Theoretical Analysis of Hospitals' Response to a Per Diem Prospective Payment System

Dmitry Shapiro

Japan has one of the longest average length of stay in hospital (ALOS) among developed countries. To curb the high ALOS, the Ministry of Health, Labor and Welfare has launched a payment system reform where instead of the pre-reform fee-for-service system (FFS) a new per-diem prospective payment system (DPC/PDPS) has been gradually adopted. We develop a theoretical framework to model hospitals' incentives under different payment systems and to study the impact of the reform on the ALOS. We show that hospitals with a longer (shorter) pre-reform ALOS shorten (lengthen) their post-reform ALOS. Furthermore, hospitals with longer pre-reform ALOS have stronger incentives to use planned readmission to decrease the post-reform length of stay associated with a single admission. The theoretical predictions of our model match empirical evidence from the literature.

Keywords: Health care financing, Prospective payment system, Per-diem rate, Length of stay, Readmission rate

JEL Classification: I12, I18, D21, D22

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I. Introduction

Japan, like many other OECD countries, has been struggling with the containment of soaring health care costs. Aging of the population as well as the spread of new expensive medical technologies resulted in the Japanese social health insurance system becoming highly subsidized (Besstremyannaya 2016). By 2012, central government financed 25.3% of health care expenditure (MHLW 2012c), which represented 10.2% of the government budget (Ministry of Finance 2012). With rapidly increasing medical care expenses, shortening the average length of stay (ALOS) in a hospital became an important political issue in Japan (Nawata and Kawabuchi 2013). Japan has one of the longest ALOS among developed countries, and it is more than twice as long as the ALOS for all OECD countries. In 2013, for example, the ALOS in Japan was 17.2 days as compared to 8.1 days for all OECD countries (OECD 2015).

In response, the Ministry of Health, Labor and Welfare (MHLW) introduced a reform which was "*... one of the largest and most important revisions of the payment system since the Second World War.*" (Nawata and Kawabuchi 2013, p. 77). The new payment system is a prospective payment system (PPS), as opposed to the pre-reform fee-for-service (FFS) payment system. At first, it was introduced in 82 special functioning hospitals. By April 2013, 20% of acute-care (general) hospitals that account for 54.3% of hospital beds in Japan were financed by the new payment system (MHLW 2013).

The new payment system, called Diagnosis Procedure Combination/Per Diem Payment System (DPC/PDPS), is an original prospective payment system developed in Japan. Similar to the prospective payment systems used in other countries, such as the DRG system in the U.S., the DPC/PDPS classifies various diseases, operations, treatments, and patient conditions and most of DPCs can be viewed as homogeneous. Differently from the prospective payment systems used in other countries, the Japanese DPC/PDPS is a per diem, rather than per episode, prospective payment system.

The per diem rate is set to incentivize hospitals to shorten the LOS via its stepdown feature: the rate becomes lower as the LOS becomes longer. Three periods, Period I, Period II, and the Specific Hospitalization Period, are determined for each DPC code. The initial period, Period I, corresponds to the 25th percentile of average length of stay (ALOS) for a given DPC, and is reimbursed at the highest per-diem rate. Period II is set as the average LOS, that is, the 50th percentile. Once the patient's stay goes beyond Period I, it is is reimbursed at a lower per-diem rate. Similarly, once the stay goes beyond Period II and reaches the Specific Hospitalization Period (defined as a stay between the average LOS and the average LOS plus 2 standard deviations) the per-diem rate becomes even lower.[1]

Despite all the attention to the long ALOS in Japan, surprisingly, *"there are limited empirical studies on the impacts of the payment systems on LOS"* (Takaku and Yamaoka 2019, p. 53). The DPC Evaluation Division of the Central Social Insurance Medical Council regularly publishes reports on the effects of the DPC/PDPS, however, as argued in Nawata and Kawabuchi (2013), these reports are no more than simple comparisons of the LOS. To address this issue, Nawata and Kawabuchi (2013) developed a proper econometric model to study the effect of the reform on the LOS for cataract operations in Japan. They use the data from six general hospitals, and find that the effect of the Japanese payment system reform on the LOS varied among the hospitals. For the short-ALOS hospitals, the ALOSs did not decrease. On the other hand, for the long-ALOS hospitals, the ALOS decreased significantly. Besstremyannaya (2016) reaches similar conclusion using a much larger dataset which includes nationwide administrative data for 15 major diagnostic categories in 1068 Japanese hospitals. She finds that average length of stay significantly increases for hospitals with short pre-reform length of stay and significantly decreases for hospitals with long pre-reform ALOS.

The change in hospitals' incentives due to the introduction of the per-diem prospective payment system resulted in some undesirable changes in hospitals' behavior bordering plain manipulation.[2] The switch to the per-diem prospective system was accompanied by a rise of the early

[1] Here and below the description of the Japanese DPC/PDPS is based on Nawata and Kawabuchi (2013) and Besstremyannaya (2016).

[2] Takaku and Yamaoka (2019) show that the "midnight-to-midnight" definition of a "day" incentivizes health care providers to manipulate hospital acceptance times in emergency patients. They document a significant bunching in the number of acceptances at the emergency hospital around midnight: the number heaps a few minutes before midnight, but suddenly drops just after midnight. This is despite emergency episodes being smoothly distributed during nighttime.

readmission rate and, specifically, planned readmissions (Hamada *et al.* 2012; Yasunaga *et al.* 2005; Okamura *et al.* 2005). Notably, empirical evidence indicates that an increased reliance on planned readmission was specifically caused by the stepdown feature of the Japanese DPC/PDPS, whereby longer LOS is reimbursed under a lower per-diem rate (Kondo and Kawabuchi 2012).

In this paper, we develop a theoretical model to study the impact of different payment systems on the hospitals' LOS and hospitals' incentives to rely on planned readmission. The payment systems we consider are the fee-for-service reimbursement scheme, *FFS*, which corresponds to the pre-reform system, and a per diem PPS with a length-of-stay-dependent step-down rate, *SDR*, which corresponds to the post-reform DPC/PDPS. To disentangle the effect of a switch to per-diem reimbursement system from the additional effect of the LOS-dependent per-diem rate, we also study an intermediate reimbursement system which is a simple flat per-diem rate. We label it as *PD*.

We show that in our model the impact of the reform will differ across hospitals. The introduction of the per-diem prospective system gives hospitals with shorter pre-reform ALOS incentives to lengthen it, and to hospitals with longer pre-reform ALOS incentives to shorten it. This matches the findings from the empirical literature that we discussed earlier (Nawata and Kawabuchi 2013; Besstremyannaya 2016). Adding LOS-dependent reimbursement rates such that initial stay is reimbursed at a higher tariff, as in the DPC/PDPS, has unambiguously perverse incentives on hospitals' LOS. The higher initial tariff increases hospitals' marginal benefit from longer stay without affecting marginal cost. All hospitals, except for those with the longest ALOS, find it profitable to treat patients longer.

We then model the effect of the reform on the planned readmission rate. We introduce an extension of the model where we allow hospitals to choose in advance whether to treat a patient with one or two admissions, where the second admission is a planned readmission. While, naturally, there are purely medical reasons to provide a treatment with planned readmissions, in this paper we look at decision to use planned readmission solely due to financial considerations.[3]

[3] According to MHLW (2005) readmissions are classified into planned, anticipated, and unplanned. The reasons for anticipated readmissions are: 1)anticipated worsening of medical condition; 2)anticipated worsening of

We show that the reform and, specifically, its stepdown per diem rate financially encourages hospitals to use planned readmission, and that hospitals with longer pre-reform ALOS have stronger incentives to treat patients using planned readmission. Intuitively, since each admission is reimbursed separately, the DPC/PDPS enables hospitals to benefit twice from higher initial rates by means of planned readmission. This result is consistent with evidence reported in Kondo and Kawabuchi (2012) and analysis of Besstremyannaya (2016). Besstremyannaya (2016) shows that the most pronounced effect of the reform on planned readmission rate was among hospitals in the 76-100 percentiles of the pre-reform ALOS, where it increased in 11 out of 15 Major Diagnostic Categories (Besstremyannaya 2016, Table V).

One theoretical consequence of hospitals using planned readmissions to game the system is that even though the LOS of a single admission becomes shorter under the post-reform DPC/PDPS, the complete treatment becomes longer. Thus, while the ALOS in Japanese has been steadily declining — 25 days in 2000, 17.2 days in 2013, 16.2 days in 2017 (OECD 2015 and 2019) — our theoretical results suggests that one should be cautious when interpreting this decline and that it might not be entirely due to increased efficiency.

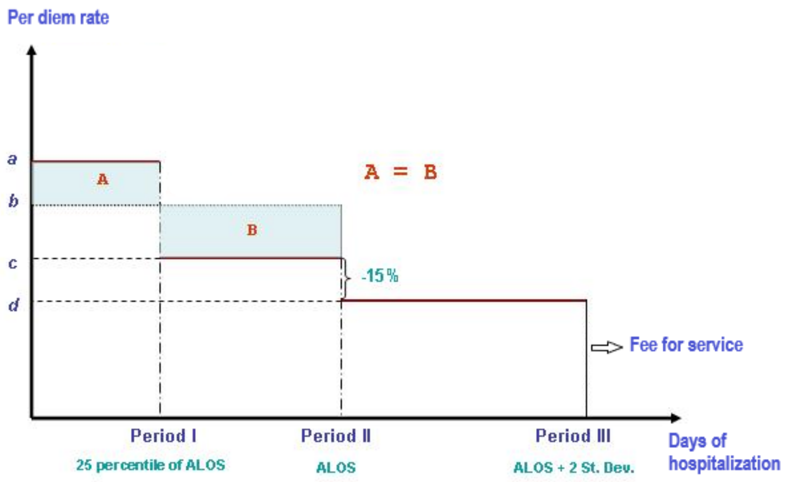
II. Japan's inpatient prospective payment system

The Japanese inpatient PPS is a mixed system. The reimbursement is the sum of DPC and fee-for-service components. The DPC component is constructed as a per diem step-down rate based on the hospital's length of stay. For each DPC, the amount of the daily inclusive payment is flat over each of the three consecutive periods: period I that contains up to the 25-percentile of ALOS calculated for all hospitals submitting data to MHLW;[4] period II that contains the rest of the ALOS; and period III (the

comorbidity; 3)patient was temporarily discharged to raise his/her quality of life; 4)discharged from previous hospital stay at the patient's request; 5)other.

The reasons for planned readmissions are: 1)operation after preliminary tests; 2) planned operation or procedures; 3) chemotherapy or radiation therapy; 4) planned examinations/tests; 5) examination/operation was stopped during the previous treatment, and the patient was discharged; 6) patient was sent home to recuperate before an operation.

[4] The initial rates were set on the basis of 267,000 claim data on patients discharged from 82 targeted hospitals in July-October 2002.



Notes: Rate b is determined as the average amount of per diem payment in hospitals submitting data to MHLW. Rates a and c are set so that area A in Period I is equal to area B in Period II. Rate d is 15% lower than rate c. After period III expires, hospitals are reimbursed according to the fee-for-service system. Source: Besstremyannaya (2016).

Figure 1
Step-down per diem payment scheme for a given DPC

Specific Hospitalization Period) that contains two standard deviations from the ALOS. After period III expires, hospitals are reimbursed according to the fee-for-service system. To create incentives for shorter length of stay, per diem DPC in Period I is set 15% higher than the average per diem payment of the patients whose stays were within the average LOS. For stays between Period II and Period III, on the other hand, the per diem rate is set 15% lower (see Figure 1).

The first version of DPCs consisted of 2552 diagnosis groups. Most of the groups (1860) had a sufficiently large number of cases and were rather homogeneous (Ikegami 2005). The per diem rates were set on the basis of these groups, which corresponded to about 90% of admission. The numbers of diagnoses and DPCs gradually increased from 2003, and as of 2012 there were 2927 diagnosis groups and 2241 DPCs. Along with the diagnosis, each DPC incorporates three essential issues: algorithm, procedure, and co-morbidity. Diagnoses are coded according to ICD-10 and the Japanese Procedure Code (commonly used under

FFS reimbursement) is employed for coding procedures (Matsuda *et al.* 2008, MHLW 2004).

The DPC component covers basic hospital fee, hospital expenditures on examinations, diagnostic images, pharmaceuticals, injections, and procedures costing less than 10,000 yen. The fee-for-service component reimburses the cost of medical teaching, surgical procedures, anesthesia, endoscopies, radioactive treatment, pharmaceuticals, and materials used in operating theaters, as well as procedures worth more than 10,000 yen (MHLW 2012a; Yasunaga *et al.* 2005).

The introduction of inpatient PPS is a voluntary reform for each Japanese hospital. The records of the Ministry of Health, Labor, and Welfare, and anecdotal evidence (*e.g.*, Okuyama 2008) demonstrate that participation in PPS is voluntary: the decision is made by the hospital itself with no governmental pressure. There are several eligibility criteria: a hospital has to meet a threshold value of the MHLW nurse staffing ratio equal to 2 inpatients per nurse; has to follow the methodology for accounting of inpatient expenditure; and has to collect standardized data on prescribed drugs. In particular, the methodology for accounting inpatient expenditure includes the employment of special administrative staff, detailed book keeping, ICD-10 coding, and data processing (Sato 2007).

III. Basic Setup. Length of Stay

We consider three reimbursement systems: fee-for-service (FFS), which corresponds to the payment system used before the reform; the per diem prospective system with a fixed per diem rate (PD); and the per diem prospective system with a <u>s</u>tep<u>d</u>own <u>r</u>ate (SDR), which corresponds to the post-reform reimbursement, as explained in the previous section. The PD system is an intermediary between the FFS and the SDR, and enables us to isolate the effects of the switch to a per diem system from the effects of different per diem rates.

For a given diagnosis we assume that there is a variety of medical procedures and input combinations that could be used to treat a given condition, that we classify as discretionary and non-discretionary. Non-discretionary procedures and input combinations is something that, for medical reasons, has to be done in order to treat the patient's condition. Discretionary inputs and procedures are something that is employed beyond non-discretionary procedures either to complement or enhance the effect of non-discretionary procedures. Discretionary inputs are not wasteful in terms of patients' health and could include items such follow-up tests or pre-treatment screening.

Given that non-discretionary inputs procedures is something that the hospital has to perform, we will normalize them to zero. As for discretionary inputs, we will label them as I, where $I \in [0, \infty)$. Employing discretionary inputs increases the patient's length of stay as given by a function $L(I)$ where $L(0) = 0$, $L'(I) > 0$ and $L''(I) < 0$. As hospitals deal with many cases of a given diagnosis, we can think of $L(I)$ as the average length of stay for the diagnosis in a hospital. It will be convenient to describe hospitals' optimization problem using the inverse function $I(L)$, which is an increasing convex function of L.

The hospitals' cost associated with the length of stay is given by a function $\gamma g(L)$, where g is a strictly increasing and convex function such that $g'(\infty) = \infty$.[5] Different hospitals have different γ, so that cost (and marginal cost) is higher for hospitals with higher γ. The heterogeneity parameter γ may reflect differences in equipment costs, human capital, or opportunity costs due to availability of personnel or bed occupancy rates. In addition, there is a direct cost associated with purchasing discretionary inputs which is equal to $cI(L)$, where $c \geq 0$. Thus, the total hospital's cost is $cI(L) + \gamma g(L)$, and it is a convex function of L.

Two remarks are in order. First, the additive functional form above is used for its simplicity. One could use a more general cost function $h(\gamma, I, L)$. With some technical conditions, such as h is an increasing function of all three inputs, convexity and $h''_{\gamma L} > 0$, the results below will hold. Second, given that L is a function of I, discretionary inputs affect the cost via two sources: directly and indirectly via L. This is to reflect the fact that there is direct cost of running a given test or procedure and then there are also costs associated with keeping a patient in the hospital, *e.g.,* due to the load on medical personnel and medical equipment or the bed occupancy rate.

[5] The assumption that g is a strictly increasing function of L is not without loss of generality. One can imagine that a faster treatment could be considerably costlier as it might require modern and more expensive equipment. Thus, the situation where g declines at first and becomes an increasing function later is conceivable. However, neither the FFS nor the PD systems will lead to a choice of L at the interval where g declines.

A. Fee-for-service system

We model the fee-for-service as a system which reimburses hospital's inputs usage at a fixed rate p_I, where $p_I > c$. The hospital's maximization problem is

$$\max_I \; p_I I - cI(L) - \gamma g(L)$$

To allow comparison with per-diem and step-down per diem prospective payment systems, that we introduce later in the paper, we can equivalently re-write it as

$$\max_L \; p_I I(L) - cI(L) - \gamma g(L).$$

Optimal L is given by the FOC

$$p_I I'(L) = cI'(L) + \gamma g'(L). \tag{1}$$

The second-order condition is

$$p_I I''(L) - cI''(L) - \gamma g''(L) < 0.$$

It is satisfied whenever the cost function $g(L)$ is a more convex function than $I(L)$, *i.e.* there exists a convex function $\phi(\cdot)$ such that $g(L) = \phi(I(L))$.[6]

We denote the solution to (1) as L_{FFS}. By the envelope theorem it is a decreasing function of γ:

$$\frac{\partial L_{FFS}}{\partial \gamma} = -\frac{-g'(L)}{p_I I'' - cI'' - \gamma g''(L)} < 0.$$

Indeed, the denominator is the SOC and is negative, and term $g'(L)$ is positive since $g(\cdot)$ is an increasing function of L. Intuitively, higher γ results in higher costs associated with the LOS and, therefore, it is optimal for hospitals to choose lower L.

Proposition 1 summarizes the reasoning above.

[6] Since $g(L) = \phi(I(L))$, the FOC can be re-written as $(p_I - c - \gamma\phi'(I(L))) \cdot I'(L) = 0$. The SOC then is $(p_I - c - \gamma\phi'(I(L)))I''(L) - \gamma\phi''(I(L)))I'(L) = -\gamma\phi''(I(L)))I'(L) < 0$.

Proposition 1. *The optimal length of stay under the fee-for-service system, L_{FFS}, satisfies (1) and it is a decreasing function of γ.*

B. Per diem prospective payment system

Under the flat per-diem PPS, hospitals are paid a fixed per-diem rate, $\bar{d}$, for each day that a patient stays in the hospital. The profit-maximization problem under the per diem PPS is

$$\max_{L} \bar{d}L - cI(L) - \gamma g(L). \tag{2}$$

This formulation of a per diem PPS is related to, though different, from that in Grabowski *et al.* (2011) who study the Medicare's adoption of a per diem PPS for skilled nursing facilities (SNFs) in 1998. The differences are as follows. First, in Grabowski *et al.* (2011) the intensity and the length of stay are two independent choice variables for SNFs. In our model, the only choice variable for hospitals is the length of stay, which is a function of intensity, *i.e.* *I*-inputs. Second, in our model the per diem rate is either constant (as in this section), or a decreasing step function of the length of stay (later in the paper). This assumption is appropriate given the specifics of the Japanese PPS reform.

The post-reform per-diem rate in Japan, $\bar{d}$, was determined based on the average per diem reimbursement under the pre-reform fee-for-service system. In this subsection we assume that it is constant regardless of the duration of stay.[7] In the next subsection we introduce the step-down per-diem rate that depends on the duration of stay which is similar to the payment system implemented in Japan.

Let L_{FFS} be the optimal LOS under fee-for-service system for a given hospital with a given γ. Then, for a given hospital, the effective per diem reimbursement under FFS was:[8]

[7] This system is similar to the Korean "new DRG" reimbursement system (described in Section V) where the per-diem rate for most cases (those within 5%-95% of the LOS distribution) is fixed and does not depend on the duration of stay.

[8] Under FFS, of course, hospitals were not reimbursed based on per-diem rate. We use term *effective per-diem rate* for an average daily payment the hospital effectively received under the FFS system.

$$d = \frac{p_I I(L_{FFS})}{L_{FFS}}.$$

Taking the average over all hospitals we get the expression for $\bar{d}$:

$$\bar{d} = E_\gamma \left[\frac{p_I I(L_{FFS})}{L_{FFS}} \right]. \tag{3}$$

The optimal length of stay under the per-diem PPS, L_{PD}, satisfies the FOC for (2):

$$\bar{d} - cI'(L_{PD}) - \gamma g'(L_{PD}) = 0. \tag{4}$$

As one would expect, higher values of $\bar{d}$, *ceteris paribus*, lead to longer LOS.

Proposition 2. *In general, when comparing LOS under the FFS and PD reimbursement systems three scenarios are possible. Either*

i) $L_{PD} > L_{FFS}$ for any γ; or

ii) $L_{PD} < L_{FFS}$ for any γ; or

iii) there exists γ_0 such that $L_{PD} > L_{FFS}$ if $\gamma > \gamma_0$, and $L_{PD} < L_{FFS}$ if $\gamma < \gamma_0$.

When per-diem rate is given by (3) the first scenario is impossible.

The proof is given in Appendix but the intuition is straightforward. Under the per-diem PPS the marginal benefit does not depend on L and is equal to $\bar{d}$. Under FFS the marginal benefit is $p_I I'(L)$ and it *does* depend on L. Given convexity of $I(L)$, hospitals with lower L_{FFS} have lower marginal benefit under FFS. A switch to the per-diem system will increases their marginal benefit making longer LOS optimal. Similarly, hospitals with higher L_{FFS} have higher marginal benefit under the FFS. A switch to the per-diem system will result in a decline of the marginal benefit making shorter stay optimal. The hospital for which $p_I I'(L) = \bar{d}$, if it exists, is what determines the threshold value of γ_0. For this hospital the LOS will not change. In general, if $\bar{d}$ is too high (low) then for all hospitals $L_{PD} > L_{FFS}$ ($L_{PD} < L_{FFS}$). But given definition of $\bar{d}$ in (3) the first scenario is impossible. This is because $I(L)$ is convex and so $I'(L) > I(L)/L$. As we show in the proof it puts an upper bound on $\bar{d}$ such that it cannot be too high so that $L_{PD} > L_{FFS}$ for all γ.

C. Per diem prospective payment system with a step-down rate

Previous analysis compared the LOS under the *FFS* and *PD* reimbursement rules, where per-diem rate was constant. To capture the specifics of the health care reform in Japan, where the per-diem rate is not constant but depends on the length of stay as shown on Figure 1, we consider an additional reimbursement system wherein the per-diem rate depends on the LOS.

To simplify the analysis, we assume that there are two, and not three as in the DPC/PDPS, periods with different per-diem rates. Specifically, let $\bar{L}$ denote the the average LOS under the *FFS* system. We assume that during the initial $\alpha\bar{L}$ period a high per diem rate, $q\bar{d}$, is paid, where $q > 1$ and $\alpha < 1$. A lower per diem rate, $\tau\bar{d}$ where $\tau \leq 1$, is paid afterwards. We will refer to this reimbursement system as the SDR system (a reimbursement system with Step-Down per diem Rate).

The hospital's profit function under the *SDR* is:

$$\pi(L) = \begin{cases} q\bar{d}L - cI(L) - \gamma g(L) & \text{if } L \leq \alpha\bar{L} \\ (q\bar{d}) \cdot \alpha\bar{L} + \tau\bar{d}(L - \alpha\bar{L}) - cI(L) - \gamma g(L) & \text{if } L \leq \alpha\bar{L} \end{cases} \tag{5}$$

In what follows, we use $L^*_{PD}(\gamma)$ and $L^*_{SDR}(\gamma)$ to denote the optimal lengths of stay under *PD* and *SDR* reimbursement rules. The next Proposition characterizes the optimal LOS choice depending on γ.

Proposition 3. *Let γ_{PD} be such that for a hospital with γ_{PD} the optimal LOS under the PD system is exactly $\alpha\bar{L}$. Then*

i) $L^*_{PD}(\gamma) \geq L^*_{SDR}(\gamma)$ if $\gamma \leq \gamma_{PD}$;

ii) $L^*_{PD}(\gamma) < L^*_{SDR}(\gamma)$ if $\gamma > \gamma_{PD}$.

The proof is given in the Appendix. The intuition is as follows. For low values of γ, as in case i), introducing a higher premium for shorter stay does not affect hospitals' behavior compared to the *PD* payment system. With low γ the cost associated with LOS is small so that extra benefits from shorter stay are not sufficient to change hospitals' incentives. At the same time, lower per-diem rate $\tau\bar{d}$ motivates those hospitals to decrease their LOS. At the same time, for high values of γ, those in case ii), having a higher per-diem rate for shorter stays perversely affects hospitals' incentives and makes them willing to keep patients longer than they would under *PD*.

The combined effect of the change from *FFS* to *SDR* reimbursement systems is, in general, ambiguous. It depends on the sizes of *FFS* → *PD* and *PD* → *SDR* effects, which in turn depend on parameter values, such as q and α. However, for hospitals with high γ, those with $\gamma > \max\{\gamma_0, \gamma_{PD}\}$, and for hospitals with low γ, those with $\gamma < \min\{\gamma_{PD}, \gamma_0\}$, both *FFS* → *PD* and *PD* → *SDR* changes have the same effect on the LOS. The Table below summarizes it:

	low γ (high LOS)	high γ (low LOS)
FFS→SDR	$L_{FFS} > L_{SDR}$	$L_{FFS} < L_{SDR}$

Thus, our model predicts that hospitals should respond differently to the reform depending on their pre-reform LOS. On the one hand, hospitals high LOS will have incentives to decrease it, as the reform intends. On the other hand, those with low LOS will have financial incentives to prolong it in order to enjoy a higher per-diem rate. This is the opposite of the reform's goal. Empirical literature provides support for these predictions. Nawata and Kawabuchi (2013) were the first to document that the national decrease in ALOS came along with some hospitals increasing their ALOS. The most direct test of our theoretical predictions comes from Besstremyannaya (2016) whose results directly confirm our predictions. Table IV shows a significant post-reform increase among hospitals with the shortest (0 to 25 percentile) pre-reform length of stay and a significant decrease in the length of stay among hospitals with longest pre-reform LOS (51-100 percentile). Furthermore, the decrease of the ALOS is larger for hospitals in higher percentiles of the pre-reform length of stay.

D. Profit

Finally, we compare hospitals' profitability under the three reimbursement systems. Let L^*_{FFS} denote the optimal LOS under FFS, and for notational brevity we do not reflect that it depends on γ. The hospital's effective per diem rate under FFS is

$$d\left(L^*_{FFS}\right) = \frac{p_I I\left(L^*_{FFS}\right)}{L^*_{FFS}}. \tag{6}$$

We use a qualifier "*effective*" to highlight that it is not the actual per diem rate since there is no per diem rate under the FFS system. From (6) and convexity of $I(L)$ follows that effective per diem rate under FFS is an increasing function of LOS. That is hospitals with a longer length of stay (smaller γ) have a higher effective per diem rate under the FFS system; hospitals with a shorter length of stay have a lower effective per diem rate under the FFS system.

Under the *PD* system, the per diem rate is determined based on the average daily payments under the *FFS* system, that is

$$\bar{d} = E_{\gamma}\left(\frac{p_I I\left(L^*_{FFS}\right)}{L^*_{FFS}}\right).$$

One can show that a change from FFS to PD will increase (decrease) profitability of hospitals with short (long) pre-reform length of stay. Indeed, consider a hospital with γ high enough so that $d(L^*_{FFS}) < \bar{d}$. Then

$$\pi_{FFS} = d\left(L^*_{FFS}\right)L^*_{FFS} - cI\left(L^*_{FFS}\right) - \gamma g\left(L^*_{FFS}\right) <$$
$$< \bar{d}L^*_{FFS} - cI\left(L^*_{FFS}\right) - \gamma g\left(L^*_{FFS}\right) \leq \bar{d}L^*_{PD} - cI\left(L^*_{PD}\right) - \gamma g\left(L^*_{PD}\right) = \pi_{PD}$$

Here, the first inequality comes from the fact that $d(L^*_{FFS}) < \bar{d}$, and the second inequality comes from the fact that under per-diem rate $\bar{d}$ it is L^*_{PD}, not L^*_{FFS}, that is optimal.

Similarly, hospitals with long LOS will have lower profit under PD than under FFS. Indeed, consider a hospital with γ low enough so that $d(L^*_{PD}) > d$. Then

$$\pi_{PD} = \bar{d}L^*_{PD} - cI\left(L^*_{PD}\right) - \gamma g\left(L^*_{PD}\right) <$$
$$< d\left(L^*_{PD}\right)L^*_{PD} - cI\left(L^*_{PD}\right) - \gamma g\left(L^*_{PD}\right) \leq d\left(L^*_{FFS}\right)L^*_{FFS} - cI\left(L^*_{FFS}\right) - \gamma g\left(L^*_{FFS}\right) = \pi_{FFS}.$$

The first inequality comes from the fact that $\bar{d} < d(L^*_{PD})$, the second inequality comes from the fact that under *FFS* it is L^*_{FFS}, not L^*_{PD}, that is optimal.

As for comparison between the *PD* and the *SDR*, it depends on τ. When $\tau = 1$ then the *SDR* payment system leads to a strictly higher profit. However, by the envelope theorem as τ declines the profit weakly declines as well so the effect is, in general, ambiguous. For hospitals with $\gamma > \gamma_{PD}$, however, the profit effect is unambiguously positive since, as it follows from the proof of Proposition 3, the value of τ affects neither the PD-profit nor the SDR-profit. Combining the two results we get that $\pi_{FFS} < \pi_{SDR}$ for hospitals with sufficiently high γ and low pre-reform LOS, those with γ_{PD}. For other hospitals the effect is ambiguous.

Proposition 4 summarizes the reasoning above.

Proposition 4. *For hospitals with low pre-reform LOS the reform will have positive effect on their profitability. For hospitals with high pre-reform LOS the total effect is ambiguous and depends on values of* q,τ *and* $\alpha\bar{L}$.

IV. Planned Readmission

Although there is still much inconsistency in economic research about the association between readmission and inpatient care (Ashton *et al.* 1997), a number of studies demonstrate that early readmissions may serve as an indicator of quality for hospital performance (Halfon *et al.* 2006; Lopes *et al.* 2004; Weissman *et al.* 1999; Ashton *et al.* 1997). There are three types of readmissions (see footnote 4) and in this section we focus on planned readmissions as this is the type where the hospitals have the most control when deciding whether to use it.

While there are many purely medical reasons for planned readmissions, hospitals can use planned readmission to shorten the average length of stay at each readmission since, even if the same patient is readmitted with the same diagnosis, his or her treatment is recorded and reimbursed as a separate instance.[9] Kondo and

[9] The Japanese government seems to be aware of hospitals' incentives to manipulate the length of stay via readmissions. When the new payment system has been first introduced and it became clear that adoption of the DPC system led to an increase in readmission rate, the Japanese government summoned the chief executive officers of hospitals that had high readmission rates to have them explain the increase. It turned out that the increase was due to the large number of cancer patients who were discharged and then readmitted for chemotherapy and/or radiation therapy (both are classified as reasons for planned readmissions). In response the government adjusted the tariff so that the LOS period was no longer reset if the patient were to be readmitted within three days of the discharge: the LOS period continues to be counted from the date of the first admission and the discharge period were not to be included in

Kawabuchi (2012) argue that patients who require long treatment (*e.g.* rehabilitation after surgery owing to hip fractures) are vulnerable to premature discharges owing to the incentives inherent to the step-down per-diem inclusive payment. Therefore, it is important to understand a hospital's financial incentives regarding planned readmissions and how the *FFS* and the *SDR* reimbursement systems affect these incentives.

We introduce the possibility of readmission changes as follows. In addition to determining the optimal length of stay the hospital needs to decide whether to treat a patient using one admission or two admissions, where the second would be a planned readmission. We assume that the decision regarding the number of admissions is made at the beginning of the treatment.

If a hospital chooses to treat a patient with one admission then, as before, its total cost is $cI(L) + \gamma g(L)$, where L is the LOS. Consider now the case when a hospital chooses to treat a patient with planned readmission. Let the patient's LOS under the initial admission be L_1 and under the readmission be L_2. Then the total cost is $cI(L_1) + cI(L_2) + \gamma g(L_1 + L_2) + F$.[10] Here $cI(L_1)$ is the cost of discretionary inputs used for the first admission, $cI(L_2)$ is the cost of discretionary inputs used for the second readmission, and $F \geq 0$ is the fixed cost of the readmission. We assume that F is a random variable, distributed with cdf $\Phi(\cdot)$. The reason for the assumption is two-fold. First, with a deterministic F, a planned readmission is a 0/1 decision, which is different from what is observed in the data. Second, random F captures the idea that the cost of readmission can vary depending on the circumstances such as patient condition or hospital occupancy rate.

A. Fee-for-service system

Hospital's profit without the readmission is

the hospitalization period (Anderson and Ikegami 2011). Later, the three-day period was further increased to seven days (MHLW 2015, p. 32).

[10] Alternatively one could use term $\gamma g(L_1) + \gamma g(L_2)$ in the cost function instead of $\gamma g(L_1 + l_2)$. The only difference is that the latter, *i.e.* the one used in the paper, makes planned readmission less attractive financially because of convexity of $g(\cdot)$. We chose to use formulation where hospitals' have weaker financial incentives to rely on planned readmission.

$$\max_{L_1} p_I I - cI(L) - \gamma g(L).$$

If a planned readmission is used the hospital's profit is

$$\max_{L_1, L_2} p_I I(L_1) + p_I I(L_2) - cI(L_1) - cI(L_2) - \gamma g(L_1 + L_2) - F.$$

Proposition 5. *Under FFS hospitals will not use planned readmission iff $F > 0$.*

Proof. Assume not. Let $L_1 > 0$ and $L_2 > 0$ be the optimal LOS under the first and second admissions. Without loss of generality we can assume that $L_1 \geq L_2$. From the convexity of $I(\cdot)$ follows that for a small $\varepsilon > 0$

$$\begin{aligned} &\left(p_I - c\right) I\left(L_1 + \varepsilon\right) + \left(p_I - c\right) I\left(L_2 - \varepsilon\right) - \gamma g\left(L_1 + \varepsilon + L_2 - \varepsilon\right) - F \\ &> \left(p_I - c\right) I\left(L_1\right) + \left(p_I - c\right) I\left(L_2\right) - \gamma g\left(L_1 + L_2\right) - F, \end{aligned}$$

which is a contradiction to $L_1 \geq L_2 > 0$ being optimal. Thus the two strict optima are $(L^*,0)$ and $(0,L^*)$, and therefore it is always optimal to avoid cost F and use one admission.

B. Per diem prospective payment system with a step-down rate

The profit without the planned readmission is (5). The profit with the planned readmission is

$$-F - cI\left(L_1\right) - cI\left(L_2\right) - \gamma g\left(L_1 + L_2\right) + \begin{cases} q\bar{d}\left(L_1 + L_2\right) & \text{if } L_1, L_2 \leq \alpha\bar{L} \\ 2\left(q\bar{d}\right)\cdot\alpha\bar{L} + \tau\bar{d}\left(L_1 + L_2 - 2\alpha\bar{L}\right) & \text{if } L_1, L_2 \geq \alpha\bar{L} \\ q\bar{d}L_j + \left(q\bar{d}\right)\cdot\alpha\bar{L} + \tau\bar{d}\left(L_i - \alpha\bar{L}\right) & \text{if } L_i > \alpha\bar{L} > L_j \end{cases} \tag{7}$$

The first part of (7) is the treatment cost which does not depend on whether L_1, L_2 are above or below the threshold $\alpha\bar{L}$. The second part of (7) is calculated based on the length of each admission. The top line in (7) corresponds to the reimbursement when the length of both admissions is *short*, *i.e.* shorter than $\alpha\bar{L}$, so that the hospital is reimbursed under the premium per-diem rate $q\bar{d}$. The middle line corresponds to the case when both admissions are *long*, *i.e.* longer than $\alpha\bar{L}$, and end up receiving daily payment $\tau\bar{d}$ for stays above $\alpha\bar{L}$. The last line is hospital's profit when one admission is long and another is short.

Let π^1 denote the optimal profit without the readmission and π^2 the optimal profit with the readmission *without* the fixed cost F. Planned readmission is more profitable if and only if $\pi^2 - \pi^1 > F$. Then, for a given hospital the likelihood of using planned readmission is $\Phi(\pi^2 - \pi^1)$. Note that the likelihood of readmission is a readmission rate, which is an observable variable (*e.g.* it is reported in MHLW's administrative database).

The next statement shows that $\pi^2 - \pi^1$ is a decreasing function of γ, which means that hospitals with low γ have stronger incentives to use planned readmission than with high γ. The immediate and testable corollary of this result is that, other things being equal, hospitals with higher LOS are more likely to use planned readmission for financial reasons. It also shows that when hospitals choose to use planned readmission to decrease ALOS they succeed in that $(L_1^* + L_2^*) \ / \ 2 \leq L^*$. However, it is not due to faster and more efficient treatment of patients, as $L^* \leq L_1^* + L_2^*$, but rather due to increased financial incentives to treat patients with two admissions.

Proposition 6. *Let L^* be the optimal LOS without readmission and L_1^* and L_2^* be two LOS with planned readmission. Then $L_1^* = L_2^*$ and*

i) $\pi^2(L_1^*, L_2^*) - \pi^1(L^*)$ is a decreasing function of γ.

ii) $(L_1^* + L_2^*) \ / \ 2 \leq L^* \leq L_1^* + L_2^*$ for every γ. The former inequality is strict for hospitals with low γ. The latter inequality is strict for hospitals with intermediate values of γ.

The proof is given in the Appendix. Intuitively, a higher per diem rate during the initial period of stay incentivizes hospitals to double the number of days for which they receive the premium rate. Hospitals with low γ, *i.e.* those with longer LOS have more to gain from planned readmission, as a long LOS can be split in two, thus doubling the number of days for which hospitals is compensated under the higher rate $q\bar{d}$. Hospitals with higher γ, on the other hand, have short LOS so that their entire stay is reimbursed at a premium per diem rate. Therefore, there is no additional monetary benefits from splitting a treatment into two admissions.

Corollary 1. *The likelihood of planned readmission, $\Phi(\pi^2(L_1^*, L_2^*) - \pi^1(L^*))$, is a decreasing function of γ. Under the SDR rule, as compared to the FFS* *reimbursement rule, hospitals with lower (higher) LOS are more (less) likely to use planned readmission.*

Corollary 1 can be tested and is supported by empirical evidence. Empirical literature indicates that, as predicted by our framework, the post-reform decrease of ALOS was accompanied by a rise of the early readmission rates and, specifically, planned readmission rates (Hamada *et al.* 2012; Yasunaga *et al.* 2005; Okamura *et al.* 2005). Corollary 1 is directly supported by Table V in Besstremyannaya (2016). Table V shows that for hospitals in 76-100 percentiles of the pre-reform ALOS the readmission rate increased for eleven out of 15 MDCs,[11] as well as for the pooled data where all MDCs are combined.

V. Discussion. Per Diem Payment System in Korea (new DRG)

The Japanese payment system is different from prospective payment systems employed by other OECD countries in that its DPC component is based on a per-diem system. The primary reason for adopting this system was to provide hospitals with incentives to treat patients faster in order to curb the unusually long ALOS in Japanese hospitals. The approach has worked. The ALOS in Japan has declined from 25 days in 2000 to 16.2 days in 2017 (OECD 2019). Recently South Korea—that used to have the second longest ALOS after Japan and that now has the longest ALOS among OECD countries (OECD 2019, Figure 9.9)—has also implemented a similar per-diem-based payment system.

Historically, South Korea has used FFS as its primary payment system, but increasing health care costs along with the lengthy ALOS led to a policy debate on an effective way of cost containment (Tchoe 2002; Kang 2010). Both experts and the government agreed that the FFS system, which had been in use since 1977 when the National Health Insurance (NHI) was introduced, was the root of uncontrolled health care costs (Jang *et al.* 2016).[12] The adoption of a prospective

[11] MDC means Major Diagnostic Category, which is an aggregate group of diagnoses such as Nervous System (MDC 1), Eye system (MDC 2) and so on. In total there are 18 MDCs, however for Table V data for 15 MDCs was used. See Besstremyannaya (2016) for more details.

[12] For example, Yang and Park (1991) has shown that under incentives

payment system was officially proposed in 1994, however, due to strong opposition from private hospitals the implementation of a DRG-based payment system has been slow. In 2002, the Korean government officially introduced a DRG PPS system though it only applied to a limited number of disease categories (seven) and the participation was voluntary (Annear *et al.* 2018). The participation became mandatory for 7 principal diagnoses since July 2012 and included all medical institutions, except for long-term care hospitals and public hospitals, in July 2013.

In 2009, the government has introduced another reimbursement system which is similar to the Japanese DPC/PDPS system and, just like the Japanese system, is a combination of the FFS payments and per diem payments (Jang *et al.* 2016). In July 2012 the system was expanded and became a payment system for 550 principal diagnoses at all public hospitals. The Korean name for the new system is simply "new DRG" (sinpogwaljibuljedo), and in the English-language literature it has been called as either Korean Case Payment System (KCPS) or as Korean DPC (Ju *et al.* 2018; Jang *et al.* 2016). According to this system, if hospital days are in the range of 5-95% of its distribution, DRG fee is computed as Basic Case Payment + (Hospital days − Average hospital days) × per-diem rate. Here the Basic Case Payment is the average expenditure per case evaluated at the average of hospital days. For the cases whose hospital days are less than 5% or more than 95% of the distribution, DRG based fees are not applied and those stays are treated as outliers (Tchoe 2010). The "new DRG" system is currently under a review by the Ministry of Health and Welfare of Korea and is showing mixed results (Shin *et al.* 2020).

While our paper's focus is on the Japanese payment system reform, as this brief overview of the the Korean payment system indicates, Japan is not the only country that moved from the FFS to the per-diem based system to try to shorten the LOS. South Korea is employing a similar approach and Korean "new DRG" system "*appears to be heavily influenced by the Japanese DPC system*" (Tchoe 2010, p. 222). While there are some distinct differences (for a comparison of Japanese and Korean payment systems see Tchoe, 2010), the theoretical framework

provided by the fee-for-service payment system hospitals were overinvesting into new technologies despite those investment being not financially sound.

developed in this paper can be extended to provide theoretical insights on how the Korean reform affects hospitals' financial incentives.

VI. Concluding Remarks

The paper develops a theoretical model that studies how the average length of stay is affected by hospitals' financial incentives under three reimbursement policies: a standard fee-for-service system (*FFS*); a per diem PPS system with the per diem rate equal to the average daily payments under the FFS system (*PD*); and a per diem PPS with a step-down tariff (*SDR*), where the per diem rate during the initial period of stay is higher than for the rest of the patient's stay. The model is designed to incorporate the essential features of the inpatient PPS with an LOS-dependent step-down tariff, as implemented in Japan.

We show that a higher per diem rate for initial period, *e.g.* for the first 25% of ALOS as it was implemented in the Japanese reform, does not generate incentives to shorten the length of stay. Instead, hospitals have financial incentives to treat patients longer in order to fully benefit from the higher per diem rate. Furthermore, given the emphasis on shorter ALOS under the SDR system, hospitals have incentives to use planned readmission to shorten the reported length of stay of a single admission. Finally, we provide a theoretical explanation for a heterogeneous response of hospitals to the reform depending on their pre-reform ALOS and our theoretical predictions are supported by empirical evidence. First, as predicted in our model, hospitals with longer pre-reform ALOS shortened their post-reform ALOS, while for hospitals with shorter pre-reform ALOS the effect of the reform was the opposite and their post-reform ALOS has increased (Table IV, Besstremyannaya 2016). Second, as also predicted in our model, it is hospitals with longer pre-reform ALOS that have most incentives to use planned readmissions (Table V, Besstremyannaya 2016).

Although Japan acknowledges the limitations of the per diem rates, the country does not plan a changeover to the pure PPS. Moreover, introduced in 2003 with the name "inclusive payment system according to diagnosis-procedure combinations", the Japanese PPS was renamed in 2010 as "diagnosis-procedure combination/per diem payment system", or DPC/PDPS (MHLW 2012a). In 2012, in an attempt to fine-tune the step-down per diem rates Japan introduced a modification of the reimbursement schedule: regardless of a hospital's position in the empirical distribution of ALOS, no more than 50% of days for each hospital stay can be reimbursed at the highest rates. Based on our model, we predict that this change has no effect on less efficient hospitals. However, the incentives of more efficient hospitals to keep patients longer are weakened. Therefore, the attempt to loosen the stimuli within the step-down per diem rate is beneficial from a social planner point of view.

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Appendix

Proof of Proposition 2: From (1) follows that

$$p_I I'(L_{FFS}) = cI'(L_{FFS}) + \gamma g'(L_{FFS}),$$

and from (4) follows that

$$\bar{d} = cI'(L_{PD}) + \gamma g'(L_{PD}).$$

The RHS, which is the derivative of the cost function, is an increasing function of L. Therefore,

$$L_{FFS} \lesseqgtr L_{PD} \text{ if and only if } p_I I'\left(L_{FFS}\right)) \lesseqgtr \bar{d}.$$

The per-diem rate, $\bar{d}$, does not depend on γ. Term $p_I I'(L_{FFS})$ is a decreasing function of γ. Indeed, $I'(L)$ is an increasing function of L because $I(L)$ is convex; and L_{FFS} is a decreasing function of γ by Proposition 1. Let γ_0 be such that $p_I I'(L_{FFS})|_{\gamma=\gamma_0} = \bar{d}$, if it exists. Then

1. if $\gamma > \gamma_0$ then $p_I I'(L_{FFS}) < \bar{d}$ and $L_{PD} > L_{FFS}$;
2. if $\gamma < \gamma_0$ then $p_I I'(L_{FFS}) > \bar{d}$ and $L_{PD} < L_{FFS}$.
3. if γ_0 does not exist then either $L_{PD} > L_{FFS}$ for all γ, or $L_{PD} < L_{FFS}$ for all γ.

The result above holds regardless of the value of $\bar{d}$. However, given the definition of $\bar{d}$ the first case is impossible. Indeed, let $\underline{\gamma}$ be the lowest bound of γ's support. Then

$$\bar{d} = p_I E_\gamma \left[\frac{I\left(L_{FFS}(\gamma)\right)}{L_{FFS}(\gamma)} \right] < p_I E_\gamma I'_L \left(L_{FFS}(\gamma)\right) < p_I I'\left(L_{FFS}\left(\underline{\gamma}\right)\right),$$

where the first inequality follows from convexity of $I(L)$ and the fact that $I(0) = 0$. The second inequality follows from the fact that L_{FFS} is a decreasing function of γ. Thus the only two cases possible are: $p_I I'(L_{FFS}(\bar{\gamma})) \leq \bar{d} < p_I I'(L_{FFS}(\underline{\gamma}))$ and then γ_0 exists; or $\bar{d} < p_I I'(L_{FFS}(\bar{\gamma})) < p_I I'(L_{FFS}(\underline{\gamma}))$ and then $L_{PD} < L_{FFS}$ for all values of $\gamma \in [\underline{\gamma}, \bar{\gamma}]$.

Proof of Proposition 3: From (5), $\pi(L)$ is a concave function of L. It is differentiable everywhere except for the kink point at $L = \alpha\bar{L}$. Therefore, the optimum is either reached at the point where $\pi'(L) = 0$ or at $\alpha\bar{L}$. Let $L_1^*(\gamma)$ denote the unconstrained maximum of the first part of (5) and $L_2^*(\gamma)$ denote the unconstrained maximum of the second part of (5). Formally, $L_1^*(\gamma)$ satisfies

$$q\bar{d} = cI'(L) + \gamma g'(L),$$

and $L_2^*(\gamma)$ satisfies

$$\tau\bar{d} = cI'(L) + \gamma g'(L).$$

Finally let $L_{PD}^*(\gamma)$ be as defined in equation (4). From the convexity of g and I follows that $L_1^*(\gamma) > L_{PD}^*(\gamma) \geq L_2^*(\gamma)$, and that all three are decreasing functions of γ. Let γ_2 be such that $L_2^*(\gamma_2) = \alpha\bar{L}$, γ_1 be such that $L_1^*(\gamma_1) = \alpha\bar{L}$, and γ_{PD} be such that $L_{PD}^*(\gamma_{PD}) = \alpha\bar{L}$. From q $> 1 \geq \tau$ follows that $\gamma_1 > \gamma_{PD} \geq \gamma_2$.

There are four cases possible:

a) $\gamma \leq \gamma_2$: in this case $L_1^*(\gamma) > L_{PD}^*(\gamma) \geq L_2^*(\gamma) \geq \alpha\bar{L}$. Therefore, the global maximum is $L_{SDR}^*(\gamma) = L_2^*(\gamma)$. The maximum is global because $\pi(L)$ is an increasing function when $L < \alpha\bar{L}$, so the maximum of $\pi(L)$, cannot be achieved when $L < \alpha\bar{L}$. Compared to the PD system the LOS goes down: $\alpha\bar{L} \leq L_{SDR}^*(\gamma) \leq L_{PD}^*(\gamma)$.

b) $\gamma_2 < \gamma \leq \gamma_{PD}$: in this case $L_1^*(\gamma) > L_{PD}^*(\gamma) \geq \alpha\bar{L} \geq L_2^*(\gamma)$. This case happens only when $\tau < 1$, since $\gamma_2 = \gamma_{PD}$ when $\tau = 1$. The global maximum is $L_{SDR}^*(\gamma) = \alpha\bar{L}$. Indeed, the first line in (5) is increasing (since $L_1^*(\gamma) > \alpha\bar{L}$) and the second line is decreasing (since $L_2^*(\gamma) < \alpha\bar{L}$) on their respective domains. Compared to the PD system the LOS goes down: $\alpha\bar{L} = L_{SDR}^*(\gamma) \leq L_{PD}^*(\gamma)$.

c) $\gamma_{PD} < \gamma \leq \gamma_1$: in this case $L_1^*(\gamma) \geq \alpha\bar{L} > L_{PD}^*(\gamma) \geq L_2^*(\gamma)$. As in case ii), the global maximum is $L_{SDR}^*(\gamma) = \alpha\bar{L}$. Compared to the PD system, the LOS goes up: $\alpha\bar{L} = L_{SDR}^*(\gamma) > L_{PD}^*(\gamma)$.

d) $\gamma > \gamma_1$: in this case $\alpha\bar{L} > L_1^*(\gamma) > L_{PD}^*(\gamma) \geq L_2^*(\gamma)$. The global maximum is $L_{SDR}^*(\gamma) = L_1^*(\gamma)$. Comparing it to the *PD* case, the LOS goes up.

Cases a) and b) correspond to case i) of the Proposition's statement. Cases c) and d) correspond to case ii) of the Proposition's statement.

Proof of Proposition 6: It follows from (7) that it is not optimal to have $L_i > \alpha\bar{L} > L_j$. This is because the per diem payment on admission *j* pays at premium q, whereas the one on admission i does not. Increasing the j's admission and shortening the i's admission would result in a higher profit.

Lemma 1. *At the optimum* $L_1^* = L_2^*$.

Proof. If L_1, $L_2 < \alpha\bar{L}$. then they satisfy the FOCs:

$$q\bar{d} - cI'(L_1) = \gamma g'(L_1 + L_2)$$
$$q\bar{d} - cI'(L_2) = \gamma g'(L_1 + L_2),$$

so that $L_1^* = L_2^*$ and $q\bar{d} - cI'(L_2^*) = \gamma g'(2L_2^*)$. Similarly, if L_1, $L_2 > \alpha\bar{L}$ then $L_1^* = L_2^*$.

Having $L_i = \alpha\bar{L} < L_j$ is not optimal. The FOCs are

$$q\bar{d} \geq cI'(\alpha\bar{L}) + \gamma g'(L_1 + L_2) \geq \tau\bar{d}$$
$$\tau\bar{d} = cI'(L_j) + \gamma g'(L_1 + L_2),$$

where the first line reflects the fact that the profit function is not differentiable at $L_i = \alpha\bar{L}$. Thus,

$$cI'(\alpha\bar{L}) \geq cI'(L_j),$$

which is a contradiction to $\alpha\bar{L} < L_j$. By a similar argument $L_i < \alpha\bar{L} = L_j$ cannot be optimal either.

It follows from Lemma 1 that both admissions have equal length, $L_1^* = L_2^*$. We will use L_2^* to denote the length of one admission when the hospital treats a patient using planned readmission. If $L_2^* < \alpha\bar{L}$ then $q\bar{d} = cI'(L_2^*) + \gamma g(2L_2^*)$; if $L_2^* = \alpha\bar{L}$ then $q\bar{d} \geq cI'(L_2^*) + \gamma g'(2L_2^*) \geq \tau\bar{d}$; if $L_2^* > \alpha\bar{L}$ then $\tau\bar{d} = cI'(L_2^*) + \gamma g'(2L_2^*)$.

Several cases are possible depending on the value of γ:

1. γ is such that $\gamma g'(2\alpha\bar{L}) + cI'(\alpha\bar{L}) > \gamma g'(\alpha\bar{L}) + cI'(\alpha\bar{L}) \geq q\bar{d}$. Then the profit with readmission has the global maximum at point where $\gamma g'(2L_2^*) + cI'(L_2^*) = q\bar{d}$, and the profit without readmission has the global maximum at point $\gamma g'(L^*) + cI'(L^*) = q\bar{d}$. Then $2L_2^* > L^* > L_2^*$. That $L^* > L_2^*$ follows from

   $$\gamma g'(2L^*) + cI'(L^*) > \gamma g'(L^*) + cI'(L^*) = q\bar{d} = \gamma g'(2L_2^*) + cI'(L_2^*).$$

That $2L_2^* > L^*$ follows from

$$\gamma g'(2L_2^*) + cI'(2L_2^*) > \gamma g'(2L_2^*) + cI'(2L_2^*) = q\bar{d} = \gamma g'(L^*) + cI'(L^*).$$

Let $\Delta\pi$ denote $\pi_2 - \pi_1$. We can write it as

$$\Delta\pi = \left[q\bar{d}\left(2L_2^*\right) - 2cI\left(L_2^*\right) - \gamma g\left(2L_2^*\right)\right] - \left[q\bar{d}\left(L^*\right) - cI\left(L^*\right) - \gamma g\left(L^*\right)\right].$$

By the envelope theorem

$$\frac{\partial\Delta\pi}{\partial\gamma} = -g\left(2L_2^*\right) + g\left(L^*\right) < 0.$$

2. γ is such that $\gamma g'\left(2\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right) > q\bar{d} > \gamma g'\left(\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right) \geq \tau\bar{d}$. The last two inequalities imply that that $L^* = \alpha\bar{L}$. The first inequality means that if a hospital is to use planned readmission it is optimal to use two planned readmissions, and that $L_2^* < \alpha\bar{L} = L^*$. That $2L_2^* > L^*$ follows from

$$\gamma g'\left(2L_2^*\right) + cI'\left(2L_2^*\right) > \gamma g'\left(2L_2^*\right) + cI'\left(L_2^*\right) = q\bar{d} > \gamma g'\left(L^*\right) + cI'\left(L^*\right),$$

where the last inequality is due to the fact that $\alpha\bar{L} = L^*$.
In this case $\Delta\pi$ becomes

$$\Delta\pi = \left[q\bar{d}\left(2L_2^*\right) - 2cI\left(L_2^*\right) - \gamma g\left(2L_2^*\right)\right] - \left[q\bar{d}\left(\alpha\bar{L}\right) - cI\left(\alpha\bar{L}\right) - \gamma g\left(\alpha\bar{L}\right)\right].$$

By the envelope theorem the derivative of the first term with respect to γ is $-g(2L_2^*)$. Since $\alpha\bar{L}$ is a constant and does not depend on γ the derivative of the second term is $-g(\alpha\bar{L})$. Thus again $\partial\Delta\pi / \partial\gamma < 0$.

Two cases are possible as we decrease γ. We will label these two cases as Case 3 and Case 3'.

3. γ is such that $q\bar{d} \geq \gamma g'\left(2\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right) > \gamma g'\left(\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right) \geq \tau\bar{d}$. Then the optimal solution with the readmission is to have $L_1^* = L_2^* = \alpha\bar{L}$. The optimal solution without the readmission is also $L^* = \alpha\bar{L}$. Thus $L_2^* = L^* < 2L_2^*$. The profit difference is

$$\Delta\pi = \left[q\bar{d}\left(2\alpha\bar{L}\right) - 2cI\left(\alpha\bar{L}\right) - \gamma g\left(2\alpha\bar{L}\right)\right] - \left[q\bar{d}\alpha\bar{L} - cI\left(\alpha\bar{L}\right) - \gamma g\left(\alpha\bar{L}\right)\right],$$

and its derivative with respect to γ is negative.

3'. Alternatively, γ is such that $\gamma g'(2\alpha\bar{L}) + cI'(\alpha\bar{L}) > q\bar{d} > \tau\bar{d} \geq \gamma g'(\alpha\bar{L}) + cI'(\alpha\bar{L})$. In this case without readmission hospitals would go for long admission and with readmission the hospital would go for two short admissions. Thus $L^* \geq \alpha\bar{L} > L_2^*$. By the same logic as in case 2, we conclude that $2L_2^* > L^*$. Thus, with planned readmission LOS will decrease, $L_2^* < L^*$, but the total number of days will go up $2L_2^* > L^*$.
As for profit difference,

$$\Delta\pi = \left[q\bar{d}\left(2L_2^*\right) - 2cI\left(L_2^*\right) - \gamma g\left(2L_2^*\right)\right] - \left[q\bar{d}\alpha\bar{L} + \tau\bar{d}\left(L^* - \alpha\bar{L}\right) - cI\left(L^*\right) - \gamma g\left(L^*\right)\right],$$

its derivative with respect to γ is $-g(2L_2^*) + g(L^*) < 0$.

4. γ is such that $q\bar{d} \geq \gamma g'\left(2\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right) > \tau\bar{d} > \gamma g'\left(\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right)$. The solution with the readmission is $L_1^* = L_2^* = \alpha\bar{L}$ and without it is a long readmission L^* such that $\tau\bar{d} = \gamma g'(L^*) + cI'(L^*)$. Thus $L_2^* = \alpha\bar{L} < L^*$. That $2\alpha\bar{L} > L^*$ follows from

$$\gamma g'\left(2\alpha\bar{L}\right) + cI'\left(2\alpha\bar{L}\right) > \gamma g'\left(2\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right) > \tau\bar{d} = \gamma g'\left(L^*\right) + cI'\left(L^*\right).$$

As in all other cases, the LOS per admission declines but the total number of days goes up. Profit difference is

$$\Delta\pi = \left[q\bar{d}\left(2\alpha\bar{L}\right) - 2cI\left(\alpha\bar{L}\right) - \gamma g\left(2\alpha\bar{L}\right)\right] - \left[q\bar{d}\alpha\bar{L} + \bar{d}\left(L^* - \alpha\bar{L}\right) - cI\left(L^*\right) - \gamma g\left(L^*\right)\right],$$

and its derivative is $-g(2\alpha\bar{L}) + g(L^*) < 0$.

5. γ is such that $\tau\bar{d} \geq \gamma g'\left(2\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right) > \gamma g'\left(\alpha\bar{L}\right) + cI'\left(\alpha\bar{L}\right)$. Then the profit with readmission has the global maximum at a point where $\gamma g'(2L_2^*) + cI'(L_2^*) = \tau\bar{d}$, and the profit without readmission has the global maximum at a point where $\gamma g'(L^*) + cI'(L^*) = \tau\bar{d}$. Thus, and $L_2^* > \alpha\bar{L}$ and $L^* > \alpha\bar{L}$. Furthermore, one can show that $2L_2^* > L^* > L_2^*$. That $L^* > L_2^*$ follows from

$$\gamma g'\left(2L^*\right) + cI'\left(L^*\right) > \gamma g'\left(L^*\right) + cI'\left(L^*\right) = \tau\bar{d} = \gamma g'\left(2L_2^*\right) + cI'\left(L_2^*\right).$$

That $2L_2^* > L^*$ follows from

$$\gamma g'\left(2L_2^*\right) + cI'\left(2L_2^*\right) > \gamma g'\left(2L_2^*\right) + cI'\left(L_2^*\right) = \tau\bar{d} = \gamma g'\left(L^*\right) + cI'\left(L^*\right).$$

As before the derivative of the profit difference with respect to γ is equal to $\partial\Delta\pi / \partial\gamma = -g\left(2L_2^*\right) + g\left(L^*\right) < 0$.

Thus we showed that for every γ using the readmission becomes more lucrative as γ goes down.

Furthermore, $2L_2^* \geq L^* > L_2^*$.