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Xidong GUO
University College Dublin

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An Analysis of a Rural Hospital's Investment Decision under Different Payment Systems

Xidong GUO*

Healthcare payment systems influence to a great extent the hospitals' investment decision and thereby, their ability to treat patients. A payment system is optimal provided it incentivises hospitals to undertake an investment level that is appropriate, when considering treatment costs, patients' welfare and the possible externalities generated. In this paper I focus on a hospital in a rural community where the frequency of utilisation of expensive equipment is possible low, and where patients may incur transfer costs. Considering both, a rural and an urban hospital, I identify the first-best investment level of a rural hospital and compare it with the investment levels arising from two payment systems: The Fee-for-service (FFS) system and the Diagnosis-Related Groups (DRG) system. Under the FFS system, the investment only depends on the characteristics of the rural hospital while it depends on characteristics of both hospitals under the DRG system. I show that the DRG performs better than the FFS system when the rural hospital has a lower treatment cost than the urban hospital. When the rural hospital has a higher cost, the FFS system is superior when the HA intends to motivate investment. Lastly, I show that incorporating location factor into the DRG pricing formula to incentivise the rural hospital is effective only when it has a higher treatment cost.

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Keywords: Healthcare payment system, rural hospitals, hospital investment, externality.

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* Contact information: Xidong Guo, School of Economics, and Geary Institute for Public Policy, University College Dublin (UCD). Email: Xidong.guo@ucdconnect.ie.

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1. Introduction

The financial payments that hospitals receive play an important role in the adjustment of medical resources (Kim and McCue, 2008). In particular, a hospital's investment decision and its ability to deliver care, depend on its financial situation and on the reimbursement method that applies. The literature has largely documented the fact that hospitals who are under financial pressure may reduce their investment and/or opt to target specific patients (Ellis and McGuire, 1986; Gelijns and Rosenberg, 1994; Castro et al., 2014; Kifmann and Siciliani, 2017). More generally, the payment system in place will have an impact on a hospital's investment decision regardless of whether it faces financial distress.

There are two main reimbursement methods that are used in practice: The Fee-for-service (FFS) system and the Diagnosis-Related Group (DRG) payment system. The FFS payment system reimburses hospitals according to the actual expenses incurred on the services provided. A large literature has shown that unnecessary treatments tend to be provided under the FFS system because of treatment costs are disregarded (see, for instance, Ellis and McGuire, 1986). Therefore, this system is gradually being replaced by the DRG payment system which rewards efficiency and reduces medical cost per case.[1] Under the DRG payment scheme, the amount of money for each treated patient depends on the patient's particular diagnostic group. The rationale behind the DRG scheme is that patients who have similar illnesses are expected to require similar medical treatments, and thus incur similar costs (Healthcare Pricing Office, 2015). The price per patient is based on the average cost among all participating hospitals (World Bank, 2010).[2] The DRG system was first introduced in America for Medicare patients in 1983, before being adopted by the UK (1991), Ireland (1991), Portugal (2003), France (2004), Germany (2005) and many other European countries. A growing number of Asian countries have since applied the DRG system also, including Thailand (1998), Japan (2003), and China (2019). Although

[1] Please see Busse et al. (2013) for more detailed discussions about the DGR system and its implementations in the Europe.

[2] There are some special cases. For example, while the unit DRG price in Norway is only 40% - 60% of average cost, hospitals are provided with an extra block grant (Siciliani et al., 2013).

the yardstick competition introduced by the DRG payment systems has some advantages, it can also incentivise doctors to unnecessarily admit low-cost patients (cream-skimming).[3,4] It can also lead to up-coding low severity level patients, and classify them as high-severity patients for the purpose of extracting extra payments.[5]

Because the DRG price depends on the average cost of all hospitals, it generates a form of yardstick competition. Yardstick competition is a regulatory instrument used to award institutes or agents who have a better relative performance when originally there was no direct competition between them.[6] In the context of health provision, while it may seem desirable to reward more efficient hospitals, one should also consider some of the specific characteristics of certain types of hospitals. In particular, concerns arose surrounding rural hospitals' financial status following the implementations of a DRG system.[7]

The medical equipment needed to treat some patients is associated with very large fixed costs. For instance, ventilators and Computerized Tomography (CT) scanners have been shown to play a vital role during the COVID-19 pandemic in terms identifying ground-glass opacity in lungs and saving lives. However, these machines are generally prohibitively costly. The resulting benefits that these investments generate depends on the number of patients that will be treated thanks to such an equipment. On the one hand, one may argue that only urban hospitals (who treat a large number of patients) should acquire expensive medical resources to make sure that economies of scale render these investments profitable.[8, 9] However, this argument fails to take the well-being of rural patients

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[3] See Lazear and Rosen (1981), Laffont and Tirole (1986), and Mayer and Vickers (1996) for discussion of payment system considering ranking of performance and contract designing from economic theory.

[4] See seminal contributions by Ellis and McGuire (1986), Dranove (1987), O'Dougherty et al. (1992), Busse et al. (2013), Kifmann and Siciliani (2017) for distorted behaviors of health providers.

[5] See discussion by Dafny (2005), Fang and Gong (2017).

[6] For more about yardstick competition, please refer to Shleifer (1985).

[7] According to Conrad (1994), after the U.S. first applied the DRG system, the Special Committee on Aging of the U.S. Congress estimated that the DRG system has a marked negative impact on financial situation of rural hospitals in 1988, with about 600 hospitals estimated to be at risk of closing.

[8] Many rural hospitals cannot admit enough patients to cover the fixed cost (Scheller-Kreinsen et al., 2011; Sun et al., 2016).

[9] According to a report from The New York Times (2020), a $100 Billion financial stimulus package

and the positive externalities associated with investment by rural hospitals into consideration. The inability for rural hospitals to treat some patients means that these must be transferred to urban hospitals, which generates welfare losses (see James, 1999; Doeksen et al., 1990; Cole, 2009).[10]

This paper assesses the level of investment that a rural hospital should undertake accounting for cost efficiency, direct and indirect social benefits to patients. It contrasts the first-best level of investment with the ones that the hospital undertakes when subjected to distinct reimbursement schemes.

I consider a three-period model with three stakeholders: the patients (urban and rural patients, who can be mildly or severely ill), two hospitals (one urban and one rural), and the Health Authority (HA). The HA chooses the payment system that it wishes to implement, perfectly anticipating its impact on the rural hospital's incentive to invest and the associated impact on rural patients' welfare and the externalities. These externalities for local communities include job opportunities in the local health sector, as well as perceived psycho-social perspective. For example, James (1999) mentions that the services provided by rural hospitals have both tangible and symbolic roles to rural communities. The hospitals differ in their average cost of treating severely ill patients. The "average cost" refers to "average treatment cost per patient". It does not include the costs associated land rent, electricity, wages, or expensive medical devices. These are not accounted for in the calculation of the DRG price (Hendricks and Cromwell, 1989). I assume that the cost of treating patients with a low severity of illness is the same for both hospitals. However, I make no assumption about the cost of treating patients with a severe illness. The possibility that it is lower for rural hospitals receives support in Hendricks and Cronmwell (1989) who find that the average treatment cost for each Medicare inpatient is higher in urban hospitals than in rural hospitals. All urban patients attend the urban hospital. Mildly ill rural patients attend the rural hospital and can be treated locally. Some severely ill rural

is provided but generally more concentrated on big urban hospitals; consequently, rural patients cannot get proper and timely treatment from local hospitals. Kumar et al. (2020) report a similar situation in India.

[10] James (1999) mentions that the services provided by rural hospitals play both a tangible and symbolic role in rural communities and Doeksen et al. (1990) state that the closure of rural hospitals would damage local communities.

patients attend the rural hospital, while the rest attends the urban hospital directly. The rural hospital's ability to cure severely ill patients depends on its investment level. The rural patients who cannot be cured locally have to be transferred to the urban hospital, which generates a loss in utility. Finally, the HA maximises the total surplus accounting for a shadow cost of raising public funds.

The paper addresses three research questions. Firstly, what is the first-best level of investment that a rural hospital should undertake, considering the associated impact on rural patients' welfare and the externality? This equates to a situation where a social welfare maximisation planner could directly decide the rural hospital's investment level. Secondly, what levels of investment would a rural hospital choose, under the FFS system and under the DRG system? It is equivalent to a situation where the social planner can only use payment system to incentivise the rural hospital's investment decision. Lastly, to what extent, should the rural hospital be subsidised under a DRG system?[11]

The model captures the fact that when the rural hospital increases its investment levels, it reduces the number of patients that must be transferred to the urban hospital for treatment which generates positive externalities for the rural community. Furthermore, in the rural hospital's evaluation of its investment strategy is based on the perfect anticipation of the number of patients that it will be able to cure and the number of patients that will have to be transferred. Therefore, the model allows me to address a possible endogeneity issue. The investment decision impacts the number of patients with severe illness that can be treated locally and therefore the average costs on which the payment system is based. This, in turn, impacts the revenue of the hospital which determines the investment decision. I believe that this approach fully captures the strategic dimension associated with investments and thus makes an important contribution to the literature.

The results can be summarised as follows. The welfare analysis shows that

[11] An instance is the Medicare in America, which provides rural and urban hospitals with different rate (Vogl, 2012). Meanwhile, many European countries such as the UK (Mason et al, 2009), France (Langenbrunner and Wiley, 2002), and Germany (Advisory Council on Health Care, 2018) are using or considering payment systems containing regional factors.

of the investment undertaken by the rural hospital should increase when the transfer cost is high, when the treatment cost of the urban hospital is high, when the rural hospital has a lower treatment cost, or when a higher proportion of the rural population attends the rural hospital. If the opportunity cost of raising public funds increases, then the first-best investment level is higher provided the rural hospital has a lower treatment cost. Lastly, the investment level should increase when the associated externality on the rural community is large.

The FFS payment system breaks the yardstick competition so that the investment only depends on the characteristics of the rural hospital. The DRG system triggers some countervailing incentives. On the one hand, a higher investment induces more patients to attend the rural hospital. These patients are associated with a profit provided that the rural hospital has a lower average cost than the urban one (or a loss in the opposite case). However, the marginal profit (or loss) per patient is diminishing with the level of investment. When the proportion of severely ill patients is the same for both hospitals, the effect of "margin per patient" dominates.

In the situation where the rural hospital has a lower treatment cost for severely ill patients, both payment systems lead to an under-investment relative to the first best. Between the two, the DRG payment system leads to a higher total welfare because it stimulates investment more than the FFS payment system. In the opposite case, that is when the urban hospital has a lower treatment cost, I establish that the FFS system introduces a higher level of investment than the DRG system, because of the monetary concerns of the rural hospital manager in the latter system. However, the second-best solution is more complicated because it depends on the level of the first-best investment. When the first-best investment level is very high, the FFS provides a second best as it helps to address systematic under-investment issues. By opposition, when the first-best level is very low, the DRG system performs better as one must deter the hospital manager from over-investing. For the first-best level is in between, the outcome is not so clear due to the fact that the hospital manager may under-invest or over-invest under the DRG system. Lastly, this paper finds that incorporating a location factor into DRG pricing to incentivise the rural hospital would be effective only when the rural hospital has a higher treatment cost.

The relevant literature will be reviewed in Section 2. Section 3 outlines the theoretical framework and model. Section 4 focuses on the first-best level of investment from a welfare perspective. Section 5 compares the levels of investment under the FFS and DRG systems. I discuss the effect of introducing a location factor parameter into the DRG system in Section 6. Lastly, Section 7 concludes and discusses the policy implications.

2. Literature Review

To date, only a few papers focus on rural hospitals' investment strategies and on the potential welfare effects that these decisions have on patients. It is important to recall that investment in medical equipment constitutes a large fixed cost. Its profitability is therefore conditional on having a large number of patients.[12]

There are two distinct strands of literature relevant to this paper. The first strand focuses on the investment decisions of hospitals. The second strand studies how regional differences and healthcare payment systems affect the quality of care. However, with very few exceptions, this second strand of literature has ignored the fact that the calculation of DRG price is often based on the average cost of hospitals in practice.

The literature in the first strand acknowledges that the DRG payment system affects the investment decision of hospitals but it is still inconclusive about the sign of this effect. Gelijns and Rosenberg (1994) find that the DRG scheme may reduce the financial incentives for hospitals to use new technologies, because the compensation for these sophisticated technology-based services is reduced. Castro et al. (2014) test this claim empirically. They find that the DRG scheme provides negative incentives for investment in technology equipment, particularly in relation to complex and expensive medical devices. Mason et al. (2009) consider

[12] Isaacs (2019) shows that one cause of the bankruptcies of rural hospitals is that small communities are not able to support the operations at their local rural hospitals.

public and private healthcare providers, and show that the prospective payment systems (such as the DRG scheme) used in the UK underfunds the hospitals who need big investment projects. They also call for further investigation into hospitals' investment costs and compensating those healthcare providers who have undertaken major capital projects. A more optimistic view is provided in Lee and Rosenman (2013). They consider two types of technologies: quality-enhancing and cost-saving. They show that under retrospective payment system (e.g. the FFS scheme), no hospital will invest in cost-saving technologies, and not-for-profit hospitals will invest in quality-enhancing technologies. However, under prospective payment systems (e.g. the DRG scheme), both for-profit and not-for-profit hospitals will invest in cost-saving technologies and quality-enhancing technologies. Levaggi and Moretto (2008) establish that under the DRG system, a hospital has an incentive to make investments in the earlier period, provided the number of patients being treated in the later period depends on the investment in the earlier period. However, if the treatment cost associated with new technologies is higher, then this may not be the case. Levaggi et al. (2012; 2014) mention an alternative payment system where the reimbursement includes two parts: a lump-sum grant and a DRG payment per patient. They find that the societal optimum can be achieved by this mixed reimbursement system. However, in their model, there is only one representative hospital so that the strategic interaction between hospitals who might have different costs is questionable, requiring future study.[13]

While the importance of rural hospitals is emphasised, they are not the focus of this first strand of the literature. Yet, and as argued in the introduction, in the case of rural hospitals, the optimal level of investment is not obvious. Hart et al. (1990) mention that since the 1980s, many rural hospitals in the US are closing down.[14] They recommend using a federal policy to support these hospitals, arguing that these small rural hospitals differ intrinsically from other hospitals. For example, they typically have lower occupation rates and shorter lengths of

[13] For more discussions about investment of hospitals in this stream, please see Baumgardner (1991), Weisbrod (1991), Cutler and McClellan (1996), Li and Benton (2003), Selder (2005), Bech et al. (2009), Bokhari (2009), Scheller-Kreinsen et al. (2011) and more.

[14] Note that the DRG payment scheme was firstly applied in the US in 1983.

stay, but they have to deal with a high share of Medicare patients and provide vital basic services to rural populations. Doeksen et al. (1990) use a simulation model of a rural community in Oklahoma to study how the DRG payment system affects the rural population. They find that the closure of rural hospitals has a devasting negative impact on rural residents' health and on the economy of the local community. Dawson et al. (2001) show that difference between hospitals, or in the heterogeneous environments in which they operate, should be considered, using a regression analysis to control for teaching status or rural region. Meanwhile, they also argue that a policy maker should be prepared to let some hospitals go bankrupt as it is only by doing so that the yardstick competition can be effective.[15]

The papers in the second strand take regional difference into consideration and focus on the quality of care (which can be seen as the improvement in medical devices) provided under the DRG payment system. Siciliani et al. (2013) study the quality competition in a market with sluggish demand and altruistic providers, relying on a Hotelling model.[16] They find that in the market where the competition is intense, the quality of care will accordingly be high when the healthcare price is sufficiently high. However, when the price is lower than unit cost, the quality of care will be higher under a less competitive market. Another important contribution is that they bring to light the relation between quality of care and demand, through the channel of altruism. They state that the quality of care is higher for providers with higher demand because the marginal intrinsic benefit from quality is greater for such providers. This channel of altruism provides them with a higher incentive to improve quality of care for attracting more patients. When the demand decreases, the quality of care reduces accordingly. Brekke et al. (2016) apply Salop's model (See Salop (1979)) and study the effect of mobility of patients on the quality of healthcare. They consider variation in income across regions. They show that under the DRG payment system, a lower non-monetary mobility cost (e.g. administrative procedure) has no impact on the welfare of high-income regions, because all the treatment expenses on external patients will be

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[15] This point gets support from De Pouvourville (2004), who mentions that the effectiveness of yardstick competition among public hospitals in France is questioned because they do not face a real threat of bankruptcy owing to their public status.

[16] Please see Hotelling (1929) for details of Hotelling model.

fully paid by their home region. However, a lower non-monetary mobility cost does have a negative effect on the quality of care in mid-income and low-income regions, because fewer patients attending the local hospitals makes the improvement in quality less worthwhile. If the co-payment (the portion of treatment cost borne by patients) for external healthcare service reduces, it will positively affect the local quality of care in both mid-income and low-income regions. The reason is that the local governments want patients to be treated locally rather than having to incur the expense of transferring them elsewhere.

Many existing theoretical papers, including the two papers referred to in the preceding section (Siciliani et al., 2013; Brekke et al. 2016), adopt the standard assumption in the literature and consider the DRG price as given.[17] In most countries however, the DRG price is endogenously determined by the average cost of all hospitals. To the best of my knowledge, there are only two notable exceptions in the literature which consider this possibility. The first is Hafsteinsdottir and Siciliani (2010). The most remarkable contribution of this paper is that they consider the average treatment cost as the determinant of DRG price, which is consistent with actual practice. They analyse two possible DRG payment systems, the first of which is "the unrefined DRG system" where the DRG price is the same for any given illness, regardless of the treatment method. The second system is "the refined DRG system", where the DRG price differs between surgical and medical treatments.[18] They establish that under the refined DRG payment system, hospitals are incentivised to over-provide high-intensity treatments. Under an unrefined DRG payment system, whether hospitals over-provide intense treatments depends on other factors such as the altruism level and the opportunity cost of public funds. The second exception is Bisceglia et al. (2018), who consider the issue of setting an appropriate DRG price in a context where the health authority perfectly anticipates the behaviour of health providers. They consider two scenarios: one is a decentralised situation where there are

[17] For example, Levaggi and Moretto (2008) and more.

[18] As mentioned, different hospitals may treat different types of patients. For example, some medical centres are taking care of mostly severely ill patients. Therefore, there is support for a DRG system refined by severity of illness (or complexity) to guarantee the admission of patients with complex needs (See Bojke et al. (2018)).

many regional regulators. The other situation is centralised where there is only one central government. They use Salop's model, and find that when there is a centralised HA who can set DRG prices at regional level, then the higher DRG price should be awarded to the region with more efficient hospitals. The authors argue that the reason behind this is that for these more efficient providers, it is cost-efficient to let them treat more patients with a higher quality of care. Rewarding them with a higher DRG price can motivate them to do so. They argue that their finding is opposite to what occurs in practice, where normally the average treatment cost is higher in regions with less efficient hospitals, resulting a higher DRG price.

This paper adds to the work of Hafsteinsdottir and Siciliani (2010), based on suggestions from their paper. Firstly, I consider an endogenously determined DRG price based on the average treatment cost of hospitals. However, I relax one their assumption that hospitals are identical. In my model, hospitals differ in their treatment costs so that a strategic interaction incorporated. Moreover, I restrict the attention to a situation where we have two representative hospitals as opposed to considering an infinite number of hospitals. This emphasises even more the strategic issues associated with the investment decision. This paper also builds on the work of Bisceglia et al. (2018) by considering the general setting used in their paper, and expanding its scope as follows. This paper pays more attention to the welfare of rural residents. In other words, patients who cannot be cured locally experience an unambiguously negative welfare because they have to be transferred. Secondly, I allow for the rural hospital to be either more or less cost-efficient than the urban one. The results show that this distinction can lead to very different policy implications.

3. Model

I consider a setting with two hospitals who provide healthcare to patients who are either mildly ill or severely ill. The treatment costs are reimbursed via a payment system that is implemented by the central HA. The patients reside in one of two locations: an urban area and a rural area. The rural population is small relative to the urban population. I normalise the number of rural patients to 1 and let $Q > 1$ denote the number of urban patients.

There is a hospital in each region. The rural patients are such that a proportion $\alpha \in [0,1]$ are severely ill while $(1-\alpha)$ have a mild illness. There are a proportion $\beta \in [0,1]$ of urban patients who are severely ill and a proportion $(1-\beta)$ who are mildly ill. Both hospitals have the ability to cure all of mildly ill patients. The urban hospital can also treat all severely ill patients. But the rural hospital can only cure a proportion $q(I)$ of the severely ill patients, where $q(I) \in [0,1]$ is increasing and concave in I. This proportion depends on the level of investment $I > 0$, that the rural hospital undertakes. This assumption is motivated considering that local regions have some autonomy enabling them to decide on their hospitals' investment. I assume that $q(0) = 0$, $\lim_{I \to \infty} q(I) = 1$, $q'(0) = 1$, $\lim_{I \to \infty} q'(I) = 0$.[19] The severely ill patients who cannot be treated in the rural hospital are transferred to the urban hospital.

The medical services for mild illnesses provided by the two hospitals are known to be perfect substitutes and patients are aware of their level of illness. Therefore, rural patients with a mild illness systematically seek treatment locally. The provision of care for sever illness is not necessarily believed to be identical in both hospitals. As a result, some of the rural patients who are severely ill believe that the urban hospital has better facilities and will directly seek treatment in the urban hospital, while a proportion p will attend the rural hospital. This proportion p is exogenous.[20] The severely ill rural patients who decide to attend the local hospital can be cured with probability $q(I)$. Table 1 below summarises the partition of patients.

[19] In this paper, cure rate refers to the probability of being cured if one patient attends a hospital. The cure rate of the rural hospital for severely ill rural patients is captured by $q(I)$.

[20] For example, it may be determined by patients' preferences of being treated locally, and the contracted hospitals from their private health insurance (for discussion about the determinants of bypass behaviours of rural patients, please see Radcliff et al., 2003). It can also be interpreted that patients' choice in response to quality of care is sluggish in the short term (for discussion about sluggish demand, please see Siciliani et al., 2013).

	Low severity illness	High severity illness
Cured in the rural hospital	$1-\alpha$	$\alpha pq(I)$
Cured in the urban hospital	$(1-\beta)Q$	$\alpha(1-p)+\alpha p(1-q(I))+\beta Q$

Table 1: Distribution of patients in each hospital based on the severity of illness

All patients value the access to care $v > 0$, which is independent from their severity of illness. In other words, v captures patient's utility from recovery. The severely ill rural patients who decide to attend the urban hospital directly incur a travel cost $t > 0$, which captures possible out-of-pocket expenses.[21] The severely ill rural patients who must be transferred to the urban hospital incur a transfer cost $T > 0$ capturing the disutility that they suffer. We assume that $v > t$, and $v > T$ meaning that the benefits of being cured always surpasses the costs.

The presence of a hospital in an urban area is, rightly so, taken for granted. The accessibility of care in a rural area is tends to be valued by patients living in remote areas as there is some understanding that such provision is not always commonplace. Therefore, I consider the medical services provided by the rural hospital generate positive externalities (captured by γ) to the rural patients who are treated locally. The externalities can be relevant to economy such as more job opportunities in the local health sector, also it can reflect the benefits from the psycho-social perspective. For example, James (1999) mentions that the services provided by rural hospitals have both tangible and symbolic roles to rural communities. Because hospitals are publicly owned, this positive externality is valued by the rural hospital manager, as well as by the central HA.

The rural hospital receives a reimbursement for the healthcare provided

[21] Some country will cover the travel cost of patients such as Norway. So t here refers the disutility of not being cured locally.

which depends on the payment scheme in place. Under the FFS scheme, all the costs are reimbursed. Under the DRG scheme, the rural hospital gets a DRG payment per treated patient which is based on some calculations of an average cost of treating patients considering costs from both hospitals. The details of how the DRG price is calculated are provided in Section 5.2. Let c_L denote the cost of treating mildly ill patients, which is the same for both hospitals. Let μc_L, where $\mu > 1$, denote the treatment cost per severely ill patient for the urban hospital. Finally, let ρc_L, where $\rho > 1$, denote the cost of treating a severely ill patient for the rural hospital. We allow either $\mu \geq \rho$ or $\mu < \rho$ because the literature is inconclusive as to which type of hospital faces a lower treatment cost per patient.[22] For tractability, I consider the treatment costs of hospitals are exogenous, which are irrelevant to the payment system in place.

I consider that decisions by the HA and the rural hospital are taken sequentially. More specifically, the timing that I consider is as follows:

T=1: The HA announces the payment system it will use (the FFS system or the DRG system).

T=2: The rural hospital's manager selects an investment level that maximises the hospital's profits and the potential externality.

T=3: Patients are treated either locally or not.

I solve for a sub-game Nash equilibrium which is characterised such that the outcomes of the future periods are perfectly anticipated.

4. The First-best Investment Level

In this section, I characterise the investment level that maximises the overall social welfare (i.e. the total surplus, TS). The total surplus is the sum of the surplus for all patients (consumer surplus, CS), the hospital's profits and the externalities generated by the rural hospital (producer surplus, PS). I consider that

[22] See the discussions from: Posnett (2002); Modern Healthcare (2007); Health Resources and Services Administration (2017); OECD and WHO (2019); Sheaff et al. (2020).

there is an opportunity cost of raising public funds which are raised to pay for the treatment costs. This shadow cost is captured via a parameter $\lambda \geq 1$. Overall, we have

$$TS = CS + PS - \lambda TC,$$

where overall consumer surplus is given by

$$CS = v(Q+1) - t\alpha(1-p) - \alpha pT\big(1-q(I)\big),$$

and

$$PS = \gamma[1-\alpha+\alpha pq(I)] - I,$$

and finally, the treatment cost TC is given by:

$$TC = c_L[(1-\alpha)+(1-\beta)Q] + \rho c_L \alpha pq(I) + \mu c_L\big[\alpha(1-p)+\alpha p\big(1-q(I)\big)+\beta Q\big].$$

Firstly, let us focus on the expression for CS. The first term captures the welfare to patients from accessing healthcare. The second term is the cost incurred by severely ill rural patients who decide to travel to the urban hospital. The last term is the cost associated with patients who must be transferred. The effect of investment on the consumer surplus can be derived as $\frac{dCS}{dI} = \alpha pq'(I)T \geq 0$. It shows the consumer surplus is non-decreasing with the investment level because of the transfer cost saved by the increased cure rate.

Now, let us consider PS. Because healthcare reimbursement is a monetary transfer between two parties (hospitals and the central HA), the treatment costs do not appear in the expression of PS (they are however subject to the shadow cost). Therefore, PS only accounts for the externalities experienced by the patients who are treated locally from which we deduct the investment. The effect of investment on the PS is that $\frac{dPS}{dI} = \gamma\alpha pq'(I) - 1$, and the sign is unclear.

Finally, the total of the treatment costs is calculated using Table 1 above.

The effect of investment on the treatment cost is $\frac{dTC}{dI} = -\alpha p c_L(\mu - \rho)q'(I)$, which captures the saving (or cost, depends on the value of ρ and μ) that arises when a patient is cured in the rural hospital rather than in the urban hospital. When the rural hospital has a higher cost and $\mu - \rho < 0$, the sign of $\frac{dTC}{dI}$ is positive. It is because a higher level of investment will make the rural hospital treat more patients with a relative higher treatment cost. When the rural hospital has a lower cost and $\mu - \rho > 0$, the sign of $\frac{dTC}{dI}$ is negative.

Proposition 1:

Let $\gamma^{FB} = \frac{1}{\alpha p} - [T + (\mu - \rho)\lambda c_L] > 0$. *The first-best investment level* I^{FB} *is characterised as follows.*

1) $I^{FB} = 0$, *when the externalities are such that* $\gamma \leq \gamma^{FB}$*;*

2) $I^{FB} > 0$ *solves* $q'(I^{FB}) = \frac{1}{\alpha p[(T+\gamma)+\lambda c_L(\mu-\rho)]}$, *when the externalities are high so that* $\gamma > \gamma^{FB}$.

Proof: see Appendix.

Proposition 1 establishes that the externalities experienced by rural patients treated locally must be high enough to warrant a positive investment. Define the term $[T + (\mu - \rho)\lambda c_L]$ as the “direct social benefits from being treated locally”. One can note that when the direct social benefits are large, the threshold of externality decreases. The intuition is that, considering a huge direct social benefit, the central HA would like the rural hospital to invest even the externality level is low. Therefore, the direct social benefits and externality are substitutes when it comes to the first-best investment level.

Lemma 1:

When positive, the first-best level of investment I^{FB} increases with transfer cost (T), the externality (γ), the treatment cost of the urban hospital (μ), the number of severely ill rural patients directly attending the local hospital (αp). It decreases with the treatment cost of the rural hospital (ρ). If the rural hospital has a lower cost of treating sever illness $(\mu - \rho > 0)$, then the first-best investment level increases with the raising fund cost parameter (λ); otherwise, it decreases with λ.

Proof: see Appendix.

The comparative statics provide some insights as to when the rural hospital should invest. Firstly, from monetary perspective, a higher investment reduces the frequency with which when the transfer cost (T) is paid. This is even more beneficial when the treatment cost of the urban hospital (μ) is high, or when the rural hospital has a lower treatment cost (ρ). The investment is more worthwhile when a large rural population (αp) attend the local hospital. In relation to the funds that need to be raised captured via the cost parameter λ, the benefit of the investment depends on which hospital has a lower treatment cost: if the rural hospital has a lower cost that $\mu - \rho > 0$, a higher level of λ calls for a higher I^{FB}. This is so because more patients should be treated in the rural hospital which is cost-wise. If the rural hospital has a higher cost, then it is more cost-efficient to decrease the investment level such that letting the urban hospital treats more patients. Finally, the investment level should increase when externalities increase (as captured via γ) which is quite intuitive.

5. The FFS Scheme vs. The DRG Scheme

In this section, I consider a decentralised situation where the central HA uses a payment system to incentivise the rural hospital manager to invest. Particularly, I compare the investment levels produced by two payment systems: the FFS payment system and the DRG payment system.

5.1 The Fee-for-service (FFS) Payment System

Under the FFS system, the central HA fully reimburses the costs incurred in each hospital. Therefore, the rural hospital manager decides on the investment level maximising the following payoffs:

$$\Pi(I) = \gamma[1 - \alpha + \alpha p q(I)] - I = PS,$$

where PS is given above.

Proposition 2:

Let $\gamma^{FFS} = \frac{1}{\alpha p} > 0$*. Under the FFS system, the rural hospital invests* I^{FFS} *such that:*

1) $I^{FFS} = 0$*, if externalities are low and* $\gamma \leq \gamma^{FFS}$*;*

2) $I^{FFS} > 0$ *such that* $\gamma \alpha p q'(I^{FFS}) = 1$*, if externalities are high and* $\gamma > \gamma^{FFS}$*.*

Proof: see Appendix.

Under the FFS system the investment level undertaken by the rural hospital only depends on the externality γ and on the number of severely ill rural patients who attend the rural hospital (αp). Given the number of treated patients in the rural hospital, a higher level of externality incentivises the rural hospital manager to invest more. Meanwhile, given the level of externality, as a larger number of patients choose the rural hospital the rural hospital manager invests more. Note the "direct social benefits" $[T + (\mu - \rho)\lambda c_L]$ no longer matter.

Notice as well that the FFS system would be equivalent to a DRG system refined completely by region.[23] The reason is that there is only one representative

[23] The DRG refined by region payment system is that, hospitals only compete with other hospitals according to their locations, e.g. a rural hospital only competes with other rural hospitals. Thus, this system provides DRG prices to the rural hospital and the urban hospital separately.

rural hospital in the model.

5.2 The DRG system

Under the DRG payment system, the central HA sets the DRG prices considering patients' severity of illness (SOI). I refer to "DRG" to capture this system. For each mildly ill patient, the two hospitals get the same DRG price k_L, because they have the same cost so that $k_L = c_L$. For each severely ill patient, the DRG price k_H is based on the calculation of the overall average cost:

$$k_H = \frac{\rho c_L \alpha p q(I) + \mu c_L[\alpha(1-p) + \alpha p(1-q(I)) + \beta Q]}{\alpha + \beta Q}.$$

Let us define the margin per severely ill patient for the rural hospital as

$$M(I) = k_H - \rho c_L = c_L(\mu - \rho)\frac{\alpha - \alpha p q(I) + \beta Q}{\alpha + \beta Q}.$$

We have $M(0) = c_L(\mu - \rho)$. The first derivative of margin is given by $M'(I) = -c_L(\mu-\rho)\frac{\alpha p q'(I)}{\alpha+\beta Q}$, so we also have $\lim_{I\to\infty} M'(I) = 0$, and $M'(0) = -c_L(\mu-\rho)\frac{\alpha p}{\alpha+\beta Q}$. Furthermore, let $\widetilde{M} = c_L(\mu-\rho)\frac{\alpha-\alpha p+\beta Q}{\alpha+\beta Q}$.

Lemma 2:

If $\mu - \rho > 0$, the margin $M(I)$ is positive, decreasing and convex and such that $M(I) > 0$, $M'(I) < 0$, $M''(I) > 0$, and $\lim_{I\to\infty} M(I) = \widetilde{M} > 0$;

If $\mu - \rho < 0$, the margin $M(I)$ is negative, increasing and concave and such that $M(I) < 0$, $M'(I) > 0$, $M''(I) < 0$and $\lim_{I\to\infty} M(I) = \widetilde{M} < 0$.

Proof: see Appendix.

Lemma 2 illustrates a strategic dimension that emerges when the rural hospital adjusts its investment level when subjected to a DRG price. In a market where there are few healthcare providers, hospitals can manipulate the DRG price and consequently their margins, by adjusting their investment behaviours.

When the rural hospital has a lower cost of treating a severely ill patient, each additional severely ill patient is associated with a positive margin. However, this margin per patient decreases as the investment increases. The reason is that more rural patients can be cured in the rural hospital as the investment increases. Therefore, the DRG price is calculated putting more weight on the rural hospital's cost and it becomes less advantageous. Thus, a trade-off emerges: under a low investment level, each patient is associated with a large margin, but under a high investment level the margin per patient is low as more patients attend the rural hospital.

When the rural hospital has a higher cost of treating a severely ill patient, a higher investment level reduces the negative margin that it gets for each extra patient that it treats. A low level of investment induces fewer patients to attend the hospital but the negative margin per patient is large. Figure 1 below illustrates the trade-off that faced by the rural hospital manager.

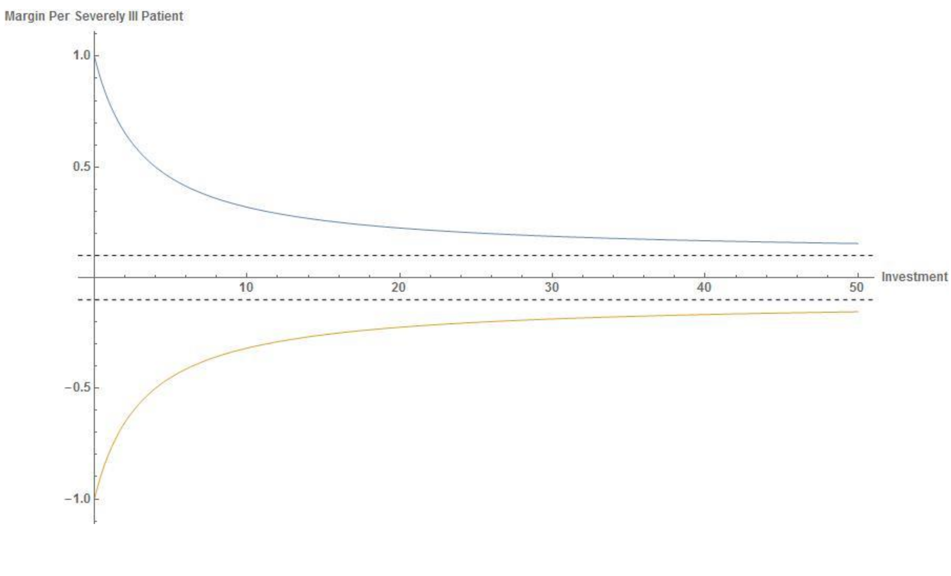

Figure 1: The Absolute Value of Margin Declines in Investment

Note: We let $p(I) = \frac{I}{1+I}$ *and* $\alpha = 0.5$, $p = 0.9$, $c_L = 1$, $Q = 1.1$. *The margin is positive and decreasing in* I *when* $\mu - \rho > 0$. *It is negative and increasing in* I *when* $\mu - \rho < 0$.

Because all mildly ill patients will be reimbursed by actual cost, the rural hospital manager maximises their payoff under DRG system considering the externality, the monetary profit of severely ill patients, and the investment cost. The pay-off function is given by

$$\Pi(I) = \gamma[1 - \alpha + \alpha p q(I)] + M(I)\alpha p q(I) - I.$$

Sadly, the concavity of $\Pi(I)$ is subject to certain conditions and comparisons are difficult to assess. Thus, for tractability, I pursue the analysis under two assumptions which ensure that the payoff is concave in I and enable me to compare the outcomes.

Assumption 1: The proportion of severely ill patients is the same for both the urban area and the rural area such that $\alpha = \beta$.

This assumption is helpful to simplify the comparison of investment levels induced by different payment systems.

Assumption 2: The population in the urban area is sufficiently high relative to the rural population (captured by Q) such that $q''(I^{DRG}) - \frac{2\alpha^2 p^2 c_L(\mu-\rho)}{\alpha+\alpha Q}[q'(I^{DRG})]^3 < 0$.

This second assumption guarantees the concavity of the payoff function in the below Proposition 3.

Proposition 3:

Let $\gamma^{DRG} = \frac{1}{\alpha p} - c_L(\mu - \rho)$*.The investment level under the DRG system* I^{DRG}*is such that*

1) $I^{DRG} = 0$*, if externalities are low and* $\gamma \leq \gamma^{DRG}$*;*

2) $I^{DRG} > 0$ *such that*

$$\gamma \alpha p q'(I^{DRG}) - 1 = -\frac{\alpha p c_L(\mu - \rho)}{\alpha + \alpha Q} q'(I^{DRG})[-2\alpha p q(I^{DRG}) + \alpha + \alpha Q],$$

if externalities are high and $\gamma > \gamma^{DRG}$.

Proof: see Appendix.

Once again, a higher externality motivates the rural hospital manager to invest. Moreover, the threshold of externality level γ^{DRG} depends on the relative treatment cost between the rural hospital and the urban hospital. In particular, if the rural hospital has a lower cost than its urban competitor, then the threshold γ^{DRG} is lower. The reason is straightforward: considering the patients treated in the rural hospital are associated a positive margin which motivates the rural hospital manager to invest although the externality level is low. Similarly, when the rural hospital has a higher cost, the threshold γ^{DRG} would be higher.

5.3 Comparisons

In above subsection 5.1 and subsection 5.2, I establish that the FFS payment system and the DRG system incentivise the investment undertaken by the rural hospital in different ways. In this subsection, I will compare the investment levels resulting from the two systems.

Before we take the first-best level into consideration, I firstly compare the investment levels produced by the FFS system (captured by I^{FFS}) to the DRG system (captured by I^{DRG}). If only system produces a corner solution, it is straightforward that the other system leads to a higher investment level; meanwhile, if both systems produce corner solutions, then investment levels are the same (both at zero). Thus, the following Proposition 4 addresses a question that, which system produces a higher investment, when the externality level is sufficient large such that there are interior solutions under both systems ($I^{FFS} > 0$ and $I^{DRG} > 0$).

Proposition 4:

For any $\gamma > \frac{1}{\alpha p}$ *under the situation where* $\mu - \rho > 0$, *or for any* $\gamma > \frac{1}{\alpha p} - c_L(\mu - \rho)$ *under the situation where* $\mu - \rho < 0$, *we have*

1) $I^{FFS} < I^{DRG}$, *if* $M'(I^{DRG})q(I^{DRG}) + M(I^{DRG})q'(I^{DRG}) > 0$.

2) $I^{FFS} > I^{DRG}$, *if* $M'(I^{DRG})q(I^{DRG}) + M(I^{DRG})q'(I^{DRG}) < 0$.

In particular, if the proportion of severely ill patients is the same for both rural area and urban area ($\alpha = \beta$), *we have*

1) $I^{FFS} < I^{DRG}$, *if* $\mu - \rho > 0$.

2) $I^{FFS} > I^{DRG}$, *if* $\mu - \rho < 0$.

Proof: see Appendix.

As explained in Proposition 3, the rural hospital faces a trade-off when setting its investment level under the DRG system and consider the "margin per patient" and the "number of patients". This trade-off is important for determining whether the rural hospital invests at a higher level under DRG payment system. In the scenario where the rural hospital has a higher cost ($\mu - \rho < 0$), the margin per patient is always negative but this loss per patient will be diminishing with the increase of the investment. If the benefits of curing more patients is greater than the cost, that is if $M'(I^{DRG})q(I^{DRG}) + M(I^{DRG})q'(I^{DRG}) > 0$, the rural hospital will invest a higher level under DRG system. On the other hand, in the scenario where $\mu - \rho > 0$, the margin per patient is always positive but this profit per patient will be diminishing with the increase of the investment. Thus, it also ends with the trade-off between the "margin per patient" and the "number of patients".

When $\alpha = \beta$, the impact of the "margin per patient" always dominates. Therefore, if the rural hospital has a cost advantage, it will invest at a higher level when under the DRG system; if the rural hospital has a cost disadvantage, it will invest at a higher level when under the FFS system.

Now we move to the key part of this paper: which payment system could incentivise the rural hospital manager to invest a level closer to the first-best level?

Case 1 ($\boldsymbol{\mu - \rho > 0}$):

In this Case 1, the fact that $\mu - \rho > 0$ gives us $\gamma^{FB} < \gamma^{DRG} < \gamma^{FFS}$. These thresholds divide the levels of externality into four regions, which are shown as Figure 2 below.

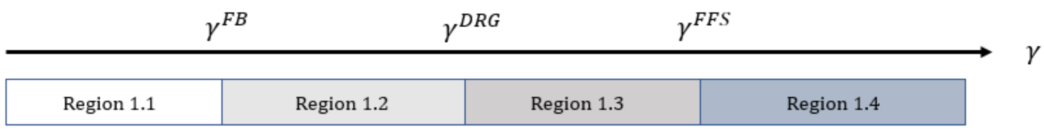

Figure 2: The externality levels and the investment thresholds for Case 1

Proposition 5:

In the Region 1.1 where the externality is very low such that $\gamma < \gamma^{FB} < \gamma^{DRG} < \gamma^{FFS}$*, we have* $I^{FB} = I^{FFS} = I^{DRG} = 0$*.*

In the Region 1.2 where the externality is relatively low such that $\gamma^{FB} < \gamma < \gamma^{DRG} < \gamma^{FFS}$*, we have* $I^{FB} > 0$ *and* $I^{FFS} = I^{DRG} = 0$*.*

In the Region 1.3 where the externality is relatively high such that $\gamma^{FB} < \gamma^{DRG} < \gamma < \gamma^{FFS}$*, we have* $I^{FB} > I^{DRG} > 0$ *and* $I^{FFS} = 0$*.*

In the Region 1.4 where the externality is very high such that $\gamma^{FB} < \gamma^{DRG} < \gamma^{FFS} < \gamma$*, we have* $I^{FB} > I^{DRG} > I^{FFS} > 0$*.*

Proof: see Appendix.

A very low level of externality (Region 1.1) aligns the objective of the central HA and the rural hospital manager: the investment is not worthwhile.

However, as the externality starts to increase, the interest of the HA and the hospital manager diverge. For a relatively low externality level which falls in the Region 1.2, the central HA would like a positive investment $I^{FB} > 0$. However, this level is still not large enough to incentivise the rural hospital manager to invest under any payment systems (shown in Figure 2.2). In the Region 1.3, the increasing level of externality motivates the investment level under the DRG system only because the rural hospital could make some positive profits from treating more patients by investment. In this case, the first-best level is still higher than the level introduced by the DRG system (shown in Figure 2.3). In the last Region 1.4 where the externality is very high, we have $I^{FB} > I^{DRG} > I^{FFS} > 0$ (shown in Figure 2.4).

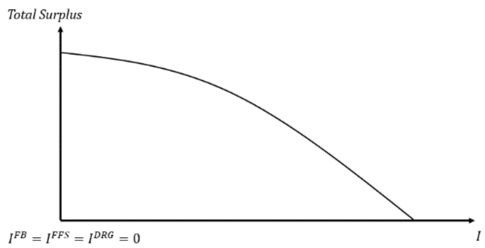

Figure 2.1

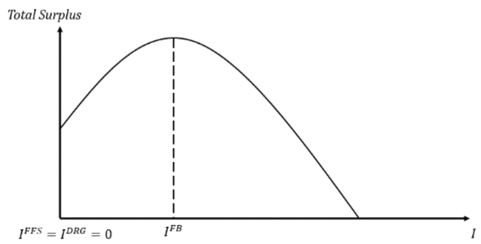

Figure 2.2

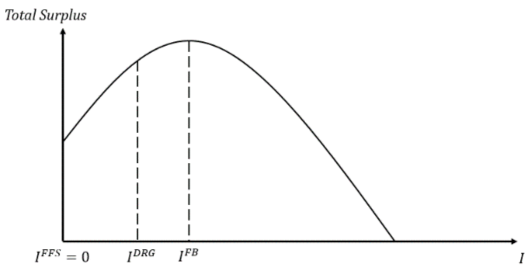

Figure 2.3

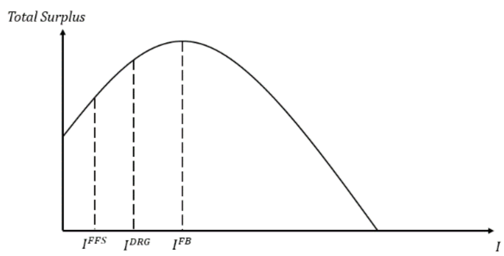

Figure 2.4

In the situation where the rural hospital has a lower treatment cost for severely ill patients, both payment systems lead to an under-investment relative to the first best. Between the two, the DRG payment system leads to a higher total welfare because it stimulates investment more than the FFS payment system.

Case 2 ($\mu - \rho < 0$):

Now we move to the other scenario where the rural hospital has a higher treatment cost. Recall that the threshold of externality for the first best level is $\gamma^{FB} = \frac{1}{\alpha p} - [T + (\mu - \rho)\lambda c_L]$; the threshold under the FFS system is $\gamma^{FFS} = \frac{1}{\alpha p}$; and under the DRG system is $\gamma^{DRG} = \frac{1}{\alpha p} - c_L(\mu - \rho)$. It is clear that $\gamma^{DRG} > \gamma^{FFS}$ as $\mu - \rho < 0$. However, the location of γ^{FB} is ambiguous because it depends on the direct net social benefits (transfer cost T and the shadow cost of public funds λ). Figure 3 illustrates the three possible sub-cases that can arise: Subcase 2.1 arise when T is large and λ is low and has $\gamma^{FB} < \gamma^{FFS} < \gamma^{DRG}$. Subcase 2.2 has $\gamma^{FFS} < \gamma^{FB} < \gamma^{DRG}$. Finally, Subcase 2.3 arises when T is low and λ is large and has $\gamma^{FFS} < \gamma^{DRG} < \gamma^{FB}$. I will discuss these three subcases one by one.

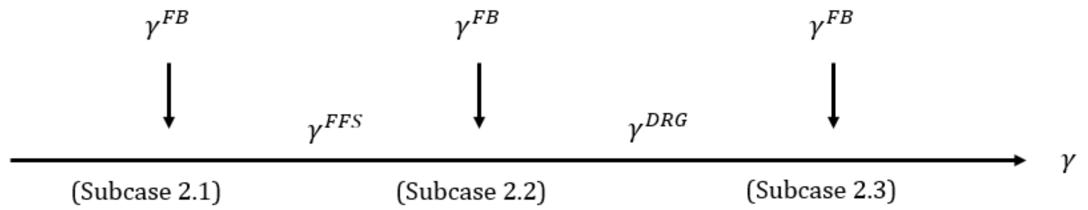

Figure 3: Three possible sub-cases when under Case 2

Subcase 2.1 where $\gamma^{FB} < \gamma^{FFS} < \gamma^{DRG}$:

Note that in this Subcase 2.1, we have the "direct social benefits" (captured by $T + (\mu - \rho)\lambda c_L$) is positive, while the rural hospital's financial concerns under the DRG system (captured by $c_L(\mu - \rho)$) is negative, such that $T + (\mu - \rho)\lambda c_L > 0 > c_L(\mu - \rho)$. In other words, this Subcase 2.1 could occur when the transfer cost is very large, or/and the shadow cost of public funds is small. These exogenous variables make the investment be very demanded for the central HA: a higher level of investment saves the transfer cost of patients; although the cost of rural hospital is higher, the shadow cost parameter is low.

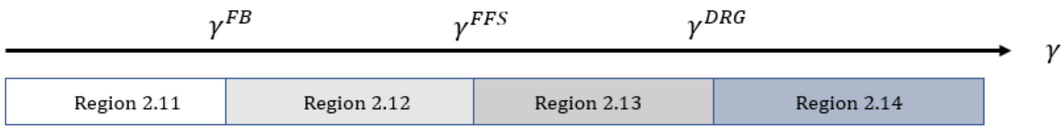

Figure 4: The externality levels and the investment thresholds for Subcase 2.1

Proposition 6:

Consider the Subcase 2.1 where $\mu - \rho < 0$ *and* $\gamma^{FB} < \gamma^{FFS} < \gamma^{DRG}$*:*

In the Region 2.11 where the externality is very low such that $\gamma < \gamma^{FB} < \gamma^{FFS} < \gamma^{DRG}$*, we have* $I^{FB} = I^{FFS} = I^{DRG} = 0$*.*

In the Region 2.12 where the externality is relatively low such that $\gamma^{FB} < \gamma < \gamma^{FFS} < \gamma^{DRG}$*, we have* $I^{FB} > 0$ *and* $I^{FFS} = I^{DRG} = 0$*.*

In the Region 2.13 where the externality is relatively high such that $\gamma^{FB} < \gamma^{FFS} < \gamma < \gamma^{DRG}$*, we have* $I^{FB} > I^{FFS} > 0$ *and* $I^{DRG} = 0$*.*

In the Region 2.14 where the externality is very high such that $\gamma^{FB} < \gamma^{FFS} < \gamma^{DRG} < \gamma$*, we have* $I^{FB} > I^{FFS} > I^{DRG} > 0$*.*

Proof: see Appendix.

This Subcase 2.1 is very similar to the one depicted in Case 1 in that there is systematic under-investment under each of the payment schemes. However, by opposition to what we established before, the FFS system performs better than the DRG system as it leads to larger investments (shown in Figure 4.1 to Figure 4.4 below).

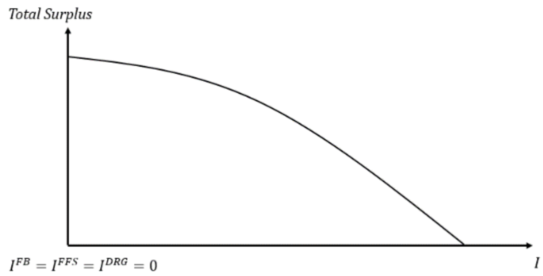

Figure 4.1

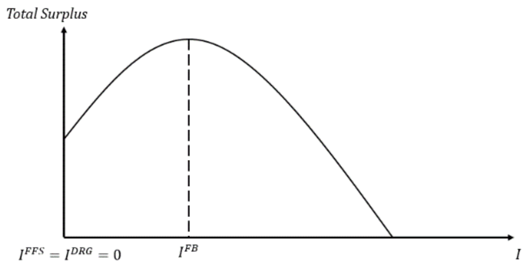

Figure 4.2

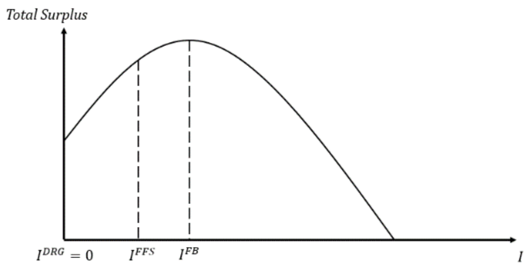

Figure 4.3

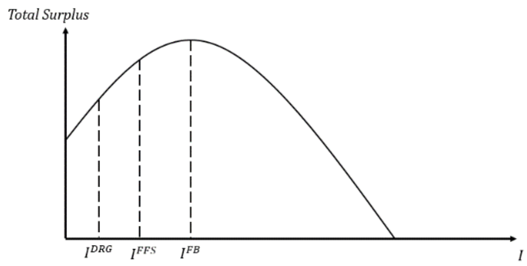

Figure 4.4

Subcase 2.2 where $\gamma^{FFS} < \gamma^{FB} < \gamma^{DRG}$:

Note that this Subcase 2.2 could occur when the "direct social benefits" (captured by $T + (\mu - \rho)\lambda c_L$) is negative. In this case, Figure 5 represents the relevant regions we must consider.

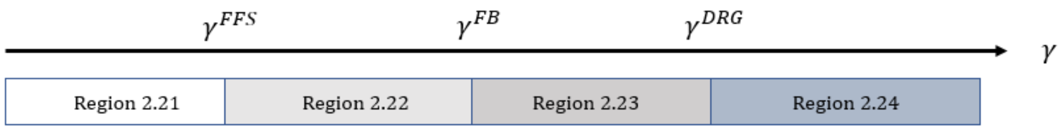

Figure 5: The externality levels and the investment thresholds for Subcase 2.2

Proposition 7:

Consider the Subcase 2.2 where $\mu - \rho < 0$ and $\gamma^{FFS} < \gamma^{FB} < \gamma^{DRG}$:

In the Region 2.21 where the externality is very low such that $\gamma < \gamma^{FFS} < \gamma^{FB} < \gamma^{DRG}$, we have $I^{FB} = I^{FFS} = I^{DRG} = 0$.

In the Region 2.22 where the externality is relatively low such that $\gamma^{FFS} < \gamma < \gamma^{FB} < \gamma^{DRG}$, *we have* $I^{FFS} > 0$ *and* $I^{FB} = I^{DRG} = 0$.

In the Region 2.23 where the externality is relatively high such that $\gamma^{FFS} < \gamma^{FB} < \gamma < \gamma^{DRG}$, *we have* $I^{FFS} > I^{FB} > 0$ *and* $I^{DRG} = 0$.

In the Region 2.24 where the externality is very high such that $\gamma^{FFS} < \gamma^{FB} < \gamma^{DRG} < \gamma$, *we could have either* $I^{FFS} > I^{FB} > I^{DRG} > 0$ *or* $I^{FFS} > I^{DRG} > I^{FB} > 0$.

Proof: see Appendix.

Once again, investment is discouraged when the externality is very low, and this matches the first best. However, there is now a risk that the hospital manager will over-invest if the FFS payment is in place. The DRG system may lead to over or under investments (shown in Figure 5.4). This means that it is not clear which, of the two systems achieves a second best.

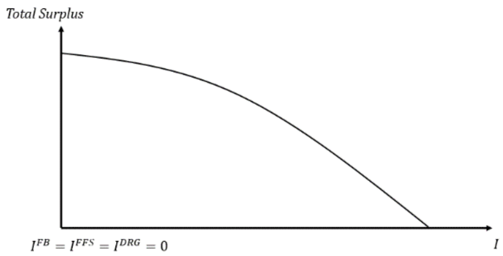

Figure 5.1

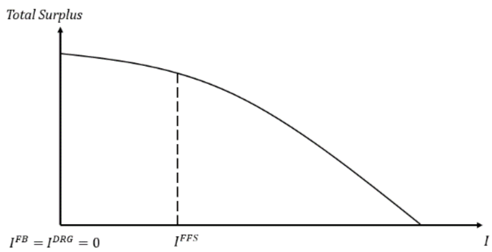

Figure 5.2

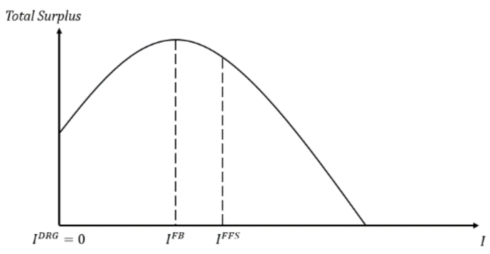

Figure 5.3

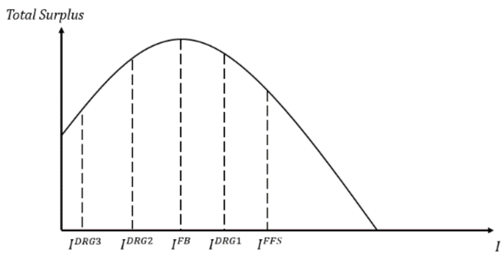

Figure 5.4

Subcase 2.3 where $\gamma^{FFS} < \gamma^{DRG} < \gamma^{FB}$:

This Subcase 2.3 could occur when $T + (\mu - \rho)\lambda c_L < (\mu - \rho)c_L < 0$, which means the "direct social benefits" (captured by $T + (\mu - \rho)\lambda c_L$) is very negative. Figure 6 highlights the main regions in this case.

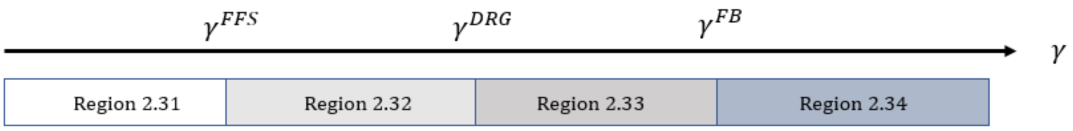

Figure 6: The externality levels and the investment thresholds for Subcase 2.3

Proposition 8:

Consider the Subcase 2.3 where $\mu - \rho < 0$ and $\gamma^{FFS} < \gamma^{DRG} < \gamma^{FB}$:

In the Region 2.31 where the externality is very low such that $\gamma < \gamma^{FFS} < \gamma^{DRG} < \gamma^{FB}$, we have $I^{FB} = I^{FFS} = I^{DRG} = 0$.

In the Region 2.32 where the externality is relatively low such that $\gamma^{FFS} < \gamma < \gamma^{DRG} < \gamma^{FB}$, we have $I^{FFS} > 0$ and $I^{FB} = I^{DRG} = 0$.

In the Region 2.33 where the externality is relatively high such that $\gamma^{FFS} < \gamma^{DRG} < \gamma < \gamma^{FB}$, we have $I^{FFS} > I^{DRG} > 0$ and $I^{FB} = 0$.

In the Region 2.34 where the externality is very high such that $\gamma^{FFS} < \gamma^{DRG} < \gamma^{FB} < \gamma$, we have $I^{FFS} > I^{DRG} > I^{FB} > 0$.

Proof: see Appendix.

This situation leads us to an outcome that is diametrically opposed to the one we reached in Case 1. The main issue is over-investment which is more drastic under the FFS system. Hence the DRG system reaches a second best.

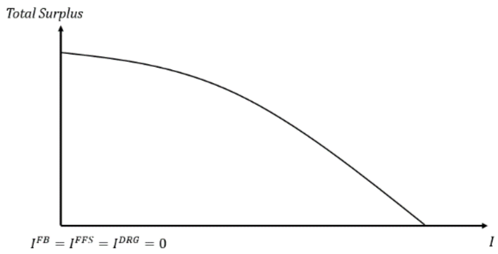

Figure 6.1

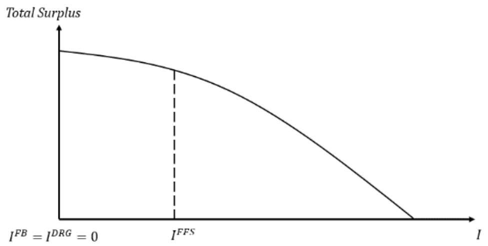

Figure 6.2

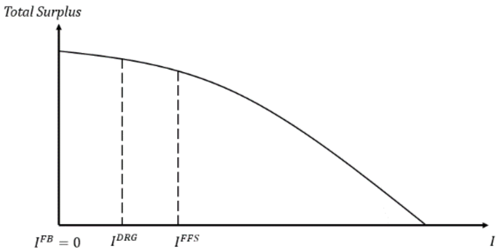

Figure 6.3

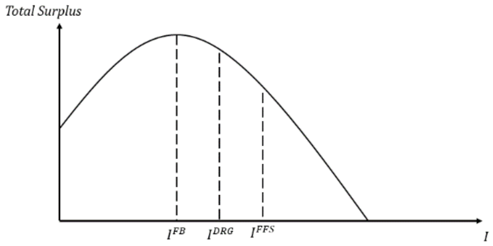

Figure 6.4

Above results bring the following policy implications. Several variables play a role in determining the optimal pricing system. The flow chart below (Figure 7) summarises the main information. When the rural hospital has a lower cost of treatment for sever illnesses, the DRG system provides a systematic second best because it incentivises investment. In the opposite case, that is when the urban hospital is more efficient at treating severe illnesses, the situation is more complicated. When the direct social benefits are positive, the FFS provides a second best as it helps to address systematic under-investment issues. By opposition, when the direct social benefits are largely negative, the DRG system performs better as one must deter the hospital manager from over-investing. For the direct social benefits in between, the outcome is not so clear due to the fact that the hospital manager may under-invest or over-invest under the DRG system.

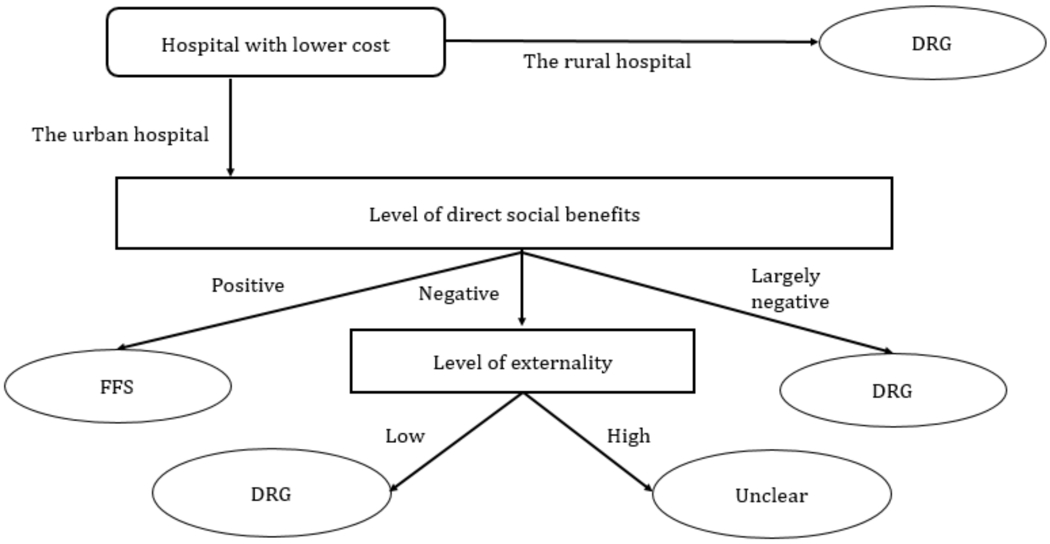

Figure 7: The Flow Chart of Public Policy Implications

6. The DRG-MIX Scheme

In this final section I consider a DRG based system which accounts for both, the SOI of patients, and the location of the hospital. I use the term "DRG-MIX" to capture this payment system. Specifically, I consider the payment for each treated mildly ill patient is $k_L = c_L$ as was the case in the DRG system. However, I now consider that, for each treated severely ill patient treated in the rural hospital, the DRG payment k_H^{MIX} is calculated based on the original DRG payment price k_H multiplied by a multiplier $\theta > 0$, which is given by

$$k_H^{MIX} = \theta k_H = \theta \frac{\rho c_L \alpha p q(I) + \mu c_L[\alpha(1-p) + \alpha p(1-q(I)) + \beta Q]}{\alpha + \beta Q}.$$

One can note that when the multiplier $\theta > 1$, the rural hospital is subsidised while it is taxed when the multiplier $0 < \theta < 1$. For tractability, I assume that there is no shadow cost of public funds associated with subsidy or tax through this multiplier θ. Thus, the margin for the rural hospital, $M_{MIX}(I)$, is given by

$$M_{MIX}(I) = k_H^{MIX} - \rho c_L = \theta k_H - \rho c_L.$$

One can easily show that $M_{MIX}(I)$ is increasing in θ such that $\frac{dM_{MIX}(I)}{d\theta} = k_H > 0$. Moreover, when the investment converges towards infinity, the margin converges to a constant number $\lim_{I \to \infty} M_{MIX}(I) = \widetilde{M}_{MIX} = \theta c_L \frac{\rho\alpha p + \mu(\alpha - \alpha p + \beta Q)}{\alpha + \beta Q} - \rho c_L$.

Lemma 3:

1) If $\mu - \rho > 0$, then $M'_{MIX}(I) = \theta M'(I) < 0$.

2) If $\mu - \rho < 0$, then $M'_{MIX}(I) = \theta M'(I) > 0$.

Proof: see Appendix.

Under the DRG-MIX payment system, the rural hospital maximises the following payoff function

$$\Pi(I) = \gamma[1 - \alpha + \alpha p q(I)] + M_{MIX}(I)\alpha p q(I) - I.$$

Proposition 9:

1) When $\mu - \rho > 0$, the effect of the multiplier θ on the investment decision is ambiguous.

2) When $\mu - \rho < 0$, a higher value of the multiplier θ will incentivise the rural hospital to increase its investment.

Proof: see Appendix.

Proposition 9 provides a policy implication when incorporating the regional factor into the DRG price to adjust the investment behaviour of the rural hospital manager. In the scenario where the rural hospital has a lower cost ($\mu -$

$\rho > 0$), the effect of the multiplier is unclear. On the one hand, a higher multiplier implies that each patient is associated with a higher price. This incentivises the rural hospital to invest. But, on the other hand, a higher investment leads to a lower profit per patient, and this negative effect grows with θ. This discourages the investment undertaken by the rural hospital.

In the scenario where the rural hospital has a higher cost ($\mu - \rho < 0$), the effect of the multiplier is clear: a higher multiplier incentivises the investment behaviour of the rural hospital manager. A higher multiplier implies that the patients who attended the rural hospital are associated with a higher margin. Also, the loss per patient reduces as more patients attend the rural hospital. Therefore, the rural hospital invests at a higher level as the parameter θ increases. In this case, the multiplier θ is a good tool for the HA to adjust the rural hospital manager's behaviour.

7. Conclusion

This paper intends to propose a thorough analysis of the investment strategy adopted by a rural hospital. The model captures the benefits that are generated when the rural hospital raises its level of investment in terms of higher ability to cure patients (which means that fewer patients must be transferred). It also considers the impact on costs of public funds. Finally, it accounts for the positive externalities experienced by the rural community. An important contribution lies in the fact that I allow the DRG price to depend on the level of investment. This is so because the investment level affects the number of patients that the rural hospital can treat, which affects the affected the average cost of hospitals and consequently, the DRG price. This enables the rural hospital manager to adjust their investment decision based on the perfect anticipation of the impact that it will have on the DRG price.

In terms of the optimal investment level, this paper finds that the investment undertaken by the rural hospital is worthwhile if the travel cost is large; the externality level is high; the number of severely ill rural patients directly attending the local hospital is large; the treatment cost at the urban hospital is high; or the treatment cost at the rural hospital is low.

In general, we show that when the level of the externalities generated for rural patients is low, incentives between the HA and the rural hospital manager are aligned and there is no investment undertaken. As the externality increases, investing becomes optimal and the objectives of the HA and the rural hospital manager may be misaligned. This paper shows that the DRG system provides a second-best solution when the rural hospital is more efficient at curing severely ill patients because it motivates investment. When the urban hospital is more efficient, the situation is more complicated. The reason is that the first-best investment level can be either high or low. When the first-best investment level is very high, the FFS provides a second-best solution as it helps to address systematic under-investment issues. By opposition, when the first-best investment level is very low, the DRG system performs better as one must deter the hospital manager from over-investing.

Although the merits of a DRG-based payment system in terms of saving public expenditure has been well documented in the literature, it does not always incentivise the rural hospital to undertake the optimal investment decisions. This paper explains the situations where the FFS system could incentivise the rural hospital to invest at a level which more closely approximates the first-best investment level and provides the intuitions behind it.

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APPENDIX

Proof of Proposition 1:

The overall Total Surplus is given by

$$TS = v(Q+1) - t\alpha(1-p) - \alpha pT\big(1-q(I)\big) + \gamma[1-\alpha+\alpha pq(I)] - I$$
$$- \lambda\{c_L[(1-\alpha)+(1-\beta)Q] + \rho c_L \alpha pq(I)$$
$$+ \mu c_L\big[\alpha(1-p) + \alpha p\big(1-q(I)\big) + \beta Q\big]\}.$$

The first derivative of the above is given by

$$\frac{dTS}{dI} = \alpha pq'(I)[(T+\gamma) + \lambda c_L(\mu-\rho)] - 1.$$

The first order condition (FOC) is such that

$$q'(I^{FB}) = \frac{1}{\alpha p[(T+\gamma)+\lambda c_L(\mu-\rho)]}.$$

The second derivative is given by

$$\frac{d^2TS}{dI^2} = \alpha pq''(I)[(T+\gamma) + \lambda c_L(\mu-\rho)].$$

At solution, we have $\left.\frac{d^2TS}{dI^2}\right|_{I^{FB}} = q''(I^{FB})$, which is a negative.

We have $\left.\frac{dTS}{dI}\right|_{I\to\infty} = -1$ and $\left.\frac{dTS}{dI}\right|_{I=0} = \alpha p[(T+\gamma) + \lambda c_L(\mu-\rho)] - 1.$

Let $\gamma^{FB} = \frac{1}{\alpha p} - [T + \lambda c_L(\mu-\rho)]$. If $\gamma > \gamma^{FB}$, the optimal investment level is positive. If $\gamma \le \gamma^{FB}$, the optimal investment level is zero. ■

Proof of Lemma 1:

The first order condition (FOC) is such that

$$\frac{dTS}{dI} = \alpha pq'(I)[(T+\gamma) + \lambda c_L(\mu-\rho)] - 1 = 0.$$

Note that at the solution $I^{FB} > 0$, we must have $(T + \gamma) + \lambda c_L(\mu - \rho) > 0$.

Let $H(I^{FB}) = \frac{dTS}{dI} = 0$, given any $x \in \{T, \gamma, \mu, \rho, \alpha, p, \lambda\}$ we have

$$\left.\frac{dH}{dI}\right|_{I^{FB}} \frac{\partial I^{FB}}{\partial x} + \left.\frac{\partial H}{\partial x}\right|_{I^{FB}} = 0.$$

The second order condition holds at $I^{FB} > 0$, so that $\left.\frac{dH}{dI}\right|_{I^{FB}} < 0$. Therefore the sign of $\frac{\partial I^{FB}}{\partial x}$ is the same as the sign of $\left.\frac{\partial H}{\partial x}\right|_{I^{FB}}$.

- Parameters of interest: $x \in \{T, \gamma, \mu, \alpha, p\}$.

We have

$$\left.\frac{\partial H}{\partial x}\right|_{I^{FB}} > 0.$$

- Parameters of interest: $x \in \{\rho\}$.

We have

$$\left.\frac{\partial H}{\partial x}\right|_{I^{FB}} < 0.$$

- Parameters of interest: $x \in \{\lambda\}$.

We have

$$\left.\frac{\partial H}{\partial \lambda}\right|_{I^{FB}} = \alpha p q'(I) c_L(\mu - \rho).$$

When $\mu - \rho > 0$, we have $\left.\frac{\partial H}{\partial \lambda}\right|_{I^{FB}} > 0$; when $\mu - \rho < 0$, we have $\left.\frac{\partial H}{\partial \lambda}\right|_{I^{FB}} < 0$.

Therefore, the first-best investment level $I^{FB} > 0$ increases with transfer cost (T), the externality (γ), the treatment cost of the urban hospital (μ), the number of severely ill rural patients attending the local hospital (αp). It decreases with the treatment cost of the rural hospital (ρ). If the rural hospital has a lower cost such that $\mu - \rho > 0$, the first-best investment level increases with the raising fund cost parameter (λ); otherwise when the rural hospital has a higher cost $\mu - \rho < 0$, it decreases with λ. ■

Proof of Proposition 2:

Under FFS payment system, the rural hospital manager maximises the payoff

$$\text{Max } \Pi(I) = \gamma[1 - \alpha + \alpha p q(I)] - I.$$

The FOC is such that:

$$\frac{d\Pi(I)}{dI} = \gamma \alpha p q'(I) - 1 = 0.$$

The SOC holds as

$$\frac{d^2\Pi(I)}{dI^2} = \gamma \alpha p q''(I) < 0.$$

We find that $\left.\frac{d\Pi(I)}{dI}\right|_{I\to\infty} = -1$ and $\left.\frac{d\Pi(I)}{dI}\right|_{I=0} = \gamma \alpha p - 1$.

Let γ^{FFS} represents the threshold between corner solution and interior solution such that $\left.\frac{d\Pi(I)}{dI}\right|_{I=0} = 0$, where $\gamma^{FFS} = \frac{1}{\alpha p}$. For all $\gamma > \gamma^{FFS}$, we have an interior solution such that $I^{FFS} > 0$; for all $\gamma \leq \gamma^{FFS}$, we have a corner solution that $I^{FFS} = 0$. ■

Proof of Lemma 2:

The margin per severely ill patient is given by

$$M(I) = c_L(\mu - \rho)\frac{\alpha - \alpha p q(I) + \beta Q}{\alpha + \beta Q}.$$

The term $\frac{\alpha - \alpha p q(I) + \beta Q}{\alpha + \beta Q}$ is always positive. Therefore, the sign of $M(I)$ depends only on $\mu - \rho$. If $\mu - \rho > 0$, then $M(I) > 0$; If $\mu - \rho < 0$, then $M(I) < 0$.

One could easily find that when the investment converges towards infinity, the margin $M(I)$ converges to a constant number $\widetilde{M}$:

$$\widetilde{M} = \lim_{I\to\infty} M(I) = c_L(\mu - \rho)\frac{\alpha - \alpha p + \beta Q}{\alpha + \beta Q}.$$

The first derivative $M'(I)$ is given by

$$M'(I) = -c_L(\mu - \rho)\frac{\alpha p}{\alpha + \beta Q}q'(I).$$

The second derivative $M''(I)$ is given by

$$M''(I) = -c_L(\mu - \rho)\frac{\alpha p}{\alpha + \beta Q}q''(I).$$

One can find that the sign of $M'(I)$ and $M''(I)$ depends only on $(\mu - \rho)$. If $\mu - \rho > 0$, then $M'(I) < 0$ and $M''(I) > 0$; If $\mu - \rho < 0$, then $M'(I) > 0$ and $M''(I) < 0$.

■

Proof of Proposition 3:

The payoff function is given by

$$\text{Max } \Pi(I) = \gamma[1 - \alpha + \alpha p q(I)] + M(I)\alpha p q(I) - I.$$

The FOC is given by:

$$\frac{d\Pi(I)}{dI} = \gamma\alpha p q'(I) + \alpha p M'(I)q(I) + \alpha p M(I)q'(I) - 1 = 0.$$

Recall that $M'(I) = -c_L(\mu - \rho)q'(I)\frac{\alpha p}{\alpha+\beta Q}$ and $M(I) = c_L(\mu - \rho)\frac{\alpha-\alpha p q(I)+\beta Q}{\alpha+\beta Q}$, the FOC can be rewritten as

$$\frac{d\Pi(I)}{dI} = \gamma\alpha p q'(I) + \frac{\alpha p c_L(\mu - \rho)}{\alpha + \beta Q}q'(I)[-2\alpha p q(I) + \alpha + \beta Q] - 1 = 0.$$

The second derivative is given by:

$$\frac{d^2\Pi(I)}{dI^2} = \gamma\alpha p q''(I) + \frac{\alpha p c_L(\mu - \rho)}{\alpha + \beta Q}q''(I)[-2\alpha p q(I) + \alpha + \beta Q] - \frac{2\alpha^2 p^2 c_L(\mu - \rho)}{\alpha + \beta Q}[q'(I)]^2.$$

We multiple FOC by $q''(I)$ and we have

$$\gamma\alpha p q'(I)q''(I) + \frac{\alpha p c_L(\mu - \rho)}{\alpha + \beta Q}q'(I)q''(I)[-2\alpha p q(I) + \alpha + \beta Q] = q''(I).$$

We multiple the second derivative by $q'(I)$ and we have

$$\gamma\alpha p q'(I)\, q''(I) + \frac{\alpha p c_L(\mu-\rho)}{\alpha+\beta Q} q'(I)\, q''(I)[-2\alpha p q(I) + \alpha + \beta Q] - \frac{2\alpha^2 p^2 c_L(\mu-\rho)}{\alpha+\beta Q}[q'(I)]^3.$$

At solution, after substituting above two equations and we have

$$q''(I) - \frac{2\alpha^2 p^2 c_L(\mu-\rho)}{\alpha+\beta Q}[q'(I)]^3.$$

The sign of above equation should be the same as the sign of the second derivative. Applying the assumptions, we have the SOC is negative at the solution. We also find that $\left.\frac{d\Pi(I)}{dI}\right|_{I\to\infty} = -1$ and $\left.\frac{d\Pi(I)}{dI}\right|_{I=0} = \alpha p[\gamma + c_L(\mu-\rho)] - 1$.

If we have a large externality $\gamma > \gamma^{DRG}$ such that $\left.\frac{d\Pi(I)}{dI}\right|_{I=0} > 0$, there must exists one interior solution such that $I^{DRG} > 0$, where $\gamma^{DRG} = \frac{1-\alpha p c_L(\mu-\rho)}{\alpha p}$. If we have $\gamma \leq \gamma^{DRG}$ such that $\left.\frac{d\Pi(I)}{dI}\right|_{I=0} \leq 0$, there must exists $I^{DRG} = 0$. ■

Proof of Proposition 4:

Under FFS system, we have the invest level (interior solution $I^{FFS} > 0$) undertaken by the rural hospital such that

$$\gamma\alpha p q'(I^{FFS}) - 1 = 0.$$

Under DRG system, the investment level (interior solution $I^{DRG} > 0$) is such that

$$\gamma\alpha p q'(I^{DRG}) - 1 = -\alpha p[M'(I^{DRG})q(I^{DRG}) + M(I^{DRG})q'(I^{DRG})].$$

We substitute above equation into the first derivative of profit function under FFS system, and we have

$$\left.\frac{d\Pi(I)^{FFS}}{dI}\right|_{I^{DRG}} = -\alpha p M'(I^{DRG})q(I^{DRG}) - \alpha p M(I^{DRG})q'(I^{DRG}).$$

One can see that the sign of $\left.\frac{d\Pi(I)^{FFS}}{dI}\right|_{I^{DRG}}$ depends on the sign of

$M'(I^{DRG})q(I^{DRG}) + M(I^{DRG})q'(I^{DRG})$. In particular, if $M'(I^{DRG})q(I^{DRG}) + M(I^{DRG})q'(I^{DRG}) > 0$, then we have $\frac{d\Pi(I)^{FFS}}{dI}\Big|_{I^{DRG}} < 0$, which means that $I^{DRG} > I^{FFS}$. If $M'(I^{DRG})q(I^{DRG}) + M(I^{DRG})q'(I^{DRG}) < 0$, then we have $\frac{d\Pi(I)^{FFS}}{dI}\Big|_{I^{DRG}} > 0$, which means that $I^{DRG} < I^{FFS}$.

In a special case when $\alpha = \beta$, the investment level under the DRG system can be rewritten as

$$\gamma\alpha pq'(I^{DRG}) - 1 = -\frac{\alpha pc_L(\mu - \rho)}{\alpha + \alpha Q} q'(I)[-2\alpha pq(I) + \alpha + \alpha Q].$$

Note that $-2\alpha pq(I) + \alpha + \alpha Q > 0$ because of $Q > 1$. Therefore, we have the below conclusion:

We have $\gamma\alpha pq'(I^{DRG}) - 1 < 0$, if $(\mu - \rho) > 0$;

We have $\gamma\alpha pq'(I^{DRG}) - 1 > 0$, if $(\mu - \rho) < 0$.

Recall that $\gamma\alpha pq'(I^{FFS}) - 1 = 0$, the above is equivalent to the following:

We have $I^{DRG} > I^{FFS}$, if $(\mu - \rho) > 0$;

We have $I^{DRG} < I^{FFS}$, if $(\mu - \rho) < 0$. ■

Proof of Proposition 5:

The first two points of Proposition 5 are straightforward. For the point 3, we need to prove that under Case 1 where $\mu - \rho > 0$, if $I^{FB} > 0$ and $I^{DRG} > 0$, we will have $I^{DRG} < I^{FB}$. Recall that I^{FB} and I^{DRG} are such that

$$\begin{cases} q'(I^{FB})\alpha p[(T + \gamma) + \lambda c_L(\mu - \rho)] - 1 = 0; \\ \gamma\alpha pq'(I^{DRG}) + \frac{\alpha pc_L(\mu - \rho)}{\alpha + \alpha Q} q'(I^{DRG})[-2\alpha pq(I^{DRG}) + \alpha + \alpha Q] - 1 = 0. \end{cases}$$

Above equations can be rewritten as

$$\begin{cases} q'(I^{FB})\alpha p[(T + \gamma) + \lambda c_L(\mu - \rho)] - 1 = 0; \\ q'(I^{DRG})\alpha p[\gamma + c_L(\mu - \rho)] - 2\frac{\alpha^2 p^2 c_L(\mu - \rho)}{\alpha + \alpha Q} q'(I^{DRG})q(I^{DRG}) - 1 = 0. \end{cases}$$

Because $-2\frac{\alpha^2 p^2 c_L(\mu-\rho)}{\alpha+\alpha Q}q'(I^{DRG})q(I^{DRG}) < 0$, we have

$$q'(I^{FB})[(T+\gamma)+\lambda c_L(\mu-\rho)] < q'(I^{DRG})[\gamma + c_L(\mu-\rho)].$$

Moreover, because $(T+\gamma)+\lambda c_L(\mu-\rho) > \gamma + c_L(\mu-\rho) > 0$, we can have above as $q'(I^{DRG}) > q'(I^{FB})$, which indicates $I^{DRG} < I^{FB}$. Thus, the point 3 of Proposition is proved.

Then we need to prove the point 4 of Proposition 5: under Case 1 where $\mu - \rho > 0$, if $I^{FFS} > 0$, $I^{FB} > 0$ and $I^{DRG} > 0$, then we have $0 < I^{FFS} < I^{DRG} < I^{FB}$. In other words, we need to prove $0 < I^{FFS} < I^{DRG}$. This has been proved in the Proposition 4. ■

Proof of Proposition 6:

The first two points of Proposition 6 are straightforward. For the point 3, we need to prove that under Subcase 2.1 (where $\mu - \rho < 0$, and $\gamma^{FB} < \gamma^{FFS} < \gamma^{DRG}$), if $I^{FB} > 0$ and $I^{FFS} > 0$, we will have $0 < I^{FFS} < I^{FB}$. Recall that I^{FB} and I^{FFS} are

$$\begin{cases} \gamma\alpha p q'(I^{FB}) + q'(I^{FB})\alpha p[T + \lambda c_L(\mu-\rho)] - 1 = 0; \\ \gamma\alpha p q'(I^{FFS}) - 1 = 0. \end{cases}$$

Because that we consider the Subcase 2.1 where $\gamma^{FB} < \gamma^{FFS} < \gamma^{DRG}$, which is $\gamma^{FB} = \frac{1}{\alpha p} - [T + (\mu-\rho)\lambda c_L] < \gamma^{FFS} = \frac{1}{\alpha p}$, or $[T + (\mu-\rho)\lambda c_L] > 0$. Thus, above investment levels have the following relation: $q'(I^{FB}) < q'(I^{FFS})$, or $I^{FB} > I^{FFS} > 0$. The point 3 is proved.

Then we need to prove the point 4 such that when $\gamma^{FB} < \gamma^{FFS} < \gamma^{DRG} < \gamma$, we have $I^{FB} > I^{FFS} > I^{DRG} > 0$. Proposition 4 establishes that when $\mu - \rho < 0$, we have $I^{FFS} > I^{DRG}$. Thus, the point 4 is proved. ■

Proof of Proposition 7:

The first two points of Proposition 7 are straightforward. For the point 3, we need to prove that under Subcase 2.2 ($\mu - \rho < 0$, and $\gamma^{FFS} < \gamma^{FB} < \gamma^{DRG}$), if $I^{FFS} > 0$ and $I^{FB} > 0$, then we have $I^{FB} < I^{FFS}$. Recall that I^{FB} and I^{FFS} are

$$\begin{cases}\gamma\alpha p q'(I^{FB}) + q'(I^{FB})\alpha p[T + \lambda c_L(\mu - \rho)] - 1 = 0; \\ \gamma\alpha p q'(I^{FFS}) - 1 = 0.\end{cases}$$

Because that we consider the subcase 2.2 where $\gamma^{FFS} < \gamma^{FB} < \gamma^{DRG}$, which is $\gamma^{FB} = \frac{1}{\alpha p} - [T + (\mu - \rho)\lambda c_L] > \gamma^{FFS} = \frac{1}{\alpha p}$, or $[T + (\mu - \rho)\lambda c_L] < 0$. Thus, above investment levels have the following relation: $q'(I^{FB}) > q'(I^{FFS})$, or $I^{FFS} > I^{FB} > 0$. Thus, the point 3 is proved.

Now we need to prove the point 4: when $\gamma^{FFS} < \gamma^{FB} < \gamma^{DRG} < \gamma$, we could have either $I^{FFS} > I^{FB} > I^{DRG} > 0$, or $I^{FFS} > I^{DRG} > I^{FB} > 0$. Recall that from Proposition 4: under Case 2 ($\mu - \rho < 0$), if $I^{FFS} > 0$ and $I^{DRG} > 0$, then we have $I^{FFS} > I^{DRG}$. However, the relation between I^{DRG} and I^{FB} is ambiguous and the reason is the following. Recall that I^{FB} and I^{DRG} are

$$\begin{cases}q'(I^{FB})\alpha p[(T + \gamma) + \lambda c_L(\mu - \rho)] - 1 = 0; \\ \gamma\alpha p q'(I^{DRG}) + \dfrac{\alpha p c_L(\mu - \rho)}{\alpha + \alpha Q} q'(I^{DRG})[-2\alpha p q(I^{DRG}) + \alpha + \alpha Q] - 1 = 0.\end{cases}$$

Above equations can be rewritten as

$$\begin{cases}q'(I^{FB})\alpha p[(T + \gamma) + \lambda c_L(\mu - \rho)] - 1 = 0; \\ q'(I^{DRG})\alpha p[\gamma + c_L(\mu - \rho)] - 2\dfrac{\alpha^2 p^2 c_L(\mu - \rho)}{\alpha + \alpha Q} q'(I^{DRG}) q(I^{DRG}) - 1 = 0.\end{cases}$$

Because $-2\frac{\alpha^2 p^2 c_L(\mu-\rho)}{\alpha+\alpha Q} q'(I^{DRG}) q(I^{DRG}) > 0$, we have

$$q'(I^{FB})[(T + \gamma) + \lambda c_L(\mu - \rho)] > q'(I^{DRG})[\gamma + c_L(\mu - \rho)].$$

Moreover, because we have $0 < \gamma + c_L(\mu - \rho) < (T + \gamma) + \lambda c_L(\mu - \rho)$ in the Subcase 2.2, the relation between $q'(I^{DRG})$ and $q'(I^{FB})$ is unclear, which makes the relation between I^{DRG} and I^{FB} ambiguous.

Thus, in the Region 2.24 of Subcase 2.2, we could have either $0 < I^{DRG} < I^{FB} < I^{FFS}$, or $0 < I^{FB} < I^{DRG} < I^{FFS}$. ■

Proof of Proposition 8:

The first two points of Proposition 8 is straightforward. For the point 3, we need to prove $I^{FFS} > I^{DRG} > 0$. Proposition 4 proved so.

Then we need to prove the point 4: under Subcase 2.3 ($\mu - \rho < 0$, and $\gamma^{FFS} < \gamma^{DRG} < \gamma^{FB}$), we should have $0 < I^{FB} < I^{DRG} < I^{FFS}$. In other words, we need prove $0 < I^{FB} < I^{DRG}$. Recall that I^{FB} and I^{DRG} are

$$\begin{cases} q'(I^{FB})\alpha p[(T+\gamma)+\lambda c_L(\mu-\rho)]-1=0; \\ \gamma\alpha p q'(I^{DRG})+\dfrac{\alpha p c_L(\mu-\rho)}{\alpha+\alpha Q}q'(I^{DRG})[-2\alpha p q(I^{DRG})+\alpha+\alpha Q]-1=0. \end{cases}$$

Above equations can be rewritten as

$$\begin{cases} q'(I^{FB})\alpha p[(T+\gamma)+\lambda c_L(\mu-\rho)]-1=0; \\ q'(I^{DRG})\alpha p[\gamma+c_L(\mu-\rho)]-2\dfrac{\alpha^2 p^2 c_L(\mu-\rho)}{\alpha+\alpha Q}q'(I^{DRG})q(I^{DRG})-1=0. \end{cases}$$

Because $-2\frac{\alpha^2 p^2 c_L(\mu-\rho)}{\alpha+\alpha Q}q'(I^{DRG})q(I^{DRG}) > 0$, we have

$$q'(I^{FB})[(T+\gamma)+\lambda c_L(\mu-\rho)] > q'(I^{DRG})[\gamma+c_L(\mu-\rho)].$$

Moreover, because $0 < (T+\gamma)+\lambda c_L(\mu-\rho) < \gamma + c_L(\mu-\rho)$ in the subcase 2.3, we have $q'(I^{DRG}) < q'(I^{FB})$, which means $I^{DRG} > I^{FB} > 0$.

Thus, in the Region 2.34 of Subcase 2.3, we have $0 < I^{FB} < I^{DRG} < I^{FFS}$. ■

Proof of Lemma 3:

Under the DRG-MIX system, I can do the following transformation on $M_{MIX}(I)$:

$$M_{MIX}(I) = \theta k_H - \rho c_L = \theta k_H - \theta\rho c_L + \theta\rho c_L - \rho c_L = \theta M(I) - (1-\theta)\rho c_L.$$

The first derivative of $M_{MIX}(I)$ with respect to investment is given by

$$M'_{MIX}(I) = \theta M'(I).$$

Applying Lemma 2, we have that:

If $\mu - \rho > 0$, then $M'_{MIX}(I) < 0$; if $\mu - \rho < 0$, then $M'_{MIX}(I) > 0$. ■

Proof of Proposition 9:

Under the Mixed DRG, the rural hospital maximizes its payoff

$$\text{Max } \Pi(I) = \gamma[1 - \alpha + \alpha p q(I)] + M_{MIX}(I)\alpha p q(I) - I.$$

The first derivative is:

$$\frac{d\Pi(I)}{dI} = \gamma\alpha p q'(I) + \alpha p[M'_{MIX}(I)q(I) + M_{MIX}(I)q'(I)] - 1.$$

One can see that the subsidy parameter θ will influence the rural hospital's behaviour only through the term $[M'_{MIX}(I)q(I) + M_{MIX}(I)q'(I)]$.

Recall that $M'_{MIX}(I) = \theta M'(I)$ and $M_{MIX}(I) = \theta k_H - \rho c_L$, I reformat above term as follows:

$$\begin{aligned} M'_{MIX}(I)q(I) + M_{MIX}(I)q'(I) &= \theta M'(I)q(I) + (\theta k_H - \rho c_L)q'(I) \\ &= \theta[M'(I)q(I) + k_H q'(I)] - \rho c_L q'(I). \end{aligned}$$

Therefore, the first derivative is given by

$$\frac{d\Pi(I)}{dI} = \gamma\alpha p q'(I) + \alpha p\{\theta[M'(I)q(I) + k_H q'(I)] - \rho c_L q'(I)\} - 1.$$

From above equation, we can find out that when $\mu - \rho > 0$, the sign of $[M'(I)q(I) + k_H q'(I)]$ is unclear; when $\mu - \rho < 0$, we have all terms associated with θ is positive. ■

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