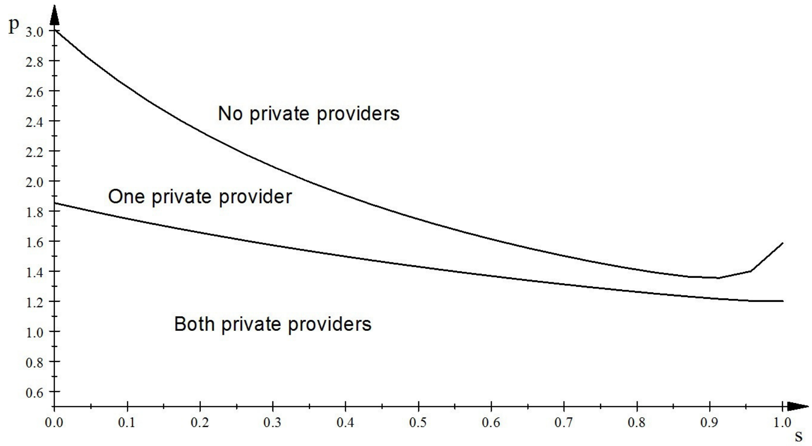

Figure 3.5.1: Optimal funding coverage

alternative parameter configurations. The different regimes depicted in Figure 3.5.1 reveal that there exists a trade-off between the *generosity* of the funding (the size of $\overline{p}$) and the *extension* of public funding (how many private providers that are included in the public funding scheme). If the regulated price is relatively low, welfare is maximised by extending funding to both private providers. On the other hand, for a sufficiently high price, it is optimal not to fund any private provider. However, for intermediate ranges of $\overline{p}$, the welfare optimal funding extension is given by our benchmark case, where only one of the private providers is included in the public funding scheme. This conclusion holds for all values of s, although the benchmark case is optimal for a larger range of parameters if the copayment rate is relatively low.

3.6 Concluding remarks

In this paper we have analysed quality competition among a welfare-maximising public provider and two profit-maximising private providers, where the public and one of the private providers face regulated prices and copayment rates, while the second private provider is free to set the price of its good. This is a market structure that applies to health care and education markets in many countries.

A common pattern among our findings is a differential response (in terms of quality provision) across providers to changes in the parameters of the funding scheme or in the intensity of competition. The details of these results are described elsewhere. In this final section of the paper we would like to briefly highlight some of the potential policy implications of our analysis. First, if we take the presence of publicly funded provision with (relatively low) copayment rates as given, we find that the welfare-maxmising price (given to the publicly funded providers) is increasing in the copayment rate, as long as the copayment rate is at a sufficiently low level. This indicates that these two funding instruments are *policy complements*. In other words, if policy makers wish to increase the copayment rate (from a sufficiently low level), such a policy change should optimally be accompanied by a corresponding increase in the regulated price, and *vice versa*. Second, we find that the welfare effects of either extending public funding to more private providers, or removing funding from currently funded providers, depend on the level of the regulated price. More precisely, we find that more (fewer) providers should be publicly funded if the regulated price is sufficiently low (high). This suggests that the extent of the funding coverage (i.e., how many private providers to include in the public funding scheme) and the generosity of the funding (i.e., the regulated price level) are *policy substitutes*.

Our analysis is obviously not without limitations, and we would here like to mention two of them. Importantly, we have conducted the model in a framework where consumer preferences are heterogeneous only along a horizontal dimension. This means that we are not able to capture effects that might result from vertical preference differentiation, where some consumers have higher willingness to pay for quality than others, for example. However, our model already includes asymmetries along two different dimensions (provider objectives and public funding coverage), and adding asymmetry along a third dimension would simply render the model intractable. Another limitation is that we do not allow for any (exogenous or endogenous) differences in cost efficiency across public and private providers. There are several reasons why public versus private ownership might lead to different incentives for cost-efficient provision, for example the presence of soft budgets associated with public ownership. Potential explorations along these lines are left for further research.

APPENDIX

Appendix 3.A Equilibrium existence

Benchmark model

In the quality subgame, there are two conditions that do not trivially hold. First, the problem of the welfare-maxmising public provider is well-behaved if

$$\frac{\partial^2 W}{\partial q_1^2} = -\frac{(16kt - 15\beta^2)}{16t} < 0, \tag{3.A.1}$$

which requires $k > 15\beta^2/16t$. Second, the Nash equilibrium is locally stable if the Jacobian of the system of first-order conditions is negative definite, which requires

$$\frac{\partial^2 W}{\partial q_1^2}\frac{\partial^2 \pi_2}{\partial q_2^2} - \frac{\partial^2 \pi_2}{\partial q_2 \partial q_1}\frac{\partial^2 W}{\partial q_1 \partial q_2} = \frac{k}{16t}\left(16kt - 15\beta^2\right) > 0 \tag{3.A.2}$$

and

$$\begin{vmatrix} \frac{\partial^2 W}{\partial q_1^2} & \frac{\partial^2 W}{\partial q_1 \partial q_2} & \frac{\partial^2 W}{\partial q_1 \partial q_3} \\ \frac{\partial^2 \pi_2}{\partial q_2 \partial q_1} & \frac{\partial^2 \pi_2}{\partial q_2^2} & \frac{\partial^2 \pi_2}{\partial q_2 \partial q_3} \\ \frac{\partial^2 \pi_3}{\partial q_3 \partial q_1} & \frac{\partial^2 \pi_3}{\partial q_3 \partial q_2} & \frac{\partial^2 \pi_3}{\partial q_3^2} \end{vmatrix} = -\frac{k\left(kt\left(16kt - 23\beta^2\right) + 6\beta^4\right)}{16t^2} < 0. \tag{3.A.3}$$

(3.A.2) holds if (3.A.1) holds, while (3.A.3) holds if $kt\left(16kt - 23\beta^2\right) + 6\beta^4 > 0$. Notice that

$$kt\left(16kt - 23\beta^2\right) + 6\beta^4\Big|_{k=\frac{15\beta^2}{16t}} = -\frac{3}{2}\beta^4 < 0 \tag{3.A.4}$$

and

$$\frac{\partial\left(kt\left(16kt - 23\beta^2\right) + 6\beta^4\right)}{\partial k} = t\left(32kt - 23\beta^2\right) > 0 \text{ for } k > \frac{15\beta^2}{16t}, \tag{3.A.5}$$

which implies that the condition in (3.A.3) holds if k is above some threshold value higher than $15\beta^2/16t$, which in turn implies that (3.A.1) and (3.A.2) always hold if (3.A.3) holds.

Furthermore, the regulator's optimal pricing problem (for a given copayment rate) is well-behaved if

$$\frac{\partial^2 W}{\partial \overline{p}^2} = -\frac{\left(2kt - 3\beta^2\right)\Theta}{64kt^2\left(kt\left(16kt - 23\beta^2\right) + 6\beta^4\right)^2} < 0, \tag{3.A.6}$$

where

$$\Theta := 16kst\left(\beta^2 + 16kt\right)\left(kt - \beta^2\right)\left(7\beta^2 + 4s\left(2kt - \beta^2\right)\right)$$
$$+ 49\beta^2\left(8k^2t^2\left(16kt - 37\beta^2\right) + \beta^4\left(205kt - 36\beta^2\right)\right). \tag{3.A.7}$$

Assuming that $\Theta > 0$, the condition in (3.A.6) holds if $k > 3\beta^2/2t$. Evaluating the numerator in (3.A.3) at $k = 3\beta^2/2t$ yields

$$kt\left(16kt - 23\beta^2\right) + 6\beta^4\Big|_{k=\frac{3\beta^2}{2t}} = \frac{15}{2}\beta^4 > 0. \tag{3.A.8}$$

Thus, the condition in (3.A.3) always holds if (3.A.6) holds. It remains to show that $\Theta > 0$. To do so, we derive

$$\frac{\partial^3\Theta}{\partial k^3} = 768t^3\left(7\beta^2(2s+7) + s^2\left(64kt - 23\beta^2\right)\right). \tag{3.A.9}$$

Notice that $\partial^3\Theta/\partial k^3 > 0$ if $k > 3\beta^2/2t$. This implies that $\partial^2\Theta/\partial k^2$ is monotonically increasing in k. Evaluated at the lower bound $k = 3\beta^2/2t$, we derive

$$\left.\frac{\partial^2\Theta}{\partial k^2}\right|_{k=\frac{3\beta^2}{2t}} = 112t^2\beta^4\left(114s + 272s^2 + 245\right) > 0. \tag{3.A.10}$$

Thus, Θ is strictly convex for $k > 3\beta^2/2t$. Furthermore,

$$\left.\frac{\partial\Theta}{\partial k}\right|_{k=\frac{3\beta^2}{2t}} = t\beta^6\left(6944s + 10\,336s^2 + 8869\right) > 0 \tag{3.A.11}$$

and

$$\Theta|_{k=\frac{3\beta^2}{2t}} = \frac{75}{2}\beta^8\left(56s + 64s^2 + 49\right) > 0. \tag{3.A.12}$$

Since Θ is positive and increasing in k at $k = 3\beta^2/2t$, and since Θ is strictly convex for all $k > 3\beta^2/2t$, it follows that Θ is positive also for all $k > 3\beta^2/2t$. Thus, the second-order condition (3.A.6) is satisfied if

$$k > \underline{k} := \frac{3\beta^2}{2t}, \tag{3.A.13}$$

and this condition ensures that the critical conditions in the quality subgame, (3.A.1)-(3.A.3), are also satisfied.

Public funding of all private providers

In the quality subgame, the second-order conditions are satisfied for Provider 2 and 3:

$$\frac{\partial^2 \pi_2}{\partial q_2^2} = \frac{\partial^2 \pi_3}{\partial q_3^2} = -k < 0. \tag{3.A.14}$$

The problem of the welfare-maxmising provider is well-behaved if

$$\frac{\partial^2 W}{\partial q_1^2} = -\frac{(kt - \beta^2)}{t} < 0, \tag{3.A.15}$$

which is true for $k > \underline{k}$. Furthermore, equilibrium stability requires that the Jacobian is negative definite, which is true if

$$\frac{\partial^2 W}{\partial q_1^2}\frac{\partial^2 \pi_2}{\partial q_2^2} - \frac{\partial^2 \pi_2}{\partial q_2 \partial q_1}\frac{\partial^2 W}{\partial q_1 \partial q_2} = \frac{(kt - \beta^2)\, k}{t} > 0 \tag{3.A.16}$$

and

$$\begin{vmatrix} \frac{\partial^2 W}{\partial q_1^2} & \frac{\partial^2 W}{\partial q_1 \partial q_2} & \frac{\partial^2 W}{\partial q_1 \partial q_3} \\ \frac{\partial^2 \pi_2}{\partial q_2 \partial q_1} & \frac{\partial^2 \pi_2}{\partial q_2^2} & \frac{\partial^2 \pi_2}{\partial q_2 \partial q_3} \\ \frac{\partial^2 \pi_3}{\partial q_3 \partial q_1} & \frac{\partial^2 \pi_3}{\partial q_3 \partial q_2} & \frac{\partial^2 \pi_3}{\partial q_3^2} \end{vmatrix} = -\frac{(kt - \beta^2)\, k^2}{t} < 0. \tag{3.A.17}$$

Both conditions hold if $k \geq \underline{k}$.

No public funding for the private providers

In the pricing subgame, the second order conditions are satisfied,

$$\frac{\partial^2 \pi_2}{\partial p_2^2} = \frac{\partial^2 \pi_3}{\partial p_3^2} = -\frac{2}{t} < 0, \tag{3.A.18}$$

and equilibrium stability requires that the Jacobian is negative definite, which is easily verified:

$$\frac{\partial^2 \pi_2}{\partial p_2^2}\frac{\partial^2 \pi_3}{\partial p_3^2} - \frac{\partial^2 \pi_2}{\partial p_2 \partial p_3}\frac{\partial^2 \pi_3}{\partial p_2 \partial p_3} = \frac{15}{4t^2} > 0. \tag{3.A.19}$$

In the quality subgame, there are two sets of conditions that do not trivially hold. First, the problem of each profit maximising provider is well-behaved if

$$\frac{\partial^2 \pi_2}{\partial q_2^2} = \frac{\partial^2 \pi_3}{\partial q_3^2} = \frac{1}{225t}\left(98\beta^2 - 225kt\right) < 0, \tag{3.A.20}$$

and the problem of the welfare-maxmising provider is well-behaved if

$$\frac{\partial^2 W}{\partial q_1^2} = \frac{1}{9t}\left(8\beta^2 - 9kt\right) < 0. \tag{3.A.21}$$

Second, the Nash equilibrium is locally stable if the Jacobian is negative definite, which requires

$$\frac{\partial^2 W}{\partial q_1^2}\frac{\partial^2 \pi_2}{\partial q_2^2} - \frac{\partial^2 \pi_2}{\partial q_2 \partial q_1}\frac{\partial^2 W}{\partial q_1 \partial q_2} = \frac{kt\left(225kt - 298\beta^2\right) + 56\beta^4}{225t^2} > 0, \tag{3.A.22}$$

and

$$\begin{vmatrix} \frac{\partial^2 W}{\partial q_1^2} & \frac{\partial^2 W}{\partial q_1 \partial q_2} & \frac{\partial^2 W}{\partial q_1 \partial q_3} \\ \frac{\partial^2 \pi_2}{\partial q_2 \partial q_1} & \frac{\partial^2 \pi_2}{\partial q_2^2} & \frac{\partial^2 \pi_2}{\partial q_2 \partial q_3} \\ \frac{\partial^2 \pi_3}{\partial q_3 \partial q_1} & \frac{\partial^2 \pi_3}{\partial q_3 \partial q_2} & \frac{\partial^2 \pi_3}{\partial q_3^2} \end{vmatrix} = -\frac{k\left(5kt - 6\beta^2\right)\left(25kt - 14\beta^2\right)}{125t^2} < 0, \tag{3.A.23}$$

All the above conditions are satisfied if $k \geq \underline{k}$.

Appendix 3.B Proofs

Proof of Proposition 3.1

From (3.4.15)-(3.4.17) we derive

$$\frac{\partial q_1^*}{\partial \overline{p}} = -\beta \frac{16kst\left(\beta^2 + kt\right) + 21\beta^2\left(3kt - 2\beta^2\right)}{8kt\left(6\beta^4 + \left(16kt - 23\beta^2\right)kt\right)}, \tag{3.B.1}$$

$$\frac{\partial q_2^*}{\partial \overline{p}} = \frac{7\beta}{8kt}, \tag{3.B.2}$$

$$\frac{\partial q_3^*}{\partial \overline{p}} = \beta \frac{4kst\left(8kt - 7\beta^2\right) - 7\beta^2\left(2kt - 3\beta^2\right)}{4kt\left(6\beta^4 + \left(16kt - 23\beta^2\right)kt\right)}. \tag{3.B.3}$$

(i) The numerator in (3.B.1) is monotonically increasing in k and positive for all $k > \underline{k}$. Thus, $\partial q_1^* / \partial \overline{p} < 0$ for all $k > \underline{k}$.

(ii) The positive sign of (3.B.2) is trivial.

(iii) The numerator in (3.B.3) is monotonically increasing in s. Setting the numerator equal to zero and solving for s, we derive

$$\frac{\partial q_3^*}{\partial \overline{p}} < (>)\, 0 \text{ if } s < (>)\, \overline{s} := \frac{7\beta^2\left(2kt - 3\beta^2\right)}{4kt\left(8kt - 7\beta^2\right)}. \tag{3.B.4}$$

Notice that $\overline{s} \in (0, 1)$, since

$$1 - \overline{s} = \frac{21\beta^4 + 2kt\left(16kt - 21\beta^2\right)}{4kt\left(8kt - 7\beta^2\right)} > 0 \text{ for } k \geq \underline{k}. \tag{3.B.5}$$

Q.E.D.

Proof of Proposition 3.2

Using (3.4.19), we derive

$$\frac{\partial \overline{q}}{\partial \overline{p}} = \frac{\beta\left(\theta \overline{p} + \varpi\right)}{96kt\left(6\beta^4 + \left(16kt - 23\beta^2\right)kt\right)^2}, \tag{3.B.6}$$

where

$$\theta := 3k \left(\begin{array}{c} 16s\left(12s\left(\beta^6 + 4kt\left(4\beta^4 + 3kt\left(2kt - 3\beta^2\right)\right)\right) - 7\left(39\beta^6 + 2k^2t^2\left(16kt - 41\beta^2\right)\right)\right) \\ +49\beta^2\left(219\beta^4 + 16kt\left(14kt - 27\beta^2\right)\right) \end{array} \right) \tag{3.B.7}$$

and

$$\begin{aligned} \varpi := {} & 56\left(54\beta^8 + kt\left(2kt\left(519\beta^4 + kt\left(80kt - 389\beta^2\right)\right) - 495\beta^6\right)\right) \\ & + 21ck\left(16kt\left(16kt - 27\beta^2\right)\left(kt - 7\beta^2\right) - 1221\beta^6\right) \\ & + 32kst\left(18\beta^6 + kt\left(147\beta^4 + 2kt\left(8kt - 115\beta^2\right)\right)\right) \\ & + 24cks\left(249\beta^6 - 2kt\left(192\beta^4 + kt\left(176kt - 145\beta^2\right)\right)\right). \end{aligned} \tag{3.B.8}$$

(i) Define $A := \theta \overline{p} + \varpi$. It follows immediately from (3.B.6) that the sign of $\partial \overline{q} / \partial \overline{p}$ is equal to the sign of A. Consider first the case of $s = 0$. In this case, we derive

$$\frac{\partial^4 A}{\partial k^4} = 43\,008t^3\left(3c + 5t\right) > 0, \tag{3.B.9}$$

which implies that $\partial^3 A/\partial k^3$ is monotonically increasing in k. Evaluating at the lower bound of k, we derive

$$\left.\frac{\partial^3 A}{\partial k^3}\right|_{k=\underline{k}} = 672t^2\beta^2\left(294\overline{p} - 129c + 91t\right) > 0. \tag{3.B.10}$$

Thus, we conclude that $\partial^3 A/\partial k^3 > 0$ for all $k \geq \underline{k}$, which implies that $\partial^2 A/\partial k^2$ is monotonically increasing in k. Repeating the above logic, we derive

$$\left.\frac{\partial^2 A}{\partial k^2}\right|_{k=\underline{k}} = 336t\beta^4\left(504\overline{p} - 441c - 101t\right), \tag{3.B.11}$$

$$\left.\frac{\partial A}{\partial k}\right|_{k=\underline{k}} = 315\beta^6\left(203\overline{p} - 247c - 84t\right) \tag{3.B.12}$$

and

$$A|_{k=\underline{k}} = \frac{4725\beta^8\left(7\overline{p} - 11c - 4t\right)}{2t}. \tag{3.B.13}$$

It follows that $A > 0$ for all $k \geq \underline{k}$ if the three expressions in (3.B.11), (3.B.12) and (3.B.13) are all positive. This is true if

$$t < \frac{7}{4}\overline{p} - \frac{11}{4}c. \tag{3.B.14}$$

Thus, if t is sufficiently low relative to $(\overline{p} - c)$, then $\partial\overline{q}/\partial\overline{p} > 0$ for all $k > \underline{k}$. This has been shown for $s = 0$ but, by continuity, the result also holds for s sufficiently close to zero. Consider next the case of $s = 1$. Following the same logic as for the case of $s = 0$, we derive

$$\frac{\partial^4 A}{\partial k^4} = 6144t^3\left(12\left(\overline{p} - c\right) + 37t\right) > 0, \tag{3.B.15}$$

$$\left.\frac{\partial^3 A}{\partial k^3}\right|_{k=\underline{k}} = 864t^2\beta^2\left(404\left(\overline{p} - c\right) + 41t\right) > 0, \tag{3.B.16}$$

$$\left.\frac{\partial^2 A}{\partial k^2}\right|_{k=\underline{k}} = 48t\beta^4\left(6918\left(\overline{p} - c\right) - 1603t\right), \tag{3.B.17}$$

$$\left.\frac{\partial A}{\partial k}\right|_{k=\underline{k}} = 45\beta^6\left(3701\left(\overline{p} - c\right) - 1212t\right) \tag{3.B.18}$$

and

$$A|_{k=\underline{k}} = \frac{675\beta^8 \left(169 \left(\overline{p} - c\right) - 60t\right)}{2t}. \tag{3.B.19}$$

It follows that $A > 0$ for all $k \geq \underline{k}$ if the expressions in (3.B.17), (3.B.18) and (3.B.19) are all positive. This is true if

$$t < \frac{169}{60} \left(\overline{p} - c\right). \tag{3.B.20}$$

Thus, if t is sufficiently low relative to $(\overline{p} - c)$, then $\partial \overline{q}/\partial \overline{p} > 0$ for all $k > \underline{k}$. This has been shown for $s = 1$ but, by continuity, the result also holds for s sufficiently close to one.

(ii) Evaluating A at the lower bound $k = \underline{k}$ yields

$$A|_{k=\underline{k}} = \frac{675\beta^8 \left(49\overline{p} - \left(77 + 92s\right)c + 4\left(8s + 7\right)\left(2\overline{p}s - t\right)\right)}{2t}. \tag{3.B.21}$$

The sign of this expression depends on the sign of the numerator, which is monotonically decreasing in t. Since t is unbounded from above, the numerator is negative if t is sufficiently large. Thus, at $k = \underline{k}$, $\partial \overline{q}/\partial \overline{p} < 0$ for all $s \in [0, 1]$ if t is sufficiently high. By continuity, this result holds also for k sufficiently close to $\underline{k}$. Furthermore, we also see that the numerator in (3.B.21) is monotonically increasing in $\overline{p}$ and monotonically decreasing in c. Setting $\overline{p}$ at the lower bound, i.e., $\overline{p} = c$, we derive

$$A|_{k=\underline{k};\overline{p}=c} = -\frac{1350\beta^8 \left[\left(16s + 7\right)\left(1 - s\right)c + \left(7 + 8s\right)t\right]}{t} < 0. \tag{3.B.22}$$

Thus, at $k = \underline{k}$, $\partial \overline{q}/\partial \overline{p} < 0$ for all $s \in [0, 1]$ if $(\overline{p} - c)$ is sufficiently small. Again, by continuity, this result holds also for k sufficiently close to $\underline{k}$. *Q.E.D.*

Proof of Proposition 3.3

From (3.4.15)-(3.4.17), we derive

$$\frac{\partial q_1^*}{\partial s} = -\frac{2\overline{p}\beta\left(\beta^2 + kt\right)}{6\beta^4 + kt\left(16kt - 23\beta^2\right)} < 0, \tag{3.B.23}$$

$$\frac{\partial q_2^*}{\partial s} = 0, \tag{3.B.24}$$

$$\frac{\partial q_3^*}{\partial s} = \overline{p}\beta \frac{8kt - 7\beta^2}{6\beta^4 + kt\left(16kt - 23\beta^2\right)} > 0, \tag{3.B.25}$$

It is straightforward to verify the unambiguous signs of these expressions for all $k \geq \underline{k}$. *Q.E.D.*

Proof of Proposition 3.4

Using (3.4.20), we derive

$$\frac{\partial \overline{q}}{\partial s} = \frac{\beta\overline{p}\left(3\overline{p}\Upsilon + \chi\right)}{12t\left(6\beta^4 + kt\left(16kt - 23\beta^2\right)\right)^2}, \tag{3.B.26}$$

where

$$\Upsilon := -7\left(2k^2t^2\left(16kt - 41\beta^2\right) + 39\beta^6\right) + 24s\left(4kt\left(4\beta^4 + \left(2kt - 3\beta^2\right)3kt\right) + \beta^6\right) \tag{3.B.27}$$

and

$$\chi := \left(\begin{array}{c} 4t\left(18\beta^6 + kt\left(147\beta^4 + \left(8kt - 115\beta^2\right)2kt\right)\right) \\ -3c\left(3\beta^4\left(128kt - 83\beta^2\right) + 2k^2t^2\left(176kt - 145\beta^2\right)\right) \end{array}\right) \tag{3.B.28}$$

Define $E := 3\overline{p}\Upsilon + \chi$. From (3.B.26) it is clear that the sign of $\partial\overline{q}/\partial s$ is given by the sign of E. Notice that E is monotonically increasing in s for all $k > \underline{k}$, which implies that $\overline{q}$ is a convex function of s. Consider first the case of $s = 0$. In this case, we derive

$$\frac{\partial^3 E}{\partial k^3} = -192t^3\left(21p + 33c - 2t\right). \tag{3.B.29}$$

We see that $\partial^3 E/\partial k^3 < 0$ if t is sufficiently low, which in turn implies that $\partial^2 E/\partial k^2$ is monotonically decreasing in k. Evaluating at the lower bound of k, we derive

$$\frac{\partial^2 E}{\partial k^2}|_{k=\underline{k}} = -4t^2\beta^2\left(1941c + 651\overline{p} + 316t\right) < 0, \tag{3.B.30}$$

which implies that $\partial E/\partial k$ is decreasing in k. Furthermore,

$$\frac{\partial E}{\partial k}|_{k=\underline{k}} = -30t\beta^4\left(189c - 21\overline{p} + 58t\right), \tag{3.B.31}$$

and

$$E|_{k=\underline{k}} = -\frac{225}{2}\beta^6\left(23c - 7\overline{p} + 8t\right). \tag{3.B.32}$$

It follows that $E < 0$, and thus $\partial \overline{q}/\partial s < 0$, for all $k > \underline{k}$, if the expressions in (3.B.29), (3.B.31) and (3.B.32) are all negative. This is true if

$$\overline{p} < \frac{23}{7}c + \frac{8}{7}t. \tag{3.B.33}$$

Consider next the case of $s = 1$. Following the same logic as for the case of $s = 0$, we derive

$$\frac{\partial^3 E}{\partial k^3} = 192t^3 \left(33(\overline{p} - c) + 2t\right) > 0, \tag{3.B.34}$$

$$\frac{\partial^2 E}{\partial k^2}|_{k=\underline{k}} = -4t^2\beta^2 \left(1941c - 1941p + 316t\right), \tag{3.B.35}$$

$$\frac{\partial E}{\partial k}|_{k=\underline{k}} = -30t\beta^4 \left(189c - 189\overline{p} + 58t\right) \tag{3.B.36}$$

and

$$E|_{k=\underline{k}} = -\frac{225}{2}\beta^6 \left(23c - 23\overline{p} + 8t\right) \tag{3.B.37}$$

It follows that $E > 0$, and thus $\partial \overline{q}/\partial s > 0$, for all $k > \underline{k}$, if the expressions in (3.B.35)-(3.B.37) are all positive. This is true if

$$\overline{p} > c + \frac{8}{23}t. \tag{3.B.38}$$

Since E is monotonically increasing in s, we can conclude that, if $\overline{p}$ is neither very low nor very high, or more precisely, if

$$c + \frac{8}{23}t < \overline{p} < \frac{23}{7}c + \frac{8}{7}t, \tag{3.B.39}$$

there exists a threshold value of s which lies strictly between 0 and 1, such that $\partial \overline{q}/\partial s < (>)\, 0$ if s is below (above) this threshold value. *Q.E.D.*

Proof of Proposition 3.6

From (3.4.15)-(3.4.17), we derive

$$\frac{\partial q_1^*}{\partial t} = -\frac{\beta\Phi}{8kt^2\left(6\beta^4 + \left(16kt - 23\beta^2\right)kt\right)^2}, \tag{3.B.40}$$

where

$$\Phi := -\overline{p}\left(21\beta^2\left(3k^2t^2\left(32kt-55\beta^2\right)+4\beta^4\left(23kt-3\beta^2\right)\right)+16k^2st^2\left(16k^2t^2+\beta^2\left(32kt-29\beta^2\right)\right)\right)$$
$$+c\left(256k^4t^4+84\beta^6\left(23kt-3\beta^2\right)+k^2t^2\beta^2\left(2528kt-3929\beta^2\right)\right) \tag{3.B.41}$$
$$+16kt^2\beta^2\left(kt\left(37kt-36\beta^2\right)+12\beta^4\right),$$

$$\frac{\partial q_2^*}{\partial t} = -\frac{7\beta\left(\overline{p}-c\right)}{8kt^2} < 0, \tag{3.B.42}$$

$$\frac{\partial q_3^*}{\partial t} = \frac{\beta\Psi}{6kt^2\left(6\beta^4+\left(16kt-23\beta^2\right)kt\right)^2}, \tag{3.B.43}$$

where

$$\Psi := -3\overline{p}\left(63\beta^8+665k^2t^2\beta^4-224k^3t^3\beta^2-483kt\beta^6+256k^4st^4+226k^2st^2\beta^4-448k^3st^3\beta^2\right)$$
$$+3c\left(k^2t^2\left(891\beta^4+32kt\left(8kt-21\beta^2\right)\right)-21\beta^6\left(23kt-3\beta^2\right)\right) \tag{3.B.44}$$
$$+16kt^2\beta^2\left(\left(12\beta^2+kt\right)kt-9\beta^4\right)$$

(i) From (3.B.40) we see that the sign of $\partial q_1^*/\partial t$ is the opposite of the sign of Φ. It is easily verified that Φ is monotonically decreasing in $\overline{p}$. Evaluating Φ at the lower bound of the regulated price, $\overline{p}=c$, yields

$$\Phi|_{\overline{p}=c} = 16kt^2\left(\beta^2\left(12\beta^4+kt\left(37kt-36\beta^2\right)\right)+ck\left(1-s\right)\left(\beta^2\left(32kt-29\beta^2\right)+16k^2t^2\right)\right) > 0. \tag{3.B.45}$$

Since $\overline{p}$ is unbounded from above and Φ is monotonically decreasing in $\overline{p}$, it follows that Φ changes sign from positive to negative if $\overline{p}$ exceeds some threshold level. Thus, $\partial q_1^*/\partial t < (>)\, 0$ if $\overline{p}$ is sufficiently low (high).

(ii) The negative sign of (3.B.42) is trivial.

(iii) From (3.B.43) we see that the sign of $\partial q_3^*/\partial t$ is given by the sign of Ψ. It is also easy to verify that Ψ is monotonically decreasing in s:

$$\frac{\partial\Psi}{\partial s} = -6k^2\overline{p}t^2\left(113\beta^4+\left(4kt-7\beta^2\right)32kt\right) < 0. \tag{3.B.46}$$

Setting s at the lower bound, $s = 0$, we derive

$$\frac{\partial^4 \Psi}{\partial k^4} = 18\,432ct^4 > 0, \tag{3.B.47}$$

implying that $\partial^3 \Psi / \partial k^3$ is monotonically increasing in k. Evaluated at the lower bound of k , we have

$$\left.\frac{\partial^3 \Psi}{\partial k^3}\right|_{k=\underline{k}} = 96t^3\beta^2\left(42\overline{p} + 162c + t\right) > 0. \tag{3.B.48}$$

Following the same logic, we also derive

$$\left.\frac{\partial^2 \Psi}{\partial k^2}\right|_{k=\underline{k}} = 6t^2\beta^4\left(343\overline{p} + 1323c + 88t\right) > 0 \tag{3.B.49}$$

and

$$\left.\frac{\partial \Psi}{\partial k}\right|_{k=\underline{k}} = 90t\beta^6\left(37c + 6t\right) > 0, \tag{3.B.50}$$

implying that Ψ is monotonically increasing in k. Evaluating Ψ at the lower bound of k yields

$$\Psi|_{k=\underline{k}} = \frac{135}{4}\beta^8\left(33c - 7\overline{p} + 8t\right) > 0 \text{ if } \overline{p} < \frac{33}{7}c + \frac{8}{7}t. \tag{3.B.51}$$

Thus, if $s = 0$ and $\overline{p} < (33c + 8t)/7$, $\Psi > 0$ for all $k \geq \underline{k}$.

Now setting s at the upper bound, $s = 1$, and using the same logic as for the case of $s = 0$, we derive

$$\frac{\partial^4 \Psi}{\partial k^4} = -18\,432t^4\left(\overline{p} - c\right) < 0, \tag{3.B.52}$$

$$\left.\frac{\partial^3 \Psi}{\partial k^3}\right|_{k=\underline{k}} = -96t^3\beta^2\left(162\left(\overline{p} - c\right) - t\right), \tag{3.B.53}$$

$$\left.\frac{\partial^2 \Psi}{\partial k^2}\right|_{k=\underline{k}} = -6t^2\beta^4\left(1323\left(\overline{p} - c\right) - 88t\right), \tag{3.B.54}$$

$$\left.\frac{\partial \Psi}{\partial k}\right|_{k=\underline{k}} = -90t\beta^6\left(37\left(\overline{p} - c\right) - 6t\right), \tag{3.B.55}$$

$$\Psi|_{k=\underline{k}} = -\frac{135}{4}\beta^8\left(33\left(\overline{p} - c\right) - 8t\right) \tag{3.B.56}$$

It follows that $\Psi < 0$ for $s = 1$ and all $k \geq \underline{k}$ if the expressions in (3.B.53)-(3.B.56) are all negative. This is true if

$$\overline{p} > c + \frac{8}{33}t. \tag{3.B.57}$$

Since Ψ is monotonically decreasing in s, we can conclude that, if $\overline{p}$ is neither very low nor very high, or more precisely, if

$$c + \frac{8}{33}t < \overline{p} < \frac{33}{7}c + \frac{8}{7}t, \tag{3.B.58}$$

there exists a threshold value of s which lies strictly between 0 and 1, such that $\partial q_3^*/\partial t > (<)\, 0$ if s is below (above) this threshold value. *Q.E.D.*

Proof of Proposition 3.7

From (3.4.24), we derive

$$\frac{\partial \overline{p}\,(s)}{\partial s} = \frac{8kt\,(\beta^2 + 16kt)\,(kt - \beta^2)\,\varsigma}{3\Delta^2}, \tag{3.B.59}$$

where Δ is defined by (3.4.26) and where

$$\begin{aligned}
\varsigma &:= 3136t\beta^2 \left(kt - \beta^2\right) \left(2kt - 3\beta^2\right) \left(3\beta^4 + \left(16kt - 15\beta^2\right) kt\right) \\
&\quad - 128st \left(2kt - \beta^2\right) \begin{pmatrix} 8k^2st^2\,(kt - \beta^2)\,(\beta^2 + 16kt) \\ +84\beta^6\,(17kt - 3\beta^2) + 7k^2t^2\beta^2\,(144kt - 311\beta^2) \end{pmatrix} \\
&\quad - 3c \begin{pmatrix} 49\beta^2\,(8k^2t^2\beta^2\,(864kt - 995\beta^2) + 5\beta^6\,(727kt - 108\beta^2) - 2048k^4t^4) \\ +16s\,(2kt - \beta^2) \begin{pmatrix} 7\beta^2\,(16k^2t^2\,(64kt - 137\beta^2) + \beta^4\,(1427kt - 252\beta^2)) \\ +4kst\,(kt - \beta^2)\,(16kt - \beta^2)\,(\beta^2 + 16kt) \end{pmatrix} \end{pmatrix}
\end{aligned} \tag{3.B.60}$$

The sign of $\partial \overline{p}\,(s)\,/\partial s$ depends on the sign of ς. Taking the fourth-order derivative of ς with respect to k yields

$$\frac{\partial^4 \varsigma}{\partial k^4} = -49\,152t^4 \left(80ks^2t\,(3c + t) - t\beta^2 \left(49 - 126s + 23s^2\right) - 3c\beta^2 \left(49 - 112s + 24s^2\right)\right). \tag{3.B.61}$$

It is easy to verify that this expression is positive (negative) if s is sufficiently low (high). Let us first consider that case of $s = 0$, which implies that $\partial^4\varsigma/\partial k^4 > 0$, thus implying that $\partial^3\varsigma/\partial k^3$ is monotonically increasing in k. By evaluating the subsequent expressions at the lower bound of k, we derive

$$\frac{\partial^3 \varsigma}{\partial k^3}|_{k=\underline{k},s=0} = 37\,632t^3\beta^4\left(126c+41t\right) > 0, \tag{3.B.62}$$

$$\frac{\partial^2 \varsigma}{\partial k^2}|_{k=\underline{k},s=0} = 2352t^2\beta^6\left(563c+176t\right) > 0, \tag{3.B.63}$$

$$\frac{\partial \varsigma}{\partial k}|_{k=\underline{k},s=0} = 147t\beta^8\left(1237c+352t\right) > 0, \tag{3.B.64}$$

$$\varsigma|_{k=\underline{k},s=0} = \frac{11025c\beta^{10}}{2} > 0. \tag{3.B.65}$$

Thus, we conclude that $\varsigma > 0$, and thus, $\partial\overline{p}\left(s\right)/\partial s > 0$, for all $k > \underline{k}$, if $s = 0$. By continuity, this result also applies for values of s sufficiently close to zero.

Next, consider the case of $s = 1$, which implies that $\partial^4\varsigma/\partial k^4 < 0$, thus implying that $\partial^3\varsigma/\partial k^3$ is monotonically decreasing in k. By evaluating the subsequent expressions at the lower bound of k, we derive

$$\frac{\partial^3 \varsigma}{\partial k^3}|_{k=\underline{k},s=1} = -768t^3\beta^4\left(22\,635c+8381t\right) < 0, \tag{3.B.66}$$

$$\frac{\partial^2 \varsigma}{\partial k^2}|_{k=\underline{k},s=1} = -48t^2\beta^6\left(270\,901c+100\,112t\right) < 0, \tag{3.B.67}$$

$$\frac{\partial \varsigma}{\partial k}|_{k=\underline{k},s=1} = -3t\beta^8\left(702\,827c+256\,992t\right) < 0, \tag{3.B.68}$$

$$\varsigma|_{k=\underline{k},s=1} = -\frac{225}{2}\beta^{10}\left(6351c+1408t\right) < 0. \tag{3.B.69}$$

Thus, we conclude that $\varsigma < 0$, and thus, $\partial\overline{p}\left(s\right)/\partial s < 0$, for all $k > \underline{k}$, if $s = 1$. By continuity, this result also applies for values of s sufficiently close to one. *Q.E.D*

Proof of Proposition 3.10

A comparison of the equilibrium expressions in (3.5.1)-(3.5.2) with the corresponding expressions in (3.4.15)-(3.4.17) yields:

$$q_1^{PF} - q_1^* = \frac{\beta \Xi}{24kt\left(kt-\beta^2\right)\left(kt\left(16kt-23\beta^2\right)+6\beta^4\right)}, \tag{3.B.70}$$

where

$$\begin{aligned} \Xi := & \ 3kt\beta^4\left(79\overline{p}-63c\right) - 48kt\left(k^2t^2\left(c-s\overline{p}\right)+\beta^4\left(t+s\overline{p}\right)\right) \\ & -3\beta^2\left(6\beta^4+65k^2t^2\right)\left(\overline{p}-c\right) - 8k^2t^3\left(2kt-7\beta^2\right), \end{aligned} \tag{3.B.71}$$

$$q_2^{PF} - q_2^* = \frac{\beta\left(\overline{p}-c\right)}{8kt} > 0, \tag{3.B.72}$$

$$q_3^{PF} - q_3^* = \frac{\beta \rho}{12kt\left(kt\left(16kt-23\beta^2\right)+6\beta^4\right)}, \tag{3.B.73}$$

where

$$\begin{aligned} \rho =: & \ 3\overline{p}\left(3\beta^4+\left(32kt-39\beta^2\right)2kt\right) - 16kt^2\left(2kt-3\beta^2\right) \\ & -3c\left(2kt-3\beta^2\right)\left(16kt-\beta^2\right) - 12k\overline{p}st\left(8kt-7\beta^2\right). \end{aligned} \tag{3.B.74}$$

(i) The sign of (3.B.70) depends on the sign of Ξ . Taking the third-order derivative of Ξ with respect to k yields

$$\frac{\partial^3 \Xi}{\partial k^3} = -96t^3\left(3\left(c-s\overline{p}\right)+t\right). \tag{3.B.75}$$

This expression is negative if s is sufficiently low, which in turn implies that $\partial^2\Xi/\partial k^2$ is monotonically decreasing in k. By evaluating the subsequent expressions at the lower bound of k, we derive

$$\frac{\partial^2 \Xi}{\partial k^2}|_{k=\underline{k}} = -2t^2\beta^2\left(3\overline{p}\left(65-72s\right)+21c+16t\right), \tag{3.B.76}$$

$$\frac{\partial \Xi}{\partial k}|_{k=\underline{k}} = -12t\beta^4\left(\overline{p}\left(29-23s\right)-6c-t\right), \tag{3.B.77}$$

$$\Xi|_{k=\underline{k}} = -\frac{45}{4}\beta^6\left(\overline{p}\left(9-8s\right)-c\right). \tag{3.B.78}$$

It follows that $\Xi < 0$, and thus $q_1^{PF} < q_1^*$, for all $k > \underline{k}$ if the expressions in (3.B.76)-(3.B.78) are all negative. It is straightforward to verify that (3.B.78) is negative for all $s \in (0,1)$ while (3.B.76) is negative if s is sufficiently low.

For (3.B.77) to be negative, we need the additional condition that $\overline{p} - c$ is sufficiently high relative to t.

(ii) The positive sign of (3.B.72) is trivial.

(iii) The sign of (3.B.73) is given by the sign of ρ. Taking the second-order derivative of ρ with respect to k yields

$$\frac{\partial^2 \rho}{\partial k^2} = 64t^2 \left(3\overline{p}\left(2-s\right) - 3c - t\right). \tag{3.B.79}$$

It is easy to verify that the expression in (3.B.79) is positive if $\overline{p} - c$ is sufficiently high relative to t, which in turn implies that $\partial \rho / \partial k$ is monotonically increasing in k. By evaluating the subsequent expressions at the lower bound of k, we derive

$$\frac{\partial \rho}{\partial k}|_{k=\underline{k}} = 6t\beta^2 \left(57\overline{p} - 34s\overline{p} - 23c - 8t\right), \tag{3.B.80}$$

$$\rho|_{k=\underline{k}} = 90\overline{p}\beta^4 \left(1-s\right). \tag{3.B.81}$$

Both of these expressions are positive, implying that $\rho > 0$ and thus $q_3^{PF} > q_3^*$ for all $k > \underline{k}$, if $\overline{p} - c$ is sufficiently high relative to t. *Q.E.D*

Proof of Proposition 3.11

A comparison of (3.5.3)-(3.5.4) with (3.4.15)-(3.4.17) yields:

$$q_1^{NFP} - q_1^* = \frac{\beta \xi}{216kt\left(5kt - 6\beta^2\right)\left(6\beta^4 + \left(16kt - 23\beta^2\right)kt\right)}, \tag{3.B.82}$$

where

$$\begin{aligned}\xi =: {} & 567\overline{p}\beta^2 \left(3kt - 2\beta^2\right)\left(5kt - 6\beta^2\right) \\ & - 16s\overline{p}\left(\left(105kt - 94\beta^2\right)k^2t^2 - \left(5kt - 6\beta^2\right)14\beta^4\right) \\ & + 8t\left(2kt - 3\beta^2\right)\left(84\beta^4 + \left(7kt - 32\beta^2\right)5kt\right) \\ & + c\left(\left(527kt - 195\beta^2\right)28\beta^4 + \left(1680kt - 10\,009\beta^2\right)k^2t^2\right),\end{aligned} \tag{3.B.83}$$

$$q_2^{NPF} - q_2^* = 7\beta \frac{16t\left(2kt-3\beta^2\right)+16\overline{p}s\left(3kt-2\beta^2\right)-27\overline{p}\left(5kt-6\beta^2\right)-c\left(130\beta^2-87kt\right)}{216kt\left(5kt-6\beta^2\right)}, \tag{3.B.84}$$

$$q_3^{NPF} - q_3^* = \frac{\beta\varrho}{108kt\left(5kt-6\beta^2\right)\left(6\beta^4+\left(16kt-23\beta^2\right)kt\right)}, \tag{3.B.85}$$

where

$$\begin{aligned} \varrho =: \; & 189\overline{p}\beta^2\left(5kt-6\beta^2\right)\left(2kt-3\beta^2\right)+8t\left(2kt-3\beta^2\right)\left(42\beta^4+\left(22kt-53\beta^2\right)kt\right) \\ & + c\left(\left(173kt-78\beta^2\right)35\beta^4+\left(816kt-2599\beta^2\right)2k^2t^2\right) \\ & - 4\overline{p}s\left(\left(12\beta^2+17kt\right)14\beta^4+\left(408kt-827\beta^2\right)k^2t^2\right). \end{aligned} \tag{3.B.86}$$

(i) The sign of (3.B.82) depends on the sign of ξ . Taking the third-order derivative of ξ with respect to k yields

$$\frac{\partial^3\xi}{\partial k^3} = 3360t^3\left(3(c-s\overline{p})+t\right). \tag{3.B.87}$$

This expression if positive, implying that $\partial^2\xi/\partial k^2$ is monotonically increasing in k, if s is sufficiently low. Evaluating at the lower bound k, we derive

$$\frac{\partial^2\xi}{\partial k^2}|_{k=\underline{k}} = 2t^2\beta^2\left(\overline{p}\left(8505-6056s\right)-2449c-880t\right), \tag{3.B.88}$$

$$\frac{\partial\xi}{\partial k}|_{k=\underline{k}} = t\beta^4\left(\overline{p}\left(9639-5708s\right)-3931c-1236t\right), \tag{3.B.89}$$

$$\xi|_{k=\underline{k}} = \frac{15}{4}\beta^6\left(\overline{p}\left(567-520s\right)-47c\right). \tag{3.B.90}$$

The signs of (3.B.88)-(3.B.90) are all positive if $\overline{p}-c$ is sufficiently large relative to t. It follows that $\xi > 0$ and thus $q_1^{NFP} > q_1^*$, for all $k > \underline{k}$, if s is sufficiently low and $\overline{p}-c$ is sufficiently large relative to t.

(ii) The sign of (3.B.84) depends on the sign of the numerator, which we define as

$$F := -27\overline{p}\left(5kt-6\beta^2\right)-c\left(130\beta^2-87kt\right)+16t\left(2kt-3\beta^2\right)+16\overline{p}s\left(3kt-2\beta^2\right), \tag{3.B.91}$$

and from which we derive

$$\frac{\partial F}{\partial k} = -t\left(3\overline{p}\left(45 - 16s\right) - 87c - 32t\right). \tag{3.B.92}$$

It is easily confirmed that the sign of (3.B.92) is negative if s is sufficiently low and $\overline{p} - c$ is sufficiently large relative to t, implying that F is monotonically decreasing in k. Evaluating F at the lower bound of k yields

$$F|_{k=\underline{k}} = -\frac{1}{2}\beta^2\left(\overline{p}\left(81 - 80s\right) - c\right) < 0. \tag{3.B.93}$$

It follows that $F < 0$ and thus $q_2^{NPF} < q_2^*$, for all $k > \underline{k}$, if s is sufficiently low and $\overline{p} - c$ is sufficiently large relative to t.

(iii) The sign of (3.B.85) depends on the sign of ϱ. Taking the third-order derivative of ϱ with respect to k yields

$$\frac{\partial^3 \varrho}{\partial k^3} = 192t^3\left(51\left(c - s\overline{p}\right) + 11t\right). \tag{3.B.94}$$

For a sufficiently low value of s, this expression is positive, which implies that $\partial^2\varrho/\partial k^2$ is monotonically increasing in k. Evaluating the subsequent expressions at the lower bound of k yields

$$\frac{\partial^2 \varrho}{\partial k^2}|_{k=\underline{k}} = 4t^2\beta^2\left(1073c + 945p + 104t - 2018s\overline{p}\right), \tag{3.B.95}$$

$$\frac{\partial \varrho}{\partial k}|_{k=\underline{k}} = t\beta^4\left(1477c + 567p + 192t - 2044s\overline{p}\right), \tag{3.B.96}$$

$$\varrho|_{k=\underline{k}} = 165\beta^6\left(c - s\overline{p}\right). \tag{3.B.97}$$

It is straightforward to see that (3.B.95)-(3.B.97) are all positive if s is sufficiently low. In this case, it follows that $\varrho > 0$ and thus $q_3^{NPF} > q_3^*$ for all $k > \underline{k}$. *Q.E.D*

CHAPTER 4

INVESTMENT AND QUALITY COMPETITION IN HEALTHCARE MARKETS[1]

4.1 Introduction

Investments in medical innovations and new technologies can improve the efficacy of treatments and enhance patient outcomes (Cutler & McClellan, 2001; Fuchs & Sox, 2001), and in some cases reduce the cost of providing medical care. For example, laparoscopic surgery can both improve health outcomes and reduce length of stay and treatment costs, leading to substantial efficiency gains in service provision, therefore freeing up resources to improve care for other patients. But costly investments can also put pressure on the sustainability of health spending in publicly-funded health systems (OECD, 2010; Smith, Newhouse, & Freeland, 2009). In 2018, EU member states allocated around 0.4 percent of their GDP on capital investment in the health sector. Similarly, the European Structural and Investment Funds provided more than EUR 9 billion to member states for health-related investments in 2014-2020 (OECD, 2020a).

Hospital spending accounts for a significant share of health spending, about 39% in 2018 across the EU. The dominant payment model for hospitals across the OECD is activity-based funding, where hospitals are reimbursed a fixed price based on a Diagnosis Related Group (DRG) for each patient treated. Hospitals compete on quality to attract patients with higher quality leading to higher demand and higher revenues. There is instead more variety in the arrangements used to reimburse hospitals for their investments. These can take the form of separate supplementary payments, either as additional funding or retrospective reimbursement (Scheller-Kreinsen, Quentin, & Busse, 2011). Alternatively, the investment cost can be covered and included in the DRG fixed price, or it can be taken into account when designing DRG groups, for example by splitting an existing DRG or by establishing a new DRG, especially when the new technologies increase costs for a well-defined subset of patients (HOPE, 2006; Quentin, Scheller-Kreinsen, & Busse, 2011).

Despite the importance of hospital investments, there is limited understanding of how hospitals make investment decisions, and in turn how these decisions affect the provision of care. This study develops a theoretical model to investigate how hospitals' investment decisions are affected by different payment arrangements. We do so in a general environment where hospitals also compete for patients based on the quality of care they provide, which allows us to explore the interaction between investment and service quality. We address several questions. What determines hospitals'

[1] This chapter is co-authored with Luigi Siciliani and Odd Rune Straume.

incentives to invest in new medical technology, and do these incentives lead to underinvestment or overinvestment? Similarly, do hospitals' investment incentives lead to under- or overprovision of quality of care? What is the optimal payment contract and what are the welfare implications of different policies regarding payment for medical innovations?

In order to answer these questions, we use a spatial competition framework where hospitals are partly altruistic and we allow for investment and service quality to be either substitutes or complements in the health benefit and cost functions. We also assume that hospitals are financed by a third-party payer with a per-treatment price and a lump-sum transfer, where each of the policy instruments might depend on the level of investment. As a benchmark, we derive the equilibrium levels of investment and service quality under the assumption that these decisions are made simultaneously. We then proceed by considering the arguably more realistic setting of a two-stage game, where each hospital commits to a certain investment level before deciding on the provision of service quality. A key question addressed in this part of our analysis is whether sequential decision making leads to over- or underinvestment, and we find that the answer to this question depends crucially on two different factors: (i) whether the treatment price is higher or lower than the marginal treatment cost in equilibrium, which in turn depends on the degree of provider altruism, and (ii) whether increased investment by one hospital will spur an increase or a reduction in the quality provision of the competing hospital. If the price-cost margin is *positive*, we show that hospitals underinvest (overinvest) if own investment and the quality of the competing hospital are strategic complements (substitutes). On the other hand, if the price-cost margin is *negative*, strategic substitutability leads to underinvestment whereas strategic complementarity leads to overinvestment. Whether own investment and rival's quality are strategic substitutes or complements depends in turn on the characteristics of the hospital cost and patient benefit functions.

In the second part of the paper we offer a welfare analysis. A key underlying assumption is that, although service quality is observable, it is not verifiable and thus not contractible (Laffont & Martimort, 2009). Investments, on the other hand, are both observable and verifiable. Thus, regulators can design payment contracts based on investment with the purpose of indirectly incentivising quality improvements, which is one of the key objectives of hospital regulation. We start out by deriving the *first-best solution* and show that it can be implemented by a simple payment contract, consisting only of a fixed DRG tariff, as long as investment and quality choices are made simultaneously. However, if these decisions are made sequentially, the first-best solution is generally not attainable, since the price that induces the first-best quality level will lead to either under-or overinvestment. In this case, the regulator must complement the payment contract with at least one more instrument to correctly incentivise investments, either through a lump-sum payment or a treatment price which depends on investment. We show that the regulator has to incentivise investment when (i) investment and quality are strategic complements and the provider works at a positive price cost-margin, or (ii) investment and quality are strategic substitutes and the provider works at a negative price cost margin.

Finally, under the realistic assumption that payment contracts do not generally coincide with the ones that implement the first-best solution, we study the welfare effects of several plausible policies and payment mechanisms. First, we show that the introduction of a separate payment which directly incentivises investment can be welfare improving if, for example, investment and quality are initially below the first-best levels and investment and quality are complements or if they are substitutes but the degree of substitutability is sufficiently small. Second, we find that paying for investments through a higher activity-based tariff per patient treated, rather than through a separate funding scheme, can also be welfare improving if equilibrium investment and quality are below the first-best level and a higher DRG tariff increases the marginal revenue of both investment and service quality. Finally, we find that a policy incentivising investment through refinements of DRG pricing (so that additional investments are rewarded with a higher per unit price) stimulates quality provision while the effect on investment is, perhaps surprisingly, a priori ambiguous. Since such a payment scheme reinforces each hospital's incentive to use own investments to strategically affect the rival's quality provision, this could lead to a counterproductive outcome (i.e., lower investments) if own investment and rival's quality are strategic complements and providers are sufficiently profit oriented.

The rest of the paper is organised as follows. In the next section, we discuss the existing literature. In Section 4.3, we describe the key assumptions of the model. In Section 4.4, we derive the benchmark scenario where decisions on investments and service quality are made simultaneously. In Section 4.5, we consider the more realistic scenario of sequential decision making where hospitals first decide on investment and then on service quality. Section 4.6 is devoted to a welfare analysis where we adopt both a normative approach, to derive the socially optimal level of investment and quality and optimal regulation, and a more positive approach by investigating possible policy reforms to incentivise hospital investments. Section 4.7 concludes and discusses policy implications.

4.2 Related literature

Our study contributes and integrates two strands of the literature. The first one is the literature on quality competition in regulated markets, using a spatial framework, where key contributions include Wolinsky (1997), Gravelle (1999), Beitia (2003), Karlsson (2007), Brekke, Nuscheler, and Straume (2007); Brekke et al. (2011), among many others. This literature identifies the conditions under which competition amongst providers increases or reduces quality provision under different assumptions on providers' objective function, including altruistic preferences, non-profit status and costs. Using a similar spatial framework, but assuming an unregulated market, Brekke et al. (2010) investigate price and quality competition in a simultaneous-move game. They find that equilibrium quality is always below the socially optimal level when the utility function of consumers is concave in consumption, therefore allowing for the presence of income effects.

Incentives for underprovision are reinforced if instead quality choices are made before price competition takes place, which gives the firms an incentive to reduce quality provision in order to dampen price competition, as first shown by Ma and Burgess (1993). Finally, Brekke et al. (2006) analyse optimal regulation in a sequential-game framework with location and quality choices and find that the optimal price induces first-best quality, but horizontal differentiation is inefficiently large if the regulator cannot commit to a price before the location choices. None of these studies makes a distinction between investments and service quality.[2]

The second strand of literature investigates investment decisions and implications for regulation and design of optimal payment systems. One key issue addressed in this literature is the timing of investment and how this might be affected by different regulatory schemes. For example, using a real options approach, R. Levaggi and Michele (2008) find that long-term contracts are more effective in offering incentives for a provider to invest early. This analysis is extended by Pertile (2008) to account for cost uncertainty, investigating the optimal timing of investment in new health-care technologies by providers competing for patients. The analysis reveals a potentially counterintuitive relationship between payment characteristics and investment decisions, for example that a more generous payment scheme does not necessarily lead to earlier investment. In another related study, R. Levaggi, Moretto, and Pertile (2012) address how uncertainty about patients' benefits affects the incentives to invest in new technologies. They find that efficiency can be ensured both in the time of adoption (dynamic efficiency) and the intensity of use of technology (static efficiency) if reimbursement by the purchaser includes both a variable (per-patient) component and a lump-sum component.[3] A similar conclusion is reached by R. Levaggi, Moretto, and Pertile (2014), who show that it is optimal to pay the provider based on a fixed fee per patient and a lump-sum component to fund capital costs separately, a result which loosely resembles some of the insights derived in our welfare analysis.

Another key issue, with important regulatory implications, is contractibility. Whereas we in the present paper assume that investment is a contractible variable while service quality is not, Bös and De Fraja (2002) consider only non-contractible investments (interpreted as 'quality'). Using an incomplete contract framework, they focus on the effects of investment by the health care authority in contingency plans, which give it the option to purchase care from outside providers. In the first stage, hospitals choose investment decisions before patients are treated in the second stage. In such a setting, hospitals underinvest in quality while the health authority overinvests in the contingency arrangements,

[2]There is also a recent literature on multi-stage competition, including quality choices, in mixed oligopolies. For example, Laine and Ma (2017) use a model of vertical differentiation, where firms first choose product qualities, then simultaneously choose prices. Ghandour (2021) investigates quality competition under asymmetric pricing in a sequential game. Hehenkamp and Kaarbøe (2020) explore location choices and quality competition in mixed hospital markets. However, a distinction between investments and service quality is not made in any of these papers.

[3]In a non-competitive setting with demand uncertainty, Barros and Martinez-Giralt (2015) also study the relationship between payment systems and the rate of technology adoption. They find that a mixed cost reimbursement system can induce a higher adoption of health technologies compared to the DRG payment system.

as compared to the first-best outcome.

A common feature of all the above mentioned papers is that quality is a one-dimensional variable which may or may not be modelled as an investment decision, and which may or may not be contractible. In contrast, we make a conceptual separation between investment in medical technologies and other dimensions of quality provision, which we subsume under the umbrella term ‘service quality’, assuming that the former is contractible whereas the latter is not. We argue that this is a meaningful and potentially important conceptual distinction, and the main contribution of our paper is to study the interaction between investment and quality in healthcare markets.

4.3 Model

Consider a market for a healthcare treatment offered by two hospitals, denoted by $i = \{1, 2\}$, located at opposite endpoints of a Hotelling line of length 1. Patients are uniformly distributed on the unit line with a mass of one. Each patient demands one unit of treatment from the most preferred provider. A patient located at x who is treated at Hospital i has the utility

$$U_i(x, I_i, q_i) = B(I_i, q_i) - t\,|x - z_i|\,, \tag{4.3.1}$$

where $B(I_i, q_i)$ is patient health benefit from treatment, q_i is service quality of treatment at Hospital i, I_i is investment in new technologies, t is the transportation cost per unit of distance, and z_i is hospital location with $z_1 = 0$ and $z_2 = 1$. We assume that the patient health benefit is given by

$$B(I_i, q_i) = b^I I_i + b^q q_i + b^{Iq} I_i q_i, \tag{4.3.2}$$

where $b^q > 0$, $b^I \geq 0$ and $b^{Iq} \gtrless 0$, and where the relevant values of q_i and I_i are such that $b^q + b^{Iq} I_i > 0$ and $b^I + b^{Iq} q_i \geq 0$, implying that patient health benefit is increasing in service quality and (weakly) increasing in investment. We allow service quality and investment to be either complements ($b^{Iq} > 0$) or substitutes ($b^{Iq} < 0$) in health benefits, so that investments can amplify or dampen the effect of service quality on health benefits.

One example of investment is Magnetic Resonance Imaging (MRI) machines (Baker, 2001), which are used to facilitate the diagnosis of a condition or improve its assessment. Such investment can have both a direct effect on patient health ($b^I > 0$), for example the scan reveals a tumor, and an indirect effect by allowing to tailor the provision of care to the specific needs of the patients revealed by the scan, therefore increasing the effectiveness of quality provision ($b^{Iq} > 0$). Another example is investment in less invasive laparoscopic (endoscopic) technologies used for surgical interventions (e.g., for removal of gallbladder). The less invasive approach improves health outcomes through quicker recovery time, less pain, lower risks of complications, infections and transfusions, relative to more invasive open surgeries. Laparoscopy can also facilitate diagnosis therefore increasing the effectiveness of quality provision. There is also increasing interest in investment in robotic minimally invasive surgery which potentially increases precision, and reduces scope for errors.

Suppose that each patient in the market makes a utility-maximising choice of hospital and that patient health benefit is sufficiently high to ensure full market coverage. The demand function for Hospital i is then given by

$$D_i(I_i, I_j, q_i, q_j) = \frac{1}{2} + \frac{B(I_i, q_i) - B(I_j, q_j)}{2t}, \tag{4.3.3}$$

with demand for the rival hospital given by $D_j(I_i, I_j, q_i, q_j) = 1 - D_i(I_i, I_j, q_i, q_j)$.

The hospital cost function is assumed to be given by

$$C(D_i, I_i, q_i) = c(I_i, q_i)D_i + k(I_i), \tag{4.3.4}$$

where $c(I_i, q_i)$ is the cost per patient treated, which we refer to as marginal treatment costs, and $k(I_i)$ is the fixed cost of investment (e.g., a new MRI machine), which is increasing in investment and convex, $\partial k(I_i)/\partial I_i > 0$ and $\partial^2 k(I_i)/\partial I_i^2 > 0$. We assume that marginal treatment costs are given by

$$c(I_i, q_i) = c^I I_i + c^q q_i^2 + c^{Iq} I_i q_i, \tag{4.3.5}$$

where $c^q > 0$, $c^I \gtrless 0$ and $c^{Iq} \gtrless 0$. We assume that marginal treatment costs of service quality are positive, $2c^q q_i + c^{Iq} I_i > 0$, and treatment costs are convex in quality. We allow for service quality and investment to be either cost complements ($c^{Iq} < 0$) or substitutes ($c^{Iq} > 0$). We also allow the marginal treatment costs to increase or decrease with higher investment ($c^I \gtrless 0$). For example, laparoscopic surgery generally reduces the length of stay in hospital, in many cases allowing same-day discharge, requires fewer medications and only local anesthesia (as opposed to general anesthesia), therefore reducing the cost of quality provision during hospitalisation. Instead, investments in robot-assisted surgery as for robotic radical prostatectomy for treatment of localised prostate cancer can increase treatment costs relative to surgery by hand due to the specialised nature of the equipment (Park, Choi, Park, Kim, & Ryuk, 2012; Ramsay et al., 2012). Similarly, investing in MRI machines is expensive and the MRI scans cost more that CT scans. Therefore, whether investments increase or decrease treatment costs varies across technologies. Whether quality and investments are complements or substitutes is also in principle indeterminate. Laparoscopy or robotic surgery requires more doctor training, and can also take longer time than open surgery (especially if preparation time is included). A better diagnosis through an MRI scan can allow doctors to choose a treatment which is better suited for patients' needs therefore reducing unnecessary care, and reducing the cost of quality provision.

We assume that hospitals are prospectively financed by a third-party payer with a per-treatment price $p(I_i)$ and a fixed budget component or lump-sum transfer equal to $T(I_i)$. The fixed budget component ensures providers' participation in the market. Moreover, most countries use some form of payment that entails additional funding to hospitals to cover certain investments in technologies, including retrospective reimbursement of hospital reported costs outside the DRG price system (Sorenson, Drummond, Torbica, Callea, & Mateus, 2015). We therefore assume that the fixed budget component can be either independent of investment, $\partial T(I_i)/\partial I_i = 0$, or increasing in investment, $\partial T/\partial I_i > 0$, where part or all of the cost of new investments are reimbursed by the funder.

If the price is fixed (as in most DRG payment schemes) then $\partial p/\partial I_i = 0$. Although the price is fixed in this scenario, the price level can still vary depending on whether the payment system is designed to cover the investment costs. Some countries pay a higher fixed price which is meant to include investments costs, while others pay a lower price which is meant to cover treatment costs only (Scheller-Kreinsen et al., 2011). We also allow for the possibility that the price is increasing in investment, $\partial p(I_i)/\partial I_i > 0$. This assumption is consistent with payment mechanisms that allow DRGs to be split when a new technology becomes available (HOPE, 2006; Quentin et al., 2011).

Lastly, we assume that the regulator is able to pre-commit to a particular reimbursement policy for investments in health technologies. The hospital payment scheme described above relies on the assumption that investment in medical machinery and technology is verifiable, and thus contractible, while the hospitals' provision of service quality is not.[4] This assumption implies that hospital payments can be made contingent on investment. The hospitals' provision of quality, on the other hand, can only be indirectly incentivised, either through the per-treatment price, p, which affects the hospitals' incentives to attract demand, or through the payment for investment, $T(I_i)$, which affects the marginal benefits and costs of quality provision via changes in the hospitals' investment decisions (if $b^{Iq} \neq 0$ and $c^{Iq} \neq 0$).

The financial surplus of Hospital i, denoted π_i, is given by

$$\pi_i(I_i, I_j, q_i, q_j) = T(I_i) + [p(I_i) - c(I_i, q_i)]\, D_i(I_i, I_j, q_i, q_j) - k(I_i). \tag{4.3.6}$$

In line with the existing literature (e.g., Chalkley & Malcomson, 1998; Ellis & McGuire, 1986) we assume that hospitals are partly altruistic and care about the health benefit of the average patient. The objective function of Hospital i, denoted by V_i, is thus given by

$$V_i(I_i, I_j, q_i, q_j) = \alpha B(I_i, q_i) + \pi_i(I_i, I_j, q_i, q_j), \tag{4.3.7}$$

[4] More precisely, we assume that quality is observable but not verifiable, and thus not contractible.

where α is a positive parameter measuring the degree of provider altruism.

4.4 Simultaneous choices of investment and quality

As a benchmark for comparison, suppose that both hospitals choose investment in technology and service quality simultaneously. The Nash equilibrium is implicitly characterised by the first-order conditions for hospital choice of q_i and I_i given by

$$\frac{\partial V_i(I_i, I_j, q_i, q_j)}{\partial q_i} = \left(b^q + b^{Iq} I_i\right)\left[\alpha + \frac{p(I_i) - c(I_i, q_i)}{2t}\right] - \left(2c^q q_i + c^{Iq} I_i\right) D_i(I_i, I_j, q_i, q_j) = 0, \tag{4.4.1}$$

$$\begin{aligned}\frac{\partial V_i(I_i, I_j, q_i, q_j)}{\partial I_i} &= \left(b^I + b^{Iq} q_i\right)\left[\alpha + \frac{p(I_i) - c(I_i, q_i)}{2t}\right] + \frac{\partial T(I_i)}{\partial I_i} \\ &+ \left[\frac{\partial p(I_i)}{\partial I_i} - \left(c^I + c^{Iq} q_i\right)\right] D_i(I_i, I_j, q_i, q_j) - \frac{\partial k(I_i)}{\partial I_i} = 0\ .\end{aligned} \tag{4.4.2}$$

The second-order conditions are provided in the appendix section 4.A. The optimal level of service quality is set such that the marginal benefit from the altruistic health gain and the marginal revenue is traded-off against the higher costs from higher demand and higher per-patient treatment costs. The optimal level of investment is analogous. The marginal benefit from investment includes the altruistic health gain and the marginal revenues from higher demand, and potentially also a higher price and higher lump-sum transfer. Investment is optimally provided when the sum of marginal benefit is equal to marginal treatment costs from higher demand and the marginal investment cost (higher fixed costs), given by the final term in (4.4.2). Investment also affects per-patient cost, which will contribute to the marginal benefit of investments if cost reducing, $c^I + c^{Iq} q_i < 0$, or the marginal cost if cost augmenting, $c^I + c^{Iq} q_i > 0$.

At the symmetric equilibrium both hospitals choose quality and investment (denoted by q^* and I^*) which are implicitly given by[5]

$$V_q(I^*, q^*) = \left(\alpha + \frac{p(I^*) - c(I^*, q^*)}{2t}\right)\left(b^q + b^{Iq} I^*\right) - \frac{\left(2c^q q^* + c^{Iq} I^*\right)}{2} = 0, \tag{4.4.3}$$

[5] An interior solution with a positive level of service quality requires that the per-unit price p is sufficiently high.

$$V_I(I^*, q^*) = \left(\alpha + \frac{p(I^*) - c(I^*, q^*)}{2t}\right)\left(b^I + b^{Iq}q^*\right) + \frac{\partial T(I^*)}{\partial I} + \frac{1}{2}\left(\frac{\partial p(I^*)}{\partial I} - \left(c^I + c^{Iq}q^*\right)\right) - \frac{\partial k(I^*)}{\partial I} = 0 \ . \tag{4.4.4}$$

We use these expressions to compare the equilibrium under sequential choices, derived in the next section.

4.5 Sequential choices of investment and quality

In this section, we make the arguably more realistic assumption that hospitals make their investment decisions before the treatment quality decisions. This modelling approach is plausible given that investment decisions take time and are infrequent and hospitals invest before starting to treat patients, which is when service quality is provided. We therefore consider the following two-stage game:

Stage 1 Both providers choose simultaneously how much to invest.

Stage 2 Both providers simultaneously choose their service quality.

As usual, the game is solved by backward induction.

4.5.1 Quality competition

For a given pair of investment levels (I_i, I_j), the level of service quality that maximises the payoff of Hospital i is implicitly given by (4.4.1), and an analogous condition holds for Hospital j. In order to determine how the investment made by Hospital i affects the quality chosen by the two hospitals, we totally differentiate the system of first-order conditions given by $\partial V_i\left(I_i, I_j, q_i, q_j\right)/\partial q_i = 0$ and $\partial V_j\left(I_i, I_j, q_i, q_j\right)/\partial q_j = 0$ with respect to I_i by applying Cramer's Rule (see appendix section 4.B.1), yielding

$$\frac{\partial q_i\left(I_i, I_j\right)}{\partial I_i} = \frac{1}{\Delta}\left(\begin{array}{c} -\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^I + b^{Iq} q_i\right)}{t}\left(\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_j\right)}{4t} + c^q D_j\right) \\ +\left(\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_j\right)}{t} + 2c^q D_j\right)\left[\begin{array}{c} \left(b^{Iq}\frac{\left(2c^q q_i + c^{Iq} I_i\right)}{\left(b^q + b^{Iq} I_i\right)} - c^{Iq}\right) D_i \\ + \left(\frac{\partial p(I_i)}{\partial I_i} - \left(c^I + c^{Iq} q_i\right)\right)\frac{b^q + b^{Iq} I_i}{2t} \end{array}\right] \end{array}\right) \tag{4.5.1}$$

and

$$\frac{\partial q_j\left(I_i, I_j\right)}{\partial I_i}=\frac{1}{\Delta}\left(\begin{array}{c} \frac{\left(2c^q q_j+c^{Iq} I_j\right)\left(b^I+b^{Iq} q_i\right)}{2t}\left(\frac{\left(2c^q q_i+c^{Iq} I_i\right)\left(b^q+b^{Iq} I_i\right)}{2t}+c^q D_i\right) \\ +\frac{\left(2c^q q_j+c^{Iq} I_j\right)\left(b^q+b^{Iq} I_i\right)}{2t}\left[\begin{array}{c} \left(b^{Iq}\frac{\left(2c^q q_i+c^{Iq} I_i\right)}{\left(b^q+b^{Iq} I_i\right)}-c^{Iq}\right) D_i \\ +\left(\frac{\partial p(I_i)}{\partial I_i}-\left(c^I+c^{Iq} q_i\right)\right)\frac{b^q+b^{Iq} I_i}{2t} \end{array}\right] \end{array}\right), \tag{4.5.2}$$

where $\Delta > 0$ is given by (4.B.13) in the appendix section 4.B.1. The sign of (4.5.1) determines whether investment and quality for Hospital i are substitutes ($\partial q_i/\partial I_i < 0$) or complements ($\partial q_i/\partial I_i > 0$). The sign of (4.5.2) determines whether the investment of Hospital i's and the quality of Hospital j are strategic substitutes ($\partial q_j/\partial I_i < 0$) or strategic complements ($\partial q_j/\partial I_i > 0$). Both of these expressions have an *a priori* indeterminate sign.

As a benchmark, consider the case in which I_i and q_i are neither complements nor substitutes in costs ($c^{Iq} = 0$) and benefits ($b^{Iq} = 0$), and where any increase in the marginal cost of investments is exactly offset by a marginal increase in price so that the price-cost margin remains unchanged ($\partial p(I_i)/\partial I_i - c^I = 0$). In this case (4.5.1)-(4.5.2), reduce to

$$\frac{\partial q_i}{\partial I_i}=-\frac{q_i b^I\left(q_j b^q+2tD_j\right)}{3\left(b^q\right)^2 q_j q_i+4t\left(D_j q_i b^q+D_i q_j b^q+tD_i D_j\right)}<0 \tag{4.5.3}$$

and

$$\frac{\partial q_j}{\partial I_i}=\frac{q_j b^I\left(q_i b^q+tD_i\right)}{3\left(b^q\right)^2 q_j q_i+4t\left(D_j q_i b^q+D_i q_j b^q+tD_i D_j\right)}>0. \tag{4.5.4}$$

Thus, own investment and own quality are substitute strategies (i.e., $\partial q_i/\partial I_i < 0$) whereas own investment and rival's quality are strategic complements (i.e., $\partial q_j/\partial I_i > 0$). The intuition for this is fairly straightforward. All else equal, higher investment by Hospital i shifts demand from Hospital j to Hospital i (as long as $b^I > 0$). Because marginal treatment costs are increasing in quality, such a demand shift leads to higher (lower) marginal cost of quality provision for Hospital i (Hospital j), as can be seen from the third term in (4.4.1). Consequently, a higher investment by Hospital i leads to lower (higher) service quality by Hospital i (Hospital j), all else equal.

The effects in this benchmark scenario can be either reinforced or weakened by the presence of *three additional effects*. First, if higher investment increases (reduces) the price-cost margin of Hospital i, this will increase (reduce) the profitability of attracting more demand by offering higher service quality, thus leading to higher (lower) quality offered by Hospital i, all else equal. Second, if investment and quality are complements (substitutes) in the benefit function (i.e., if $b^{Iq} > (<) 0$), this will increase (reduce) both the demand responsiveness and the marginal health benefit gain of quality provision, thus leading to higher (lower) quality offered by Hospital i, all else equal. Third, if investment and quality are complements (substitutes) in the cost function (i.e., if $c^{Iq} < (>) \, 0$), this will reduce (increase) the marginal cost of quality provision, thus leading to higher (lower) quality chosen by Hospital i, all else equal.

Each of these three additional effects work in the same direction for both $\partial q_i/\partial I_i$ and $\partial q_j/\partial I_i$. In other words, an effect that establishes a *ceteris paribus* positive effect of I_i on q_i also implies a *ceteris paribus* positive effect of I_i on q_j. The reason is that qualities are strategic complements in the second-stage subgame, as defined by $\partial^2 V_i/\partial q_i \partial q_j = \left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_j\right)/2t > 0$ (see appendix section 4.B.1). This strategic relationship is due to the assumption that the marginal cost of quality provision increases with demand ($\partial^2 C/\partial D_i \partial q_i = 2c^q q_i + c^{Iq} I_i > 0$). All else equal, higher quality provision by Hospital i leads to lower demand for Hospital j, which reduces the marginal cost of quality provision and thus increases the optimal quality choice for the latter hospital.

Finally, note that it is possible for own investment and quality to be complements, $\partial q_i/\partial I_i > 0$. This arises for example if investment has no effect on health benefits, but reduces costs, and benefit and cost are independent ($b^{Iq} = c^{Iq} = b^I = 0$ and $c^I < 0$), so that

$$\frac{\partial q_i\left(I_i, I_j\right)}{\partial I_i} = \frac{c^q b^q}{t\Delta}\left(\frac{q_j b^q}{t} + D_j\right)\left(\frac{\partial p(I_i)}{\partial I_i} - c^I\right) > 0 \tag{4.5.5}$$

and

$$\frac{\partial q_j\left(I_i, I_j\right)}{\partial I_i} = \frac{c^q\left(b^q\right)^2 q_j}{2t^2\Delta}\left(\frac{\partial p(I_i)}{\partial I_i} - c^I\right) > 0. \tag{4.5.6}$$

4.5.2 Investment decisions

In the first stage of the game, hospitals decide how much to invest, taking into account the effect that the investment will have on quality decisions of both hospitals in the second stage. The first-order condition for Hospital i is given by

$$\begin{aligned}
\frac{\partial V_i(I_i, I_j, q_i, q_j)}{\partial I_i} &= \left(b^I + b^{Iq} q_i\right)\left[\alpha + \frac{p(I_i) - c(I_i, q_i)}{2t}\right] + \left(\frac{\partial p(I_i)}{\partial I_i} - \left(c^I + c^{Iq} q_i\right)\right) D_i \\
&+ \frac{\partial T(I_i)}{\partial I_i} - \frac{\partial k(I_i)}{\partial I_i} - \frac{b^q + b^{Iq} I_j}{2t}\left[p(I_i) - c(I_i, q_i)\right]\frac{dq_j}{dI_i} \\
&+ \left[\left(b^q + b^{Iq} I_i\right)\left[\alpha + \frac{p(I_i) - c(I_i, q_i)}{2t}\right] - \left(2c^q q_i + c^{Iq} I_i\right) D_i\right]\frac{dq_i}{dI_i} = 0.
\end{aligned} \tag{4.5.7}$$

The second order condition is provided in appendix section 4.B.2. The first line and the first two terms in the second line in (4.5.7) are identical to the investment condition in the simultaneous-move version of the game given by (4.4.2). The two additional terms in the second and third line of (4.5.7) capture the strategic effects of Hospital i's investment on the quality choices of both hospitals. However, the third line in (4.5.7) is equal to zero due to the envelope theorem; given that Hospital i chooses a payoff-maximising quality level, the expression in the square bracket is zero (see (4.4.1)).

Applying symmetry, quality and investment in the symmetric subgame-perfect Nash equilibrium (denoted by q^{**} and I^{**}) are implicitly given by

$$V_q(I^{**}, q^{**}) = \left(\alpha + \frac{p(I^{**}) - c(I^{**}, q^{**})}{2t}\right)\left(b^q + b^{Iq} I^{**}\right) - \frac{2c^q q^{**} + c^{Iq} I^{**}}{2} = 0, \tag{4.5.8}$$

and

$$\begin{aligned} V_I(I^{**}, q^{**}) = &\left(\alpha + \frac{p(I^{**}) - c(I^{**}, q^{**})}{2t}\right)\left(b^I + b^{Iq} q^{**}\right) + \frac{\partial T(I^{**})}{\partial I} \\ &+\frac{1}{2}\left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq} q^{**}\right)\right) - \frac{\partial k(I^{**})}{\partial I} \\ &-\frac{\left(b^q + b^{Iq} I^{**}\right)}{2t}\left[p(I^{**}) - c(I^{**}, q^{**})\right]\frac{\partial q_j\left(I^{**}\right)}{\partial I_i} = 0 \end{aligned} \tag{4.5.9}$$

where

$$\frac{\partial q_j\left(I^{**}\right)}{\partial I_i} = \frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)}{4t\Delta}\left(\begin{array}{c} c^q\left(b^I + b^{Iq} q^{**}\right) \\ +\left(b^q + b^{Iq} I^{**}\right)\left(\begin{array}{c} b^{Iq}\frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)}{\left(b^q + b^{Iq} I^{**}\right)} - c^{Iq} \\ +\frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^I + b^{Iq} q^{**}\right)}{t} \\ +\left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq} q^{**}\right)\right)\frac{b^q + b^{Iq} I^{**}}{t} \end{array}\right)\end{array}\right). \tag{4.5.10}$$

Comparing (4.4.3) and (4.5.8), we see that equilibrium quality is identical under the simultaneous and sequential solution if and only if $I^* = I^{**}$. On the other hand, equilibrium investment is generally different when $q^* = q^{**}$. Comparing (4.4.4) and (4.5.9), the difference in the investment conditions is given by the last term in (4.5.9), which captures the strategic effect of own investment on the competing hospital's quality choice in the second stage. It follows that equilibrium investment and quality are the same under simultaneous and sequential decision making (i.e., $q^* = q^{**}$ and $I^* = I^{**}$) only if the investment of Hospital i has no strategic effect on the quality choice of Hospital j (i.e., if $\partial q_j\left(I^{**}\right)/\partial I_i = 0$).

Whether hospitals have an incentive to over- or underinvest in medical technology depends on the sign of $\partial q_j\left(I^{**}\right)/\partial I_i$ and the price-cost margin, $p(I^{**}) - c(I^{**}, q^{**})$, which can be positive or negative depending on the degree of altruism.[6] Suppose that the price cost margin is positive in equilibrium. There is *underinvestment* if own investment

[6]To see that this is the case, we can re-write

$$V_q(I^{**}, q^{**}) = 0$$

and rival's quality choice are *strategic complements* ($\partial q_j \left(I^{**}\right) / \partial I_i > 0$) and *overinvestment* if they are *strategic substitutes* ($\partial q_j \left(I^{**}\right) / \partial I_i < 0$). The intuition is related to the strategic complementarity of quality choices in the second-stage subgame (i.e., $\partial^2 V_i / \partial q_i \partial q_j > 0$). If $\partial q_j / \partial I_i > 0$, each hospital has a strategic incentive to reduce investment at the first stage of the game in order to dampen quality competition at the second stage. These incentives are reversed if $\partial q_j / \partial I_i < 0$, which implies that quality competition can be dampened by *increasing* investment. The results are however reversed if the price-cost margin is negative, which requires a sufficiently high degree of altruism.

We summarise this first result in the following proposition:

Proposition 4.1. *Hospitals underinvest in a sequential game, relative to a simultaneous game, if (i) the price-cost margin is positive,* $p(I^{**}) - c(I^{**}, q^{**}) > 0$*, and investments and rival's quality are strategic complements,* $\partial q_j \left(I^{**}\right) / \partial I_i > 0$*, or if (ii) the price-cost margin is negative,* $p(I^{**}) - c(I^{**}, q^{**}) < 0$*, and investments and rival's quality are strategic substitutes,* $\partial q_j \left(I^{**}\right) / \partial I_i < 0$*. Hospitals overinvest if (i) the price-cost margin is positive,* $p(I^{**}) - c(I^{**}, q^{**}) > 0$*, and investments and rival's quality are strategic substitutes,* $\partial q_j \left(I^{**}\right) / \partial I_i < 0$*, or if (ii) the price-cost margin is negative,* $p(I^{**}) - c(I^{**}, q^{**}) < 0$*, and investments and rival's quality are strategic complements,* $\partial q_j \left(I^{**}\right) / \partial I_i > 0$.

We now turn to the comparison of quality. Whether the hospitals over- or under-provide quality relative to the simultaneous game, depends on whether investment and quality are complements or substitutes in equilibrium, which from (4.5.8) depends on the sign of

$$\frac{\partial V_q(I^{**}, q^{**})}{\partial I} = \frac{\left(b^q + b^{Iq} I^{**}\right)}{2t} \left[\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq} q^{**}\right)\right] + b^{Iq} \left(\frac{2c^q q^{**} + c^{Iq} I^{**}}{2\left(b^q + b^{Iq} I^{**}\right)}\right) - \frac{c^{Iq}}{2}. \tag{4.5.11}$$

If the price-cost margin increases with investment, $\partial p(I^{**}) / \partial I - \left(c^I + c^{Iq} q^{**}\right) > 0$, quality and investment are always complements if they are complements in health benefits and costs, but the scope for complementarity instead reduces if investment and quality are substitutes in health benefits and costs.

We summarise our second result in the following proposition:

Proposition 4.2. *Quality is underprovided in a sequential game, relative to a simultaneous game, if (i) hospitals underinvest, and investment and quality are complements,* $\partial V_q(I^{**}, q^{**}) / \partial I > 0$*, or if (ii) hospitals overinvest,*

as

$$p(I^{**}) - c(I^{**}, q^{**}) = 2t \left(\frac{2c^q q^{**} + c^{Iq} I^{**}}{2\left(b^q + b^{Iq} I^{**}\right)} - \alpha\right).$$

and investment and quality are substitutes, $\partial V_q(I^{**}, q^{**})/\partial I < 0$. Instead, quality is overprovided if (i) hospitals underinvest, and investment and quality are substitutes, $\partial V_q(I^{**}, q^{**})/\partial I < 0$, or if (ii) hospitals overinvest, and investment and quality are complements, $\partial V_q(I^{**}, q^{**})/\partial I > 0$.

To gain some further insights on whether sequential decision making leads to higher or lower investments, and higher or lower quality provision, we will consider a few special cases which allow us to isolate each of the different mechanisms at play and link them to the basic assumptions of our model. In each case, the results depend on whether each hospital's price-cost margin is positive or negative in equilibrium, which in turn depends on the degree of altruism. More specifically, the price-cost margin is positive if the hospitals are sufficiently profit-oriented, and negative if they are sufficiently altruistic:

$$p(I^{**}) - c(I^{**}, q^{**}) > (<)\, 0 \quad if \quad \alpha < (>)\, \widehat{\alpha} := \frac{2c^q q^{**} + c^{Iq} I^{**}}{2\left(b^q + b^{Iq} I^{**}\right)}. \tag{4.5.12}$$

We present the different cases as four separate Lemmas, starting with what we have previously referred to as a benchmark case.

Lemma 4.1. *Suppose that investment and quality are cost and benefit independent ($c^{Iq} = b^{Iq} = 0$), and that investments have no effect on the price-cost margin ($\partial p(I^{**})/\partial I - c^I = 0$). In this case, quality provision is identical under sequential and simultaneous choices, whereas hospitals underinvest in the sequential game if $\alpha < \widehat{\alpha}$ and overinvest if $\alpha > \widehat{\alpha}$.*

In the benchmark case, where investment and quality are independent in the health benefit and costs functions, and where investments do not affect the price-cost margin, the equilibrium level of investments have no effect on each hospital's incentive for quality provision, i.e., $\partial V_q(I^{**}, q^{**})/\partial I = 0$, which implies that equilibrium quality provision is the same in the two versions of the game. Investment incentives, on the other hand, are affected through the term $\partial q_j\left(I^{**}\right)/\partial I_i$, which is unambiguously positive in the benchmark case. All else equal, higher investment by one hospital leads to higher quality provision by the competing hospital, because of lower marginal cost of quality provision caused by lower demand. This creates a strategic incentive in the sequential game that affects the optimal investment decision. As long as the price-cost margin is positive, each hospital has an incentive to attract more patients by inducing a lower quality provision from the competing hospital, and this can be achieved by *underinvesting* at the first stage of the game. Such an incentive exists if the hospitals are sufficiently profit-oriented.

However, if the hospitals are sufficiently altruistic, so that the price-cost margin is negative in equilibrium, the investment incentives are the exact opposite. In this case, each hospital has an incentive to *reduce* demand (from unprofitable patients) by inducing a higher quality provision from the competing hospital, which can be achieved by *overinvesting* at the first stage. Notice, however, that since both hospitals have the same unilateral incentive to use the investment decision to strategically affect quality provision, these incentives cancel each other in equilibrium, leaving equilibrium quality provision unchanged.

Lemma 4.2. *Suppose that investment and quality are (weak) complements in the health benefit and cost functions, and that the price-cost margin is weakly increasing in investments: (i)* $b^{Iq} \geq 0$*, (ii)* $c^{Iq} \leq 0$ *and (iii)* $\partial p(I^{**})/\partial I - \left(c^I + c^{Iq}q^{**}\right) \geq 0$*. If at least one of the inequalities in (i)-(iii) is strict, then investment and quality provision are both lower (higher) in the sequential game if* $\alpha < (>) \widehat{\alpha}$*.*

Similar to the benchmark case, assumptions (i)-(iii) in Lemma 2 ensure that there is strategic complementarity between own investment and rival's quality provision, i.e. $\partial q_j \left(I^{**}\right) / \partial I_i > 0$. This implies that the hospital's incentives for under- or overinvestment are qualitatively the same as in the benchmark case (cf. Lemma 1). However, in contrast to the benchmark case, the introduction of these assumptions implies that investment and quality are equilibrium complements, i.e., $\partial V_q(I^{**}, q^{**})/\partial I > 0$, which implies that the strategic investment effect also affects equilibrium quality provision. More specifically, higher (lower) investments also imply higher (lower) equilibrium quality provision. Thus, depending on the degree of hospital altruism, investment and quality are either both higher or both lower in the sequential game.

Notice that only one of the assumptions in (i)-(iii) is needed in order to produce the results given by Lemma 2 (given that the other assumptions are as in the benchmark case of Lemma 1). One example that fits this case is laparoscopic (less invasive) surgery, which improves health outcomes for a given treatment quality and reduces treatment costs, and accordingly the marginal cost of quality provision.

Lemma 4.3. *Suppose that investment and quality are substitutes in the health benefit and cost functions (*$b^{Iq} < 0$ *and* $c^{Iq} > 0$*), and that the price-cost margin is decreasing in investments (*$\partial p(I^{**})/\partial I - \left(c^I + c^{Iq}q^{**}\right) < 0$*). Suppose also that all of these effects are 'small' in magnitude. In this case, in the sequential game hospitals underinvest while overproviding quality if* $\alpha < \widehat{\alpha}$ *and overinvest while underproviding quality if* $\alpha > \widehat{\alpha}$*.*

This case differs from the previous one in that investment and quality are equilibrium substitutes, implying that overinvestment will be accompanied by underprovision of quality, while underinvestment will lead to overprovision of quality. Notice that for investment and quality to be equilibrium substitutes, it is enough to have $b^{Iq} < 0$ *or* $c^{Iq} > 0$ *or* $\partial p(I^{**})/\partial I - \left(c^I + c^{Iq}q^{**}\right) < 0$, given that other assumptions are as in the benchmark case. As long as all of these effects are sufficiently small, strategic complementarity between own investment and rival's quality remains, which implies that the investment incentives are as in the benchmark case.

	$\frac{\partial(p-c)}{\partial I}$	b^{Iq}	c^{Iq}	$\frac{\partial q_j}{\partial I_i}$	$\frac{\partial V_q}{\partial I}$	If $\alpha < \widehat{\alpha}$:	If $\alpha > \widehat{\alpha}$:
(I)	0	0	0	> 0	0	$I^{**} < I^*, q^{**} = q^*$	$I^{**} > I^*, q^{**} = q^*$
(II)	> 0	> 0	< 0	> 0	> 0	$I^{**} < I^*, q^{**} < q^*$	$I^{**} > I^*, q^{**} > q^*$
(III)	$< 0\,(s)$	$< 0\,(s)$	$> 0\,(s)$	> 0	< 0	$I^{**} < I^*, q^{**} > q^*$	$I^{**} > I^*, q^{**} < q^*$
(IV)	$< 0\,(l)$	$< 0\,(l)$	$> 0\,(l)$	< 0	< 0	$I^{**} > I^*, q^{**} < q^*$	$I^{**} < I^*, q^{**} > q^*$
$s =$ 'small' in absolute value; $l =$ 'large' in absolute value							

Table 4.5.1: Comparison of equilibria under simultaneous and sequential choices

Lemma 4.4. *Suppose that investment and quality are substitutes in the health benefit and cost functions ($b^{Iq} < 0$ and $c^{Iq} > 0$), and that the price-cost margin is decreasing in investments ($\partial p(I^{**})/\partial I - \left(c^I + c^{Iq}q^{**}\right) < 0$). Suppose also that at least one of these effects is 'large' in magnitude. In this case, in the sequential game hospitals overinvest while underproviding quality if $\alpha < \widehat{\alpha}$ and underinvest while overproviding quality if $\alpha > \widehat{\alpha}$.*

In our final case considered, we assume that the degree of benefit or cost substitutability between investment and quality is so large that the strategic nature of the game changes, making own investment and rival's quality strategic substitutes, i.e., $\partial q_j\left(I^{**}\right)/\partial I_i < 0$. Alternatively, strategic substitutability could also arise if investments have a sufficiently large negative effect on the price-cost margin, for example investments that lead to considerably higher treatment costs. This changes the strategic investment incentives relative to the benchmark case. If the hospitals are sufficiently profit-oriented, so that the equilibrium price-cost margin is positive, each hospital has an incentive to invest more in order to induce lower quality from the rival hospital at the quality competition stage. The opposite incentives apply if the price-cost margin is negative, which requires that the hospitals are sufficiently altruistic. As in the case considered by Lemma 3, the incentives for quality provision follow from the fact that investment and quality are equilibrium substitutes.

The special cases covered by Lemma 4.1-4.4 are summarised in table 4.5.1.

4.6 Social welfare

In this section we present a welfare analysis in two parts. In the first part, we adopt a normative approach. We derive the first-best solution and show how this solution could be implemented through an optimal design of the payment contract. In the second part, we take a more positive approach by acknowledging that hospital payment schemes are often based on average-cost pricing rules and are unlikely to coincide with the optimal ones that maximise welfare. In this second part we analyse instead the welfare effects of several plausible policy reforms, which we define as switching between different types of hospital payment schemes that we observe across countries.

As the basis of our analysis in this section, we define social welfare, denoted by W, as the difference between aggregate patient utility and providers' costs, given by

$$W(I_i, I_j, q_i, q_j) = \varpi - \sum_{i=1}^{2} C(D_i, I_i, q_i). \tag{4.6.1}$$

where

$$\varpi = \int_0^{D_i(I_i,I_j,q_i,q_j)} (v + B(I_i, q_i) - tx)\, dx + \int_{D_i(I_i,I_j,q_i,q_j)}^{1} (v + B(I_j, q_j) - t\,(1 - x))\, dx. \tag{4.6.2}$$

is aggregate patient utility.

4.6.1 The first-best solution

Suppose that a welfarist regulator is able to choose investment, quality and demand for each hospital. Since the model is symmetric and aggregate transportation costs are minimised when each patient attends the nearest hospital, the first-best solution must necessarily be symmetric with equal investment and quality provision for each provider. Imposing symmetry, social welfare can be expressed as

$$W(I, q) = v + B(I, q) - \frac{t}{4} - c(I, q) - 2k(I). \tag{4.6.3}$$

Maximising (4.6.3) with respect to service quality and investment, we obtain the first best solution, denoted by (q^s, I^s), and implicitly given by[7]

$$\frac{\partial W(I,q)}{\partial q} = b^q + b^{Iq} I^s - \left(2c^q q^s + c^{Iq} I^s\right) = 0, \tag{4.6.4}$$

$$\frac{\partial W(I,q)}{\partial I} = b^I + b^{Iq} q^s - \left(c^I + c^{Iq} q^s\right) - 2\frac{\partial k(I^s)}{\partial I} = 0. \tag{4.6.5}$$

The socially optimal levels of investment and quality are characterised by the standard condition that marginal benefits equal marginal costs. The investment and quality levels given by (4.6.4)-(4.6.5) can be implemented as an equilibrium outcome by an appropriate design of the hospital payment scheme. However, the optimal payment contract depends on the characteristics of the game played by the hospitals, i.e., whether investment and quality decisions are made

[7] Second order conditions are provided in appendix section 4.C.1.

simultaneously or sequentially. A comparison of (4.6.4)-(4.6.5) with (4.4.3)-(4.4.4) and (4.5.8)-(4.5.9), respectively, allows us to reach the following conclusions:

Proposition 4.3. *(i) If investment and quality decisions are made simultaneously, the first-best solution can be implemented by a payment contract* $\left\{\widehat{p}\left(I_i\right), \widehat{T}\left(I_i\right)\right\}$*, where*

$$\widehat{p}\left(I^*\right) = c\left(I^*, q^*\right) + (1-2\alpha)t = c\left(I^s, q^s\right) + (1-2\alpha)t, \tag{4.6.6}$$

and

$$\frac{\partial \widehat{p}}{\partial I_i} = \frac{\partial \widehat{T}}{\partial I_i} = 0, \tag{4.6.7}$$

with $\left(I^*, q^*\right)$ *implicitly given by (4.4.3)-(4.4.4).*

(ii) If investment and quality decisions are made sequentially, the first-best solution can be implemented by a payment contract $\left\{\widetilde{p}\left(I_i\right), \widetilde{T}\left(I_i\right)\right\}$*, where*

$$\widetilde{p}\left(I^{**}\right) = c\left(I^{**}, q^{**}\right) + (1-2\alpha)t = c\left(I^s, q^s\right) + (1-2\alpha)t, \tag{4.6.8}$$

and

$$2\frac{\partial \widetilde{T}\left(I^{**}\right)}{\partial I_i} + \frac{\partial \widetilde{p}\left(I^{**}\right)}{\partial I_i} = (1-2\alpha)\left(b^q + b^{Iq}I^{**}\right)\frac{\partial q_j\left(I^{**}\right)}{\partial I_i}, \tag{4.6.9}$$

with $\left(I^{**}, q^{**}\right)$ *implicitly given by (4.5.8)-(4.5.9) and* $\partial q_j\left(I^{**}\right)/\partial I_i$ *given by (4.5.10).*

The first part of the proposition shows that, if hospitals make investment and quality decisions simultaneously, the first-best solution can be implemented by a very simple payment contract that just specifies an appropriate level of the per-treatment price. If this price is set at the level given by (4.6.6), the hospitals will both invest and provide quality at the first-best level. Thus, it is possible for the regulator to kill two birds with one stone, and no other regulatory instruments are needed to achieve the first-best outcome.

The intuition for this result is the following. The optimal first-best quality and investment depend on their marginal patient benefits, $\partial B/\partial q_i$ and $\partial B/\partial I_i$, respectively. The equilibrium quality and investment, on the other hand, depend *inter alia* on how strongly demand responds to changes in quality and investment. However, the demand responsiveness to quality and investment also depend on their respective marginal patient benefits. Thus, both the first-best and the equilibrium levels of quality and investment are proportional to their marginal patient benefits. Moreover, since the degree of demand responsiveness of both quality and investment depends on the same transportation cost parameter, t, which we can interpret as an inverse measure of competition intensity, the providers' incentives for providing quality relative to investment are exactly proportional to the social planner's relative valuation of quality and investment, for any given treatment price p. The regulator can therefore vary the price to stimulate both quality and investment proportionally up to the first best levels.

As intuitively expected, and as seen from (4.6.6), the optimal price is inversely proportional to the degree of provider altruism. The first-best solution is implemented with a price above (below) marginal treatment costs if α is below (above) one half. How the optimal price depends on competition intensity also depends on the degree of altruism. If the degree of altruism is relatively low ($\alpha < 1/2$), so that the price-cost margin in the first-best solution is positive, more competition stimulates investments and quality provision and the optimal price must therefore be adjusted downwards. On the other hand, if the degree of altruism is sufficiently high ($\alpha > 1/2$), increased competition leads to a reduction in quality provision and investments because of a negative price-cost margin, which implies that the optimal price must be adjusted upwards in order to preserve the first-best outcome.

The conclusion that the optimal payment contract only needs to specify the per-treatment price no longer holds if investment and quality decisions are made sequentially. In this case, the price p that induces the first-best level of quality will lead to either under- or overinvestment, where the conditions for one or the other to occur are given by Proposition 1. Thus, the hospitals' inability to commit to a particular level of quality provision can be identified as a source of inefficiency which necessitates a richer set of regulatory tools in order to implement the first-best outcome. The optimal payment contract must therefore be complemented by at least one more instrument which incentivises investments separately. This can be done by making either the lump-sum payment or the per-treatment price dependent on investment; i.e., $\partial T/\partial I_i \neq 0$ or $\partial p/\partial I_i \neq 0$.[8]

Notice that the optimal per-treatment price (at equilibrium) remains the same under the sequential game and the simultaneous game, while it is the dependence of the per-treatment price or the lump-sum payment on investment which allows to correct for possible under- or over-investment under the sequential game. To further illustrate this result, suppose that the payment contract is such that both the per-treatment price and the lump-sum transfer are linear in investment, i.e., $p\left(I_i\right) = p_0 + p_1 I_i$ and $T\left(I_i\right) = T_0 + T_1 I_i$. The first-best solution can then be implemented in two different ways. (i) A simple optimal payment rule is such that $\widehat{p}_0 = \widetilde{p}_0 = c\left(I^s, q^s\right) + (1-2\alpha)t$ and $\widehat{p}_1 = \widetilde{p}_1 = 0$, for both the simultaneous and the sequential game. Instead, this optimal payment involves $\widehat{T}_1 = 0$ for the simultaneous game, and $\widetilde{T}_1 = (1/2-\alpha)\left(b^q + b^{Iq} I^s\right)\left(\partial q_j\left(I^s\right)/\partial I_i\right)$ in the sequential game. This payment involves only a fixed per-treatment price under both games, and a lump-sum transfer which either increases or decreases in investment under the sequential game. (ii) An alternative optimal payment is such that $\widehat{p}_0 = c\left(I^s, q^s\right) + (1-2\alpha)t$ and $\widehat{p}_1 = \widehat{T}_1 = 0$ under the simultaneous game, whereas $\widetilde{p}_0 = c\left(I^s, q^s\right) + (1-2\alpha)t - \widetilde{p}_1 I^s$,

[8]Some countries, such as France, Italy and Poland, use a payment contract that implements two instruments, where the reimbursement of capital cost is separate from the DRG tariff.

$\widetilde{p}_1 = (1-2\alpha)\left(b^q + b^{Iq} I^s\right)\left(\partial q_j\left(I^s\right)/\partial I_i\right)$ and $\widetilde{T}_1 = 0$ under the sequential game. This payment still involves only a fixed per-treatment price under the simultaneous game, but a per-treatment price which either increases or decreases in investment in the sequential game. More specifically, this payment scheme implies $\widetilde{p}_0 \neq \widehat{p}_0$ and $\widetilde{p}_1 \neq 0$ for $I_i \neq I^s$ and $\widetilde{p}_0 = \widehat{p}_0$ and $\widetilde{p}_1 = 0$ for $I = I^s$.

Exactly how the optimal payment scheme should be designed in relation to the investment component depends on the level of hospital altruism and on the strategic relationship between investment and quality. Suppose that own investment and rival's quality are strategic complements ($\partial q_j/\partial I_i > 0$). If in addition the hospitals are sufficiently profit oriented ($\alpha < 1/2$), the first-best payment scheme should include an investment subsidy to counteract hospital incentive to underinvest, either through the lump-sum directly ($\partial T/\partial I_i > 0$) or the per-treatment price ($\partial p/\partial I_i > 0$). On the other hand, if the hospitals are sufficiently altruistic ($\alpha > 1/2$), so that the price-cost margin is negative in equilibrium, the first-best outcome is achieved by *disincentivising* investment, for example by making T a decreasing function of I. The opposite results hold when investment and rival's quality are strategic substitutes. If the price-cost margin is positive, the first-best payment scheme disincentivises investment. If the price cost margin is negative, the payment scheme incentivises investment. Therefore, although our results are in general indeterminate, we can precisely characterise the optimal payment scheme as a function of the price-cost margin and the strategic relationship between quality and investment.

4.6.2 Policy options

In this section, we investigate three different policy options, which reflect observed differences in real-world payment schemes across different countries. To do so, without much loss of generality, we restrict the payment contract to the linear specifications $p\left(I_i\right) = p_0 + p_1 I_i$ and $T\left(I_i\right) = T_0 + T_1 I_i$. We also only focus on the (more realistic) sequential game solution, implying that welfare is measured by

$$W(I^{**}, q^{**}) = v + B(I^{**}, q^{**}) - \frac{t}{4} - c(I^{**}, q^{**}) - 2k(I^{**}). \tag{4.6.10}$$

4.6.2.1 Paying separately for investment

Consider a policy that introduces a payment rule which rewards investment in health technologies through the lump-sum payment to cover part or all of the capital costs, on top of the DRG per-treatment payment, which is line with arrangements in Germany, Ireland, Norway, Portugal and Spain (Quentin et al., 2011). Analytically, the payment rule before the policy is $p\left(I_i\right) = p_0$, $T\left(I_i\right) = \overline{T}_0$, and after the policy it is $p\left(I_i\right) = p_0$, $T\left(I_i\right) = \underline{T}_0 + T_1 I_i$, with

$\overline{T}_0 > \underline{T}_0$ and $T_1 > 0$. Given that changes in $\overline{T}_0$ and $\underline{T}_0$ have no effect on quality and investment, the only effect on welfare is driven by the introduction of T_1. Thus, we can assess the effect of the reform by applying the post-policy payment rule and doing comparative statics on T_1. Differentiating (4.6.10) with respect to T_1 yields

$$\frac{dW(I^{**}, q^{**})}{dT_1} = \frac{\partial W(I^{**}, q^{**})}{\partial I}\frac{\partial I^{**}}{\partial T_1} + \frac{\partial W(I^{**}, q^{**})}{\partial q}\frac{\partial q^{**}}{\partial T_1}, \tag{4.6.11}$$

with

$$\frac{\partial I^{**}}{\partial T_1} = \frac{1}{\phi}\left[\frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^q + b^{Iq} I^{**}\right)}{2t} + c^q\right] > 0, \tag{4.6.12}$$

$$\frac{\partial q^{**}}{\partial T_1} = \frac{V_{qI}}{\phi} \gtrless 0, \tag{4.6.13}$$

where the definitions of $\phi > 0$ and $V_{qI} \gtrless 0$, and further details, are given in appendix section 4.C.2.

The effect of the reform on the equilibrium level of investment is straightforward. A marginal increase in T_1 increases the marginal revenue of investment and therefore leads to higher investment. It also leads to higher service quality if investment and quality are complements ($V_{qI} > 0$), but to lower service quality if they are substitutes ($V_{qI} < 0$).

Suppose that, pre-reform, equilibrium investment and quality are *below* the first best level ($\partial W(I^{**}, q^{**})/\partial I > 0$ and $\partial W(I^{**}, q^{**})/\partial q > 0$). For example, this could arise if the DRG price is below the first-best level, $p_0 < \widetilde{p}\,(I^{**})$, there are no payments associated to additional hospital investments, $\partial \widetilde{T}\,(I^{**})\,/\partial I_i = \partial \widetilde{p}\,(I^{**})\,/\partial I_i = 0$, own investment and rival's quality are strategic complements ($\partial q_j/\partial I_i > 0$) and hospitals are sufficiently profit oriented. Then the introduction of a payment which incentivises investment separately is always welfare improving when investment and quality are complements ($V_{qI} > 0$), or if quality and investment are substitutes as long as the degree of substitutability is sufficiently small. This policy is also welfare improving if equilibrium investment is below the first best level and equilibrium quality is above the first best level (i.e., $\partial W(I^{**}, q^{**})/\partial I > 0$ and $\partial W(I^{**}, q^{**})/\partial q < 0$) if investments and qualities are substitutes ($V_{qI} < 0$) or if they are complements but the degree of complementarity is sufficiently small.

The results are reversed when investment and quality are *above* the first best level ($\partial W(I^{**}, q^{**})/\partial I < 0$ and $\partial W(I^{**}, q^{**})/\partial q < 0$). Then the introduction of a payment scheme which financially rewards investment is always welfare reducing if investment and quality are complements, or if they are substitutes but the degree of substitutability is sufficiently small. The policy is still welfare reducing when equilibrium investment is above the first best level and equilibrium quality is below the first best level (i.e., $\partial W(I^{**}, q^{**})/\partial I < 0$ and $\partial W(I^{**}, q^{**})/\partial q > 0$), if investment and quality are substitutes, or if they are complements but the degree of complementarity sufficiently small.

In summary, the effect of a policy that pays separately for investment is driven by whether investment levels are above or below the first best level under two different scenarios: (i) indirect welfare effects through changes in service quality are sufficiently small or (ii) the quality welfare effects go in the same direction as the investment welfare effects.

4.6.2.2 Paying for investment through a higher DRG price

Consider a policy which replaces a payment rule where investment is paid through a separate lump-sum payment with one that includes payment for capital costs exclusively through the DRG per-treatment payment, like in countries such as Austria, England, Estonia, Finland, Netherlands, Sweden and Switzerland (Scheller-Kreinsen et al., 2011). Analytically, before the policy the payment rule is $p(I_i) = \underline{p}_0$, $T(I_i) = T_0$, and after the reform it is $p(I_i) = \overline{p}_0$, $T(I_i) = 0$, with $\overline{p}_0 > \underline{p}_0$ and $T_0 > 0$. Given that changes in T_0 have no effect on quality and investment, the only effect on welfare is driven by the increase in the DRG tariff. We can therefore assess the effects of this policy reform by doing comparative statics on p_0. Differentiating (4.6.10) with respect to p_0 yields

$$\frac{dW(I^{**}, q^{**})}{dp_0} = \frac{\partial W(I^{**}, q^{**})}{\partial I} \frac{\partial I^{**}}{\partial p_0} + \frac{\partial W(I^{**}, q^{**})}{\partial q} \frac{\partial q^{**}}{\partial p_0}, \tag{4.6.14}$$

with

$$\frac{\partial I^{**}}{\partial p_0} = \frac{1}{2t\phi} \left[\left(b^I + b^{Iq} q^{**} - \left(b^q + b^{Iq} I^{**} \right) \frac{\partial q_j (I^{**})}{\partial I_i} \right) (-V_{qq}) + V_{Iq} \left(b^q + b^{Iq} I^{**} \right) \right], \tag{4.6.15}$$

$$\frac{\partial q^{**}}{\partial p_0} = \frac{1}{2t\phi} \left[\left(b^q + b^{Iq} I^{**} \right) (-V_{II}) + V_{qI} \left(b^I + b^{Iq} q^{**} - \left(b^q + b^{Iq} I^{**} \right) \frac{\partial q_j (I^{**})}{\partial I_i} \right) \right], \tag{4.6.16}$$

and where the expressions for $V_{II} < 0$, $V_{qq} < 0$, $V_{qI} \gtrless 0$ and $V_{Iq} \gtrless 0$ are given in appendix section 4.C.2.

A higher DRG tariff has a direct positive effect on the marginal revenue of service quality, given by the first term in the square brackets of (4.6.16). A similar positive effect applies to the marginal revenue of investment, but here there is also an additional effect related to the strategic incentive to affect the rival hospital's quality provision through own investment. The sum of these two effects is given by the first term in the square brackets of (4.6.15), where the sign of the additional (strategic) effect depends on the sign of $\partial q_j (I^{**}) / \partial I_i$. More specifically, a higher DRG tariff increases the profit margin and therefore reinforces the incentive to increase (reduce) own investment in order to induce a reduction in the rival's quality provision if own investment and rival's quality are strategic substitutes (complements). Finally, there are also indirect effects determined by how a quality increase affects the marginal incentives for investment (V_{Iq}) and how higher investments affect the marginal incentives for quality provision (V_{qI}).

If we assume that the latter effects are sufficiently small (i.e, that the effects through V_{qI} and V_{Iq} are second-order effects), then an increase in the DRG tariff increases the marginal revenue of both investment and service quality, yielding $\partial I^{**}/\partial p_0 > 0$ and $\partial q^{**}/\partial p_0 > 0$, if own investment and rival's quality are strategic substitutes ($\partial q_j \left(I^{**}\right)/\partial I_i < 0$). This also holds if own investment and rival's quality are strategic complements, as long the degree of strategic complementarity is sufficiently small. If the equilibrium investment and quality are *below* the first best level, then this policy is always welfare improving. Analogously, if they are *above* the first best level, the policy is welfare reducing. If either equilibrium investment or quality is above the first best level with the other variable being below the first best level, then the overall effect of this policy reform is in general indeterminate.

4.6.2.3 Incentivising investment through refinements in DRG pricing

Finally, consider a policy which incentivises investment through the per-treatment price, in the sense that higher investments imply a higher DRG tariff. Several health systems have introduced a 'new DRG' in the form of an additional DRG price associated with a new technology, that effectively leads to a higher per-treatment price whenever the new technology is adopted. Examples include coronary stents in Australia, Austria, Canada, England, Germany, Japan and the United States (Hernandez, Machacz, & Robinson, 2015; Sorenson et al., 2015; Sorenson, Drummond, & Wilkinson, 2013), and transcatheter aortic-valve implantation (TAVI) in France, intracranial neurostimulators in Portugal, and Implantable cardioverter-defibrillator in Italy (Cappellaro, Fattore, & Torbica, 2009; Sorenson et al., 2015). Analytically, before the policy the payment rule is $p\left(I_i\right) = p_0$, $T\left(I_i\right) = \overline{T}_0$, and after the reform it is $p\left(I_i\right) = p_0 + p_1 I_i$, $T\left(I_i\right) = \underline{T}_0$, with $\overline{T}_0 > \underline{T}_0$. Given that changes in T_0 have no effect on quality and investment, the only effect on welfare is driven by the increase in the DRG tariff. We can therefore assess the welfare effect of this policy by considering a marginal increase in p_1. Differentiating (4.6.10) with respect to p_1 yields

$$\frac{dW(I^{**},q^{**})}{dp_1} = \frac{\partial W(I^{**},q^{**})}{\partial I}\frac{\partial I^{**}}{\partial p_1} + \frac{\partial W(I^{**},q^{**})}{\partial q}\frac{\partial q^{**}}{\partial p_1}, \tag{4.6.17}$$

with

$$\frac{\partial I^{**}}{\partial p_1} = \frac{1}{\phi}\left(V_{Ip_1}\left(-V_{qq}\right) + I^{**}\frac{V_{Iq}\left(b^q + b^{Iq}I^{**}\right)}{2t}\right), \tag{4.6.18}$$

$$\frac{\partial q^{**}}{\partial p_1} = \frac{1}{\phi}\left(I^{**}\frac{\left(b^q + b^{Iq}I^{**}\right)\left(-V_{II}\right)}{2t} + V_{qI}V_{Ip_1}\right), \tag{4.6.19}$$

and

$$V_{Ip_1} = I^{**}V_{Ip_0} + \frac{1}{2} - \frac{\left(2c^q q^{**} + c^{Iq}I^{**}\right)\left(b^q + b^{Iq}I^{**}\right)^3}{8t^3\Delta}\left(p(I^{**}) - c(I^{**},q^{**})\right) \gtrless 0, \tag{4.6.20}$$

where $\Delta > 0$ is given by (4.B.23) in appendix section 4.B.3 and

$$V_{Ip_0} = \frac{1}{2t}\left[b^I + b^{Iq}q^{**} - \left(b^q + b^{Iq}I^{**}\right)\frac{\partial q_j\left(I^{**}\right)}{\partial I_i}\right] \gtrless 0. \tag{4.6.21}$$

is the effect of a marginal increase in p_0 on investment incentives for a given quality level.

This particular policy affects incentives for investment and quality provision in two different ways. First, it implies an increase in the DRG price level. This means that the direct effect on the marginal revenue of *quality* provision is similar to the policy in the previous section (the first term in (4.6.16) is similar to the first term in (4.6.19)). The direct effects on *investment* incentives are also present under this policy, and captured by the first term in (4.6.20). However, incentivising investment through a refinement of DRG pricing yields *two additional effects* on the marginal revenue of investment, given by the second and third terms in (4.6.20). Both of these additional effects result from the fact that an increase in p_1 implies that investments have a stronger positive effect on the price-cost margin. Firstly, this directly strengthens the incentive for investment. Secondly, this also implies that the effect of own investment on rival's quality increases, as explained in Section 5.1.[9] In other words, the strategic complementarity is reinforced (or the strategic substitutability is weakened) between own investment and rival's quality. All else equal, this effect leads to weaker (stronger) investment incentives if the equilibrium price-cost margin is positive (negative). Finally, and similarly to the previous policy, the overall effects of the policy are also determined by how a quality change affects the marginal incentives for investment (V_{Iq}) and *vice versa* (V_{qI}). Once more, it seems reasonable to assume that the latter effects are second-order effects and that the sign of the overall effects are primarily determined by the direct effects described above.

Based on the direct effects, incentivising investment through the DRG price leads to higher quality provision while, perhaps surprisingly, the effect on investment is *a priori* indeterminate. Sufficient (but not necessary) conditions for this payment scheme to stimulate investment are that (i) own investment and rival's quality are strategic substitutes ($\partial q_j\left(I^{**}\right)/\partial I_i < 0$) and (ii) providers are sufficiently altruistic, such that the price-cost margin is negative in equilibrium. On the contrary, if own investment and rival's quality are strategic complements and providers are profit oriented, incentivising investment through the DRG price might possibly *reduce* investments due to each provider's incentive to strategically affect the rival's quality provision through own investment.

As before, the overall welfare effect of the reform depends crucially on whether quality and investments are

[9] It follows from (4.5.10) that

$$\frac{\partial}{\partial p_1}\left(\frac{\partial q_j\left(I^{**}\right)}{\partial I_i}\right) = \frac{\left(2c^q q^{**} + c^{Iq}I^{**}\right)\left(b^q + b^{Iq}I^{**}\right)^2}{4t^2\Delta} > 0.$$

below or above the first-best levels prior to the policy. In the former case (i.e., $\partial W(I^{**}, q^{**})/\partial q > 0$ and $\partial W(I^{**}, q^{**})/\partial I > 0$), the policy will unambiguously increase welfare if $\partial I^{**}/\partial p_1 > 0$ and $\partial q^{**}/\partial p_1 > 0$. On the other hand, if the policy is counterproductive in terms of stimulating investment incentives ($\partial I^{**}/\partial p_1 < 0$), which is a theoretical possibility as explained above, then it has an unambiguously positive effect on welfare only if the pre-policy equilibrium is characterised by underprovision of service quality but overinvestment in medical technology.

4.7 Concluding remarks

Hospital investments in medical innovations and new technologies can affect both health outcomes and provider costs. This study has investigated how hospitals make investment decisions, and the circumstances under which they lead to under- or overinvestment, and how these investment decisions affect the provision of service quality under a range of payment arrangements. Although the results are generally indeterminate, we can characterise them in a precise way. We show that hospitals underinvest if (i) own investment and the quality of the competing hospital are strategic complements and the price-cost margin is positive or (ii) own investment and quality are strategic substitutes and the price-cost margin is negative. Instead hospitals overinvest in the reversed scenarios (investment and quality are strategic complements and price-cost margin is negative; strategic substitution and positive price-cost margin).

In terms of optimal price regulation, we show that the regulator must complement the per-treatment price with at least one more instrument to correctly incentivise investments, either through a separate payment which rewards investment or a treatment price which depends on investment. The results mirror our key findings. The regulator has to incentivise investment when (i) investment and quality are strategic complements and the provider works at a positive price cost-margin, or (ii) investment and quality are strategic substitutes and the provider works at a negative price cost margin.

In terms of policy implications, our analysis informs possible policy interventions under current activity-based payment arrangements that set, in most countries, prices at the average cost instead of relating them to marginal costs as prescribed by optimal regulation theory. We show that the introduction of a policy with a separate payment which directly incentivises investment, commonly used in several countries, can be welfare improving if investment and quality are initially below the first-best levels and investment and quality are complements or if they are substitutes but the degree of substitutability is sufficiently small. This is also the case if investment is below and quality is above the first-best levels, and investment and quality are either substitutes or sufficiently weak complements. In other scenarios, the introduction of this payment rule will create trade-offs between the welfare effects arising from changes in investment and quality.

Some countries pay for investment through a higher activity-based tariff per patient treated, while others through a separate funding scheme. We show that the former is welfare improving if investment and quality are below the first-best level and a higher DRG tariff increases the marginal revenue of both investment and service quality. However, this may not be the case if either investment or quality is above the first-best level, so that a trade-off arises. Finally, we find that a policy incentivising investment through refinements of DRG pricing (so that additional investments are rewarded with a higher per unit price) stimulates quality provision while the effect on investment is, perhaps surprisingly, *a priori* ambiguous. In this case, even if both quality and investment are below the first-best level, a trade-off arises between the welfare gain from higher quality and welfare loss from lower investment.

Our analysis highlights the role of two main factors. The first is whether providers work at a positive or negative price-cost margin. This is likely to depend on the health system, with systems with fewer beds per capita and higher capacity constraints more likely to work a negative price-cost margin. This may also be the case for countries that use mixed payment systems. For example, in Norway activity-based payment only covers about 50-60% of average costs, with the rest being covered by a capitation arrangement. There are also discussions in England of moving towards 'blended' payment systems with the activity-based payment accounting for as little as 30% (Appleby, Harrison, Hawkins, & Dixon, 2012). Future empirical work on empirical estimates of marginal treatment costs could also quantify the size of price-cost margins.

A second key factor is whether investment and quality are complements or substitutes for each provider, or strategic complements or substitutes across providers. This is also an area that could be informed by future empirical work. For example, it would be useful to estimate whether an exogenous increase in hospital investments lead to an increase (complementarity) or a reduction (substitution) in service provision by the same provider, as these effects play an important role in the welfare analysis of policy interventions. Perhaps even more important, but also empirically challenging, would be to investigate how changes in provider investment affect the quality of rival providers. These could be explored using a spatial econometrics approach similar to the one adopted to investigate whether the qualities are strategic complements or substitutes (Gravelle, Santos, & Siciliani, 2014; Longo, Siciliani, Gravelle, & Santos, 2017).

APPENDIX

This appendix contains second-order conditions and supplementary calculations for each part of the analysis, where the content of Appendix 4.A, 4.B and 4.C complements the analysis of Section 4.4, 4.5 and 4.6, respectively.

Appendix 4.A Simultaneous game

The second-order conditions of the hospital are given by

$$\frac{\partial^2 V_i(q_i, q_j, I_i, I_j)}{\partial q_i^2} = -\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_i\right)}{t} - 2c^q D_i < 0, \tag{4.A.1}$$

$$\frac{\partial^2 V_i(q_i, q_j, I_i, I_j)}{\partial I_i^2} = \left(\frac{\partial p(I_i)}{\partial I_i} - \left(c^I + c^{Iq} q_i\right)\right)\frac{b^I + b^{Iq} q_i}{t} + \frac{\partial^2 p(I_i)}{\partial I_i^2} D_i + \frac{\partial^2 T(I_i)}{\partial T_i^2} - \frac{\partial^2 k(I_i)}{\partial I_i^2} < 0, \tag{4.A.2}$$

and

$$\frac{\partial^2 V_i}{\partial q_i^2}\frac{\partial^2 V_i}{\partial I_i^2} - \left(\frac{\partial^2 V_i}{\partial I_i \partial q_i}\right)^2 \geq 0, \tag{4.A.3}$$

where $\partial^2 V_i / \partial I_i \partial q_i$ is given by (4.B.10) below. These conditions are satisfied if $k(I_i)$ is sufficiently convex.

Appendix 4.B Sequential game

4.B.1 Derivation of (4.5.1) and (4.5.2)

The optimality conditions of quality, $\partial V_i\left(I_i, I_j, q_i, q_j\right)/\partial q_i = 0$ and $\partial V_j\left(I_i, I_j, q_i, q_j\right)/\partial q_j = 0$, are given more explicitly by

$$\left(b^q + b^{Iq} I_i\right)\left[\alpha + \frac{p(I_i) - c(I_i, q_i)}{2t}\right] - \left(2c^q q_i + c^{Iq} I_i\right) D_i(I_i, I_j, q_i, q_j) = 0, \tag{4.B.1}$$

$$\left(b^q + b^{Iq} I_j\right)\left[\alpha + \frac{p(I_j) - c(I_j, q_j)}{2t}\right] - \left(2c^q q_j + c^{Iq} I_j\right) D_j(I_i, I_j, q_i, q_j) = 0. \tag{4.B.2}$$

Totally differentiating these conditions with respect to I_i, we obtain

$$\begin{bmatrix} \frac{\partial^2 V_i}{\partial q_i^2} & \frac{\partial^2 V_i}{\partial q_i \partial q_j} \\ \frac{\partial^2 V_j}{\partial q_j \partial q_i} & \frac{\partial^2 V_j}{\partial q_j^2} \end{bmatrix}\begin{bmatrix} dq_i \\ dq_j \end{bmatrix} + \begin{bmatrix} \frac{\partial^2 V_i}{\partial q_i \partial I_i} \\ \frac{\partial^2 V_j}{\partial q_j \partial I_i} \end{bmatrix} dI_i = 0, \tag{4.B.3}$$

which gives

$$\frac{dq_i}{dI_i} = \frac{-\frac{\partial^2 V_i}{\partial q_i \partial I_i}\frac{\partial^2 V_j}{\partial q_j^2} + \frac{\partial^2 V_i}{\partial q_i \partial q_j}\frac{\partial^2 V_j}{\partial q_j \partial I_i}}{\frac{\partial^2 V_i}{\partial q_i^2}\frac{\partial^2 V_j}{\partial q_j^2} - \frac{\partial^2 V_i}{\partial q_i \partial q_j}\frac{\partial^2 V_j}{\partial q_j \partial q_i}}, \tag{4.B.4}$$

$$\frac{dq_j}{dI_i} = \frac{-\frac{\partial^2 V_i}{\partial q_i^2}\frac{\partial^2 V_j}{\partial q_j \partial I_i} + \frac{\partial^2 V_j}{\partial q_j \partial q_i}\frac{\partial^2 V_i}{\partial q_i \partial I_i}}{\frac{\partial^2 V_i}{\partial q_i^2}\frac{\partial^2 V_j}{\partial q_j^2} - \frac{\partial^2 V_i}{\partial q_i \partial q_j}\frac{\partial^2 V_j}{\partial q_j \partial q_i}}, \tag{4.B.5}$$

where

$$\frac{\partial^2 V_i}{\partial q_i^2} = -\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_i\right)}{t} - 2c^q D_i < 0. \tag{4.B.6}$$

$$\frac{\partial^2 V_j}{\partial q_j^2} = -\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_j\right)}{t} - 2c^q D_j < 0, \tag{4.B.7}$$

$$\frac{\partial^2 V_i}{\partial q_i \partial q_j} = \frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_j\right)}{2t} > 0, \tag{4.B.8}$$

$$\frac{\partial^2 V_j}{\partial q_j \partial q_i} = \frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_i\right)}{2t} > 0, \tag{4.B.9}$$

$$\begin{aligned} \frac{\partial^2 V_i}{\partial q_i \partial I_i} &= b^{Iq}\left(\alpha + \frac{p(I_i) - c(I_i, q_i)}{2t}\right) + \left(\frac{\partial p}{\partial I_i} - \left(c^I + c^{Iq} q_i\right)\right)\frac{b^q + b^{Iq} I_i}{2t} \\ &\quad - \left(2c^q q_i + c^{Iq} I_i\right)\frac{b^I + b^{Iq} q_i}{2t} - c^{Iq} D_i, \end{aligned} \tag{4.B.10}$$

$$\frac{\partial^2 V_j}{\partial q_j \partial I_i} = \frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^I + b^{Iq} q_i\right)}{2t} > 0. \tag{4.B.11}$$

Denote by Δ the denominator in (4.B.4) and (4.B.5), which is given by

$$\begin{aligned} \Delta = &\left(\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_i\right)}{t} + 2c^q D_i\right)\left(\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_j\right)}{t} + 2c^q D_j\right) \\ &- \left(\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_j\right)}{2t}\right)\left(\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_i\right)}{2t}\right). \end{aligned} \tag{4.B.12}$$

By rearranging and factorising some terms, we obtain

$$\Delta=\frac{1}{4t^2}\left(\begin{array}{c}3\left(2c^q q_i+c^{Iq}I_i\right)\left(b^q+b^{Iq}I_i\right)\left(2c^q q_j+c^{Iq}I_j\right)\left(b^q+b^{Iq}I_j\right)\\ +8tc^q\left(\begin{array}{c}D_j\left(2c^q q_i+c^{Iq}I_i\right)\left(b^q+b^{Iq}I_i\right)\\ +D_i\left(2c^q q_j+c^{Iq}I_j\right)\left(b^q+b^{Iq}I_j\right)+2tc^q D_i D_j\end{array}\right)\end{array}\right) \tag{4.B.13}$$

The numerator in (4.B.4) is

$$\begin{aligned}
&-\frac{\partial^2 V_i}{\partial q_i \partial I_i}\frac{\partial^2 V_j}{\partial q_j^2}+\frac{\partial^2 V_i}{\partial q_i \partial q_j}\frac{\partial^2 V_j}{\partial q_j \partial I_i}\\
&=\left(\frac{\left(2c^q q_j+c^{Iq}I_j\right)\left(b^q+b^{Iq}I_j\right)}{t}+2c^q D_j\right)\left[\begin{array}{c}b^{Iq}\left(\alpha+\frac{p(I_i)-c(I_i,q_i)}{2t}\right)-\left(2c^q q_i+c^{Iq}I_i\right)\frac{b^I+b^{Iq}q_i}{2t}\\ +\left(\frac{\partial p(I_i)}{\partial I_i}-\left(c^I+c^{Iq}q_i\right)\right)\frac{b^q+b^{Iq}I_i}{2t}-c^{Iq}D_i\end{array}\right]\\
&+\frac{\left(2c^q q_i+c^{Iq}I_i\right)\left(b^q+b^{Iq}I_j\right)}{2t}\frac{\left(2c^q q_j+c^{Iq}I_j\right)\left(b^I+b^{Iq}q_i\right)}{2t}.
\end{aligned} \tag{4.B.14}$$

Using the first-order condition optimal quality, (4.4.1), and re-arranging, we obtain

$$\begin{aligned}
&-\frac{\partial^2 V_i}{\partial q_i \partial I_i}\frac{\partial^2 V_j}{\partial q_j^2}+\frac{\partial^2 V_i}{\partial q_i \partial q_j}\frac{\partial^2 V_j}{\partial q_j \partial I_i}\\
&=\left(\frac{\left(2c^q q_j+c^{Iq}I_j\right)\left(b^q+b^{Iq}I_j\right)}{t}+2c^q D_j\right)\left[\begin{array}{c}\left(b^{Iq}\frac{\left(2c^q q_i+c^{Iq}I_i\right)}{\left(b^q+b^{Iq}I_i\right)}-c^{Iq}\right)D_i\\ +\left(\frac{\partial p(I_i)}{\partial I_i}-\left(c^I+c^{Iq}q_i\right)\right)\frac{b^q+b^{Iq}I_i}{2t}\end{array}\right]\\
&-\frac{\left(2c^q q_i+c^{Iq}I_i\right)\left(b^I+b^{Iq}q_i\right)}{t}\left(\frac{\left(2c^q q_j+c^{Iq}I_j\right)\left(b^q+b^{Iq}I_j\right)}{4t}+c^q D_j\right).
\end{aligned} \tag{4.B.15}$$

Therefore, by substitution, (4.5.1) is given by

$$\frac{dq_i}{dI_i}=\frac{1}{\Delta}\left(\begin{array}{c}\left(\frac{\left(2c^q q_j+c^{Iq}I_j\right)\left(b^q+b^{Iq}I_j\right)}{t}+2c^q D_j\right)\left[\begin{array}{c}\left(b^{Iq}\frac{\left(2c^q q_i+c^{Iq}I_i\right)}{\left(b^q+b^{Iq}I_i\right)}-c^{Iq}\right)D_i\\ +\left(\frac{\partial p(I_i)}{\partial I_i}-\left(c^I+c^{Iq}q_i\right)\right)\frac{b^q+b^{Iq}I_i}{2t}\end{array}\right]\\ -\frac{\left(2c^q q_i+c^{Iq}I_i\right)\left(b^I+b^{Iq}q_i\right)}{t}\left(\frac{\left(2c^q q_j+c^{Iq}I_j\right)\left(b^q+b^{Iq}I_j\right)}{4t}+c^q D_j\right)\end{array}\right), \tag{4.B.16}$$

To derive $\frac{dq_j}{dI_i}$, note that the numerator in (4.B.5) is

$$
\begin{aligned}
&-\frac{\partial^2 V_i}{\partial q_i^2}\frac{\partial^2 V_j}{\partial q_j \partial I_i}+\frac{\partial^2 V_j}{\partial q_j \partial q_i}\frac{\partial^2 V_i}{\partial q_i \partial I_i} \\
&=\left(\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_i\right)}{t}+2c^q D_i\right)\left(\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^I + b^{Iq} q_i\right)}{2t}\right) \\
&+\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_i\right)}{2t}\left[\begin{array}{c} b^{Iq}\left(\alpha+\frac{p(I_i)-c(I_i,q_i)}{2t}\right)+\left(\frac{\partial p}{\partial I_i}-\left(c^I + c^{Iq} q_i\right)\right)\frac{b^q + b^{Iq} I_i}{2t} \\ -\left(2c^q q_i + c^{Iq} I_i\right)\frac{b^I + b^{Iq} q_i}{2t}-c^{Iq} D_i \end{array}\right].
\end{aligned} \tag{4.B.17}
$$

Using the first-order condition for optimal quality, (4.4.1), and rearranging some terms, (4.B.17) reduces to

$$
\begin{aligned}
&-\frac{\partial^2 V_i}{\partial q_i^2}\frac{\partial^2 V_j}{\partial q_j \partial I_i}+\frac{\partial^2 V_j}{\partial q_j \partial q_i}\frac{\partial^2 V_i}{\partial q_i \partial I_i} \\
&=\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^I + b^{Iq} q_i\right)}{2t}\left(\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_i\right)}{2t}+c^q D_i\right) \\
&+\frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_i\right)}{2t}\left[\begin{array}{c} \left(b^{Iq}\frac{\left(2c^q q_i + c^{Iq} I_i\right)}{\left(b^q + b^{Iq} I_i\right)}-c^{Iq}\right)D_i \\ +\left(\frac{\partial p}{\partial I_i}-\left(c^I + c^{Iq} q_i\right)\right)\frac{b^q + b^{Iq} I_i}{2t} \end{array}\right].
\end{aligned} \tag{4.B.18}
$$

Therefore, (4.5.2) is obtained by

$$
\frac{dq_j}{dI_i}=\frac{1}{\Delta}\left(\begin{array}{c} \frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^I + b^{Iq} q_i\right)}{2t}\left(\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_i\right)}{2t}+c^q D_i\right)+ \\ \frac{\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_i\right)}{2t}\left[\begin{array}{c} \left(b^{Iq}\frac{\left(2c^q q_i + c^{Iq} I_i\right)}{\left(b^q + b^{Iq} I_i\right)}-c^{Iq}\right)D_i \\ +\left(\frac{\partial p}{\partial I_i}-\left(c^I + c^{Iq} q_i\right)\right)\frac{b^q + b^{Iq} I_i}{2t} \end{array}\right] \end{array}\right). \tag{4.B.19}
$$

4.B.2 Second order condition

In the investment game, the second order condition is given by

$$
\frac{\partial^2 V_i}{\partial I_i^2}=\left\{\begin{array}{c} \frac{dq_i}{dI_i}\left(b^{Iq}\left(\alpha+\frac{p(I_i)-c(I_i,q_i)}{2t}\right)-c^{Iq} D_i-\frac{\left(2c^q q_i + c^{Iq} I_i\right)\left(b^I + b^{Iq} q_i\right)}{2t}\right) \\ +\frac{\left(b^I + b^{Iq} q_i\right)}{t}\left(\frac{\partial p(I_i)}{\partial I_i}-\left(c^I + c^{Iq} q_i\right)\right)+\frac{\partial^2 p(I_i)}{\partial I_i^2}D_i+\frac{\partial^2 T(I_i)}{\partial I_i^2}-\frac{\partial^2 k(I_i)}{\partial I_i^2} \\ +\frac{\partial p(I_i)/\partial I_i-\left(c^I + c^{Iq} q_i\right)}{2t}\left[\frac{dq_i}{dI_i}\left(b^q + b^{Iq} I_i\right)-\frac{dq_j}{dI_i}\left(b^q + b^{Iq} I_j\right)\right] \\ -\Upsilon\frac{b^q + b^{Iq} I_j}{2t}\left[p(I_i)-c(I_i,q_i)\right] \end{array}\right\}<0, \tag{4.B.20}
$$

where Υ is the derivative of (4.5.2) with respect to I_i. Define ψ as the numerator in (4.5.2). In this case $\Upsilon =$

$\left(\psi_{I_i}\Delta - \psi\Delta_{I_i}\right)/\Delta^2$, where

$$\psi_{I_i} = \frac{\left(2c^q q_j + c^{Iq} I_j\right)}{4t^2}\left(\begin{array}{c} \left(b^I + b^{Iq} q_i\right)\left[b^q c^{Iq} + 2b^{Iq}\left(c^q q_i + c^{Iq} I_i\right) + c^q\left(b^I + b^{Iq} q_i\right)\right] \\ + \left(2c^q q_i + c^{Iq} I_i\right)\left(b^I + b^{Iq} q_i\right)\left(b^{Iq} - c^{Iq}\right) \\ + \left(b^q + b^{Iq} I_i\right)\left(\frac{\partial^2 p(I_i)}{\partial I_i^2}\left(b^q + b^{Iq} I_i\right) + 2b^{Iq}\left(\frac{\partial p(I_i)}{\partial I_i} - \left(c^I + c^{Iq} q_i\right)\right)\right) \end{array}\right) \tag{4.B.21}$$

and

$$\Delta_{I_i} = \frac{1}{4t^2}\left(\begin{array}{c} 3\left(c^{Iq} b^q + 2b^{Iq}\left(c^q q_i + c^{Iq} I_i\right)\right)\left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_j\right) \\ +4c^q\left(\begin{array}{c} 2tD_j\left(c^{Iq} b^q + 2b^{Iq}\left(c^q q_i + c^{Iq} I_i\right)\right) \\ - \left(2c^q q_i + c^{Iq} I_i\right)\left(b^q + b^{Iq} I_i\right)\left(b^I + b^{Iq} q_i\right) \\ + \left(2c^q q_j + c^{Iq} I_j\right)\left(b^q + b^{Iq} I_j\right)\left(b^I + b^{Iq} q_i\right) + 2tc^q\left(b^I + b^{Iq} q_i\right)\left(D_j - D_i\right) \end{array}\right) \end{array}\right). \tag{4.B.22}$$

The condition in (4.B.20) holds if $k(I_i)$ is sufficiently convex.

4.B.3 Symmetric equilibrium

The denominator in (4.B.4) and (4.B.5), denoted Δ, is given by

$$\Delta = \frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^q + b^{Iq} I^{**}\right)\left(3\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^q + b^{Iq} I^{**}\right) + 8tc^q\right) + \left(2tc^q\right)^2}{4t^2}. \tag{4.B.23}$$

In the symmetric equilibrium, dq_i/dI_i and dq_j/dI_i are given by, respectively,

$$\frac{\partial q_i\left(I^{**}\right)}{\partial I_i} = \frac{1}{2\Delta}\left(\begin{array}{c} -\frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^I + b^{Iq} q^{**}\right)}{t}\left(\frac{\left(b^q + b^{Iq} I^{**}\right)\left(2c^q q^{**} + c^{Iq} I^{**}\right)}{2t} + c^q\right) \\ + \left(\frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^q + b^{Iq} I^{**}\right)}{t} + c^q\right)\left[\begin{array}{c} \left(b^{Iq}\frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)}{\left(b^q + b^{Iq} I^{**}\right)} - c^{Iq}\right) \\ + \left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq} q^{**}\right)\right)\frac{b^q + b^{Iq} I^{**}}{t} \end{array}\right] \end{array}\right) \tag{4.B.24}$$

and

$$\frac{\partial q_j\left(I^{**}\right)}{\partial I_i}=\frac{\left(2c^q q^{**}+c^{Iq}I^{**}\right)}{4t\Delta}\left(\begin{array}{c} c^q\left(b^I+b^{Iq}q^{**}\right) \\ +\left(b^q+b^{Iq}I^{**}\right)\left[\begin{array}{c} \left(b^{Iq}\frac{\left(2c^q q^{**}+c^{Iq}I^{**}\right)}{\left(b^q+b^{Iq}I^{**}\right)}-c^{Iq}\right) \\ +\frac{\left(2c^q q+c^{Iq}I^{**}\right)\left(b^I+b^{Iq}q^{**}\right)}{t} \\ +\left(\frac{\partial p(I^{**})}{\partial I}-\left(c^I+c^{Iq}q^{**}\right)\right)\frac{b^q+b^{Iq}I^{**}}{t} \end{array}\right] \end{array}\right). \tag{4.B.25}$$

Appendix 4.C Welfare analysis

4.C.1 Second order conditions

The second order conditions for first-best quality and investments are given by

$$\frac{\partial^2 W}{\partial q_i^2}=-2c^q<0, \tag{4.C.1}$$

$$\frac{\partial^2 W}{\partial I_i^2}=-2\frac{\partial^2 k(I_i)}{\partial I_i^2}<0 \tag{4.C.2}$$

and

$$\frac{\partial^2 W}{\partial q_i^2}\frac{\partial^2 W}{\partial I_i^2}-\left(\frac{\partial^2 W}{\partial q\partial I}\right)^2=4c^q\frac{\partial^2 k(I_i)}{\partial I_i^2}-\left(b^{Iq}-c^{Iq}\right)^2>0. \tag{4.C.3}$$

These conditions hold if $k(I_i)$ is sufficiently convex.

4.C.2 Comparative statics

Considering the subgame-perfect Nash Equilibrium implicitly defined by (4.5.8)-(4.5.9), the comparative statics results reported in Section 4.6.2 are found by total differentiation of this system and the application of Cramer's rule. Using the notation $V_{xy}:=\partial V_x/\partial y$, we derive the following expressions:

$$\frac{\partial q^{**}}{\partial T_1}=\frac{-V_{qT_1}V_{II}+V_{qI}V_{IT_1}}{V_{qq}V_{II}-V_{Iq}V_{qI}}, \tag{4.C.4}$$

$$\frac{\partial I^{**}}{\partial T_1} = \frac{-V_{qq}V_{IT_1} + V_{qT_1}V_{Iq}}{V_{qq}V_{II} - V_{Iq}V_{qI}}, \tag{4.C.5}$$

$$\frac{\partial q^{**}}{\partial p_0} = \frac{-V_{qp_0}V_{II} + V_{qI}V_{Ip_0}}{\phi}, \tag{4.C.6}$$

$$\frac{\partial I^{**}}{\partial p_0} = \frac{-V_{qq}V_{Ip_0} + V_{qp_0}V_{Iq}}{\phi}, \tag{4.C.7}$$

$$\frac{\partial q^{**}}{\partial p_1} = \frac{-V_{qp_1}V_{II} + V_{qI}V_{Ip_1}}{\phi}, \tag{4.C.8}$$

$$\frac{\partial I^{**}}{\partial p_1} = \frac{-V_{qq}V_{Ip_1} + V_{qp_1}V_{Iq}}{\phi}, \tag{4.C.9}$$

where $\phi := V_{qq}V_{II} - V_{Iq}V_{qI} > 0$. The different terms in the numerators of (4.C.4)-(4.C.9) are defined as follows:

$$V_{qq} = -\frac{\left(2c^q q^{**} + c^{Iq}I^{**}\right)\left(b^q + b^{Iq}I^{**}\right)}{2t} - c^q < 0 \tag{4.C.10}$$

and

$$\begin{aligned} V_{II} = & \frac{\left(b^I + b^{Iq}q^{**}\right)}{2t}\left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq}q^{**}\right)\right) - \frac{\partial^2 k(I^{**})}{\partial I^2} \\ & - \Psi \frac{\left(b^q + b^{Iq}I^{**}\right)}{2t}\left[p(I^{**}) - c(I^{**}, q^{**})\right] \\ & - \frac{1}{2t}\left[\begin{array}{c} b^{Iq}\left(p(I^{**}) - c(I^{**}, q^{**})\right) + \\ \left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq}q^{**}\right)\right)\left(b^q + b^{Iq}I^{**}\right) \end{array}\right]\frac{\partial q_j\left(I^{**}\right)}{\partial I_i} < 0 \,, \end{aligned} \tag{4.C.11}$$

where Ψ is the derivative of (4.5.10) with respect to I. Defining Ξ as the numerator in (4.5.10), we have $\Psi = \left(\Xi_I \Delta - \Xi \Delta_I\right)/4t\Delta^2$, where the derivative of the denominator Δ with respect to I is given by

$$\Delta_I = \frac{\left[c^{Iq}b^q + 2b^{Iq}\left(c^q q^{**} + c^{Iq}I^{**}\right)\right]\left[3\left(2c^q q^{**} + c^{Iq}I^{**}\right)\left(b^q + b^{Iq}I^{**}\right) + 4tc^q\right]}{2t^2}, \tag{4.C.12}$$

and the derivative of Ξ with respect to I, is given by

$$\Xi_I = c^{Iq}\begin{pmatrix} c^q\left(b^I + b^{Iq}q^{**}\right) + b^{Iq}\left(2c^q q^{**} + c^{Iq}I^{**}\right) - c^{Iq}\left(b^q + b^{Iq}I^{**}\right) \\ +\frac{\left(2c^q q^{**}+c^{Iq}I^{**}\right)\left(b^I+b^{Iq}q^{**}\right)\left(b^q+b^{Iq}I^{**}\right)}{t} \\ +\left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq}q^{**}\right)\right)\frac{\left(b^q+b^{Iq}I^{**}\right)^2}{t} \end{pmatrix}$$

$$+\left(2c^q q^{**} + c^{Iq}I^{**}\right)\begin{pmatrix} \left(c^{Iq}b^q + 2b^{Iq}\left(c^q q^{**} + c^{Iq}I^{**}\right)\right)\frac{\left(b^I+b^{Iq}q^{**}\right)}{t} \\ +\frac{\partial^2 p(I^{**})}{\partial I^2}\frac{\left(b^q+b^{Iq}I^{**}\right)^2}{t} \\ +2b^{Iq}\left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq}q^{**}\right)\right)\frac{\left(b^q+b^{Iq}I^{**}\right)}{t} \end{pmatrix}. \qquad (4.C.13)$$

Further:

$$V_{qI} = b^{Iq}\left(\frac{2c^q q^{**} + c^{Iq}I^{**}}{2\left(b^q + b^{Iq}I^{**}\right)}\right) + \frac{b^q + b^{Iq}I^{**}}{2t}\left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq}q^{**}\right)\right) - \frac{c^{Iq}}{2} \lesseqgtr 0 \qquad (4.C.14)$$

and

$$V_{Iq} = b^{Iq}\left(\frac{2c^q q^{**} + c^{Iq}I^{**}}{2\left(b^q + b^{Iq}I^{**}\right)}\right) + \frac{\left(2c^q q^{**} + c^{Iq}I^{**}\right)}{2t}\left(\left(b^q + b^{Iq}I^{**}\right)\frac{\partial q_j\left(I^{**}\right)}{\partial I_i} - \left(b^I + b^{Iq}q^{**}\right)\right)$$
$$-\frac{c^{Iq}}{2} - \Phi\frac{\left(b^q + b^{Iq}I^{**}\right)}{2t}\left(p(I^{**}) - c(I^{**}, q^{**})\right) \lesseqgtr 0, \qquad (4.C.15)$$

where Φ is the derivative of (4.5.10) with respect to q and given by $\Phi = \left(\Xi_q\Delta - \Xi\Delta_q\right)/4t\Delta^2$, where the derivative of the denominator Δ in (4.5.10) with respect to q is given by

$$\Delta_q = \frac{c^q\left(b^q + b^{Iq}I^{**}\right)\left[3\left(2c^q q^{**} + c^{Iq}I^{**}\right)\left(b^q + b^{Iq}I^{**}\right) + 4tc^q\right]}{t^2}, \qquad (4.C.16)$$

and the derivative of the numerator Ξ in (4.5.10) with respect to q, is given by

$$\Xi_q = 2c^q \left(\begin{array}{c} c^q \left(b^I + b^{Iq} q^{**}\right) + b^{Iq} \left(2c^q q^{**} + c^{Iq} I^{**}\right) - c^{Iq} \left(b^q + b^{Iq} I^{**}\right) \\ + \frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^I + b^{Iq} q^{**}\right)\left(b^q + b^{Iq} I^{**}\right)}{t} \\ + \left(\frac{\partial p(I^{**})}{\partial I} - \left(c^I + c^{Iq} q^{**}\right)\right) \frac{\left(b^q + b^{Iq} I^{**}\right)^2}{t} \end{array} \right)$$

$$+ \left(2c^q q^{**} + c^{Iq} I^{**}\right) \left(\begin{array}{c} 3b^{Iq} c^q - c^{Iq} \frac{\left(b^q + b^{Iq} I^{**}\right)^2}{t} \\ + \left(b^q + b^{Iq} I^{**}\right) \frac{2c^q\left(b^I + 2b^{Iq} q^{**}\right) + c^{Iq} b^{Iq} I^{**}}{t} \end{array} \right). \tag{4.C.17}$$

Finally,

$$V_{qT_1} = 0, V_{IT_1} = 1, \tag{4.C.18}$$

$$V_{qp_0} = \frac{b^q + b^{Iq} I^{**}}{2t} > 0, \tag{4.C.19}$$

$$V_{Ip_0} = \frac{1}{2t} \left[b^I + b^{Iq} q^{**} - \left(b^q + b^{Iq} I^{**}\right) \frac{\partial q_j\left(I^{**}\right)}{\partial I_i} \right] \gtrless 0, \tag{4.C.20}$$

$$V_{qp_1} = I^{**} \left(\frac{b^q + b^{Iq} I^{**}}{2t} \right) > 0 \tag{4.C.21}$$

and

$$V_{Ip_1} = \frac{1}{2t} \left[\begin{array}{c} I^{**} \left(b^I + b^{Iq} q^{**} - \left(b^q + b^{Iq} I^{**}\right) \frac{\partial q_j(I^{**})}{\partial I_i} \right) + t \\ - \frac{\left(2c^q q^{**} + c^{Iq} I^{**}\right)\left(b^q + b^{Iq} I^{**}\right)^3}{4t^2 \Delta} \left(\frac{2c^q q^{**} + c^{Iq} I^{**}}{2\left(b^q + b^{Iq} I^{**}\right)} - \alpha \right) \end{array} \right]. \tag{4.C.22}$$

CHAPTER 5

CONCLUSION

This thesis explored the strategic interaction between providers, with applications to health care and education markets, and examined the role of provider competition in the provision of quality, investments, and social well-being. Acknowledging the specific features of these sectors, chapters 2-4 delivered new results on the above themes, and contributed to the theoretical literature on quality competition in regulated markets, and addressed fundamental policy implications for welfarist policymakers or regulators.

Chapter 2 studied quality competition in a mixed duopoly where the public provider is subject to price regulation while the private provider is not. The model sheds light on some of the mechanisms that determine the quality ranking of public and private providers in mixed markets. Besides, we revealed how the presence of a semi-altruistic public provider affects the strategic behavior of a profit maximising private provider. More precisely, if providers are profit-driven, more competition unambiguously increases the quality of the public provider, while the private provider increases quality if and only if the marginal willingness to pay for quality is sufficiently high and the regulated price is sufficiently low. In this case, there is a positive relationship between competition and average quality. However, in the presence of altruism, we find that increased competition has an a priori ambiguous effect on the quality offered by the public provider, while the scope for a quality reduction by the private provider is larger. In terms of policy implications, we have shown that the first-best solution can be implemented either by privatizing the public provider or by regulating it in a way that makes it mimic a private profit-maximising provider, which implies a copayment fee equal to the price of the private provider. Furthermore, we revealed that the two funding instruments, the optimal price and the copayment fee, are policy substitutes if the public provider is sufficiently profit oriented.

Chapter 3 investigated quality competition among three providers, where the providers differ in both their objectives and the regulatory measures they face. In particular, we considered a welfare-maximising public provider and two profit-maximising private providers, where the public and one of the private providers face regulated prices and copayment rates, while the second private provider is free to set the price of its good. We demonstrated that stronger competition stimulates the quality provision of the publicly funded private provider but has a generally ambiguous effect on the quality provision of the other two providers. Furthermore, we inquired the relationship between the characteristics of the funding scheme and the equilibrium quality provision in the market, and concluded that a higher regulated price or a higher copayment rate will reduce the quality provision of the public provider while increasing the quality provision of at least one of the private providers. The resulting effect on average quality is generally ambiguous. What is perhaps surprising is that the highest quality in the market is provided by one of the publicly funded providers, unless the copayment rate is very high. In terms of welfare effects and policy implications of different funding policies, we have shown that the regulated price and the copayment rate are policy complements (substitutes) for sufficiently low (high) levels of the copayment rate. Moreover, the chapter's most innovative contribution is to scrutinise the optimal degree of public funding coverage. We show that there exists a welfare trade-off between funding generosity and funding coverage where welfare is maximised when both, one and no private providers are funded for low, intermediate and high values, respectively, of the regulated price.

Chapter 4 investigated the strategic relationship between investment in health technologies and quality provision. A key question addressed in our analysis is whether sequential decision making leads to over- or underinvestment, and we have shown that, if the price-cost margin is positive in equilibrium, hospitals underinvest (overinvest) if own investment and the quality of the competing hospital are strategic complements (substitutes). On the other hand, if the price-cost margin is negative, strategic substitutability leads to underinvestment whereas strategic complementarity leads to overinvestment. The sign of the strategic relationship between own investment and rival's quality is driven by the characteristics of the hospital cost and patient benefit functions. In terms of optimal price regulation, we have shown that the regulator must complement the per-treatment price with at least one more instrument to correctly incentivise investments, either through a separate payment which rewards investment or a treatment price which depends on investment. This result reflects the presence of a variety of different capital cost reimbursement schemes across different countries, where no clear prevalence of one particular scheme emerges. Acknowledging that hospital payment contracts tend to be based on historic cost patterns and are often unlikely to coincide with the ones that maximise social welfare, we revealed that a policy incentivising investments through a separate funding or a higher activity-based tariff per patient treated can be welfare improving under some conditions. We also uncovered circumstances in which a policy incentivising investment through refinements of DRG pricing might yield counterproductive, and even counterintuitive, effects. In particular, we found that the policy stimulates quality provision, while the effect on investment might, perhaps surprisingly, be negative if the hospitals are profit-oriented and if own investment and rival's quality are strategic complements. This implies that increasing the number of DRGs to better capture investment costs might aggravate the problem of upcoding, which is in line with previous empirical studies showing that DRG refinement can lead to overprovision of quality (Januleviciute, Askildsen, Kaarboe, Siciliani, & Sutton, 2016; Milcent, 2021).

Finally, we highlight key limitations that can be carried as possible extensions for future research. The main limitation of the two models presented in chapters 2 and 3 is that consumer preferences are heterogeneous only along a horizontal dimension. In regulated markets, equity considerations play an important role for policy decisions, and it might therefore be worth exploring the equilibrium outcomes when we account for vertical preference differentiation, where some consumers have higher willingness to pay for quality. Another limitation in these chapters is that providers are equally cost-efficient, therefore not considering any exogenous or endogenous differences in cost efficiency between providers in mixed markets. Furthermore, chapter 4 has been conducted within the framework of a symmetric model in a one-shot game to keep our analysis reasonably tractable. This inevitably implies that some potentially relevant aspects of real-world hospital markets and payment contracts have been ignored. One possible extension could be to allow for cost asymmetries across providers, which in turn would allow for payment contracts to be provider-specific to reflect exogenous cost differences. Another possible extension could be to consider a dynamic setting to analyze how the characterization of the equilibrium influences hospitals' incentives for investment over time. This, in turn, will allow us to identify additional relevant mechanisms, related to intertemporal strategic interaction, that are absent in a static framework.

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