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PUBLIC AND PRIVATE PROCUREMENT OF SERVICES IN THE HEALTHCARE SECTOR

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Abstracts

The Impact of Public-Private Partnership on Facility Management Costs: Evidence from Healthcare Sector in England (joint with Evgenii Monastyrenko). The private finance initiative (PFI) is a type of public-private partnership (PPP) that has been extensively used in England since the 1990s. This study employs the ERIC panel dataset spanning from 2018 to 2021 to evaluate how hospital procurement type affects the costs of both hard and soft facility management (FM) services. By employing ordinary least squares and two-stage least squares estimations, followed by propensity score matching and Hausman-Taylor estimations, the findings indicate that PFI is associated with increases in both hard and soft FM costs, up to 37.1% and 20.3%, respectively. This effect is particularly pronounced for hospital sites with pre-existing buildings before the signing of PFI contracts, although the trend reverses for soft FM costs. Furthermore, the study reveals that partial PFI financing is linked to higher costs compared to hospital sites procured entirely through PFI. Nonetheless, the study suggests the potential for limited cost savings by considering moderate- and low-risk backlog maintenance costs, as well as capital investments in new construction.

Facility Management Services in UK Hospitals: In-house or Outsourcing (joint with Pierre M. Picard). This study examines the institutional organization of UK hospitals through both traditional procurement and PFIs. Initially, it describes the structure of the UK healthcare sector, highlighting the provision of hard FM services such as building maintenance, as well as soft FM services like catering and cleaning, which can be managed either in-house or outsourced. By developing an applied principal-agent model for this sector and considering the builder's partial warranty provided against construction risks, the study demonstrates that PFIs internalize the externality between builders and hard FM service suppliers, while also necessitating the payment of a risk premium, which may become excessive under significant hard FM risk. In contrast, traditional procurement generates a reverse moral hazard due to the builder's warranty that intensifies with higher levels of hard FM risk. Furthermore, traditional procurement lacks incentives for outsourcing FM services, while PFI offers incentives for outsourcing soft FM services. Ultimately, the paper argues that PFI procurement is optimal under conditions of sufficiently low or high hard FM risk.

Healthcare Provider Efforts vs Fees: Striking the Right Balance This study explores how parties within the healthcare sector can achieve an equilibrium by utilizing internal enforcement alongside external enforcement mechanisms. It particularly investigates how the optimal balance between external and internal enforcement varies with changes in the sensitivity of healthcare output to the efforts of healthcare providers and service suppliers. The analysis is conducted within the framework of a repeated game with imperfect public monitoring under double moral hazard. The study examines an optimal relational contract by solving the game in a stationary environment. The main result suggests that with an increase in healthcare output sensitivity to parties' efforts or parties' patience, in the equilibrium external enforcement should increase along with internal enforcement.

General Introduction

This Dissertation examines the healthcare sector in the United Kingdom and globally, contributing to healthcare economics by studying different service procurement methods. Specifically, it investigates the expected net benefit of healthcare providers via external sourcing and internal provision of facility management services for public hospitals, as well as those delivered through PFI. Moreover, it explores possibilities for cost savings in facility management services, along with optimal contract formulation that benefits both public and private parties involved.

The government nowadays is not the unique source of healthcare services financing and development. For instance, recently during the COVID-19 pandemic, only thanks to the collaboration of the public and private sectors was the vaccine invented. The same occurs in other industries, such as space, construction, or robotics. The future of human progress depends directly on the partnership between the public and private sectors. I, as a scientist, feel the responsibility on my shoulders to contribute to it via research. My dissertation is the first step in my career where I launch a cost-savings and net benefit analysis, along with the exploration of internal and external enforcement balance between public and private parties' partnerships in the healthcare sector.

The healthcare sector is a complex arrangement with multiple parties interaction. These parties can be generalized into risk-neutral principals and risk-neutral or risk-averse agents working together over time. I utilize principal-agent modelling to describe the interaction between healthcare service providers and medical equipment maintaining firms, pharmaceutical companies and hospitals, foundation trusts in the UK and facility management service providers. However, this model has broader potential applications.

Parties interact through different procurement types. For instance, when the government solely utilizes taxpayers' money, it constitutes public procurement. In contrast, when the government attracts private sector financing, it is termed as PPP procurement. There are multiple types of PPP procurement, including concession, build-maintain-operate, PFI, and others. This dissertation specifically focuses on the PFI procurement type. The objective is to glean insights from the utilization of this procurement type and derive lessons that would enable governments to develop more efficient PPP models in the future, with a focus on cost-savings and net-benefit perspectives. The enforcement mechanisms of procurement play a crucial role in the success of parties' interaction in the healthcare sector. I emphasize the involvement of external enforcement to establish clear contractual terms and incentives, as well as regular communication, feedback mechanisms, performance reviews, recognition, and dispute resolution processes. Additionally, I aim to balance this with internal self-enforcing mechanisms in the contract.

I establish in Chapter 1 empirically that facility management services delivered through PFI are more costly. In Chapter 2, I provide theoretical reasoning for these costs due to the choice of the wrong procurement type under a certain level of hard and soft FM risk intensity dominance background with double moral hazard problem. Finally, Chapter 3 adds that through relational contracts, the reasoning could also be due to the wrong external and internal enforcement balance in the contract.

Chapter 1 shows that hospital sites procured through PFI have higher hard and soft FM costs compared to public ones, with an increase of up to 37.1% and 20.3% respectively. This difference is particularly noticeable in specific parts of facility management service costs: for hard FM, it is seen in energy costs and estates maintenance costs, while for soft FM, it is observed in laundry and linen expenses. We found that hospital sites procured through PFI with old buildings or those partially delivered through PFI experience larger hard FM service costs, while the effect is reversed for soft FM services excluding old constructions or when delivered fully through PFI. Nevertheless, our empirical study indicates that PFIs fulfill their intended function according to theory by transferring risk and managing efficiently. Specifically, we demonstrate that they are able to minimize FM service costs on management and when ruling out moderate- and low-risk backlog buildings. Moreover, at the trust level, we show that with each additional unit of private investment, trusts managing a higher share of PFI experience lower soft FM service costs.

Chapter 2 extends the analysis by showing that PFI is optimal for small and high hard FM risks, while public procurement is preferred for intermediate risks. The reasoning arises from the builder's warranty that creates a "reverse" moral hazard in public procurement and becomes stronger for higher hard FM risk. Moreover, public procurement gives authorities no incentive to outsource facility management services, whereas PFI structures offer incentives for soft FM services being outsourced. Consequently, this result provides a simple rationale for why authorities taking over expired PFIs may return to an in-house provision of soft FM services.

Chapter 3 clarifies how contracts for outsourced healthcare-related services should be formulated. It emphasizes the need for targeted external and internal enforcement when parties' efforts sensitively contribute to healthcare output or when parties are very patient.

This Dissertation discusses the advantages and disadvantages of using PFI in the UK. It also contributes new knowledge that can be applied by other governments to develop more effective forms of PPPs in the future. The research emphasizes that there is limited study on PPPs in the healthcare sector due to insufficient data, but as data access grows, further investigation and attention to this area are warranted.

Contents

Chapter 1

The Impact of Public-Private Partnership on Facility Management Costs: Evidence from Healthcare Sector in England

1.1 Introduction

Public-private partnership (PPP) contracts and long-term contractual arrangements between government and private partners have become increasingly popular ways to build major public infrastructure projects (Hodge & Greve, 2017; Saussier & De Brux, 2018). The effectiveness of such contracts has been assessed across various dimensions, including, among others, cost savings.[1] Since the 1980s, there has been an ongoing debate regarding the cost efficiency of PPPs as an alternative form of public service delivery (De Vries & Yehoue, 2013).

This study focuses on the healthcare sector in England and its use of private finance initiatives (PFIs), which are a type of PPPs. The UK's first PFI hospital, designed for frail elderly patients and those with dementia, known as Ferryfield House, began operating in North Edinburgh in 1996 (McKendrick & McCabe, 1999). The purpose of this type of contract is to optimize government costs by easing budgetary constraints on public expenditure (Buso et al., 2017), partly reallocating risk (Bing et al., 2005), delivering projects on time, encouraging innovation, and incentivizing better performance (Committee,

[1] Other performance measures are time (Mott MacDonald, 2002; NAO, 2003, 2009), quality (Gutacker et al., 2016; Hong, 2016; Yaya, 2017) and value for money (Bain, 2010; Daito & Gifford, 2014; Reeves, 2013).

2011). By 2018, England had 109 hospitals and social care facilities funded through PFI, along with approximately 1000 financed through non-PFI means (Podaneva & Picard, 2023).

However, the PFI procurement form appears less efficient than expected (NAO, 2018). As a result, the UK government banned the PFI in 2018, stating that the model was "inflexible and overly complex" (HM Treasury, 2018, p. 29). Nevertheless, ongoing PFI contracts remain maintained until hospitals and sites are returned to the authority. The UK currently faces a wave of PFI expirations, with the National Audit Office (NAO) predicting a peak in 2036-2037 (NAO, 2020b).

This paper enriches the literature that compares alternative procurement methods of public projects, PPP and Traditional Procurement (TP), across various dimensions and industries.[2] Several related studies have been dedicated to cost efficiency. These are, to name a few, Pollock et al. (2007), Blanc-Brude et al. (2009), Raisbeck et al. (2010), and Hoppe et al. (2013). A straightforward comparison of whole-life cycle costs is typically not feasible, owing to the longevity, variety, complexity, and commercial confidentiality of PPPs data. Therefore, existing academic studies have mainly assessed projects based on their key stages: construction (Blanc-Brude et al., 2006; Hoppe et al., 2013; Raisbeck et al., 2010) and maintenance (Devapriya, 2006; Ng & Wong, 2006).

The literature explaining the variations in hospital facility management costs during the maintenance stage is primarily qualitative, e.g. Boussabaine et al. (2012), El-Haram and Horner (2002), Hassanain et al. (2013), and Sliteen et al. (2011).[3] To the best of our knowledge, the only available empirical study is conducted by Elkomy et al. (2019). This study utilizes panel data with trust-specific fixed effects to establish the relationship between outsourcing cleaning services and cleaning costs.

One notable novelty of our study is the use of granular and sparse data from the healthcare sector in England. This paper relies on the Estates Returns Information Collection (ERIC) dataset provided by the National Health Service (NHS) Digital. This collection of data covers the costs of providing and operating facility management services for NHS trusts from 2018 to 2021. The dataset also includes detailed information about NHS foundation trusts aggregated to PFI and non-PFI estate levels. Based on these data, it appears that PFI hospital sites are typically newer, larger, and fewer in number than traditional hospital sites. In addition, these hospital sites tend to be geographically concentrated in major urban

[2] See literature review in Välilä (2020).
[3] Follow Yousefli et al. (2017) for the literature review on this topic.

areas.

To the best of our knowledge, our study is the first to apply panel data empirical analysis to a comparison of public project procurement forms (i.e., PPPs and TPs) in the healthcare sector. Our dependent variables are hard facility management (FM) and soft FM service costs. Hard FM services are responsible for maintaining the physical assets of NHS buildings, including both the internal and external elements. On the other hand, soft FM services provide an extensive set of other amenities, including but not limited to catering, cleaning, security, postal services, and waste management.

Our main independent variable of interest is a dummy indicating whether the hospital site procurement form is a PFI or non-PFI. We further differentiate the PFI procurement method into several subtypes. First, we distinguish PFI projects based on their tenure: "full" or "partial". A "full" PFI signifies that the entire hospital site was constructed under a PFI contract. In contrast, a "partial" PFI means that only a fraction of hospital site buildings was built using the PFI. In a separate exercise, we distinguish between "old" and "new" PFI hospital sites. The "old" category includes hospital sites that had existing buildings before the initiation of the PFI contract. The "new" category includes hospital sites that have been recently constructed under a PFI contract.

Our analysis starts with simple OLS regressions. We control for various characteristics that fall into five categories: labor, areas, energy, backlog costs, catering, and laundry services. The tested empirical specifications include alternative sets of fixed effects: hospital site profile $\times$ year, UK region $\times$ year, and trust $\times$ UK region $+$ year.

Endogeneity issues may arise due to market conditions and political party dominance favoring the PFI procurement method. To address this, a 2SLS estimator is used with three instruments: the London Interbank Offered Rate (LIBOR), public sector net debt (as a percentage of GDP), and voting per constituency in government elections.

The main findings indicate that PFI hospital sites incur higher hard FM and soft FM costs compared to traditional hospital sites, with an increase of up to 37.1% and 20.3% respectively. The impact on hard FM service costs is more pronounced for PFI hospital sites with older buildings, whereas the effect on soft FM service costs is the opposite. Additionally, the disparity in hard FM service costs between PFI and traditional hospital sites is greater for those sites that are partially delivered under PFI contracts, while the difference in soft FM service costs is larger for fully delivered ones.

We also find that outsourcing laundry and linen services increases soft FM service costs for both PFI and non-PFI, with the fastest pace for PFI. The main areas with the largest difference in facility management costs between PFI and non-PFI are: a) energy costs and estates/property maintenance costs expanding hard FM cost difference; b) laundry and linen costs mainly increasing soft FM cost differences. In contrast, indeed management costs are lower under PFI for both FM services, allowing PFI to reduce costs in this manner. Moreover, we discover that the higher share of PFIs under the trust supervision leads to more efficient resource allocation for hard FM services.

Furthermore, our results indicate that a higher percentage of PFIs under trust supervision leads to improved effectiveness in allocating private investment towards soft FM services, which subsequently contributes to a slower growth rate in the costs of such services.

The rest of the paper is organised as follows. Section 1.2 describes our data and variables. In section 1.3, we provide details on the OLS and 2SLS estimations and the corresponding results. Section 1.4 introduces propensity score matching and Hausman–Taylor estimations, an alternative approach to address endogeneity. In section 1.5, we conduct additional estimations to help interpret the main results. Section 1.6 provides robustness checks. Finally, section 1.7 briefly concludes the paper and discusses directions for further research.

1.2 Data and variables

1.2.1 Sample and stylized facts

Our paper uses a publicly-available data about the costs of providing, maintaining, and servicing the NHS trusts.[4] Specifically, we use the annually released ERIC dataset dating back to 1999.[5] The PFI procurement method has been applied to UK hospitals since the late 1990s, and the ERIC dataset contains data on PFI sites, including hospitals, health centers, clinics, ambulatory diagnostic centers, mobile units, and treatment centers, since 2015. We further narrowed the sample to a panel of hospital sites in England between 2018 and 2021. Note that there is a significant mismatch in the convenience definition and computation of the employed variables between 2015 and 2017. For instance, in 2016-2017 any received income was offset by costs.

In the raw ERIC dataset, the unit of observation is a "site", defined as "any building or

[4] The data is made public by NHS Digital (see https://digital.nhs.uk). NHS Digital is the UK's national information and technology partner that collects, processes, and publishes data from England's health and social care system.

[5] Previously disseminated via the Hospital Estates and Facility (HEFS) website.

associated group of buildings, including administrative buildings within a specified area for which a trust incurs a cost to occupy".[6] Note that all sites provide secondary care. For this research, we employ a subsample in which we keep sites of two types: (i) having more than nine beds and (ii) with 1-9 beds and a total Gross Internal Area (GIA) of at least 500 m^2.[7] Therefore, our sample contains exclusively "inpatient" sites, and we remove from analysis "outpatient" sites, i.e. the ones mainly treating patients without overnight stays (see Appendix E1 and Table E1). Hereafter, in the remainder of this paper, we operate with the word "hospital" to refer to an "inpatient" site.

The subsamples used in our analysis varied depending on the specifications tested. In this paper, we provide descriptive statistics for the subsample used in the regression of soft FM services. Information on the other subsamples is available upon request. Our dataset covers 965 hospitals in 2018, 956 hospitals in 2019, 934 hospitals in 2020, and 1263 hospitals in 2021.[8] The initial sample consists of approximately 4000 hospital $\times$ year observations.[9] After data preprocessing, the sample size gets reduced to 2903 and 2911 observations for soft FM and hard FM service estimations, respectively. The sharp drop in the number of observations is primarily due to missing data for some components compounding hard and soft FM service costs. To ensure consistency across the years, the computation of some variables has been consolidated.

This paper aims to distinguish between sites built using the PFI procurement method (referred to as "PFI hospital sites") and those that did not use this financing method (referred to as "traditional hospital sites"). In the rest of the paper, we refer to hospital site types as "PFI hospital sites" opposed to "traditional hospital sites". Additionally, within the dataset, these two types are further differentiated into eight profiles (Fig. 1.1 and B1 in the Appendix). Of the PFI and non-PFI hospital sites in our data, 83% fall into one of three profiles: general acute (211/210 for soft FM/hard FM subsamples), mental health (233/317), and community hospital sites (116/121). General acute hospitals provide a

[6]For more details, see https://digital.nhs.uk/data-and-information/publications/statistical/estates-returns-information-collection/england-2018-19.

[7]In our data, the GIA of a hospital site is defined as the combined GIA of all buildings, whether they are occupied or vacant. This includes temporary structures, educational and training facilities, university accommodations, and areas temporarily used by building contractors. Areas that are leased out and open car parks, however, are not included in this calculation.

[8]The sharp increase in the number of observations in 2021 is due to changes in reporting. Sites without inpatient beds and with a GIA of more than 500 m^2 are now reported individually. Of the newly reported sites in 2021, 71% are mental health sites. To ensure data consistency, we have excluded these sites from the 2021 subsample. See Appendix E1 for more details.

[9]It is important to note that the source data is reported for the UK fiscal year, which runs from April 1st to March 31st of the following calendar year. This is slightly different from the standard fiscal year definition, which runs from April 6th to April 5th.

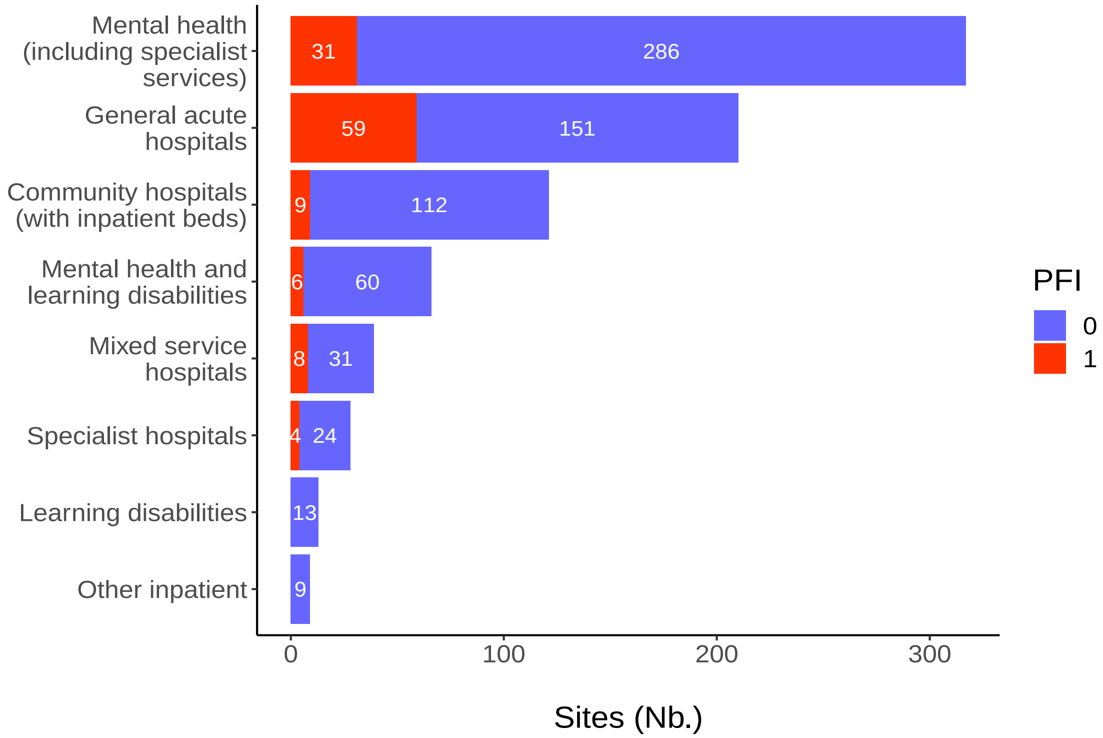


Figure 1.1: Unique sites in the hard FM sample: types, profiles and procurement method

range of inpatient medical care and related services for surgery, acute medical conditions, or injuries, usually for short-term illnesses or conditions. Mental health sites exclusively provide mental health services. Community hospitals offer an alternative to acute general hospital care by providing services closer to people's homes and tailored to local needs.[10] Fig. B1 compares the profiles and types of hospital sites in the soft FM subsample. In the hard FM subsample, the share is approximately the same. Traditional hospital sites form the majority (80%) and systematically dominate across all hospital site profiles. In total, there are 121 and 117 unique hospital sites for soft and hard FM subsamples, respectively, delivered using the PFI mechanism. Note Fig. 1.1 shows that overall, NHS is more likely to attract private financing for the construction of general acute hospitals.

The geographical location of hospital sites, including hospitals, in our sample is shown on the map (Fig. B2). We conclude that PFI hospitals are uniformly distributed over the territory of England. It is worth noting that a large fraction of PFI supplied hospitals are concentrated around London. We further account for this geographical heterogeneity in the empirical analysis. In fact, the factors related to urbanization and development of the regions should impact facility management costs.

[10]The definition for all site profiles is given in the Appendix A1.

1.2.2 Key variables

Regression analysis aims to explain the variation in two outcome variables: soft FM and hard FM service costs. These variables were computed as the sum of the corresponding components. Soft FM service costs include cleaning, food and beverages, laundry and linen, portering, and others.[11] Hard FM service costs include maintenance costs of estates and property, grounds and gardens, and electro-biomedical equipment. Another important components are the utilities of energy, water, sewerage and waste disposal. Note that, since 2018, car parking and hard FM service costs are reported as separate components within the hard FM costs.[12]

We present the distribution of soft and hard FM costs across the profiles of hospital sites in the Appendix, Fig. B3 and Fig. B4, respectively. We observe that site profiles with the largest number of observations tended to be normally distributed.

Our principal variable of interest is the PFI dummy, which takes a value of one if the site is built with a PFI contract. Such contracts are typically granted to Special Purpose Vehicles (SPVs) for a period of 25-30 years. Four PFI contracts were terminated during the study period (2018-2021), namely Whittington Hospital, Birmingham Children's Hospital, Rosberry Park FKS St Luke's Hospital, and Goodmayes Hospital. We have excluded these observations from the dataset, meaning that there is no variation in PFI over time.

The boxplots in Fig. B5 in the Appendix show that soft FM is less expensive for traditionally supplied hospitals.[13] We further note that this pattern dominates in the hard FM dataset (see Fig. B6 in the Appendix). On average, PFI spends 138 and 108 million GBP/m^2 on soft FM and hard FM services, respectively, while non-PFI expenditures are 131 and 86 million GBP/m^2 for the same services. These boxplots call forth the hypothesis that a meter squared of hospital surface is more costly to maintain for PFI hospital sites as compared to traditional ones. We further note that after the COVID-19 pandemic, the average hospital site spending on hard FM and soft FM services slightly increased, while the ratio of PFI to non-PFI hospital site spending did not change.

[11] The "other" category could not be neglected in the computation of the total soft FM service costs. This category includes, for instance telecommunications, residential accommodation, art in hospital, stores services and courier and postal services.

[12] The "other" non-negligible costs include supplier management costs, insurance (except buildings insurance), and cots of compliance services.

[13] This figure reveals a number of outliers. The majority of them correspond to three hospital profiles: general acute hospitals, mental health hospitals and community hospitals.

1.2.3 Controls

Our study employs several control variables to establish causality between public-private partnerships (in the form of PFI) and facility management costs. Table A1 in the Appendix provides summary statistics for all variables in the two panel datasets used in the regressions with different outcome variables: soft FM and hard FM service costs, respectively. The remainder of this section describes the control variables.

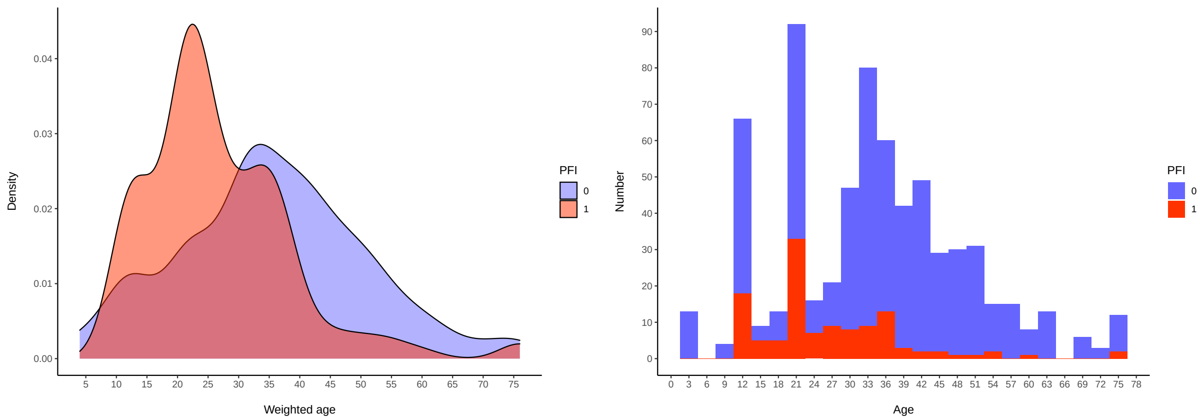
Hospital age is one of the key characteristics, and we expect that the age of hospital sites significantly influences the level of soft FM and hard FM service costs. For instance, older hospitals may require regular maintenance of their buildings. The absence of a hospital site's age variable in the dataset prompts us to create its proxy, a synthetic metric. Specifically, we construct a foundation date weighted by age profile reported in the ERIC dataset, represented by the share of the constructed hospital site per each decade, over the decade's center year. Therefore, the calculated weighted foundation date for each hospital site follows the given formula:

$$\text{Foundation date} = \frac{\sum_{i=1}^{n}(s_i \cdot d_i)}{\sum_{i=1}^{n} s_i}, \tag{1.1}$$

where $i \in \{1, .., 9\}$ represents the index of each decade in the 20th century, d_i is the center year of the i-th decade, s_i is the weight of the i-th decade, i.e. the share of buildings constructed in the i-th decade.[14] We plot the computed foundation date in Fig. B7 in the Appendix. This graph suggests that some buildings belonging to PFI hospital sites were constructed before 1996, that is, the year when the first PFI hospital site was finalized.

Based on the weighted foundation date, we compute the age of each hospital site as a simple difference between the current year in the dataset and the aforementioned foundation date. In Fig. 1.2, we plot the computed weighted age of hospitals for the 2021 subsample. Subfigure 1.2(a) shows the distribution of the weighted age. Two immediate conclusions emerge. First, the PFI hospital sites are systematically younger in age, i.e. PFI hospital sites were built between 1995 and 2005, whereas non-PFI hospital sites were mainly constructed in between 1980 and 1990. Second, both distributions have long tails and that of PFI hospitals is smoother. The bar chart in Figure 1.2(b) suggests that, as of 2021, most PFI hospitals are 21 years old. At the same time, a significant number of non-PFI hospitals are approximately 33 years old.

[14] The hospital sites' foundation date from HOSPREC dataset is a possible alternative. This dataset was developed by the Welcome Library and The National Archives and is no longer maintained since 2012. We do not employ it due to the low rate of successful matches between datasets.



(a) Weighted age distribution (b) Age of sites by PFI procurement form

Figure 1.2: Age of sites, subsample for 2021

The size of a hospital site, measured by its GIA, is expected to have a significant impact on the cost of facility management services. According to a study by Sliteen et al. (2011), 76% of the variance in maintenance costs per square meter can be attributed to the size of the hospital site. Furthermore, Gomez-Chaparro et al. (2020) established that hospital sites with areas exceeding 10,000 m^2 tend to experience reduced per-unit maintenance costs. Sliteen et al. (2011) also identified a significant correlation between the operational costs of utilities, maintenance, and operational maintenance staff and the GIA in square meters. Given these insights, we accounted for differences in size among hospital sites in our analysis. We normalize all the included variables relative to the GIA of each hospital.

The first group of controls we include is labor costs. They account for a significant fraction of the costs associated with soft FM services. Unfortunately, the dataset at our disposal does not contain information related to healthcare staff such as doctors and nurses. Nevertheless, in this study, we account for the employment of auxiliary staff, specifically porters and cleaners. These variables are measured in terms of Whole-Time Equivalent (WTE) units.[15] The cleaning staff comprises both in-house and outsourced workers performing on-site cleaning duties. Meanwhile, the portering staff is responsible for both patient and nonpatient transportation and relocation services, as well as security services. We hypothesize that an increase in auxiliary staff employment positively correlates with the costs of soft FM services.

The clinical space in a hospital includes various areas dedicated to different aspects of

[15]The WTE is calculated by dividing the number of required hours for the role by the standard number of full-time hours (37.5 hours), a traditional method for estimating labor costs (Miguel Cruz & Guarín, 2017).

patient care. These are private patient service areas, spaces directly devoted to the provision of pathology services, and those for sterile clinical procedures, among other patient-related spaces (Department of Health, 2013). However, it is important to note that clinical spaces do not include outdoor or multi-level parking facilities, which are leased or licensed out. The size of clinical spaces in hospitals may significantly impact their costs. Larger clinical areas require more comprehensive maintenance and cleaning routines, thereby elevating expenses related to supplies, equipment, and labor. They also impact utility costs due to increased energy requirements for heating, cooling, and lighting. Additionally, larger spaces may demand more medical equipment and supplies to cater to patients' needs. Moreover, upgrading or renovating these spaces to meet standards or integrating new technologies can further escalate costs. Therefore, we control for the clinical space, which is defined as the share of the hospital's estate floor area that is directly related to patient care. We foresee a positive correlation between the proportion of clinical space and costs of soft FM services. For instance, Gomez-Chaparro et al. (2020) found that hospitals with larger usable floor areas tend to incur higher maintenance costs.

Another important control variable is the number of single bedrooms with en-suite facilities provided for use by patients. These facilities may range from just a WC and washing the hand basin to a more comprehensive setup, including a shower or bath. We postulate that this control variable should positively affect soft FM service costs. This is because an increase in the number of such rooms would likely result in a higher workload for the portering and cleaning staff, more frequent use of laundry services, and increased meal provision demand.

We further aim to directly control the hospital workload. We do so by considering the use of catering and laundry services. We include a control variable for the total annual quantity of inpatient meals ordered from wards and departments. These meals are breakfast, midday, evening meal, or any substitute or alternative for such meals. It is worth noting that this variable not only reflects the hospital's workload but also indicates the intensity of patients' allocation in the hospital.

Another control for workload is the number of laundry and linen pieces per hospital. Items laundered by external organizations or personally by clients and patients are not included in this count. This variable is a proxy for patients' hospital stay duration and should increase with higher hospital capacity. Our dataset allows us to distinguish between the outsourcing of laundry and linen services. We create a corresponding dummy variable that equals unity if an external contractor provides these services, whether under one-time or repetitive contracts. It takes a value of zero if both services are delivered in-house or at another hospital within the same trust.

Energy consumption significantly affects hospital costs because of the continuous nature of their operations. Energy is required for lighting, heating, cooling, and powering diverse equipment. The total electricity consumption is computed using the following summation formula:

$$\text{Tot. electr. cons.} = \text{Electr}_{\text{def. rate}} + \text{Electr}_{\text{green rate}} + \text{Electr}_{\text{loc. renew.}} \tag{1.2}$$

Here $Electr_{def.\ rate}$ and $Electr_{green\ rate}$ denote electricity supplied by national, regional, or local electricity suppliers at the "default" and "green" rates, respectively. The "default" rate pertains to electricity generated from fossil fuels, whereas the "green" rate corresponds to renewable energy sources. $Electr_{loc.renew.}$ is the total annual electricity derived from local renewable sources, excluding those supplied through the national power grid. This category encompasses sources, such as onsite renewable rent-a-roof schemes, community-funded renewable energy projects, and renewable supplies procured through a private wire. The total consumption of other energy is expressed with the following formula:

$$\begin{aligned}\text{Tot. oth. energ. cons.} = \text{Gas} + \text{Oil} + \text{Coal} + \text{Renewable energy} \\ + \text{Hot water} + \text{Steam},\end{aligned} \tag{1.3}$$

where the total consumption of other energy equals to the sum of energy in kilowatt-hours (KWh), stemming from a variety of sources. These include fossil fuels, such as gas, oil, and coal, alongside renewable energy sources, as well as hot water and steam.

Based on the aforementioned calculations, we introduce an energy-specific variable into the regressions. We include the total energy consumption, which is measured in kilowatt-hours per square meter (kWh/m^2). This metric is derived by summing the total electricity consumption, as calculated in equation (1.2), and the aggregated consumption of all other forms of energy, as defined by equation (1.3).

We also introduce a binary variable indicating whether Combined Heat and Power (CHP) units are present within the hospital premises. CHP units serve as additional sources of electricity and energy. Utilising either renewable or non-renewable fuels, these units generate electricity and capture residual heat, transforming it into useful thermal energy (steam or hot water). These are particularly beneficial for facilities that require both electricity and thermal energy.

1.3 OLS and 2SLS estimations

This section presents the results of the empirical analysis. We explain the estimation strategy in section 1.3.1. Most importantly, we detail the use and construction of the instruments and fixed effects. In section 1.3.2, we discuss the results for hard FM costs. The results for soft FM costs are in section 1.3.3. We then disassemble the FM costs into their components and test the impact of the PFI procurement method on each component. The results are reported in section 1.3.4.

1.3.1 Estimation strategy

We begin the empirical analysis with a series of simple OLS estimations to explore the causal relationship between a hospital site's procurement form and the variation in costs related to hard and soft FM services. An empirical OLS specification in general form looks as following:

$$log(Costs_{ht}) = \alpha_0 + \alpha_1 PFI_h + A'_{ht}\gamma + FE_{hti} + \epsilon_{ht}, \tag{1.4}$$

where the dependent variable $\log(Costs_{ht})$ corresponds to either hard or soft FM service costs. The panel data consists of H hospital sites ($h = \{0, 1, 2, ..., H\}$) observed over period t, ranging from 2018 to 2021. The key variable of interest is the dummy variable PFI_h which captures the hospital site's procurement form.[16] Vector A_{ht} includes a range of site-specific controls. For a comprehensive review of these variables, refer to the detailed discussion in section 1.2.3 prior to this. Finally, we augment the estimations with three interchangeable sets of fixed effects (FE_{hti}, where $i = \{s, p, r\}$) to capture time-varying unobservable factors that are specific to the UK regions, foundation trust and site profiles.[17]

The first set of fixed effects is $FE_{\text{site profile}} \times FE_{\text{year}}$, which adjusts for time-varying unobservable factors that remain consistent across all hospital sites within a specific profile.[18] For instance, we can consider patient volume, infection control, safety measures, workplace

[16] After the expiration of PFI contracts, the hospital sites are returned to the authority. However, during the observable dataset period, only five instances of the PFI dummy variable were changed from one to zero. Due to this limited occurrence, we remove these cases, ensuring that our variable of interest remains invariant over time.

[17] We can't control for the site fixed-effect due to invariability of our endogenous variable over time.

[18] Detailed definition of hospital site profiles in in the Appendix A1.

strategies and technology innovations as changes uniquely associated with sites of a certain profile.

The second fixed effect is $FE_{\text{region}} \times FE_{\text{year}}$. It captures location-specific unobservables that vary over time. Derived from the hospital site location postcodes, these regional dummy variables align each site with one of the nine greater regions within England.[19] As a result, we are able to control region-specific economic and administrative shifts. These may include decisions by regional authorities to modify budget allocation within a specific region.

The third set of fixed effects is $FE_{\text{trust}} \times FE_{\text{region}} + FE_{\text{year}}$. This fixed effect allows us to control for the possible dynamic factors inherent to facilities within sites affiliated with the same foundation trust and allocated to similar regions, where time variation is captured separately.[20] Foundation trusts, like other healthcare providers, receive funding from the NHS, and they participate in discussions and negotiations about resource allocation at the Strategic Integrated Economy System (SIES) level. As a decision-maker, trust policy directly impacts its functioning, that is, a combination of centralized decision-making and site-based management. Hence, it is crucial to isolate its impact on FM services to accurately measure the effect of a site's procurement form on FM service costs. Introducing an additional year-specific fixed effect also allows us to control for time-specific factors such as macroeconomic trends, changes in healthcare policies, technological advancements, or other time-specific effects that may be common to all sites within a given year. This control is necessary to ensure that any observed changes in FM service costs are not solely influenced by external factors that affect all sites uniformly. It should be noted that a fraction of macroeconomic shocks are partially captured by the temporal aspect present in all sets of fixed effects.

We continue the empirical analysis by addressing potential endogeneity issues caused by omitted variables. Endogeneity problem might be due to the fact that uncaptured various management practices, a certain level of technological adoption depending on the share of funds allocation on research and development, or the quality control measures employed in

[19]The choice of regions is driven by their role in the decision-making process of the government. In particular, each greater region is ruled by Combined Authorities, Regional Assemblies (es RRB-, or similar bodies. At the greater regional level, each of them decides to make decisions on various matters that affect the region as a whole, such as economic development, transportation, health, and social care. We assume that the choice of seven NHS regions or forty two regions according to integrated care systems in England would not be able to catch properly region-specific characteristics.

[20]It is important to note that some foundation trusts may have sites in different regions. For example, the Oxleas NHS Foundation Trust has sites in both London (Queen Mary's Hospital and Memorial Hospital) and the South East region (Bracton cente), all of which fall under the London commissioning region. Our dataset includes fifteen trusts of this kind.

the production process impact both endogenous PFI variable and outcome variable.

We use three instruments. We select LIBOR as our first instrumental variable, based on the financing mechanism used in PFI projects. An SPV company is uniquely created to execute a project when the government chooses a PFI contract to deliver public services. The SPV, established by a private sector consortium, raises capital through a combination of equity and debt financing, with banks providing around 90% of funding as senior debt and around 10% from equity investors (NAO, 2012a).

The interest rate in the market directly affects the cost of bank debt allocated to the SPV for building a public project. The 2008-2009 financial crisis resulted in shifts in market conditions, reduced credit availability, and changes in the regulatory frameworks for PFIs (Demirag et al., 2015). This led to a decline in the number of lenders participating in PFI projects (Vazquez & Federico, 2015). Moreover, PFIs have undergone significant revisions in their regulatory frameworks (Ang & Marchal, 2013).

To capture the impact of market conditions on loan accessibility for SPVs, we use the LIBOR rate as an indicator of companies' participation in bidding processes and the government's choice of procurement form for sites. If the LIBOR rate during PFI contract bidding fails to meet private sector lending requirements, the likelihood of procuring the public contract through the PFI diminishes. We also believe that the LIBOR rate plays a significant role in shaping hard FM service costs through variations in the construction material prices in the market.

Another instrumental variable is the public sector net debt (percentage of GDP). The choice of the second instrument is driven by the PFI finance debt off-balance sheet accounting.[21] Following NAO (2018), we hypothesize that the UK government was more inclined to use PFI when the public sector net debt was higher. The rationale behind this assumption is that by employing the PFI, the government could potentially reduce the apparent debt burden by allocating certain expenses off the balance sheet, which might have appeared as traditional public debt if financed through conventional means (NAO, 2018). This approach allowed the government to present a more favorable fiscal outlook and maintain the debt-to-GDP ratio.

Using constituency voting as an instrumental variable, we propose that the winning party

[21] NAO (2018) discloses that "Most PFI debt is scored as off-balance sheet under the European system of accounts (ESA), which determines government debt levels. However, under the International Financial Reporting Standards (IFRS), used to produce departmental financial accounts and the Whole of Government Accounts, most PFI debt is on-balance sheet".

in the constituency influences the choice of hospital procurement method.[22] Specifically, a victory for the Conservative Party would likely lean towards the traditional procurement of hospital sites, while success for the Labour or Liberal Party would favor PFI procurement. Every five years, elections to parliament occur within 175 constituencies and are then run at the national level. The three leading parties competing during these elections are conservative party, labour party and liberal democrats. We construct a categorical variable from voting per constituency in each election and match this IV to the main dataset using postcodes because each hospital is located within a specific constituency. The winning party's impact on the PFI procurement type is through its influence on the board of directors' decisions, rather than directly impacting soft and hard FM service costs. In constituencies where the winning party leans more "pro-right," there is a higher chance of choosing "non-PFI" procurement type. Conversely, if it leans more "pro-left," there is a greater chance of choosing "PFI" procurement type. Using this idea, we follow the findings of Pollock et al. (2002).

We compute instrumental variables by taking a weighted average of LIBOR, public net debt, or voting per constituency based on the hospital site's procurement decision date across its age profile. Specifically, we employ the following formula to compute the instrumental variables:

$$Z_h = \sum_{i=1}^{n} K_{hi} \cdot Z_{D_{hij}}, \tag{1.5}$$

where i represents the decision date categorized into ten-year periods ($i = 1, \ldots, n$ with $n = 9$). K_{hi} denotes the proportion of new construction or renovation for the site within each ten-year period with $\sum_{K_{hi}} = 1$. Z_i refers to the average LIBOR rate for a specific age profile period i. The LIBOR or public sector net debt rate is taken on the decision date $D_{hij} = M_i - C_{hij}$, which we treat as the site's procurement choice date by the government. This date for each decade is computed by deducting the average number of construction years for each hospital, C_{hij}, depending on its site profile j from the mean year of each i-th decade, M_i.[23]

To eliminate the omitted variable bias, we proceed with the system of equations below that illustrates the first and second stages of the Two-Stage Least Squares (2SLS) estimation procedure:

[22] Voting per constituency data we use from the Cracknell et al. (2023).

[23] j refers to eight profiles mentioned in Section 1.2.

First stage:

$$PFI_{ht} = \beta_0 + \beta_1 L_h + \beta_2 D_h + A'_{ht}\delta + FE_{hti} + \eta_{ht}. \quad (1.6)$$

Second stage:

$$\log(Costs_{ht}) = \phi_0 + \phi_1 PFI_h + A'_{ht}\psi + FE_{hti} + \zeta_{ht}. \quad (1.7)$$

In these equations, the first instrumental variable, the weighted LIBOR rate, is denoted as L_h, the second instrumental variable, net government debt as a percentage of GDP ratio, is defined as D_h, while the third instrumental variable, voting per constituency, is defined as C_h. In our panel dataset, the instruments do not vary over time for the same hospital site. We assume that higher government net debt-to-GDP ratios and higher LIBOR rates could have been contributing factors that inclined the UK government to opt for PFI projects as a means to manage apparent debt levels and capitalize on potential cost savings during certain periods. In addition, the winning party in the constituency where the hospital is located could have an impact on the Board of Directors of foundation trusts, who play a crucial role in decision-making regarding the procurement of the hospital site.

In the first stage (eq. 1.6), we estimate the relationship between the instruments and hospital's procurement form. The estimated PFI_{ht} is then used in the second-stage equation (eq. 1.7) to examine the impact of the procurement form on the logarithm of costs. The equations also include other control variables, denoted as A'_{ht} and fixed effects, FE_{hti}.

1.3.2 Results for hard FM service costs

We begin the empirical analysis by estimating the impact of hospital site procurement form (PFI or non-PFI) on hard FM service costs per square metre. The corresponding results are presented in Table 1.1. We run OLS and 2SLS estimations across specifications, with different fixed effects. The columns (1) - (3) report estimates with $site\ profile \times year$ fixed effect, whereas (4) - (6) with $region \times year$ fixed effect, and finally (7)–(9) include the most comprehensive set of fixed effects: $trust \times region + year$.

In line with the descriptive statistics, the OLS results in columns (1), (4), and (7) suggest that PFI hospital sites have higher hard FM service costs than non-PFI sites.[24] The

[24]Detailed specifications with progressively added control variables can be found in Table C3 and Table C4 in the Appendix. Our findings indicate that the estimated effect of PFI diminishes as more confounding factors are incorporated into the analysis.

corresponding statistically significant effect ranges between 12.5% and 16.3% depending on the included set of fixed effects.

The results of the second-stage instrumental variable (IV) estimations are reported in columns (3), (6), and (9). The corresponding first-stage estimations yield Cragg-Donald and Kleibergen-Paap F statistics, which reject the weak identification of the instrumental variables. In the specification with trust fixed effects, the coefficient of PFI is estimated to be 37.1%, while additionally controlling for the LIBOR and public net debt (column (9) in Table 1.1), and 18.4%, while controlling for constituency voting (column (6) in Table C1 in the Appendix).[25] Both results are weakly statistically significant at the 10% significance level. We assume that such a drastic difference in the coefficients estimate is driven by the importance of the constituency winning party at the decision-making process at trust level, that's why significance is kept in the regression where trust fixed effect is controlled.

The results for control variables represent a certain interest from the point of view of the organization of hospital management. First of all, we note that across all tested specifications, all control variables except hospital's age have a statistically significant impact on hard FM service costs.

We find that the size of hospital, as proxied by the share of clinical space and number of single bedrooms for patients with en-suite facilities, positively impacts hard FM costs. This result is consistent with previous theoretical and empirical findings (Franco et al., 2017; Van de Glind et al., 2007). The corresponding effects are estimated to be around 0.2%.

Energy consumption is expected to significantly affect hard FM costs in hospitals. This is largely due to the maintenance and potential upgrades required for the infrastructure, such as heating, ventilation, and air conditioning (HVAC) systems, lighting, and medical equipment, which consume substantial amounts of energy. Indeed, the healthcare sector in the UK ranks among the largest energy consumers. As energy usage rises, maintenance costs escalate owing to increased wear and tear, and the need for more energy-efficient systems may arise, necessitating significant upfront investments. Although these upgrades can potentially reduce long-term costs, they contribute to initial expenses.

[25]The difference in the number of observations is due to a mismatch in the observations. Specifically, the old postcodes were terminated or renamed within each constituency. Thus, it was not possible to completely match our dataset with one that includes voting per constituency.

Table 1.1: Impact of hospital site's procurement form on hard FM costs

	log hard FM costs (GBP/m^2)								
	OLS	2SLS		OLS	2SLS		OLS	2SLS	
		First stage	Second stage		First stage	Second stage		First stage	Second stage
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PFI (1/0)	0.125***		0.099	0.163***		0.048	0.134***		0.371*
	(0.017)		(0.076)	(0.017)		(0.088)	(0.020)		(0.191)
LIBOR (%)		−0.053***			−0.037***			−0.027***	
		(0.004)			(0.004)			(0.003)	
Public sector net debt (% of GDP)		−0.004***			−0.003***			−0.002***	
		(0.000)			(0.000)			(0.000)	
log Age	0.011	0.034*	0.007	0.012	0.012	-0.004	−0.001	0.009	0.022
	(0.011)	(0.019)	(0.009)	(0.011)	(0.019)	(0.018)	(0.011)	(0.017)	(0.027)
Clinical space (%)	0.002***	−0.001*	0.002***	0.001*	−0.002***	0.001	0.001***	−0.001***	0.002**
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
log Single bedrooms (Nb/m^2)	0.002***	−0.000	0.002***	0.003***	0.002**	0.004***	0.003***	0.002***	0.002*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
log Total energy cons. (kWh/m^2)	0.235***	0.044***	0.237***	0.290***	0.087***	0.301***	0.232***	0.022*	0.226***
	(0.014)	(0.015)	(0.019)	(0.013)	(0.014)	(0.031)	(0.013)	(0.013)	(0.035)
Usage of CHP units (1/0)	−0.102***	−0.108***	-0.106***	0.023	−0.005	0.021	−0.009	−0.011	−0.004
	(0.019)	(0.020)	(0.018)	(0.017)	(0.019)	(0.017)	(0.022)	(0.021)	(0.027)
Cragg-Donald F stat		94.5			56.5			41.5	
Kleibergen-Paap rk Wald F stat		14.6			34.6			6.4	
Site profile x year FE	✓	✓	✓						
Region x year FE				✓	✓	✓			
Trust x region FE							✓	✓	✓
Year FE							✓	✓	✓
Observations	2 911	2 911	2 911	2 911	2 911	2 911	2 911	2 911	2 911

Notes: This table reports ordinary least squares (OLS) and two-stage least squares (2SLS) estimates of the effect of hospital procurement form on log soft FM service costs normalized to its GIA. Columns (1) - (3) specifications include $site\ profile \times year$ fixed effect, columns (4) - (6) specifications correspond to $region \times year$ fixed effect, while columns (7) - (9) specifications introduce by $trust \times region + year$ fixed effect. Columns (1), (4) and (7) show coefficients from OLS regressions of log soft FM service costs on sites' procurement form. Columns (2), (3), (5), (6), (8) and (9) display coefficients from two-stage least squares models instrumenting sites' procurement form with the UK bank rate, LIBOR, and Public Sector Net Debt (PSND) as a percent of GDP. Columns (2), (5) and (8) show first-stage specifications. Columns (3), (6) and (9) display the second stage excluding the instrument. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

Moreover, utility costs, which constitute a significant portion of hospital operating expenses, tend to escalate in tandem with energy consumption. Compliance with energy efficiency and environmental regulations can further impact costs by mandating changes or modifications to the existing infrastructure. Additionally, the implementation and maintenance of mandatory backup power systems, which are vital for ensuring uninterrupted care during power outages, add to the FM costs.

In this study, we have taken into account two crucial energy-related variables: total energy consumption and usage of CHP Units. Our empirical analysis reveals that total energy consumption has a robust and statistically significant impact on hard FM costs. The estimated effect size falls within the range of 23.2%–29%, indicating that the energy factor plays a substantial role in determining hospital costs.

The usage of CHP units is expected to have a negative impact on hospitals' hard FM costs. Bhandari et al. (2018) documented that they play a significant role in lowering operating costs and enhancing the reliability of uninterrupted services in healthcare facilities. For instance, Organic Rankine Cycle (ORC) - based biomass-fueled CHP systems offer excellent controllability, high automation levels, and low maintenance costs, thereby resulting in reduced operating expenses (Dong et al., 2009). Our 2SLS results suggest that a hospital site using a CHP unit face has a 10.6% lower hard FM costs.

The Appendix tables provide evidence of how hard FM service costs are influenced by various regressors. Table C3 and Table C4 display the estimates of introducing regressors sequentially into the model. Table C5 and Table C6 show the results of adding each regressor individually into the model, where we employ GIA as a regressor rather than dividing the outcome variables by the GIA, thus controlling for the hidden effect of the economy of scale. Indeed, the GIA has significant explanatory power for hard FM service costs (column (2) in Table C5 and Table C6).

1.3.3 Results for soft FM service costs

We continue the empirical analysis by estimating the impact of PFI status on soft FM costs. The main results are presented in Table 1.2. The structure of this table is similar to that in Table 1.1. According to the OLS results in columns (1), (4), and (7), a hospital site built under PFI procurement has 4.2% to 7.2% higher soft FM costs.[26] The second-stage 2SLS estimations are statistically significant for all the fixed effects. The corresponding magnitudes were higher, up to 11.1% – 20.3%. An additional control for the voting per constituency IV in Table C2 in the Appendix supports our results. The values of Cragg and Donald (1993) and Kleibergen and Paap (2006) rk Wald F statistics reported in columns (2), (5) and (8) allow us to reject the hypothesis of joint instrument weakness.

Our analysis reveals several empirical patterns regarding the influence of specific aspects of hospital site operations on soft FM costs. We account for labor employment, which is an important factor influencing soft FM costs. Since the employment of medical staff is not included in our dataset, we control for auxiliary labor. The results suggest that an increase in the use of cleaning labor by 1% augments soft FM costs by 2.1% - 4%, depending on the specification. The impact of portering staff is moderate, with a coefficient of 0.2%. Note that, in our data, the average employment of porter staff is seven times lower than that of cleaners (see Table A1 in the Appendix). Furthermore, small hospitals prefer not to recruit porters or delegate their responsibilities to cleaners or medical workers.

[26]Detailed specifications with progressively added control variables can be found in Table C7 and Table C8 in the Appendix. Our findings indicate that the estimated effect of PFI diminishes as more confounding factors are incorporated into the analysis.

Table 1.2: Impact of hospital site's procurement form on soft FM costs

	log soft FM cost (GBP/m^2)								
	OLS	2SLS		OLS	2SLS		OLS	2SLS	
		First stage	Second stage		First stage	Second stage		First stage	Second stage
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PFI (1/0)	0.042**		0.170***	0.054***		0.111*	0.072***		0.203*
	(0.017)		(0.053)	(0.016)		(0.040)	(0.019)		(0.120)
LIBOR (%)		−0.056***			−0.038***			−0.032***	
		(0.004)			(0.004)			(0.003)	
Public sector net debt (% of GDP)		−0.004***			−0.004***			−0.003***	
		(0.000)			(0.000)			(0.000)	
log Age	0.010	0.052***	0.030**	−0.008	0.023	-0.001	−0.008	0.034**	0.006
	(0.011)	(0.019)	(0.012)	(0.011)	(0.019)	(0.008)	(0.011)	(0.017)	(0.020)
Inpatient main meals requested (Nb/m^2)	0.030***	0.001	0.030***	0.028***	−0.005***	0.029***	0.031***	−0.003**	0.031***
	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.003)
Laundered pieces per annum (Nb/m^2)	0.008***	0.001	0.008***	0.008***	0.003***	0.008***	0.008***	0.002***	0.008***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Outsourced laundry and linen services (1/0)	0.103***	0.048**	0.097**	0.057**	0.017	0.053	0.010	0.004	0.009
	(0.023)	(0.024)	(0.037)	(0.023)	(0.025)	(0.031)	(0.034)	(0.034)	(0.049)
log Cleaning staff (WTE/m^2)	0.021***	−0.013***	0.022**	0.032***	−0.018***	0.033***	0.039***	−0.006	0.040***
	(0.003)	(0.004)	(0.009)	(0.003)	(0.004)	(0.005)	(0.004)	(0.004)	(0.008)
log Portering staff (WTE/m^2)	0.014***	−0.004	0.014***	0.020***	0.007**	0.020**	0.020***	0.007**	0.019***
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.006)
Cragg-Donald F stat		102.6			61.5			56.9	
Kleibergen-Paap rk Wald F stat		24.5			141.1			12.5	
Site profile x year FE	✓	✓	✓						
Region x year FE				✓	✓	✓			
Trust x region FE							✓	✓	✓
Year FE							✓	✓	✓
Observations	2 903	2 903	2 903	2 903	2 903	2 903	2 903	2 903	2 903

Notes: This table reports ordinary least squares (OLS) and two-stage least squares (2SLS) estimates of the effect of site procurement form on log soft FM service costs normalized to its GIA. Columns (1) - (3) specifications include $site\ profile \times year$ fixed effect, columns (4) - (6) specifications correspond to $region\ \times year$ fixed effect, while columns (7) - (9) specifications introduce by $trust\ \times region + year$ fixed effect. Columns (1), (4) and (7) show coefficients from OLS regressions of log soft FM service costs on sites' procurement form. Columns (2), (3), (5), (6), (8) and (9) display coefficients from two-stage least squares models instrumenting sites' procurement form with the UK bank rate, LIBOR, and Public Sector Net Debt (PSND) as a percent of GDP. Columns (2), (5) and (8) show first-stage specifications. Columns (3), (6) and (9) display the second stage excluding the instrument. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

The results in column (1) of Table 1.2 suggest that the site's soft FM costs increase by 0.8% and 0.3% for each additional laundered piece and requested meal, respectively. We note that this effect is consistent across specifications with alternative fixed effects, and is very similar in the 2SLS estimations. These variables are proxies for patient volume, that is, the number of patients that a hospital site serves within a given period. Therefore, according to our estimations, management costs increase with larger number of patients. This result might be crucial for understanding the costs during periods of higher demand, such as during the COVID-19 pandemic.

In our sample, approximately 80% of hospital sites, regardless of their procurement form, opt to outsource laundry and linen services (refer to Fig. 1.3). A survey conducted by Moschuris and Kondylis (2006) focusing on Greek hospitals reveals that the decision to outsource these services primarily arises from factors such as personnel shortages, the

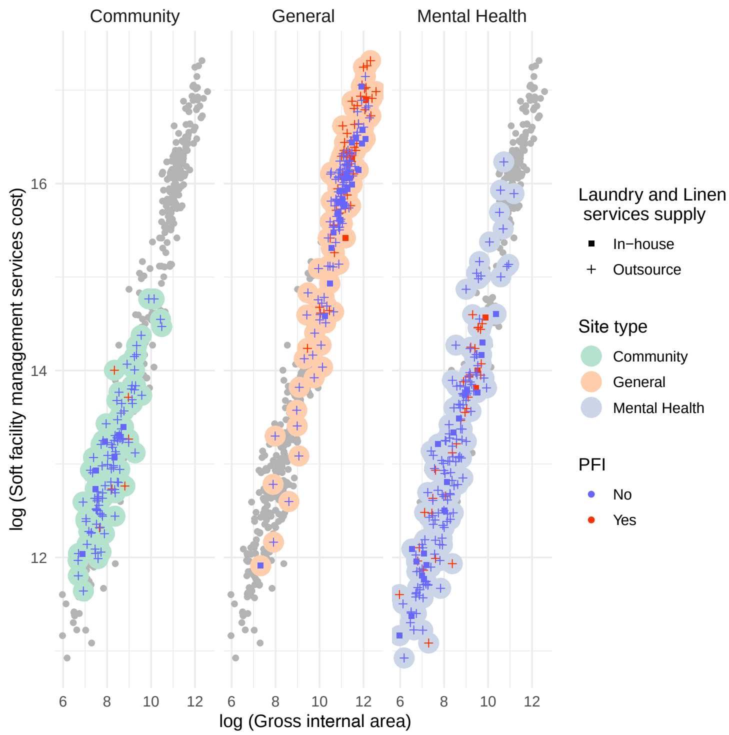


Figure 1.3: Laundry and linen outsourcing across sites' profiles

need for flexibility, and enhancing customer satisfaction, rather than being primarily driven by cost savings. Our estimations demonstrate that this outsourcing practice is likely to increase soft facility management costs. These outcomes are statistically significant within the specifications, including $site\ profile \times year$ fixed effect (ranging from 9.7% to 10.3%) and $region \times year$ fixed effect (5.7%).

However, the literature provides mixed evidence. Ciarapica et al. (2008) demonstrate that smaller hospitals experience higher costs when employing outsourced personnel compared to internal staff. Conversely, for larger hospitals, outsourcing services prove to be more cost-efficient because of the transfer of risk associated with complexity. Shohet (2003), on the other hand, advocates that the effectiveness of maintenance outsourcing depends on the hospital's occupancy level. Hospitals with high occupancy rates face accelerated facility deterioration, which necessitates the use of available in-house resources for corrective maintenance. Conversely, in cases of lower occupancy rates, outsourcing could yield enhanced cost efficiency by delegating non-core facilities management activities to an external workforce.

In Tables C9 and C10 in the Appendix, we demonstrate the individual effects of each regressor on the soft FM costs. Notably, instead of normalizing each regressor using GIA, we include it as a control in these estimations. Given the substantial joint explanatory power (as measured by R^2) ranging from 0.673 to 0.789 when including the GIA and each of the other controls, it becomes evident that floor areas play a significant role in explaining the variance in soft FM costs.

1.3.4 Results for subcategories of costs

In this section of our study, we endeavor to identify distinct subgroups of hard and soft FM service costs that are statistically significantly impacted by the hospital site's procurement form. Thus, we aim to gain insights into potential cost-saving opportunities for facilities management.

Table 1.3 reports estimated impact of PFI procurement method on hard FM costs (columns 1-3) and soft FM costs (columns 4-6). The costs elements are listed in descending order based on their relative contributions to the total. Our results highlight that the estates and property maintenance costs of PFI-procured hospital sites are statistically significantly higher. The coefficients are 8.8% and 11.5%, respectively, while controlling for $site\ profile \times year$ and $region \times year$. Furthermore, when considering the fixed effects of $region \times year$ and $trust \times region + year$, PFI hospital sites experience higher costs in categories such as energy, electro-biomedical equipment servicing, waste disposal, water and sewerage, as well as car parking. This trend is particularly pronounced for electro-biomedical equipment and car parking costs, with variances ranging from 27.6% to 49.2% and from 21.7% to 26.8%, respectively, depending on the specific set of fixed effects included in the analysis. In contrast, PFI sites demonstrate lower management costs, with effect ranging from 36.2% to 47%. This result aligns with the cost-reduction potential of bundling services under PFI procurement.

Among the components of soft FM costs, cleaning expenses account for the largest share (33 %). However, our findings do not reveal statistically significant differences in cleaning costs between PFI and non-PFI sites. Instead, the major variation in soft FM costs across sites of distinct procurement forms primarily arises from laundry and linen service costs, ranging from 18.3% to 23.4%, contingent on the specific set of fixed effects. Moreover, we find an analogous pattern as observed previously in hard FM costs, wherein the "management" component of soft FM costs is statistically significantly lower for PFI sites. Finally, other soft FM costs are higher for PFI sites (ranging from 12.7% to 33.5%). However, the identification of specific sources of cost savings poses challenges, as the "other" component comprises the various factors mentioned in Section 1.2.2.

Table 1.3: Results for the components of facility management costs

Hard FM costs	(1)	(2)	(3)	Soft FM costs	(4)	(5)	(6)
Estates and property maintenance (36%)	0.088**	0.115***	0.010	Cleaning service (33%)	0.011	−0.013	−0.009
Energy (28%)	0.041**	0.068***	0.045*	Other soft FM services (25%)	0.127*	0.335***	0.223***
Electro bio medical equipment (17%)	0.084	0.492***	0.276***	Inpatient food service (21%)	0.048*	−0.012	0.053*
Waste (5%)	0.018	0.094***	0.117***	Portering service (11%)	0.037	0.057	0.103**
Water and sewerage (4%)	−0.040	−0.029	−0.029	Laundry and linen service (7%)	0.183***	0.234***	0.187***
Car parking (3%)	0.007	0.268***	0.217**	Management (3%)	−0.446***	−0.396***	−0.312***
Management (3%)	−0.470***	−0.408***	−0.362***				
Other hard FM services (3%)	0.295***	0.144	−0.057				
Grounds and gardens maintenance (1%)	0.216***	0.068	−0.048				
Site profile × year FE	✓				✓		
UK region × year FE		✓				✓	
Trust × region + year FE			✓				✓

Notes: Each variable in the table represents a specific subgroup of costs within the hard FM or soft FM services. To ensure consistency and comparability, the costs are presented as logarithmic values in GBP, which have been normalized to the respective site's GIA. We take ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. The calculation of hard FM and soft FM management shares is limited to a three-year period, specifically from 2019 to 2021. This constraint arises from the fact that the costs associated with these services were distributed among other components in the overall hard FM and soft FM service costs during the year 2018.

1.4 Propensity score matching and Hausman–Taylor estimations

The assignment of PFI financing might be endogenous, as it might be influenced by factors internal to hospitals. To address the issue of non-random selection, we utilize a combination of Propensity Score Matching (PSM) techniques and an Ordinary Least Squares (OLS) estimator with fixed effects. PSM is a non-parametric method widely used in the evaluation and experimental literature and has been adopted in observational studies in economics and management (Imbens, 2015; M. Li, 2013). The method relies on pairwise comparisons between treated and untreated individuals or entities that are very similar in their pre-treatment observable characteristics. After matching, the only difference between the treated and untreated samples lies in their treatment status (Caliendo & Kopeinig, 2008).

We closely follow the approach of Hijzen et al. (2011). In the first step, we estimate the propensity scores, denoted by $Score_{ht}$, using a logit estimator as follows:

$$Score_{ht} = e(X_{ht}) = \frac{1}{1 + \exp(-\alpha - \beta X_{ht})} \tag{1.8}$$

where α and β represent the estimated parameters and X_{ht} refers to the vector of observed covariates for hospital h in year t. This includes the most crucial factors determining the assignment of PFI: site age and GIA. We iterate this estimation separately for each year. $Score_{ht}$ stands for the estimated at the first step PSM score and represents the propensity of the hospital to receive treatment.

In the second step, we utilize these scores to pair up the sites. To accomplish this, we employ the widely used nearest-neighbor matching algorithm commonly used in PSM-based studies (Austin, 2014). The matching process is conducted without replacement, which means that each treated observation (PFI) can only be associated with one hospital site in the control group (non-PFI). Therefore, our aim is to match sites that exhibit similarities in their pre-treatment observable characteristics but have been assigned different PFI statuses. We further refine the sample by selecting only the comparable dyads. Once we have this subsample, we proceed with the OLS estimation of equation (1.4).

Moreover, as an alternative technique to address the endogeneity issue arising from the presence of unobserved (or omitted) variables, we utilize Hausman-Taylor (HT) transformation. We prefer the HT transformation over the Generalized Method of Moments (GMM) due to the invariability of endogenous variable over time. Following Hausman and Taylor (1981), we transform eq. (1.4) to distinguish three sets of variables: time-varying exogenous ($X_{ht} = A_{ht}$), time-invariant exogenous ($Z_{1h} = \{L_h, D_h\}$), and time-invariant endogenous ($Z_{2h} = PFI_h$) variables.[27] We proceed to estimate:

$$\log(Costs_{ht}) = X'_{ht}\beta + Z_{1h}\gamma_1 + Z_{2h}\gamma_2 + \mu_h + \epsilon_{ht}. \tag{1.9}$$

First, to perform the "within" transformation, we remove Z_{1h} and Z_{2h}, obtaining the "within" estimator and "within" the residual. From this residual, we compute idiosyncratic error term $\hat{\sigma}^2_\epsilon$. Subsequently, we regress "within" residual on Z_{1h} and Z_{2h} using X and Z_{1h} as instruments to obtain consistent estimates of γ_1 and γ_2. These estimates, along with $\hat{\sigma}^2_\epsilon$, allow us to obtain $\hat{\sigma}^2_\mu$. Finally, we perform a random effects transformation for each variable, leading to the final HT estimator.

[27] Our model does not include time-varying endogenous variables. Exogenous and endogenous variables refer to their correlation with μ_h, not with ϵ_{ht}.

Table 1.4: Matching methods and Taylor

	log hard FM costs			log soft FM costs		
	PSM no caliper (1)	PSM caliper = 0.1 (2)	Hausman - Taylor (3)	PSM no caliper (4)	PSM caliper = 0.1 (5)	Hausman - Taylor (6)
PFI	0.132*** (0.021)	0.148*** (0.028)	0.287** (0.004)	0.015 (0.015)	0.000 (0.013)	0.368*** (0.000)
Other controls	✓	✓	✓	✓	✓	✓
Site profile x year FE	✓	✓	✓	✓	✓	✓
Observations	1 019	652	2 911	1 009	650	2 903
Adjusted R^2	0.304	0.291	0.063	0.560	0.530	0.137

Notes: This table reports Propensity Score Matching (PSM) estimates without caliper (columns (1) and (4), for hard FM and soft FM costs respectively) and with 0.1 caliper (columns (2) and (5), for hard FM and soft FM costs respectively). Columns (3) and (6) show estimates of the Taylor regression model, for hard FM and soft FM costs respectively. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

Our findings are presented in Table 1.4. The results concerning hard FM costs (columns 1-3) are statistically significant across PSM subsamples as well as Hausman-Taylor estimations. It is worth noting that the estimates for PSM without a caliper (13.2%) are consistent with the OLS results from the full sample (12.7% in Table 1.1, column 1). By contrast, the coefficient for the more restricted sample (with a caliper) is higher (14.8%). The Hausman-Taylor coefficient of 28.7% surpasses OLS estimates, indicating the presence of endogeneity. Concerning the impact of PFI on soft FM costs, the OLS results on PSM-matched samples are not significant, whereas the coefficient for the Hausman-Taylor estimate is strongly significant at the 1% interval. Therefore, we conclude that OLS estimates for soft FM costs are likely to be biased.

1.5 Interpretations

In this section, we delve into the interpretation and explanation of the findings presented in the previous section. We specifically focus on the properties of hard FM costs. Further robustness checks could be found in the Appendix D.

1.5.1 Heterogeneity of PFI contracts

In this subsection, we complement the principal analysis by differentiating PFI contracts. We explicitly employ the ownership dimension of hospital sites. There are nine possible types of tenure. Two of them are related to PFI procurement form: "full PFI" and "part PFI". The former one alludes to the case where the whole site is under the PFI procurement, such as the Queen Alexandra site (Portsmouth Hospitals University NHS Trust, 2019). The "part PFI" tenure applies to a hospital site where only its fraction is supplied under PFI contract. For example, the Wycombe General Hospital site's estate has a total GIA of 55 367 m^2, of which only 11 992 m^2 is within the PFI buildings (Buckinghamshire Healthcare NHS Trust,

Table 1.5: Heterogeneity of PFI projects

	log hard FM costs			log soft FM costs		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: PFI share of total						
PFI_{full} (1/0)	0.109***	0.129***	0.142***	0.052**	0.068***	0.099***
	(0.024)	(0.023)	(0.026)	(0.024)	(0.023)	(0.026)
PFI_{part} (1/0)	0.140***	0.191***	0.127***	0.034	0.043**	0.049**
	(0.022)	(0.021)	(0.024)	(0.023)	(0.021)	(0.025)
Adjusted R^2	0.266	0.278	0.476	0.312	0.356	0.508
Panel B: PFI time dimension						
PFI_{old} (1/0)	0.201***	0.354***	0.336***	0.094	0.122**	0.195***
	(0.056)	(0.056)	(0.069)	(0.060)	(0.058)	(0.073)
PFI_{new} (1/0)	0.225***	0.228***	0.183***	0.084**	0.065*	0.036
	(0.034)	(0.034)	(0.038)	(0.037)	(0.036)	(0.040)
Adjusted R^2	0.253	0.264	0.477	0.293	0.341	0.507
Site profile x year FE	✓			✓		
UK region x year FE		✓			✓	
Trust x region + year FE			✓			✓

Notes: This table reports ordinary least squares (OLS) estimates of the effect of hospital sites' procurement form on log hard FM service costs, columns (1) - (3), and log soft FM service costs, columns (4) - (6), normalized to its GIA. Columns (1) and (4) specifications correspond to $site\ profile \times year$ fixed effect, columns (2) and (5) specifications correspond to $region \times year$ fixed effect, while columns (3) and (6) specifications correspond to $trust \times region + year$ fixed effect. Columns specifications include PFIs grouped according to their tenure, fully or party build through PFI procurement form, PFI_{full} or PFI_{part} respectively. Another PFI grouping corresponds to the presense of buildings under the site built before PFI contract financial closure. Particularly, PFI_{old} variables refer to PFI hospital sites that owned buildings before the PFI contract financial closure, while PFI_{new} variables refer to PFI hospital sites that had no constructions before the PFI contract financial closure. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

2022). In our dataset, approximately 55% of the PFI sites have full tenure, whereas the remaining 45% have partial tenure. Consequently, we introduce two categorical dummy variables, PFI_{full} and PFI_{part}, in place of a single PFI dummy. Meanwhile, we maintain the benchmark group of non-PFI hospital sites.

We note that the assignment of tenure is independent of whether a site was constructed from the ground up or if the PFI project arose from the integration and renovation of previously established hospitals, as in the case of the Queen Alexandra hospital site. This observation prompts us to distinguish PFIs based on the presence of hospital structures before the financial closure date of the PFI contract.

Therefore, we introduce two categorical dummy variables, PFI_{old} and PFI_{new}. Specifically, the PFI_{old} dummy variable takes the value of one when the age profile of a hospital site indicates construction activities in the decades leading up to the financial closure date of the PFI contract. On the other hand, the PFI_{new} variable is set to one when constructions occur during or after the decade in which the financial closure of the PFI project is concluded.[28]

Panel A of Table 1.5 reports the estimation results, differentiating PFI contracts with respect to their tenure. Overall, these results align with the key findings presented in Table 1.1 and Table 1.2. We further conclude that the impact of PFI_{part} on hard FM costs (columns 1 – 3) is typically larger (12.7% – 19.1%) than that of PFI_{full} (10.9% – 14.2%). This might be attributed to the higher coordination costs arising from the need to coordinate activities and management of hospital sites under PFI and the leftovers of a hospital. A similar pattern we observe for the soft FM service costs.

Panel B reports estimates for the time dimension of the PFI. We conclude that regardless of the employed set of fixed effects, both PFI_{old} and PFI_{new} are statistically significant and increase FM costs. However, the estimated effects of hard FM costs are systematically stronger for PFI projects applied to hospital sites with pre-existing premises. We hypothesize that this may be due to the additional costs associated with the maintenance and refurbishment of properties. Due to their historical nature, older hospital sites may need to adhere to stricter regulatory and compliance standards. Furthermore, hospitals with pre-existing premises are likely to have infrastructure and facilities that need to be integrated or adapted to the new PFI project. This integration process may involve extensive modifications, resulting in higher hard FM costs to ensure proper alignment and functionality.

Our empirical results suggest that the procurement of recently constructed hospital sites through the PFI mechanism leads to a substantial increase in both hard FM costs (ranging from 18.3% to 22.8%) and soft FM costs (ranging from 6.5% to 8.4%). This can be attributed to several factors. Modern hospital facilities might demand specialized personnel for tasks, such as operating advanced medical equipment or managing sophisticated IT systems. This incurs additional setup and staff training costs. However, newer buildings often focus on sustainability and environmentally friendly practices. These initiatives might require additional monitoring and management, in addition to soft FM costs.

1.5.2 Role of backlog maintenance

As shown before, when PFI financing is employed for hospital sites with existing facilities, the impact on hard FM costs is more pronounced. We aim to dig deeper and provide an

[28]The financial closure date of a PFI contract refers to the point at which the contract is finalized and all financial aspects are fully arranged. We sourced the financial closure dates of PFI projects from the "Private Finance Initiative and Private Finance 2 projects: 2018 summary data" dataset obtained from the ERIC database. It's noteworthy that around 30% of PFI sites were successfully matched with their respective financial closure dates.

interpretation of this result. Pre-existing hospital sites might have a backlog of deferred maintenance that must be addressed during the implementation of PFI projects. A backlog refers to the portion of an asset that falls below the minimum acceptable performance condition of the building. Its resolution could require additional investments in maintenance activities.

We use backlog costs as an indicator of the risk and condition of hospital estates, based on the methodology developed by NHS Estates (2004). This methodology evaluates the backlog cost needed to maintain all estate assets, specifically elements within all buildings, assigning a certain level of risk to each asset: high, significant, moderate, or low. High-risk assets require urgent repairs/replacement to prevent catastrophic failures and major disruptions in clinical services. Significant risk assets need priority management and expenditure in the short term, while moderate risk assets should be monitored closely and repaired in the medium term. Low-risk assets can then be fixed. We enhance the regression for hard FM costs with backlog costs by grouping them into two groups: (a) high and significant risk, and (b) moderate and low risk.

Some studies argue that maintenance backlog accumulation occurs because of facility management's lack of routine maintenance or neglect (Hopland, 2015), insufficient funding, and increasing maintenance demand (Valen & Olsson, 2012). As a result, there is the possibility of reverse causality, where the level of hard FM costs affects building conditions and, in turn, influences backlog maintenance costs. To address this issue of reverse causality, we follow Leszczensky and Wolbring (2022) and use one-year lagged values for the independent variable backlog maintenance costs.

We report the estimation results considering backlog maintenance costs in Table 1.6. Columns (1) and (2) contain estimations with the same-year backlog costs. In columns (3) and (4), these costs are lagged by one year. Considering the results without lag, we conclude that moderate- and low-risk backlog costs impact hard FM costs, whereas those of high and significant risk do not. We report the results for each of the four categories of backlog risk costs in Table C11 in the Appendix.

Table 1.6: Role of backlog maintenance costs

	log hard FM costs			
	No lag		1 year lag	
	(1)	(2)	(3)	(4)
PFI (1/0)	0.145***	0.132***	0.144***	0.131***
	(0.024)	(0.022)	(0.027)	(0.024)
log High and Significant risk backlog cost (GBP/m^2)	0.001		0.002***	
	(0.001)		(0.001)	
log High and Significant risk backlog cost (GBP/m^2) × PFI	0.000		−0.000	
	(0.001)		(0.001)	
log Moderate and Low risk backlog cost (GBP/m^2)		0.003***		0.002**
		(0.001)		(0.001)
log Moderate and Low risk backlog cost (GBP/m^2) × PFI		−0.003**		−0.002
		(0.001)		(0.001)
Other controls	Yes	Yes	Yes	Yes
Trust × region + year FE	✓	✓	✓	✓
Observations	2 911	2 911	2 020	2 020
Adjusted R^2	0.477	0.479	0.491	0.489

Notes: This table reports OLS estimates of the effect of sites procurement form on log hard FM service costs normalised to its GIA. Columns (1) - (4) specification includes trust × $region$ + year fixed effect. Column (1) presents OLS regression results for the impact of high and significant backlog risk levels on hard FM costs. In contrast, column (2) examines the same relationship for moderate and low backlog risk costs. Both columns (1) and (2) do not incorporate any lags. In contrast, columns (3) and (4) introduce a one-year lag to the analysis, maintaining similar specifications. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

The interaction terms with PFI are statistically significant and negative in column (2). This suggests that the PFI procurement type allows hospitals to reduce the impact of backlog costs of a certain type (moderate or low) on the total hard FM costs in the same year. This could be interpreted in a way that the public-private partnership shifts a fraction of risks to the private counterparty.

1.5.3 Capital investment

In this subsection, we consider the role of capital investment, which is another aspect that might serve to interpret the results for hard FM costs. Capital investment includes expenditures related to the construction of new buildings, renovation or modification of existing facilities, procurement of equipment or technology, and other investments aimed at improving the physical infrastructure and operational capabilities of an organization.

In contrast to backlog maintenance costs, which are rather past oriented, capital investments involve committing funds with the expectation of generating future benefits or returns. The terms of PFI contracts might include provisions related to capital investments and their impact on FM costs. A facility with higher upfront capital investments may have reduced ongoing maintenance costs, as stipulated in the contract.

Since data on capital investments are reported exclusively for hospital trusts, we examine the regression analysis at the level of hospital trust. We proceed to aggregation as follows. Our dependent variables, hard and soft FM costs, are summed across all hospitals owned by each trust. Our variable of interest is PFI_{share} which equals the proportion of the GIA of PFI-financed hospital sites to the total GIA of all hospitals in the trust's portfolio.

In this trust-level exercise, we center the analysis around interactions between heterogeneous capital investments and PFI_{share}. First, we distinguish between private investment and public investment. Private capital investments may involve funding received through PFI arrangements, whereas public capital investments comprise loans from the Department of Health and Social Care (DHSC), public dividend capital, or internally generated funding received by trust.

We report these results in Table 1.7. The OLS estimates in columns (1), (3), (5), and (7) suggest that private investment is likely to result in higher soft FM costs while showing no significant impact on hard FM costs. The interaction terms in column (3) suggest that soft FM service costs increase at a lower pace of 5% per each additional percent of private investment for trusts having under the supervision an additional 1% of the PFIs hospital sites. In other words, private investments are more efficiently utilized by trusts with respect to soft FM services when they roll out PFI hospitals. This efficiency can be attributed to potentially more precise accountability in the presence of PFI, particularly in front of private investors. Fig. B8 shows that the higher share of PFIs under the trust supervision leads to a slower increase in soft FM service costs per each additional unit of private investments. In fact, private capital investments are often driven by profit motives as private investors seek returns on their investments. This can lead to a greater emphasis on cost efficiency, including facility management costs. By contrast, public capital investments might prioritize social welfare and public service provision over financial returns.

Table 1.7: Role of capital investment

	log hard FM costs		log soft FM costs		log hard FM costs		log soft FM costs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PFI_{share} (%)	0.141***	0.240***	0.061**	0.327	0.100***	0.223***	0.040	0.675**
	(0.027)	(0.041)	(0.028)	(0.261)	(0.028)	(0.043)	(0.029)	(0.267)
log Private investment (GBP)	0.003		0.006**		−0.001		0.004	
	(0.002)		(0.003)		(0.003)		(0.003)	
log Private investment (GBP) $\times PFI_{share}$ (%)	−0.002		−0.010**		0.003		−0.006	
	(0.004)		(0.004)		(0.004)		(0.004)	
log Public investment (GBP)	0.000		−0.000		0.001		−0.000	
	(0.002)		(0.002)		(0.002)		(0.002)	
log Investment in new build (GBP)		0.004***		0.002		0.005***		0.003**
		(0.002)		(0.001)		(0.002)		(0.001)
log Investment in new build (GBP) $\times PFI_{share}$		−0.009***				−0.010***		
		(0.003)				(0.003)		
log Investment in building upgrades (GBP)		0.009*		0.032***		0.001		0.028***
		(0.005)		(0.009)		(0.006)		(0.009)
log Investment in building upgrades $\times PFI_{share}$				−0.018				−0.042**
				(0.017)				(0.017)
log Investment in equipment (GBP)		−0.002		0.002		−0.002		0.001
		(0.002)		(0.002)		(0.002)		(0.002)
log Gross Internal Area	0.950***	0.940***	0.863***	0.840***	1.079***	1.075***	1.000***	0.979***
	(0.017)	(0.017)	(0.019)	(0.019)	(0.011)	(0.012)	(0.012)	(0.013)
Trust profile x year FE	✓	✓	✓	✓				
UK region x year FE					✓	✓	✓	✓
Observations	811	811	811	811	811	811	811	811
Adjusted R^2	0.944	0.945	0.924	0.925	0.940	0.941	0.919	0.921

Notes: This table reports ordinary least squares (OLS) estimates, examining the impact of the proportion of PFI sites managed by a Trust on log hard FM service costs (columns (1), (2), (5), (6)) and log soft FM service costs (columns (3), (4), (7), (8)). Columns (1) - (4) specifications correspond to $trust\ profile \times year$ fixed effect, while columns (5) - (8) specifications correspond to $region \times year$ fixed effect. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

Finally, we categorize investments based on their purpose: those made in new construction, building upgrades, and equipment acquisition. We conclude that investments in new construction (per each additional 1%) incentivize trusts to enlarge hard FM costs by 0.5% less while having an additional percent of PFI hospital sites under their supervision (columns (2) and (6)). A similar dynamic is driven with the growth of investments in buildings restoration (column (8)) that shows an increase in soft FM service costs at a lower pace (1.4%) in the presence of PFI.

1.6 Robustness checks

As a robustness check, we also re-estimate OLS and 2SLS restricting both soft FM and hard FM samples to only hospitals. We select the observations with the word "hospital" in the hospital site title. This reduces the sample size to approximately half of its original size and increases the share of the PFI in the sample from 17% to 20%. The results (Table D1 and Table D2 in the Appendix) are broadly in line with those of Table 1.1 and Table 1.2.

Furthermore, the difference in hard FM and soft FM costs between PFI and non-PFI hospital sites increases. Notably, OLS estimates for the variation in soft FM service costs between hospital procurement forms increase (col. (2) and (6) in Table D1), controlling for $site\ profile \times year$ and $region \times year$ fixed effects, respectively. Similarly, the 2SLS estimates for hard FM service costs expand (col. (4) and (8) in Table D2).

The distribution of hospitals' ages prompted us to further differentiate between the PFI status of hospitals. In fact, a large fraction of PFI-procured hospitals possessed buildings before the actual kick-off of PFI contracts. We account for this and create two additional dummies, $PFI > 80$% of GIA and $PFI \leq 80$% of GIA. They correspond to cases in which a PFI hospital owns more than 80% of the construction built after 1995, and where it owns 80% or less. This threshold is chosen because 80% of the total constructions are owned by an average PFI after 1995 (see Fig. B7 in the Appendix). For the purposes of robustness, we test alternative subdivisions: 90% or 70% (for the two groups), 20% - 80%, and 33% - 66% (for the three groups).

Another strategy to judge the robustness of our estimates to alternative interpretations is by changing thresholds for grouping PFIs based on the share of buildings constructed after 1995. The grouped PFIs confirm our findings. To examine the variation between PFI and non-PFI hospital sites, we alter the share of buildings built after 1995. In particular, OLS results with different PFI groupings, regardless of fixed effects, imply that PFI hospital sites have higher soft FM and hard FM service costs than non-PFI sites (Table D3 and Table D4). Moreover, as the share of constructions built after 1995 under PFI hospital site ownership decreases, the gap in hard FM service costs between hospitals of different procurement forms widens. For example, the gap in hard FM service costs is larger for PFI with 70% of buildings constructed after 1995 than for those with 90% share, 13.6%, and 12%, respectively (col. (3) and (1) in Table D4). However, for soft FM services, this trend is reversed. Namely, PFI hospital sites with newer buildings have higher soft FM service costs than those with PFI that constructed a larger share of buildings before 1995 (col. (1) and (2) in Table D3).

1.7 Conclusion

This paper contributes to the understanding of the role of public–private partnerships. More precisely, we explore the effect of PFI procurement on hard and soft FM service costs in England's hospitals and sites. We employ a dataset that covers hospital sites in England between 2018 and 2021. Our empirical strategy involves a series of simple OLS and 2SLS estimations enhanced with fixed effects, capturing location-specific and hospital-specific unobservables. We include a diverse set of controls that account for the functioning of various supportive hospital departments. We validate the main findings using propensity score matching and Hausman–Taylor estimations.

The major result of this study is that the type of hospital site procurement, PFI or traditional, appears to be a significant determinant of the soft FM and hard FM costs of hospitals. The evidence suggests that PFI projects augment both hard FM (up to 37.1%) and soft FM costs (20.3%). This matches the discussion in the report by NAO (2010), where it is explained how costly PFI contracts can contribute to facilities by improving quality of services.

Our findings have important implications for a potential of cost savings within PFI hospitals in the healthcare sector in England. They suggest that PFI projects may not be the optimal solution for delivering low-cost facility management services. They also indicate that hospitals should consider the trade-offs between different procurement forms, tenure arrangements, and outsourcing decisions when planning and managing their facility management activities.

Future research could explore the impact of additional factors on soft and hard FM costs, such as employee salaries, the presence of medical equipment, and the use of outsourcing for various FM services. A difference-in-differences analysis comparing active and expired PFIs, in which ownership has been transferred to local authorities, would also be valuable. Furthermore, investigating the effects of the COVID-19 health crisis on hard and soft FM costs, subject to data availability, is recommended.

1.8 Appendix

Appendix A: Descriptive statistics

Table A1: Summary statistics

	PFI (1)	Min (2)	Mean (3)	Max (4)	N (5)
			Soft FM sample		
Soft FM costs (GBP)	0	1 500	3 206 778	38 704 843	2 419
	1	63 248	8 357 110	38 973 467	484
Gross internal area (m^2)	0	347	24 835	23 451	2 419
	1	391	61 291	292 119	484
Cleaning staff (WTE)	0	0	39	444	2 419
	1	1	100	534	484
Portering staff (WTE)	0	0	13	172	2 419
	1	0	37	202	484
Inpatient main meals requested (Nb)	0	0	148 570	1 219 862	2 419
	1	0	355 572	1 394 073	484
Laundered pieces per annum (Nb)	0	0	560 046	5 712 061	2 419
	1	1 275	1 548 389	7 285 300	484
Outsourced laundry and linen services (1/0)	0	0	0.91	1	2 419
	1	0	0.9	1	484
			Hard FM sample		
Hard FM costs (GBP)	0	5679	2 252 827	26 752 279	2 443
	1	39 576	6 836 855	34 337 630	468
Gross internal area (m^2)	0	338	23 013	217 740	2 443
	1	387	60 428	292 119	468
Clinical space (%)	0	3.6	72	100	2 443
	1	2.7	70	100	468
Single bedrooms with en-suite facilities (Nb)	0	0	35	418	2 443
	1	0	102	594	468
Total energy consumption (kWh)	0	5564	10 155 340	160 887 976	2 443
	1	68 512	28 362 807	237 865 346	468
CHP Units (1/0)	0	0	0.18	1	2 443
	1	0	0.22	1	468
Low risk backlog cost (GBP)	0	0	1 227 401	35 871 444	2 443
	1	0	1 837 867	30 000 000	468
Moderate risk backlog cost (GBP)	0	0	3 904 148	544 088 864	2 443
	1	0	4 743 653	84 396 655	468
Significant risk backlog cost (GBP)	0	0	3 907 159	311 323 656	2 443
	1	0	3 802 901	61 807 966	468
High risk backlog cost (GBP)	0	0	1 854 935	155 027 487	2 443
	1	0	2 414 410	84 977 400	468

Notes: This table reports the mean, minimum, and maximum values of each variable in the soft and hard FM service cost samples. Column (1) defines the PFI and non-PFI subsamples, and column (5) reports the corresponding number of observations per subsample. Columns (2) and (4) show the minimum and maximum values of the variables, respectively, and column (3) displays the mean characteristics.

A1 Site profiles definition

There are eight site profiles: general acute hospital sites, specialist hospital sites (acute only), mixed service hospital sites, community hospital sites (with inpatient beds), mental health sites (including specialist services), learning disabilities sites, mental health and learning disabilities sites and other inpatient sites.

General acute hospital sites provide a range of inpatient medical care and other related services for surgery, acute medical conditions, or injuries (usually for short-term illnesses). Treatment centers providing inpatient facilities are also categorized as general acute hospitals.

Specialist hospital sites, limited to acute care only, focus on a single specific area, such as oncology, orthopedics, dental care, and maternity services for women and children's healthcare. However, this category excludes specialist hospitals in the mental health or learning disabilities sector.

Mixed service hospital sites offer a combination of different functions provided by the same provider, such as single specialty care, acute services, community services, mental health services, and learning disabilities services.

Sites that exclusively offer mental health services, including specialized ones, such as secure units, are categorized as *mental health sites*. Similarly, sites solely dedicated to providing learning disabilities services fall within the *learning disabilities category*. Sites that provide both mental health and learning disabilities services from one location by the same provider are designated *mental health and learning disabilities sites*.

Community hospital sites with inpatient beds serve as alternatives to acute, general hospital care. They are located close to people's homes and cater specifically to local needs. While they may not have emergency departments, they often have minor injury units along with services such as inpatient care for older individuals, rehabilitation programs, maternity services, outpatient clinics, day surgery/care facilities, and diagnostic options.

Other inpatient sites provide inpatient services but do not fit into the previously mentioned categories. These include hospices, intermediate or similar care units, nursing homes, residential care homes, and group homes.

Appendix B: Additional figures

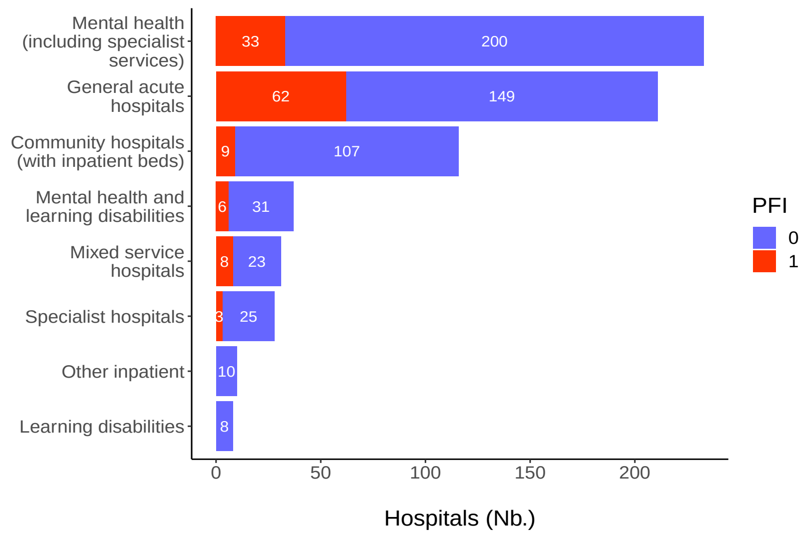


Figure B1: Unique hospitals in the soft FM sample: types, profiles and procurement method

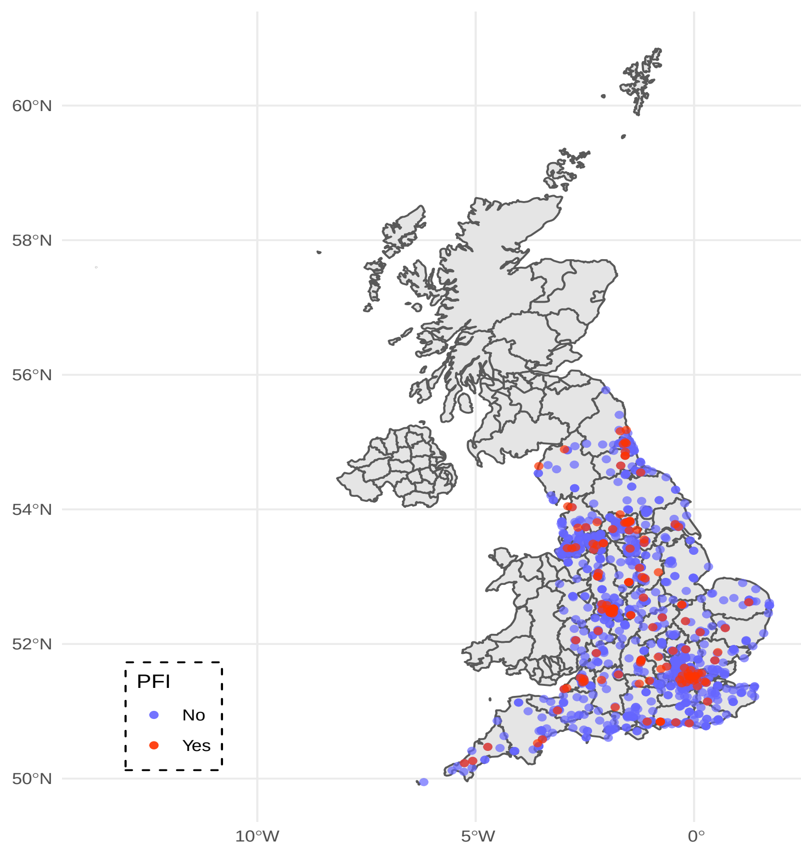


Figure B2: Hospitals location map

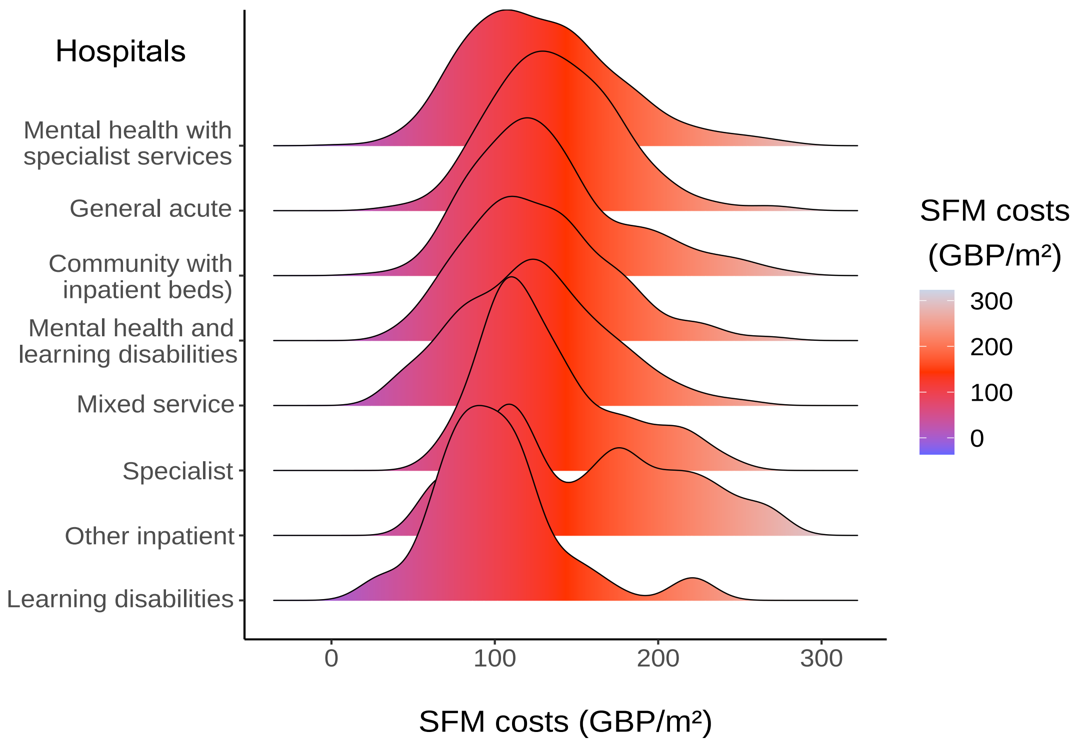


Figure B3: Distribution of soft FM costs by hospitals profiles

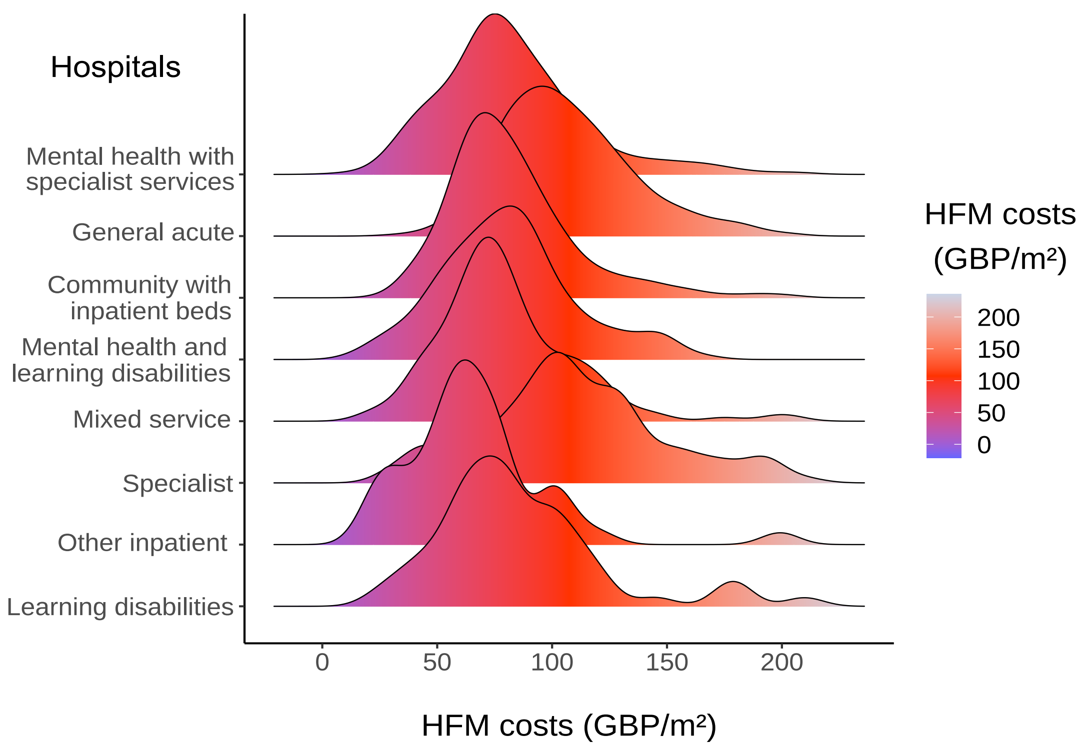


Figure B4: Distribution of hard FM costs by hospitals profiles

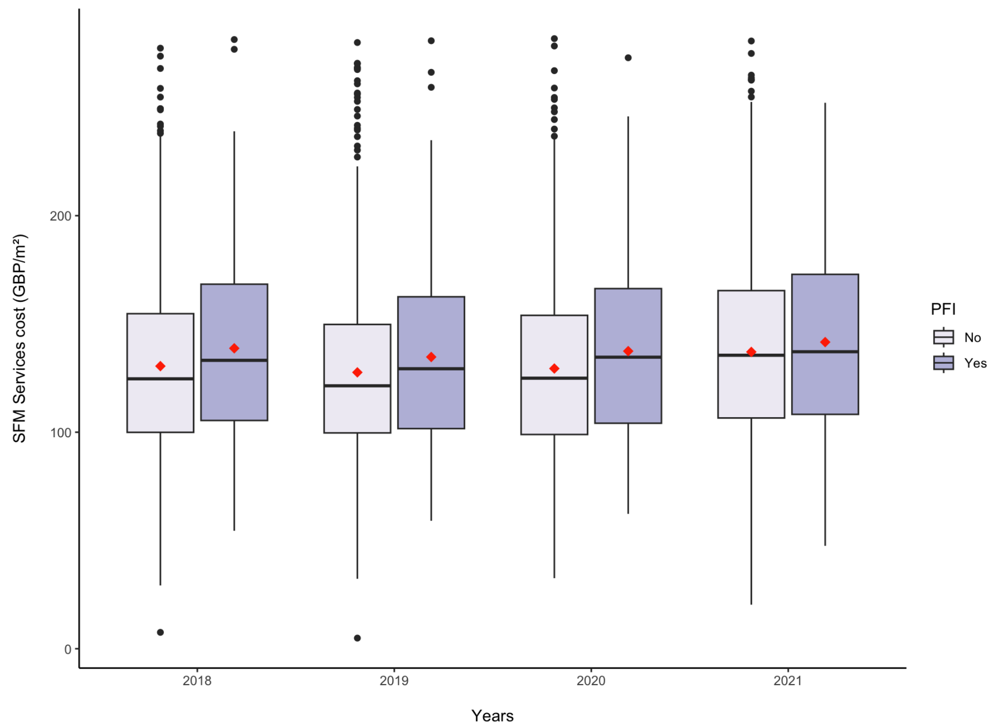


Figure B5: Boxplots of soft FM service costs, 2018 - 2021 years

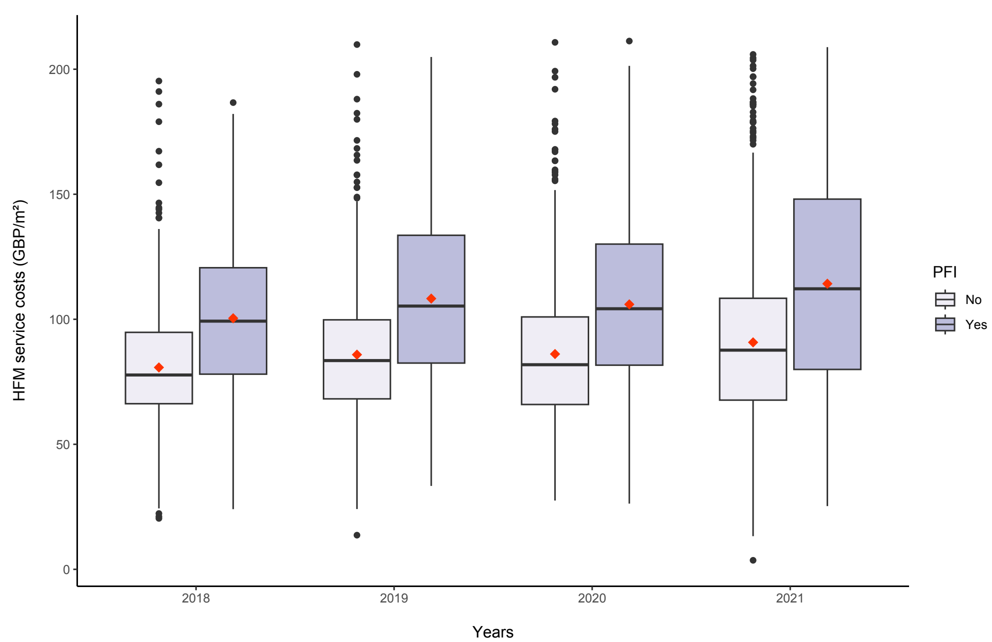


Figure B6: Boxplots of hard FM service costs, 2018 - 2021 years

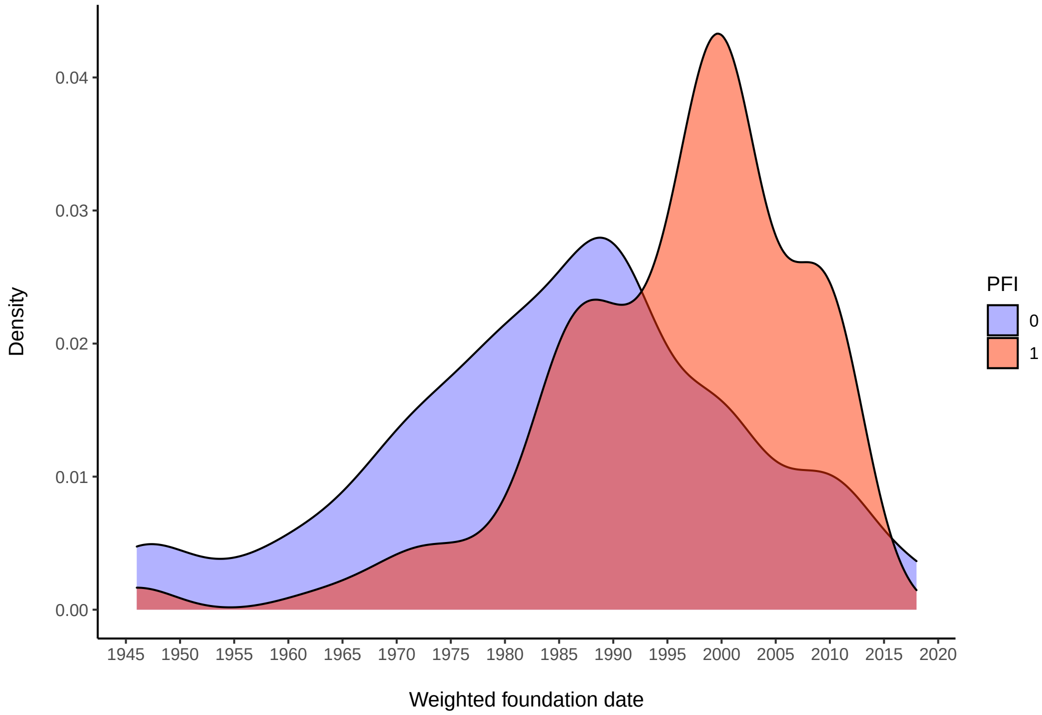


Figure B7: Weighted foundation date, all unique hospitals

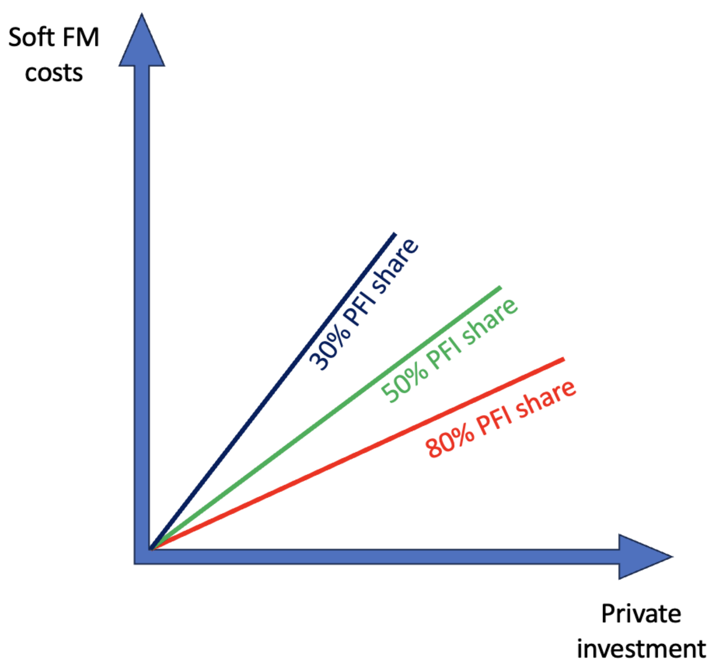


Figure B8: Private investment vs soft FM costs

Appendix C: Additional regressions

Table C1: Impact of hospital site's procurement form on hard FM costs

	log hard FM cost (GBP/m^2)					
	2SLS		2SLS		2SLS	
	First stage (1)	Second stage (2)	First stage (3)	Second stage (4)	First stage (5)	Second stage (6)
PFI (1/0)		-0.048		-0.054		0.184^{*}
		(0.061)		(0.067)		(0.103)
LIBOR (%)	-0.064^{***}		-0.045^{***}		-0.037^{***}	
	(0.005)		(0.005)		(0.004)	
Public sector net debt (% of GDP)	-0.005^{***}		-0.004^{***}		-0.003^{***}	
	(0.000)		(0.000)		(0.000)	
Voting (1-4)	0.045^{***}		0.051^{***}		0.073^{***}	
	(0.008)		(0.009)		(0.010)	
Other regressors	yes	yes	yes	yes	yes	yes
Cragg-Donald F stat	71.2		48.8		55.1	
Kleibergen-Paap rk Wald F stat	27.3		21.5		8.5	
Sargan stat		10.4		0.6		0.6
		(0.005)		(0.739)		(0.709)
Site profile x year FE	✓	✓				
Region x year FE			✓	✓		
Trust x region FE					✓	✓
Year FE					✓	✓
Observations	2 102	2 102	2 102	2 102	2 102	2 102

Notes: This table reports two-stage least squares (2SLS) estimates of the effect of hospital site procurement form on log hard FM service costs normalized to its GIA. Specifications in columns (1) and (2) include $site\ profile \times year$ fixed effect; columns (3) and (4) correspond to $region \times year$ fixed effect, while columns (5) and (6) introduce $trust \times region + year$ fixed effect. All specifications incorporate an additional instrumental variable of voting per constituency in England. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

Table C2: Impact of hospital site's procurement form on soft FM costs

	log soft FM cost (GBP/m^2)					
	2SLS		2SLS		2SLS	
	First stage (1)	Second stage (2)	First stage (3)	Second stage (4)	First stage (5)	Second stage (6)
PFI (1/0)		0.232***		0.242***		0.204*
		(0.067)		(0.053)		(0.104)
LIBOR (%)	−0.067***		−0.049***		−0.044***	
	(0.005)		(0.005)		(0.004)	
Public sector net debt (% of GDP)	−0.005***		−0.005***		−0.004***	
	(0.000)		(0.000)		(0.000)	
Voting (1-4)	0.044***		0.060***		0.080***	
	(0.008)		(0.009)		(0.010)	
Other regressors	yes	yes	yes	yes	yes	yes
Cragg-Donald F stat	76.3		58.4		74.6	
Kleibergen-Paap rk Wald F stat	20		39.9		14.7	
Sargan stat		1.5		5.7		0.2
		(0.462)		(0.058)		(0.917)
Site profile x year FE	✓	✓				
Region x year FE			✓	✓		
Trust x region FE					✓	✓
Year FE					✓	✓
Observations	2 101	2 101	2 101	2 101	2 101	2 101

Notes: This table reports two-stage least squares (2SLS) estimates of the effect of hospital site procurement form on log soft FM service costs normalized to its GIA. Specifications in columns (1) and (2) include $site\ profile \times year$ fixed effect; columns (3) and (4) correspond to $region \times year$ fixed effect, while columns (5) and (6) introduce $trust \times region + year$ fixed effect. All specifications incorporate an additional instrumental variable of voting per constituency in England. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parentheses.

Table C3: Site profiles fixed effect regressions, 2018-2021, hard FM subsampe

	log hard FM cost (GBP/m^2)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PFI (1/0)	0.149^{***}	0.149^{***}	0.151^{***}	0.146^{***}	0.143^{***}	0.125^{***}	-0.548^{**}
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.017)	(0.265)
log Age		0.001	0.011	0.008	0.019	0.011	0.010
		(0.012)	(0.012)	(0.012)	(0.012)	(0.011)	(0.011)
Clinical space (%)			0.003^{***}	0.003^{***}	0.003^{***}	0.002^{***}	0.002^{***}
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CHP units (1/0)				-0.060^{***}	-0.064^{***}	-0.102^{***}	-0.105^{***}
				(0.020)	(0.020)	(0.019)	(0.019)
log Single bedrooms for patients with en-suite facilities (Nb/m^2)					0.003^{***}	0.002^{***}	0.002^{***}
					(0.001)	(0.001)	(0.001)
log Total energy consumption (kWh/m^2)						0.235^{***}	0.228^{***}
						(0.014)	(0.014)
log Total energy consumption (kWh/m^2) · PFI							0.112^{**}
							(0.044)
Site profile $\times$ year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 911	2 911	2 911	2 911	2 911	2 911	2 911
Adjusted R^2	0.173	0.173	0.185	0.187	0.192	0.266	0.268

Note: This table provides empirical findings for OLS estimations of the impact of PFI on hard FM costs. Each specification includes $site\ profile \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C4: Regions fixed effect regressions, 2018-2021, hard FM subsampe

	log hard FM cost (GBP/m^2)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PFI (1/0)	0.216***	0.223***	0.222***	0.217***	0.207***	0.163***	−0.443*
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.017)	(0.265)
log Age		0.022*	0.021*	0.020*	0.035***	0.012	0.011
		(0.012)	(0.012)	(0.012)	(0.012)	(0.011)	(0.011)
Clinical space (%)			−0.000	0.001	0.001*	0.001*	0.001*
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CHP units (1/0)				0.154***	0.135***	0.023	0.019
				(0.017)	(0.018)	(0.017)	(0.017)
log Single bedrooms for patients with en-suite facilities (Nb/m^2)					0.005***	0.003***	0.003***
					(0.001)	(0.001)	(0.001)
log Total energy consumption (kWh/m^2)						0.290***	0.283***
						(0.013)	(0.013)
log Total energy consumption (kWh/m^2) · PFI							0.101**
							(0.044)
Region × year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 911	2 911	2 911	2 911	2 911	2 911	2 911
Adjusted R^2	0.114	0.115	0.114	0.138	0.154	0.278	0.279

Note: This table provides empirical findings for OLS estimations of the impact of PFI on hard FM costs. Each specification includes $region \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C5: Site profiles fixed effect regressions, 2018-2021, hard FM subsampe

	log hard FM cost (GBP)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PFI (1/0)	0.586***	0.236***	0.216***	0.281***	0.265***	0.185***	0.138***
	(0.050)	(0.045)	(0.046)	(0.043)	(0.045)	(0.042)	(0.023)
Gross internal area (m^2)		0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log Age			−0.051*				
			(0.028)				
Clinical space (%)				−0.017***			
				(0.001)			
CHP units (1/0)					0.227***		
					(0.050)		
log Single bedrooms for patients with en-suite facilities (Nb)						0.026***	
						(0.001)	
log Total energy consumption (kWh)							0.805***
							(0.009)
Site profile x year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 911	2 911	2 911	2 911	2 911	2 911	2 911
Adjusted R^2	0.712	0.782	0.782	0.802	0.784	0.806	0.941

Note: This table provides empirical findings for OLS estimations of the impact of PFI on hard FM costs. Each specification includes $site\ profile \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C6: Regions fixed effect regressions, 2018-2021, hard FM subsampe

	log hard FM cost (GBP)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PFI (1/0)	1.376***	0.128**	0.151***	0.190***	0.243***	0.063	0.131***
	(0.086)	(0.055)	(0.057)	(0.052)	(0.054)	(0.052)	(0.023)
Gross internal area (m^2)	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log Age			0.058*				
			(0.035)				
Clinical space (%)				−0.022***			
				(0.001)			
CHP units (1/0)					0.772***		
					(0.058)		
log Single bedrooms for patients with en-suite facilities (Nb)						0.034***	
						(0.002)	
log Total energy consumption (kWh)							0.856***
							(0.007)
Region x year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 911	2 911	2 911	2 911	2 911	2 911	2 911
Adjusted R^2	0.100	0.667	0.667	0.701	0.686	0.709	0.942

Note: This table provides empirical findings for OLS estimations of the impact of PFI on hard FM costs. Each specification includes $region \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C7: Site profile fixed effect regressions, 2018-2021, soft FM subsampe

	log soft FM cost (GBP/m^2)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PFI (1/0)	0.043**	0.043**	0.040**	0.032*	0.035**	0.042**	0.008
	(0.020)	(0.021)	(0.018)	(0.018)	(0.018)	(0.017)	(0.064)
log Age		−0.000	0.001	0.009	0.005	0.010	0.010
		(0.013)	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)
Inpatient main meals requested (Nb/m^2)			0.040***	0.031***	0.031***	0.030***	0.030***
			(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Laundered pieces per annum (Nb/m^2)				0.008***	0.008***	0.008***	0.008***
				(0.001)	(0.001)	(0.001)	(0.001)
Outsourced laundry and linen services (1/0)				0.088***	0.095***	0.103***	0.098***
				(0.024)	(0.023)	(0.023)	(0.025)
log Portering staff (WTE/m^2)					0.019***	0.014***	0.014***
					(0.003)	(0.003)	(0.003)
log Cleaning staff (WTE/m^2)						0.021***	0.021***
						(0.003)	(0.003)
Outsourced laundry and linen services (1/0) × PFI							0.037
							(0.066)
Site profile x year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 903	2 903	2 903	2 903	2 903	2 903	2 903
Adjusted R^2	0.022	0.022	0.249	0.295	0.303	0.312	0.312

Note: This table provides empirical findings for OLS estimations of the impact of PFI on soft FM costs. Each specification includes $site\ profile \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C8: Regions fixed effect regressions, 2018-2021, soft FM subsampe

	log soft FM cost (GBP/m^2)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PFI (1/0)	0.056***	0.054***	0.086***	0.046***	0.042**	0.054***	0.006
	(0.019)	(0.020)	(0.018)	(0.017)	(0.017)	(0.016)	(0.062)
log Age		−0.007	0.024**	0.003	−0.011	−0.008	−0.008
		(0.013)	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)
Inpatient main meals requested (Nb/m^2)			0.032***	0.029***	0.031***	0.028***	0.028***
			(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Laundered pieces per annum (Nb/m^2)				0.009***	0.008***	0.008***	0.008***
				(0.000)	(0.000)	(0.000)	(0.000)
Outsourced laundry and linen services (1/0)				0.047**	0.054**	0.057**	0.050**
				(0.023)	(0.023)	(0.023)	(0.024)
log Portering staff (WTE/m^2)					0.026***	0.020***	0.020***
					(0.003)	(0.003)	(0.003)
log Cleaning staff (WTE/m^2)						0.032***	0.032***
						(0.003)	(0.003)
Outsourced laundry and linen services (1/0) $\times$ PFI							0.052
							(0.064)
Region x year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 903	2 903	2 903	2 903	2 903	2 903	2 903
Adjusted R^2	0.048	0.048	0.223	0.319	0.338	0.356	0.356

Note: This table provides empirical findings for OLS estimations of the impact of PFI on soft FM costs. Each specification includes $region \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C9: Site profile fixed effect regressions, 2018-2021, soft FM subsampe

	log soft FM cost (GBP)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PFI	0.462***	0.110**	0.117***	0.091**	0.102**	0.102**	0.141***	0.133***
	(0.048)	(0.043)	(0.044)	(0.042)	(0.043)	(0.043)	(0.040)	(0.040)
Gross internal area (m^2)		0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log Age			0.020					
			(0.027)					
Inpatient main meals requested (Nb)				0.000***				
				(0.000)				
Launded pieces per annum (Nb)					0.000*			
					(0.000)			
Outsourced laundry and linen services (1/0)						0.197***		
						(0.057)		
log Portering staff (WTE)							0.134***	
							(0.006)	
log Cleaning staff (WTE)								0.140***
								(0.007)
Site profile x year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 903	2 903	2 903	2 903	2 903	2 903	2 903	2 903
Adjusted R^2	0.676	0.760	0.760	0.769	0.760	0.761	0.791	0.789

Note: This table provides empirical findings for OLS estimations of the impact of PFI on soft FM costs. Each specification includes $site\ profile \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C10: Regions fixed effect regressions, 2018-2021, soft FM subsampe

	log soft FM cost (GBP)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PFI (1/0)	1.184***	0.036	0.078	0.014	0.009	0.032	0.136***	0.096**
	(0.077)	(0.050)	(0.051)	(0.048)	(0.049)	(0.050)	(0.043)	(0.044)
Gross internal area (m^2)		0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log Age			0.105***					
			(0.031)					
Inpatient main meals requested (Nb)				0.000***				
				(0.000)				
Launded pieces per annum (Nb)					0.000***			
					(0.000)			
Outsourced laundry and linen services (1/0)						0.094		
						(0.067)		
log Portering staff (WTE)							0.200***	
							(0.006)	
log Cleaning staff (WTE)								0.229***
								(0.008)
Region x year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 903	2 903	2 903	2 903	2 903	2 903	2 903	2 903
Adjusted R^2	0.111	0.673	0.674	0.692	0.682	0.673	0.759	0.749

Note: This table provides empirical findings for OLS estimations of the impact of PFI on soft FM costs. Each specification includes $region \times year$ fixed effects. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table C11: OLS estimation of the linear relationship between backlog costs and hard FM costs

	log hard FM costs (GBP/m^2)							
	No lag				1 year lag			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PFI	0.116***	0.144***	0.134***	0.141***	0.104***	0.145***	0.133***	0.144***
	(0.029)	(0.024)	(0.023)	(0.023)	(0.033)	(0.028)	(0.026)	(0.026)
log High risk backlog cost (GBP/m^2)	0.002***				0.003***			
	(0.001)				(0.001)			
log Significant risk backlog cost (GBP/m^2)		0.001*				0.002***		
		(0.001)				(0.001)		
log Moderate risk backlog cost (GBP/m^2)			0.001				0.001*	
			(0.002)				(0.001)	
log Low risk backlog cost (GBP/m^2)				0.002***				0.002***
				(0.001)				(0.001)
log High risk backlog cost (GBP/m^2) · PFI	−0.001				−0.002*			
	(0.001)				(0.001)			
log Significant risk backlog cost (GBP/m^2)· PFI		0.000				0.000		
		(0.001)				(0.001)		
log Moderate risk backlog cost (GBP/m^2) · PFI			−0.000				−0.001	
			(0.001)				(0.001)	
log Low risk backlog cost (GBP/m^2) · PFI				−0.001				−0.000
				(0.001)				(0.001)
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region x year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2 911	2 911	2 911	2 911	2 020	2 020	2 020	2 020
Adjusted R^2	0.478	0.477	0.477	0.480	0.495	0.490	0.488	0.492

Notes: This table reports ordinary least squares (OLS) estimates of the effect of hospitals procurement type on log hard FM services costs normalised to its GIA with region × year fixed effect specification. Columns (1) - (4) include high, significant, moderate and low backlog cost normalised to its GIA without lags, while columns (5) - (8) transform similar regressors with one year lag. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Appendix D. Robustness checks

Table D1: OLS and 2SLS estimates of the hospitals' procurement type on soft FM cost

	log soft FM costs (GBP/m^2)							
	OLS		2SLS		OLS		2SLS	
	No controls (1)	Controls (2)	First stage (3)	Second stage (4)	No controls (5)	Controls (6)	First stage (7)	Second stage (8)
PFI (1/0)	0.067***	0.059***		0.025	0.081***	0.041***		0.039
	(0.020)	(0.016)		(0.104)	(0.019)	(0.015)		(0.084)
LIBOR (%)			−0.039***				−0.030***	
			(0.004)				(0.004)	
log Age		0.029**	−0.197***	0.020		0.000	−0.204***	-0.001
		(0.013)	(0.019)	(0.035)		(0.013)	(0.020)	(0.031)
Inpatient main meals requested (Nb/m^2)		0.042***	−0.001	0.042***		0.038***	−0.002	0.038***
		(0.002)	(0.003)	(0.004)		(0.002)	(0.003)	(0.003)
Laundered pieces per annum (Nb/m^2)		0.007***	0.001	0.007***		0.009***	0.003***	0.009***
		(0.001)	(0.001)	(0.002)		(0.000)	(0.001)	(0.001)
Outsourced laundry and linen services (1/0)		0.082***	0.036	0.083***		0.061***	−0.028	0.061***
		(0.023)	(0.033)	(0.023)		(0.022)	(0.036)	(0.020)
log Portering staff (WTE/m^2)		0.003***	0.001	0.003***		0.004***	0.003***	0.004***
		(0.001)	(0.001)	(0.001)		(0.001)	(0.001)	(0.001)
log Cleaning staff (WTE/m^2)		0.051***	0.003	0.052**		0.044***	0.001	0.044**
		(0.006)	(0.008)	(0.019)		(0.005)	(0.008)	(0.017)
Site profile x year FE	Yes	Yes	Yes	Yes	No	No	No	No
Region x year FE	No	No	No	No	Yes	Yes	Yes	Yes
Individual FE	No	No	No	No	No	No	No	No
Observations	1 672	1 672	1 672	1 672	1 672	1 672	1 672	1 672
Adjusted R^2	0.049	0.438	0.194	0.413	0.084	0.488	0.134	0.449
Cragg-Donald F stat			94.60				54.70	
Kleibergen-Paap rk Wald F stat			20.60				50.90	

Notes: This table reports ordinary least squares (OLS) and two-stage least squares (2SLS) estimates of the effect of hospital procurement type on log soft FM services costs normalised to its GIA. Columns (1) - (4) specifications include site profile × year fixed effect, while columns (5) - (8) specifications correspond to region × year fixed effect. Columns (1), (2), (5) and (6) show coefficients from OLS regressions of log soft FM services costs on hospitals' procurement type. Columns (3), (4), (7) and (8) display coefficients from two-stage least squares models instrumenting sites' procurement type with the UK bank rate, LIBOR. Columns (3) and (7) show first-stage specifications. Columns (4) and (8) display the second stage excluding the instrument. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table D2: OLS and 2SLS estimates of the hospitals' procurement type on hard FM cost

	log hard FM costs (GBP/m^2)							
	OLS		2SLS		OLS		2SLS	
	No controls (1)	Controls (2)	First stage (3)	Second stage (4)	No controls (5)	Controls (6)	First stage (7)	Second stage (8)
PFI (1/0)	0.152*** (0.019)	0.135*** (0.019)		0.413*** (0.068)	0.208*** (0.020)	0.165*** (0.019)		0.225* (0.119))
LIBOR (%)			−0.036*** (0.004)				−0.026*** (0.004)	
log Age		0.019 (0.015)	−0.185*** (0.019)	0.086*** (0.021)		0.000 (0.015)	−0.194*** (0.020)	0.014 (0.031)
Clinical space (%)		0.001** (0.001)	0.000 (0.001)	0.001 (0.001)		0.001* (0.001)	−0.001 (0.001)	0.001* (0.001)
CHP Units (1/0)		−0.089*** (0.018)	−0.096*** (0.023)	-0.059*** (0.021)		0.010 (0.017)	−0.012 (0.023)	0.011 (0.021)
log Single bedrooms for patients without en-suite facilities (Nb/m^2)		0.003*** (0.001)	0.001 (0.001)	0.003** (0.001)		0.005*** (0.001)	0.003** (0.001)	0.005*** (0.001)
log Total energy consumption (kWh/m^2)		0.267*** (0.020)	0.051** (0.025)	0.255*** (0.033)		0.368*** (0.019)	0.107*** (0.025)	0.362*** (0.031)
Cragg-Donald F stat			82.7				40.7	
Kleibergen-Paap rk Wald F stat			17.1				41	
Hospital profile x year FE	Yes	Yes	Yes	Yes	No	No	No	No
Region x year FE	No	No	No	No	Yes	Yes	Yes	Yes
Individual FE	No	No	No	No	No	No	No	No
Observations	1 673	1 673	1 673	1 673	1 673	1 673	1 673	1 673
Adjusted R^2	0.251	0.335	0.187	0.040	0.160	0.348	0.115	0.270

Notes: This table reports ordinary least squares (OLS) and two-stage least squares (2SLS) estimates of the effect of hospital procurement type on log hard FM services costs normalised to its GIA. Columns (1) - (4) specifications include hospital profile × year fixed effect, while columns (5) - (8) specifications correspond to region × year fixed effect. Columns (1), (2), (5) and (6) show coefficients from OLS regressions of log hard FM services costs on hospital procurement type. Columns (3), (4), (7), and (8) display coefficients from two-stage least squares models instrumenting hospital procurement type with the UK bank rate, LIBOR. Columns (3) and (7) show first stage specifications. Columns (4) and (8) display the second stage excluding the instrument. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table D3: OLS estimates of the hospital sites procurement type on soft FM costs

	log soft FM costs (GBP/m^2)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PFI (X > X_1)	0.042**	0.027	0.037**	0.028	0.032*	0.033	0.025	0.032*	0.026	0.028
	(0.021)	(0.019)	(0.019)	(0.019)	(0.018)	(0.020)	(0.019)	(0.018)	(0.019)	(0.018)
PFI ($X_1 \geq$ X $\geq$ X_2)	0.037*	0.053**	0.042*	0.061***	0.042*	0.038**	0.048**	0.041**	0.054**	0.044*
	(0.019)	(0.021)	(0.022)	(0.022)	(0.026)	(0.018)	(0.020)	(0.021)	(0.021)	(0.025)
PFI (X_2 > X)				0.015	0.064*				0.016	0.054
				(0.049)	(0.038)				(0.048)	(0.037)
X_1 % of GIA	90	80	70	80	66	90	80	70	80	66
X_2 % of GIA	0	0	0	20	33	0	0	0	20	33
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospital profile x year FE	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
Region x year FE	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Observations	2 903	2 903	2 903	2 903	2 903	2 903	2 903	2 903	2 903	2 903
Adjusted R^2	0.363	0.363	0.363	0.363	0.363	0.392	0.392	0.392	0.392	0.392

Notes: This table reports ordinary least squares (OLS) estimates of the effect of hospital sites procurement type on log soft FM services costs normalized to its GIA. X is the percentage share of hospital buildings constructed after 1995 year. X_1 and X_2 define the affiliated hospital sites subgroups limits. For instance, column (1) includes hospitals that have 90% of buildings GIA constructed after 1995 ($X > 90\%$ of GIA) and hospital sites that have 90% of buildings' GIA constructed before 1995 ($X \leq 90\%$ of GIA). Other columns vary in the subdivision of hospital sites in the corresponding groups. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Table D4: OLS estimates of the hospital sites procurement type on hard FM costs

	log hard FM costs (GBP/m^2)									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
PFI (X > X_1)	0.120***	0.129***	0.136***	0.128***	0.132***	0.117***	0.152***	0.164***	0.152***	0.164***
	(0.024)	(0.022)	(0.022)	(0.019)	(0.021)	(0.024)	(0.022)	(0.022)	(0.022)	(0.021)
PFI ($X_1 \geq$ X $\geq$ X_2)	0.133***	0.123***	0.113***	0.097***	0.086***	0.202***	0.178***	0.165***	0.171***	0.155***
	(0.022)	(0.024)	(0.025)	(0.026)	(0.030)	(0.021)	(0.024)	(0.024)	(0.025)	(0.029)
PFI (X_2 > X)				0.253***	0.188***				0.218***	0.188***
				(0.056)	(0.044)				(0.056)	(0.043)
X_1 % of GIA	90	80	70	80	66	90	70	80	80	66
X_2 % of GIA	0	0	0	20	33	0	0	0	20	33
Other controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hospital profile x year FE	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
UK region x year FE	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Observations	2 911	2 911	2 911	2 911	2 911	2 911	2 911	2 911	2 911	2 911
Adjusted R^2	0.264	0.264	0.265	0.266	0.265	0.274	0.272	0.272	0.272	0.271

Notes: This table reports ordinary least squares (OLS) estimates of the effect of hospital sites procurement type on log hard FM services costs normalized to its GIA. X is the percentage share of hospital site buildings constructed after 1995 year. X_1 and X_2 define the affiliated hospital sites subgroups limits. For instance, column (1) includes hospital sites that have 90% of buildings GIA constructed after 1995 ($X > 90\%$ of GIA) and hospital sites that have 90% of buildings' GIA constructed before 1995 ($X \leq 90\%$ of GIA). Other columns vary in the subdivision of hospital sites in the corresponding groups. ***, ** and * denote significance at the 1%, 5% and 10% level, respectively. Heteroskedasticity-robust standard errors are reported in parenthesis.

Appendix E: Data integrity and cleaning

E1 Site type choice

We remove all other sites that don't meet these two criteria. Notably, "other reportable" sites are the ones without inpatient beds at the lowest of 151 m^2, and those at most with nine inpatient bed pieces of size from 151 m^2 to 499 m^2 in 2018 and 2019. In 2019 ambulance trusts were obliged to report all sites of a size less than 1000 m^2 as "other reportable" sites, while other sites not having inpatient beds turned to be "ambulance services" sites. Therefore, we also cut out the latter ones. We follow up a similar rule for 2020. A change again came out in 2021, where:

- "Ambulance services" sites were renamed to "support facilities" sites;
- "Non inpatient" and "unoccupied" sites started being reported;
- Previously declared sites without inpatient beds and with the GIA more than 500 m^2 became individually reported at a site level rather than having a title of "other reportable" sites.

Thereby, to reach data consistency from 2021, we don't include in our dataset "support facilities", "non inpatient", "unoccupied", and sites without inpatient beds of size at least 500 m^2.

Table E1: Site types from 2017 to 2021

	Inpatient beds								
Site's GIA (m^2)	None				1-9				10 or more
IR	2018	2019	2020	2021**	2018	2019	2020	2021**	2018 - 2021**
up to 150	NR			NI	NR			NI	IR
151 - 499	OR				OR				IR
500 - 999	OR			IR & OR*	IR				IR
$\geq$ 1000	OR	OR & AS*		IR & SF*	IR				IR

Notes: This table reports the ERIC dataset subdivision of site types based on their Gross Internal Area (GIS) and inpatient beds availability from 2018 to 2021. In our paper, we use the sites coloured in grey.
Abbreviations: Ambulance Services (AS), Individually Reported (IR), Non Inpatient (NI), Not Reported (NR), Other Reportable (OR), Support facilities (SF).
* - it is a site type uniquely for ambulance trusts. ** - the new "unoccupied" site type was reported.

Chapter 2

Facility Management Services in UK Hospitals: In-house or Outsourcing

2.1 Introduction

For some years, there has been a tendency among UK hospitals to switch outsourced facility management services back to in-house delivery. As a case in point, Scottish, Welsh, and North Ireland health authorities have terminated the outsourcing of cleaning services. In England, hospital staff put pressure to prevent further outsourcing of any type of facility management services (Auffenberg, 2022).[1] These services include hard facility management (hard FM) for maintaining the condition of hospital buildings and soft FM for hospital cleaning, catering, access, and security.[2] The main reason for this trend has been the deterioration of the quality of these services. For instance, the outsourcing of cleaning services is shown to yield lower hygiene standards and more infections than in-house provision (Elkomy et al., 2019; Toffolutti et al., 2017).

Since 1996, the UK government has pushed hospital management toward local interests

[1]From 2008, the Scottish government ceased the usage of private contracts for catering, cleaning, and all clinically related soft facility management (soft FM) services, whether funded through Public Private Partnerships (PPPs) or not (Scottish Government, 2008). The Welsh government announced its decision "to end competitive tendering for NHS cleaning contracts" (Labour Party Wales and Plaid Cymru, 2007, p. 10). National Hospital Office (2006) in the "Cleaning Manual" advised health organizations to be aware that "the price is not the main determinant in contractor selection and to ensure that quality is always a key consideration" (p. 111). The message in between the lines was that in-house cleaning delivery should be a dominant strategy. NHS England still allows contracting out support services.

[2]For instance, Elkomy et al. (2019) report that the share of contracted-out cleaning services across 130 English NHS trusts was 37% in 2013.

and private financing. For this reason, it has created a system of local trusts to oversee the implementation of local health services and initiated public service procurement through private finance initiatives (PFIs) that permit local trusts to seek out private capital funding and organize buildings and operations through private entities, called special purpose vehicles (SPVs).[3] Under PFI contracts, construction, and hard and soft facility services are delegated to SPVs through a fixed-term contract. In 2018, there were 128 PFI contracts outstanding by the Department of Health and Social Care with a capital value of GBP 12.9 billion, of which 109 were PFI-funded hospitals and care centers (NAO, 2020b).[4] This represents 10 percent of England hospitals and care centers. However, many SPVs do not deliver the quality of services prescribed in their contracts. As a case in point, four out of nine surveyed representatives of hospital authorities have declared their dissatisfaction with the condition of the hospitals they took over at the end of PFI contracts (NAO, 2020b). The deplorable state of hospitals can be attributed to various factors, such as faulty design, poor-quality building materials, lack of maintenance, and inferior workmanship. These issues often stem from opportunistic behavior due to information asymmetry among PFI contracting parties.

The economics literature emphasizes two types of information asymmetries according to whether private information is realized before or after the contract signature (Laffont & Martimort, 2002). In the hospital sector, adverse selection takes place when hospital authorities have less information than investors about future construction and operations at the procurement date. A moral hazard issue occurs when hospital investors and managers obtain private information about sanitary and economic conditions and hide their decisions and actions from authorities after contract signatures. Both issues are important and deserve extensive research attention (Laffont & Tirole, 1993). Nevertheless, this paper focuses on the moral hazard problem. Indeed, in the UK hospital sector, ex-ante information asymmetry seems less relevant as procurement procedures are competitive, procurement projects and contracts are supervised by government authorities with considerable expertise, and finally, many characteristics of recurrent investors are known to the authorities. In contrast, the risk of changing conditions after contract signature is important, as PFIs include long-term contracts spanning over 25 - 40 years, which provides ample room for uncertainty to materialize. This leads to substantial cost overruns and delivery delays, as

[3]This paper doesn't discuss the role of care quality commissions and integrated care systems. Nevertheless, they also play an essential role in developing national-level strategies and solutions to improve the health of the local population.

[4]The Departments for Education and of Health and Social Care sponsor the largest number of PFI contracts in England (NAO, 2020b).

shown in the documented cases of the Royal Liverpool University Hospital and Midland Metropolitan Hospital.[5]

Our research strategy naturally follows the literature on PPPs that consider moral hazard in the context of positive externalities between construction and operation tasks. Hart et al. (1997) point out that bundling these activities within the same entity allows for the internalization of such positive externalities. Scholars like Iossa and Martimort (2012, 2015), Martimort and Pouyet (2008), and Shi et al. (2020) have further explored the role of moral hazard in shaping the contract structures implemented in PPPs.[6] Nonetheless, this literature overlooks three important features of hospital facility management. First, hospital projects include three main tasks (building, hard FM, and soft FM services) rather than two (building and operation), as discussed in the literature.[7] Second, public and private operators regularly outsource their activities to private companies. Finally, the builder must offer a warranty, as prescribed by law and/or laid down in many construction contracts.

Our paper discusses these features in the classical framework of PPP analysis. To clarify the discussion, our analysis abstracts from the potential comparative advantages of outsourcing firms, where the latter benefit from cheaper labor. This is motivated by the fact that most authorities promote equal and fair working conditions within their organizations and those of their subcontractors.[8] Importantly, this analysis also allows us to clarify the main roles of risks and moral hazard between local health authorities, SPVs, and outsourcing firms concerning facility management services. This paper extends Iossa and Martimort (2015)'s model with a three-tier hierarchical principal-agent setup. It provides a theoretical basis for discussing the factors that explain optimal procurement policies for facility management services. Our discussion, therefore, intends to give guidance to

[5]According to NAO (2020a), delays in construction resulted in significant budget increases for two hospitals: the Royal Liverpool University Hospital and the Midland Metropolitan Hospital in Sandwelland. The Royal Liverpool University Hospital initially planned to start operations in June 2017, faced extensive delays, and was finally completed five years later in 2022. During this time period, the project's cost rose from £746 million to £1.06 billion. Likewise, the Midland Metropolitan Hospital experienced substantial delays, with its scheduled opening date of October 2018 being pushed back to July 2022. As a result of these delays, the project exceeded its original budget of £686 million by over £300 million. Similarly, Love and Ika (2022) conducted a study of the low performance of PFI hospitals in Australia. They identified various factors contributing to the underperformance of hospitals, including ineffective risk management and project governance as well as optimism bias.

[6]Recent studies on two-stage moral hazard include those of Buso and Greco (2023), Hoppe and Schmitz (2021), and Martimort and Straub (2016).

[7]A wider variety of tasks at the operating stage is common in other industries. All maintenance tasks may differ according to the quality of the asset and the importance of externalities.

[8]In particular, subcontractors are required to pay 'living wages' by the principle of fairness and nondiscrimination ('equal-work equal-pay'). This restriction also stems from the practical difficulty of managing similar workers with unequal remuneration in the same work environment.

authorities on the design of facility procurement and management.

Our model offers the following results. First, the foundation trusts' choice for PFI depends on the builder's warranty and hard FM risks.[9] There are three effects: the PFI internalizes the externality between builders and hard FM services; the PFI also requires a risk premium that may become too high under strong hard FM risks; finally, the builder's warranty creates a "reverse" moral hazard that is present in the traditional procurement and becomes stronger for higher hard FM risk. The PFI is then optimal for both sufficiently small and sufficiently high hard FM risks, while traditional procurement is preferred for intermediate risks. Second, traditional procurement gives authorities no incentive to outsource facility management services, whereas PFI structures offer such incentives for soft FM services. This result provides a simple rationale for why authorities taking over expired PFIs may return to an in-house provision of soft FM services. Finally, the PFI structure is adequate to monitor the hard FM and soft FM costs in SPVs but is not appropriate to monitor the benefits from quality enhancement in each task because the PFI contract structure does not have sufficient flexibility to monitor each type of quality benefit. This finding offers a new explanation for why insufficient quality is a recurrent issue in PFIs.

The paper is organized as follows. Section 2.2 presents a literature review, and Section 2.3 describes the major agents, history of facility management outsourcing in UK hospitals, and builders' warranty lasting. Section 2.3 lays down the baseline model and develops the salient properties of traditional procurement and PFI. Section 2.5 discusses the model calibration. Section 2.6 concludes the paper. Finally, appendices include analytical details, proofs, and calibration procedure.

2.2 Literature review

This paper relates to several strands of the economics literature. First, by discussing a multitask principal-agent problem, it relates to the economics literature on agency (Holmstrom & Milgrom, 1991). Agency theory is often not applied to the healthcare sector because of the complexity of hospital services and their management. Moreover, hospitals differ according to their sizes, equipment, and types (general acute hospitals, special medical hospitals, and others). They are also characterized by unclear objective

[9] We contend that decisions made by authorities at a certain level are significantly influenced by FM service risks. NAO (2020a), using the examples of Midland Metropolitan and Royal Liverpool hospitals, illustrates that the original expected share cost borne by taxpayers for building and maintaining hospitals is approximately equivalent to the share of construction costs out of the total expenses (43% and 50%, respectively).

functions because of the nexus of managers who pursue quite different interests: profit (Feldstein, 1988), quantity (Reder, 1965), social welfare (Feldstein, 1988), sales (Finkler, 1983), capacity (Lee, 1971; Newhouse, 1970) and income per doctor (Pauly, 1968; Pauly & Redisch, 1973). Nevertheless, our analysis partly abstracts from this difficulty by focusing on the provision of building and facility management services that are provided by trusts and facility management entities whose objectives are somewhat clearer. As will be explained, foundation trusts (henceforth FTs) are governed by a local representative system acting in favor of local health care benefits, whereas SPVs and outsourcing firms are private organizations that seek profits.[10]

This paper also contributes to the literature on privatization. Hart et al. (1997) develop the theory of incomplete contracts, which extends the idea of transaction costs pioneered by Williamson (1973, 1979) and that of property rights pioneered by Grossman and Hart (1986). These theories are built on the observation that agents are unable to write all unforeseen contingencies in their contracts. Hart et al. (1997) claim that private firms reduce their costs at the expense of quality. In-house provision becomes more efficient when the adverse consequences of cost-cutting on quality become large. This problem is relevant in the healthcare sector because the damage to care quality from cost-cutting can be important.

The subsequent literature has further discussed the costs and benefits of PPPs, in which private firms are asked to finance and participate in public projects. The literature recognizes the existence of externalities between the construction and operation of public facilities. When these externalities are positive, the bundling of the two tasks within the same organization and management improves economic efficiency, as the latter are enticed to internalize the externalities (Hart, 2003). Bennett and Iossa (2006) highlight that bundling is an optimal procurement type under positive externalities and unbundling is preferred in the case of negative externalities.[11] Hart (2003) further shows that bundling may indeed be undesirable if the quality of service cannot be well defined in the initial contract, which seems relevant in the case of hospitals. Martimort and Pouyet (2008) discuss ownership and find that bundling is preferred only if the externalities are positive and the private benefits of owning an asset are sufficiently small. Iossa and Martimort (2011) study the optimal payment mechanism for the transport industry and find that PPP projects are associated

[10]Essentially, we assume that the complexity of hospital medical affairs does not impact FT behavior concerning the procurement of facility management services.

[11]A positive externality appears when higher-quality building materials yield a cost reduction at the maintenance stage. A negative externality arises when fancier and costlier building designs imply an increase in maintenance costs.

with higher power incentives and more operational risk. Relatedly, Iossa and Martimort (2015) discuss the issue of procurement with moral hazards, agency costs, and risk sharing. They show that bundling and risk transfer are the key features of PPP arrangements and explain the high risk premium observed in those contracts. Välilä (2020) summarizes other theoretical and empirical papers closely related to the results of the previous studies. This paper contributes several important features of PFIs in the hospital sector: the existence of more than two tasks, the outsourcing of those tasks, and the structural warranty of builders.

Finally, this paper relates to the literature on outsourcing. The costs and benefits of outsourcing are discussed again through the lens of agency theory. Outsourcing enhances productive efficiency through stronger competition and higher incentives in ownership (Domberger & Piggott, 1986). Shleifer and Vishny (1994) mention the positive benefits of outsourcing, such as cost reduction and competition strengthening. Schmidt (1996) and Shapiro and Willig (1991) discuss the possibility of cost increases caused by multiple management channels. Laffont and Tirole (1993) highlight the information losses in contracts and the related worsening of the quality of services. This paper discusses a practical instance of information extraction and contracting.

Cost savings arguably constitute the main benefit that encourages public authorities to outsource services. Economics studies have evaluated the existence and magnitude of such cost savings through a comparison of per-unit costs before and after the launch of outsourced services (Hensher, 1989). However, such comparisons do not take into account confounding factors that impact costs, demand, technology, and input prices. Domberger et al. (1987) and Szymanski (1996) show that outsourcing refuse (i.e., solid waste) collection yields stronger cost reductions by for-profit than not-for-profit organizations.[12] In contrast, other authors conclude that competitive tendering is not cost-effective, reduces service standards and leads to cost reduction mainly through wage cuts and worse working conditions (Shaw et al., 1994).

The literature also discusses the benefits of soft FM services outsourcing in the health care sector. In 2022, health care is predominantly delivered in England via trusts and FTs that outsource various nonclinical tasks in hard FM and soft FM services. Cleaning is one of the most frequently outsourced functions across government institutions (Sasse et al., 2019). Despite its ubiquity across the public sector, empirical evidence of the efficiency of outsourcing cleaning services is mostly found within the healthcare sector. When cleaning was first outsourced, large savings were achieved. For example, Domberger et al. (1987)

[12] Bae (2010) and Bel and Costas (2006) find similar results for the USA and Spain.

report that competitive tendering of cleaning services by UK hospitals in the mid-1980s generated 34% savings when they were allocated to private providers and only 22% savings when they were assigned to the cleaning services of other public hospitals. More recent evidence also shows cost savings.[13]

Shohet (2003) advocates that the success of a maintenance outsourcing practice depends on hospital occupancy. Under high occupancy rates, facilities are subject to severe deterioration and require in-house staff to perform corrective maintenance. Under low occupancy rates, outsourcing creates efficiency gains by delegating non-core facility management activities to more cost-efficient firms. Ciarapica et al. (2008) show that employing outsourced personnel is costlier for small hospitals, while outsourcing services are more cost-efficient in large hospitals. Domberger et al. (1987) show that hospitals outsourcing cleaning, ward orderly and housekeeping services achieve 34% cost savings with private providers and 22% with public providers. Using audits and surveys, NAO (1987) generally find larger cost reductions with outsourcing to private organizations. Using panel data, Milne and Wright (2004) suggest that outsourcing reduces cleaning costs in Scottish NHS hospitals by 24.4% when outsourcing to for-profit firms and by 17% with not-for-profit firms. Angeles and Milne (2015) find that outsourcing is indeed more cost efficient. However, cost savings are not maintained for subsequent outsourcing contracts (Szymanski, 1996; Szymanski & Wilkins, 1993).

On balance, evidence about hard FM service cost savings suggests that greater private involvement leads to cost savings between 2% and 7%, even after controlling for quality (Blom-Hansen, 2003; Lindholst et al., 2018). An Australian survey from the late 1990s finds that public sector clients that outsource infrastructure maintenance report savings of 6.8% (Domberger & Fernandez, 1999). Moreover, Lindholst et al. (2018) claim that increased competition in bidding for maintenance contracts does not reduce costs, although this result may be due to market saturation.

[13] Angeles and Milne (2015) and Christoffersen et al. (2007) show cost savings of more than 25%. Milne and Wright (2004) and Toffolutti et al. (2017) find cost savings between 7.5% and 10%. Cost savings also depend on the extent of competition at the tendering stage, as each additional bidder can improve costs by an amount between 2.5% and 3.0% (Angeles & Milne, 2015; Milne & Wright, 2004). This possibility applies regardless of whether the final contract was awarded to a private or a public provider. Angeles and Milne (2015) demonstrate the persistence of savings in the cleaning sector. Private providers achieve greater and longer-lasting cost savings in subsequent tenders. The Auditor General for Scotland (2003) shows evidence that cost savings are achieved by employing fewer staff, which is associated with lower-quality cleaning. Toffolutti et al. (2017) also find empirical evidence of 28% higher rates of infection in hospitals with outsourced cleaning services. Bourn (2003) finds a slight decrease in quality for privately provided cleaning in Scottish hospitals.

Finally, the role of the builder's warranty has not been studied in the context of PPPs, particularly in the healthcare sector. Hospitals are complex entities requiring the involvement of multiple agents and are usually built under unique bespoke contracts in the UK. The number of collateral warranties signed by the agents participating in the agreement varies between the builder and corresponding suppliers, or in the case of PFI, between the design subcontractor and funder, the building contractor and authority, the building contractor and funder, or others.[14] Nevertheless, the builder's commitment to rectify construction snags during the building liability and limitation periods differs mainly with respect to the time frames. The economics literature covers warranties in the general product context (Cooper & Ross, 1985; Dybvig & Lutz, 1993; Emons, 1989), where warranties perform as insurance (Heal, 1977), signaling (Grossman, 1981; Lutz, 1989), or incentive motives (Priest, 1981; Spence, 1977) for agents. Studies explaining the role of defect warranties in the construction industry within agency theory offer limited discussion.[15] Ong (1997) claims that a longer defect warranty period, more stringent inspection standards, and restrictions on the ability to sell the property before its completion can alleviate the number of defects. He explains the limited effectiveness of defect warranties through the inability to meet a specific condition, which is necessary to eliminate the disincentive effects.

In summary, this paper expands the theoretical literature on agency theory, privatization, and public-private partnerships in several new directions. It also contributes to the literature on outsourcing to private firms.

2.3 Industry description

The National Health Service (NHS) is the national health care system of the United Kingdom. The organization is funded primarily by taxation and provides free or low-cost health care to all legal residents of the UK. For three decades, the NHS has decentralized the procurement of its hospital services through FTs. In this section, we explain the salient factors of this hospital provision.

[14] Our study does not discuss the role of structural warranty, which is usually provided by an external party. On the one hand, the construction methods are homogenous, i.e. building process, technology, and materials. On the other hand, home buyers' protection against defects is unique from country to country (Royal et al., 2021; Sommerville, 2008).

[15] Empirical studies typically examine the factors leading to defects during the post-handover period of newly built houses. See, for example, Pan and Thomas (2015) and Sommerville and McCosh (2006).

2.3.1 NHS trusts and foundation trusts

In January 1989, the British government published the "Working for Patients" white paper on health services (Secretaries of State for Social Services, Wales, Northern Ireland and Scotland., 1989). The paper changed the structure of the internal market for UK health care as it proposed transforming hospitals into self-governing NHS trusts. Health authorities then started to act as purchasers of health care services provided by NHS trusts. Each trust is run by a board of directors that oversees one or a few hospitals. From a legal viewpoint, an NHS trust is a public sector corporation that serves a geographical area or a specialized function (for instance, an ambulance service). NHS Trusts are established under the "National Health Service and Community Care Act 1990". However, since the Health and Social Care Act 2003, the NHS has transformed NHS trusts into NHS FTs to make those entities even more locally oriented. The transformation of these trusts is overseen by independent institutions sponsored by the NHS.[16] This change ensures elevated levels of services that hospitals must meet to qualify for the transformation. The new status gives trusts greater local autonomy in their governance through the election of local governors who nominate and supervise hospital management. It also grants greater autonomy to raise funds outside the NHS system and allows hospitals to provide services that were not available before within the NHS, such as home care.

Hence, at present, NHS trusts and NHS FTs are both present in the UK. As of 2022, there are 71 trusts and 145 FTs in England. The goal of the UK government is to foster the transition of all trusts into FTs. Although this target has not yet been achieved, the number of trusts has been decreasing and the number of FTs had been increasing. As shown in Fig. 2.1, the transformation process is (slowly) converging. This policy dictates our choice of the NHS FT as the principal object of our research. Thus, we will concentrate on NHS FTs.

2.3.2 FT mission

The Health and Social Care Act 2012 (hereafter abbreviated HSCA 2012) establishes the FT as a "public benefit corporation" whose principal purpose is "to provide goods and services for the purposes of the health service in England", more specifically, services "provided to individuals for or in connection with the prevention, diagnosis or treatment of illness" or linked to "the promotion and protection of public health" (Health and Social Care Act 2012,

[16] These regulatory institutions have included the NHS Trust Development Authority, Monitor, NHS Improvement, NHS England, and NHS England and Improvement. Some of these institutions have been active at different periods and have merged.

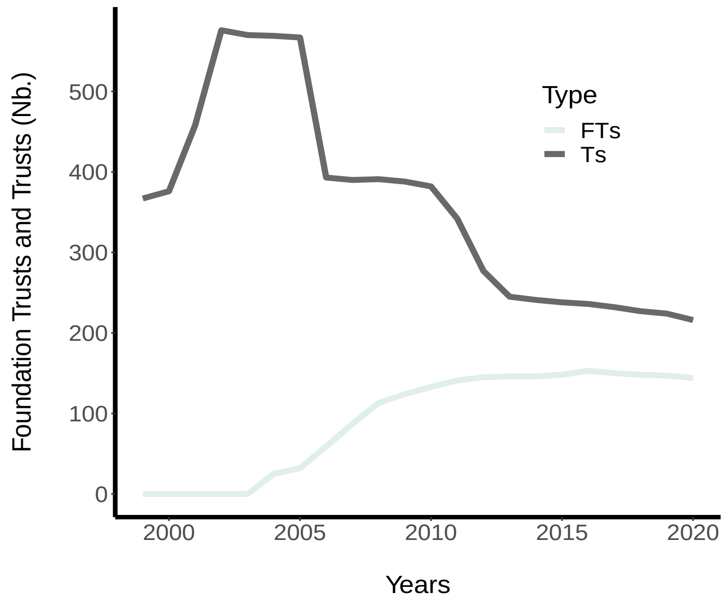


Figure 2.1: Numbers of Trusts and Foundation Trusts in England
Source: The Estates Return Information Collection (ERIC), NHS Digital.

c. 7, 2012, p. 158). The HSCA 2012 allows an FT to carry out any other activities if they generate additional income to successfully deliver its principal purposes. The Act sets an important criterion that determines fulfillment of the FT's principal purpose, i.e., "total income from the provision of goods and services for the purposes of the health service in England is greater than its total income from the provision of goods and services for any other purposes" (Health and Social Care Act 2012, c. 7, 2012, p. 163).

A pitfall of this criterion is the absence of methodology imposed to estimate and compare incomes from activities that may or may not be relevant to health services in England. The Act obliges each FT to mention in its annual reports how non-NHS goods and services have achieved the purposes of the FT. The "NHS Foundation Trust Annual Reporting Manual" also requires FTs to "include a statement in their annual report that they have met" this criterion (NHS England and NHS Improvement, 2022, p. 29). However, our research reveals that only one FT, the Norfolk and Norwich University Hospital NHS Foundation Trust, has mentioned the income generated from health services provision in their 2019 reports. In summary, this discussion suggests that despite some lack of reporting, FTs seek to maximize health services.

2.3.3 FT decision structure

FTs manage hospitals through the actions of their boards and chief executives. Each FT has two bodies: the Council of Governors (CoGs) and the Board of Directors (BoDs). The HSCA 2012 assigns the CoGs with the power to appoint leading actors to oversee the machinery of the FT while the BoDs are responsible for managing the day-to-day operations of hospitals.

The CoGs consist of elected and appointed governors. Elected governors are chosen by three constituencies, namely, the public, patients, and staff members. The constituency of public members comprises a set of residents who live in the area covered by the FT and voluntarily register and vote for a specific set of elected governors. They are split into geographical classes. The constituency of patients is formed only in a fraction of FTs and entails a set of individuals who have used the health services of the FT in recent years.[17] The constituency of staff members includes a set of members who are employees of the FT or exercise regular functions for the FT. They are split into professional classes (e.g., medical, dental, and nursing activities) and vote for another set of elected governors. In contrast, appointed governors are nominated by local authorities, universities, charities and/or clinical commissioning groups. In particular, the HSCA 2012 obliges FTs to appoint at least one member by the local authority and at least one member by a university when a medical or dental school belongs to any hospital managed by the FT. Although each FT's constitution freely defines the number of elected and appointed governors, the HSCA 2012 imposes a minimum of three governors for the constituency of the staff members or one for each of its professional classes. The Act also imposes that the constituency of staff members is permitted to elect less than half of the members of the CoGs. This restriction is seen as a fundamental feature of the promotion of a publicly oriented institution and devolution to local citizens. Figure 2 compares the numbers of governors in FTs in 2022 and confirms that elected governors form the strong majority of the members of CoGs.

Although the design of the FTs favors the interests of the local community, the representation of the public is weaker. Indeed, the election turnout and representation rate are significantly lower in the public constituency. As a case in point, Table 2.1 summarizes the 2020 voting sheets of the Manchester University FT election, where the cast and turnout numbers are much smaller for the public constituency.

We now describe the nomination and duties of the BoDs in charge of FTs' daily operation. The HSCA 2012 first empowers the CoGs to appoint a set of Non-Executive Directors (NEDs), one of whom becomes the Chairman. The NEDs and the Chairman are then called to elect

[17] In 2022, only 39 out of 145 FTs include a constituency of patients.

Table 2.1: Voting turnout and participation rates in Manchester University NHS FT (2020)

Constituency	Class	Governors	Eligible voters	Turnout	Population	Represen-tation rate
Public	Manchester	7	8799	7.1%	549123	0.11%
	Trafford	2	3451	11.0%	234140	0.16%
	Eastern Cheshire	1	1113	16.1%	382090	0.05%
	Rest of Greater Manchester	5	8065	6.3%	2811773	0.02%
	Rest of England and Wales	2	-	-		
	Total	19	21428	10.1%		
Staff	Medical and Dental	1	2358	16.3 %	2358	16.3 %
	Non-Clinical and Support	2	7540	9.6%	7540	9.6%
	Nursing and Midwifery	2	7517	7.0%	7517	7.0%
	Other Clinical	2	8869	6.7%	8869	6.7%
	Total	7	26224	9.9%		

Note: The representation rate is equal to the ratio of eligible voters times turnout divided by total population above age 11.
Source: Civica Election Services and Office for National Statistics.

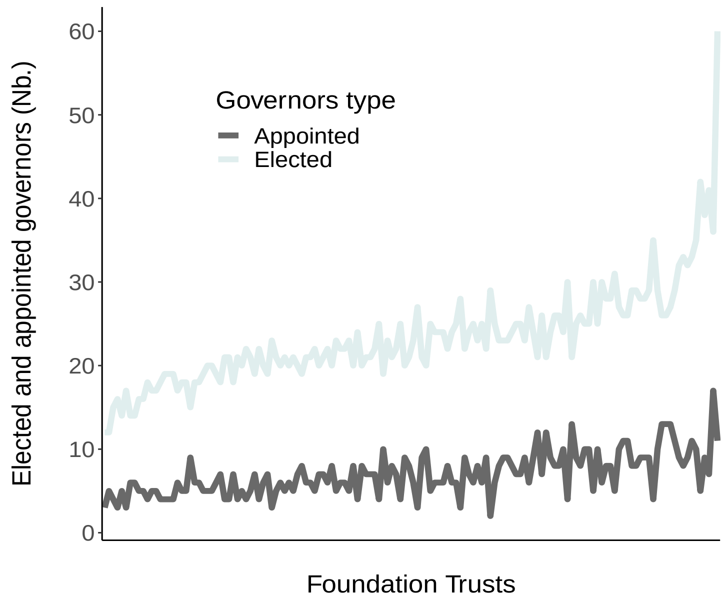


Figure 2.2: Numbers of elected and appointed governors in 2022
Note: The dark and light gray bars reports the number of elected and appointed governors in the FTs in England in 2022. Those numbers are extracted from the websites of the 145 FTs active in 2022.
Source: NHS Provider Directory.

the chief executive officer (CEO) with the approval of the CoGs. Finally, the chairman, the CEO, and the NEDs nominate another set of Executive Directors (EDs) for finance, medical practice, nursing and other functions, including a director for estates and facilities (i.e. hard FM and soft FM) when appropriate. According to the Act, the duty of the BoD is "to act with a view to promoting the success of the corporation so as to maximize the benefits for the members of the corporation as a whole and for the public" (Health and Social Care Act 2012, c. 7, 2012, p. 153).

Some questions arise about how to measure success and define the benefits of FTs. The success of an FT can indeed be assessed by a simple comparison of annual incomes. It can also be assessed by a comparison of performance indicators published by the FTs in their annual reports. Such comparisons are mostly not adequate because of FTs' heterogeneity in size and specialization. Their success can also be assessed by the finance and governance risk ratings that are published by independent regulators, which include patients' waiting times, transfer delays, experience feedback, etc.[18] Similar standardized indicators are reported in FTs' annual reports. However, FTs also report their own indicators. For example, the Manchester University Trust has created a monthly self-assessment audit tool called the Quality Care Round, which reports on cleanliness, communication, and infection control,

[18] See the regulatory institutions named in the footnote 16.

pain, patient safety, etc.

The above description suggests that FTs are governed by and for the interests of their public communities and staff members. Both groups' concerns regarding hard FM and soft FM services most generally coincide. Indeed, building conditions and cleanliness improve the experiences of both patients and staff members. However, the multiplicity of indicators and the absence of clear definitions for 'success' make challenging any prospect of a clear objective function for FTs.

2.3.4 Private finance initiatives

As the UK government struggled with rising healthcare costs in the 1980s, it created PFIs as an alternative form of procuring public hospitals, thus providing innovative ways to control costs and improve services. Under a PFI program, a trust or foundation trust tenders for a private firm, called the Special Purpose Vehicle (SPV), to finance and construct a new hospital, maintain the facility, and provide nonclinical services such as laundry, security, parking, and catering. The SPV receives annual payments for 15 - 25 years as reimbursement for its capital costs and its recurrent costs for maintenance and services. However, the authorities in charge still manage medical services.

An NHS trust or FT generally oversees more than one hospital and health care center. Hence, each trust and FT may hold several PFI contracts, generally one for each project at a hospital or health care center. Figure 3 displays the evolution of the number of projects at trusts and FTs. Around 20% of these projects are PFI projects while the majority continue to be implemented through traditional procurement methods.

2.3.5 Special purpose vehicles

The SPV is the legal entity that is the counterpart to a PFI project contract. It is a UK-incorporated limited company created for the PFI project and managing its activities. The FT contracts the SPV to implement the PFI project that shall build and maintain a hospital(s). The SPV is also in charge of financing the project with banks or bondholders. The SPV raises funds from lenders and shareholders and sets up its equity and debt levels. It usually chooses a high debt leverage that makes it averse to cost fluctuations resulting from the construction and operation risks that it bears on behalf of the FT. This risk transfer is reflected in the risk premium that is required in the contract with the FT.

Although the SPV formally has no employees, day-to-day management activities are

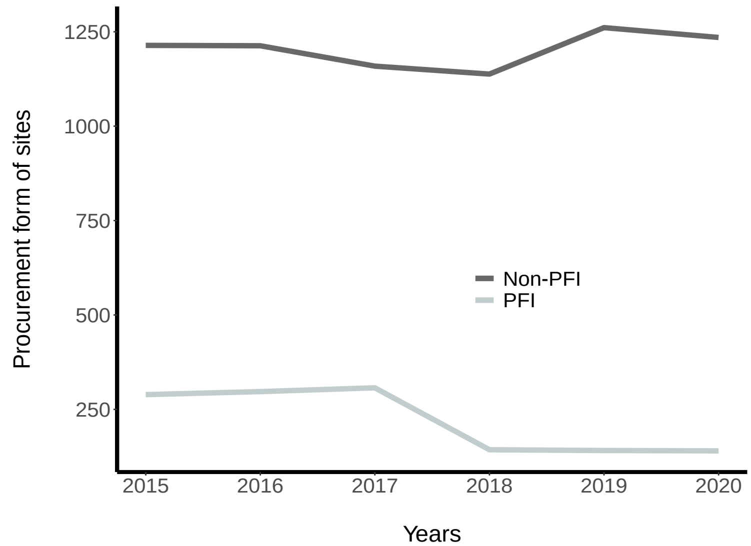


Figure 2.3: PFI and traditionally procured projects in England
Note: Light and dark gray represent the PFI and traditionally procured projects of NHS Trusts and FTs.
Source: Estates Return Information Collection dataset, NHS Digital.

subcontracted to a "management services company" with limited decision-making power. The shareholders of the SPV are the capital investors who participate in the tender for the PFI contract. Often, these investors are also the subcontractors of the SPVs, who are in charge of construction and hard FM services. SPVs are highly leveraged so that returns on investment are important and investors are averse to fluctuations of revenues and costs. The final PFI model is designed to be self-monitoring as the SPV is responsible for reporting the hospital's performance. In summary, the distinctiveness of the PFI is the strong collaboration between SPV investors, builders, and management service companies in setting up and operating an infrastructure project. This feature calls for understanding the SPV behavior as a risk-averse management team that bundles construction and hard FM tasks.

The authority pays back private investors using regular transfers, called unitary charges, only after the SPV has delivered its infrastructure. The unitary charges are linked to inflation and agreed upon at the start of the PFI contract. The PFI program permits the financing of public hospitals and therefore enables local authorities to free up resources for other public projects with insufficient capital budgets. NAO (2018) shows that the PFI increases budget flexibility in the short run while it does the opposite in the long term because PFI maintenance costs are growing over time and constrain government budgets again.

The main economic virtue of PFIs advocated in the literature is the bundling of hospital construction and hard FM services. Such bundling gives incentives to the private partners to reduce project costs between the construction and operation stages (Hart, 2003). Such cost savings, however, do not always happen because of the complexity and rigidity of the PFI contract. In addition, the collaboration between SPV stakeholders is not always very good. Indeed, cost-reducing and quality-enhancing interactions with construction and hard FM suppliers have been prevented by the management and investors of the SPV (including creditors) (NAO, 2018). Finally, the maintenance risk is fully transferred to the private sector as the SPV must repair and replace assets' facilities during the contract.[19] As mentioned, this fact induces additional costs that are reflected in the risk premium negotiated in the PFI contract.[20]

2.3.6 Outsourcing facility management

There is always a need for NHS provider organizations to consider what actions they can undertake to deliver long-term financial viability (NHS, 2019). One initiative could be outsourcing to provide nonclinical services.

Contracting out of public services began in the late 1970s (Trades Union Congress, 2015). Margaret Thatcher's government officially instructed health authorities to introduce competitive tendering for all support services in 1983 (Toffolutti et al., 2017), with the main objective to make "maximum possible savings by putting services like laundry, catering, and hospital cleaning out to competitive tender" (Conservative party, 1983). The introduction of compulsory competitive tendering in the local government by the Local Government Acts 1988 and 1992 initiated a move by both the central and local governments to outsource services to private sector providers (Trades Union Congress, 2015).

In the case of hospital FTs, the structure of the outsourcing process is as follows. The decision to outsource is made by the BoD on the recommendations of the hard FM and soft FM teams. The decision is argued by an appraisal exercise and business case that assess the costs and benefits. In practice, the decision is based mostly on price, quality of service, implementation, innovation and technology. A key feature of outsourcing contracts is the existence of a "service level agreement" where the quality and volume of services are described in detail. The contracts define key performance indicators (KPIs) that the

[19] As a case in point, the Committee (2011, p. 29) states that "the obvious risks to transfer to the private sector are those they are best able to manage and cost. So infrastructure construction risks (delay, price, quality), infrastructure maintenance risks, infrastructure operating risks, and infrastructure financing risks are best put to the private sector rather than retained in the public sector".

[20] Some observers have reported additional cost items that raise the total cost of the PFI. For NAO (2018), insurance, cash management, external advisers, lender fees, management and administration fees are also important cost items specific to PFIs.

Table 2.2: Outsourcing of laundry and linen services within healthcare sites in England

	2017		2018		2019		2020	
Procurement type (%)	PFI	Trad.l	PFI	Trad.	PFI	Trad.	PFI	Trad.
Outsourced	0.83	0.77	0.83	0.77	0.82	0.76	0.83	0.80
Mix in-house/outsourced	0.17	0.23	0.17	0.23	0.18	0.24	0.17	0.20
In-house	0.08	0.12	0.08	0.11	0.07	0.10	0.06	0.02

Note: Trad. means traditional procurement.
Source: Estates Returns Information Collection dataset, NHS Digital.

firm must achieve to avoid penalties. This feature contrasts with the objectives of in-house facility management services that are often poorly documented.

The outsourcing process varies according to the number of outsourced services, contracts, and suppliers (Ancarani & Capaldo, 2005). In the majority of cases, a contract specifies a bundle of services. Some suppliers accept more than one contract. In UK hospital facility management, outsourcing contracts have an average duration of four or five years (Wiggins, 2020). The FT organizes a tender for each contract. Various private firms usually participate in the tendering process while bids by other public firms are also invited.

Payments to outsourcing firms differ according to each FT and facility management service. There is no standard model for outsourcing contracts. The latter are bespoke according to the objectives of the FT or SPV. They vary from fixed cost, cost plus and cost plus guarantee to fixed cost per user, performance-based, and 'Nil' subsidy (Wiggins, 2020). Penalties are foreseen for the cases where outsourcing firms do not achieve the KPIs. In our model below, we simplify the contract complexity by assuming that KPI are always met. Moreover, we consider two contracts that separately bundle the tasks of hard FM and soft FM services.

Outsourcing is present in both PFIs and traditionally procured hospitals. However, it is more important in PFIs. Table 2.2 shows that laundry and linen services are more often outsourced in PFIs. Traditional procurement uses more in-house delivery. Rationals in this context are studied in the theoretical model below.

2.3.7 Builder's warranty

Once the construction of a hospital is completed, a certificate of practical completion is issued and triggers the start of a "rectification period" (defects liability period). It typically lasts from 6 to 24 months for traditionally procured hospitals and 12 months for PFI contracts (HM Treasury, 2007). During this period, the hospital's owner, the FT, can require the builder to remedy defects in the works that have been carried out under the contract at its own cost. The rectification period is not the end of a contractor's liability for defects arising in its works. Afterward, the builder bears statutory responsibility for rectification of defects that may arise in workmanship and materials, which lasts for a "limitation period" of 6 to 12 years, depending on the contract type (Limitation Act 1980, c. 58, 1980). Moreover, manufacturers issue an additional warranty on materials used by the constructor, e.g., roof, windows, building envelope, etc. For example, roofing constructors often install a single polymembrane roof on which the manufacturer provides a 20-year warranty. If there are issues with the roof during the defects liability period, the builder would be obliged to rectify the defects at no cost to the FT. During the limitation period thereafter, there is an option to pursue the original contractor for defects in either workmanship or materials or as an alternative to rely on the manufacturer's warranty.

2.4 The model

In this section, we present the decision variables and payoffs of the foundation trust, Private Finance Initiative entity, hospitals, and outsourcing firms. We first study the first-best allocation as a benchmark case and then discuss traditional procurement and PFI.

The FT chooses between traditional procurement and PFI contract.[21] The FT represents the authority's interests and maximizes the social net benefit. It is assumed to be risk-neutral.[22] In contrast, the builder and outsourcing facility management firms are entities run by risk-averse managers endowed with the utility function $u(x) = -e^{-\rho x}$, where $x \in \mathbb{R}^+$

[21] For simplicity, we do not model an extensive decision procedure of the NHS hospital procurement choice. In reality, for all capital projects that cost over GBP 25 (40 million from 2004), the FT must develop a Strategic Outline Case (SOC). This case discusses the FT's strategic context, health services needs, formulation of options, and cost affordability. This document states and evaluates funding options, procurement routes, and PFI costs and benefits. The Department of Health approves or rejects SOC, considering the risk assessment delivered by Monitor, an executive non-departmental public body sponsored by the Department of Health. Subsequently, HM Treasury endorses the SOC. A similar course of action is taken to validate the Outline Business Case (OBS) before publication in the Official Journal of the European Communities (OJEC), which leads to a call for an official bidding process.

[22] The FT has significant independence from the Department of Health because it has the power to retain and redistribute project surpluses, as well as borrow money and reinvest it across its projects. Furthermore, including PFIs in the FTs' governance brings additional support from the Department of Health. For instance, in February 2012, seven FTs with 'unaffordable' PFI schemes were eligible for central support for their PFI-related costs (NAO, 2012b). For FTs not involved in PFI management, there is always an opportunity to develop new business in case of financial balance breaches. Moreover, the regulating institution Monitor identifies and assesses governance and financial risks in FTs. If Monitor discovers that any FT breaches their regulatory conditions (governance or financial), it can intervene, e.g. by forcing FTs to an independent review of their governance arrangements or by requiring them to develop a recovery plan (of Public Accounts, 2014).

is their income and $\rho > 0$ is their (common) constant absolute risk aversion parameter ($\rho = -u''/u'$).[23] Random variables are denoted by a tilda $\sim$. When the deterministic income x is added, an i.i.d. random shock $\widetilde{\varepsilon}$, that follows a normal distribution with zero mean and variance σ^2, the expected utility $\mathrm{E}\left[u(x + y\widetilde{\varepsilon})\right]$ with $y \in \mathbb{R}$ is given by $u\left(x - \frac{1}{2}\rho\sigma^2 y^2\right)$ (see the Appendix A1). The expression $x - \frac{1}{2}\rho\sigma^2 y^2$ is referred to as the certainty equivalent. The term $\rho\sigma^2 y^2/2$ is the risk premium. This premium is nil in the absence of risk aversion. All managers have an outside option with zero values.

Hospital activity yields the social benefit

$$B = b_0 + b_B e_B + b_H e_H + b_S e_S, \tag{2.1}$$

where $b_0 \geq 0$ is the social benefit that the hospital generates in the absence of efforts from any agent. For instance, this value represents the benefit from hospital beds that the FT supplies in its particular region. The social benefit may increase with the builder's effort in enhancing the building *quality* ($e_B \geq 0$) and with the hard FM and soft FM managers' efforts in raising the *quality* of hard and soft facility services (e_H, $e_S \geq 0$).[24] These benefits represent the construction quality, the speed of the repair of the building and its facilities, and the quality of the catered food or the friendliness of the cleaning staff. All marginal benefits from quality enhancements are positive ($b_B, b_H, b_S > 0$).[25] Importantly, we assume in this text that this type of quality items cannot be contracted upon.[26]

The soft FM takes care of catering, cleaning, car parking, etc., at an observable, verifiable, and idiosyncratic cost

$$\widetilde{C}_S = \gamma_0 - \gamma_S e_S + \widetilde{\varepsilon}_S, \tag{2.2}$$

where $\gamma_0 \geq 0$ is the base level expenses of soft FM services and $\widetilde{\varepsilon}_S$ is an i.i.d. random shock that is normally distributed with zero mean and variance σ_S^2. The cost of soft FM depends

[23]The risk-aversion of outsourcing firm managers stems from their reputation risk. They sign contracts with the FT on a 5-year basis with the expectation of a prolongation in case of satisfactory services. The SPVs are highly indebted and can be punished for unsatisfactory services by reduced unitary-charge payments. The CARA utility function is convenient when the environment is multitasked and contracts are linear in their variables (see Holmstrom and Milgrom (1987, 1991).

[24]In particular, for soft FM services, including chocolate on the patients' menu could increase their happiness level; for hard FM services, the color of the walls and paintings in the ensuite rooms stimulate the patients' mood.

[25]In other words, social benefit growth follows a rise in infrastructure quality-enhancing, hard FM, and soft FM efforts.

[26]Other types of quality items can be contracted upon, for example, with KPIs: the concrete chemical composition, the calory content of food, the nurse presence, patients-perceived service quality, etc. Those are assumed to be included in the term b_0.

only on the efforts of its manager, which is measured by the parameter γ_S.[27] She exerts the unobservable and unverifiable effort e_S and incurs a private cost equal to $e_S^2/2$. When she receives a transfer T_S, her utility is given by $u(T_S - \widetilde{C}_S - e_S^2/2)$.

The hard FM manager takes care of hospital building maintenance and incurs an observable, verifiable, and idiosyncratic cost given by

$$\widetilde{C}_H = \delta_0 - \delta_B e_B - \delta_H e_H + \widetilde{\varepsilon}_H, \tag{2.3}$$

where e_B and e_H represent the efforts of the builder and hard FM manager, respectively. In this expression, $\delta_0 \geq 0$ represents the base-level expenses of hard FM services. The cost is subject to an i.i.d. random shock, $\widetilde{\varepsilon}_H$, is normally distributed with zero mean and variance σ_H^2. The hard FM costs decrease with the effort of the manager ($\delta_H > 0$). The model also includes a positive externality between the builder and hard FM through the parameter $\delta_B > 0$. For example, the selection of a more costly but more reliable lift, roof, window, etc., reduces the costs of their maintenance.[28] For several years after the construction, the hard FM can use the warranty for building defects so that the builder pays to fix those problems. We capture this fact in the assumption that the hard FM services bear the share $\theta \in [0, 1]$ of the hard FM's verifiable cost while the builder covers the remainder.[29] A full warranty ($\theta = 0$) implies insurance by the builder for the entire period of asset management. In contrast, the absence of the builder's warranty ($\theta = 1$) gives the whole responsibility to the operator if a shock occurs during this period.[30] The builder's insurance coverage period expands with smaller θ. Finally, the hard FM exerts the unobservable and unverifiable effort e_H with a private cost equal to $e_H^2/2$. When he receives a transfer T_H, the hard FM manager has a utility given by $u(T_H - \theta\widetilde{C}_H - e_H^2/2)$.

In this text, we do not discuss the risk in the construction process borne by the builder because we focus on the issue of FM services. We therefore consider that the production cost of the hospital building has a deterministic value $\phi_0 > 0$. The builder nevertheless covers the idiosyncratic cost of hard FM services through the warranty. The builder's cost is

[27] For simplicity, we assume no impact of the builder's effort on soft FM services.

[28] In practice, the builder's effort has a large impact on hard FM services but a small impact on soft FM services. For instance, combined heat and power systems reduce the cost of hard FM services. These systems implement energy-efficient technologies that capture the heat, and generate electricity and thermal energy that is used for space heating, cooling, domestic hot water, and industrial processes.

[29] Consider a 40-year hospital project with a 10-year warranty and with hard FM maintaining only the hospital structure. This case would give a value of $\theta = 10/40$.

[30] In practice, the builder's warranty decreases with time, stopping after a definite period. Such a pattern does not qualitatively alter our results in a PFI since the PFI remains responsible for the hospital defects until the contract ends. See below.

therefore equal to

$$\widetilde{C}_B = \phi_0 + (1-\theta)\,\widetilde{C}_H. \tag{2.4}$$

The builder can improve the building quality by exerting an effort e_B that will impact facility management. This effort is neither observable nor verifiable and can therefore not be contracted. The cost of his effort is given by $e_B^2/2$. When he receives a monetary transfer T_B, the builder has a utility equal to $u\left(T_B - \widetilde{C}_B - e_B^2/2\right)$.

Finally, the FT has a payoff that depends on the hospital social benefit B and the costs and transfers during the project. We look at two scenarios in which the FT delivers the hospital either in a traditional way or through a PFI contract. In the first scenario, the FT builds and maintains the hospital using public funding. It delegates the construction work and either provides in-house hospital maintenance or outsources the work. In the second scenario, the FT makes a take-or-leave-it contract to an SPV, which is a consortium of builders and hard FM service firms. The SPV then acts as the hospital's management company and its management makes decisions at both the construction and operating stages. SPVs are usually highly leveraged and avoid generating losses. To capture the fact that their management teams are very careful about idiosyncratic cost overruns, we assume that the SPV consortium management is risk-averse. For simplicity, we assume the latter has the same risk aversion parameter ρ as the other managers. The SPV has the possibility to outsource soft FM services.[31] Before discussing those scenarios, we first analyze the optimal net benefit when the FT is able to exert efforts by itself.

2.4.1 First-best

We begin by discussing the effort levels in the first-best allocation. We show that those effort levels increase with the unit benefit and unit cost of effort while the type of warranty doesn't matter.

In the first-best, the FT performs all construction and maintenance tasks by itself and incurs the cost of the respective efforts.[32] It is represented by the following program:

$$\max_{e_B(\cdot),e_H(\cdot),e_S(\cdot)} \mathrm{E}[B - \widetilde{C}_B - \theta\widetilde{C}_H - \widetilde{C}_S - \frac{1}{2}e_B(\cdot)^2 - \frac{1}{2}e_H(\cdot)^2 - \frac{1}{2}e_S(\cdot)^2], \tag{2.5}$$

where $\mathrm{E}[\cdot]$ denotes the expectation operator over both random variables $\widetilde{\varepsilon}_H$ and $\widetilde{\varepsilon}_S$, while

[31]The SPV does not outsource hard FM services under PFI to internalize the positive externality generated between builders and hard FM services.

[32]The FT can achieve this outcome by observing efforts and offering contracts after the shock realizations.

$e_i(\cdot)$, $i \in \{B, H, S\}$, denotes the effort levels as functions of the realization of the random variables. Since random shocks are linear in the above objective function, the optimal effort levels are independent of the shocks. Solving the order conditions of this objective function gives the following first-best effort levels:

$$e_B^{FB} = b_B + \delta_B \qquad \text{and} \qquad e_H^{FB} = b_H + \delta_H \qquad \text{and} \qquad e_S^{FB} = b_S + \gamma_S. \tag{2.6}$$

The first-best efforts increase with the marginal benefits from quality enhancement (b_B, b_H, b_S) and marginal cost reduction of efforts in each task $(\delta_B, \delta_H, \gamma_S)$. The first-best net benefit is then written as

$$W^{FB} = b_0 - \phi_0 - \delta_0 - \gamma_0 + \frac{1}{2}(b_B + \gamma_B)^2 + \frac{1}{2}(b_S + \gamma_S)^2 + \frac{1}{2}(b_H + \gamma_H)^2.$$

The first three terms report benefit and cost in the absence of effort. The next three terms then reflect the net benefit from efforts in quality enhancement and cost reduction.

2.4.2 Traditional procurement

We now study the case of traditional procurement of UK hospitals. Under traditional procurement, the FT delegates the realization of hospital construction to the builder. After the construction is terminated, the FT either performs the hard FM and soft FM services in-house or outsources them. The FT proposes compensations that are linked to observed costs. We first describe the compensation structure and the objective and constraints of the FT and then solve the equilibrium by backward induction. We highlight the FT's incentives for in-house hard FM and soft FM services and the presence of a "reverse" moral hazard generated by the builder's warranty.

The FT proposes a contract to the builder that links the compensation with the observed costs. We consider that the FT offers a fixed payment contract $t_B = \alpha_B \in \mathbb{R}$. Under outsourcing, the contracts to the hard FM and soft FM depend on their respective shares of verifiable costs: $t_H(\widetilde{C}_H) = \alpha_H + (1 - \beta_H)\left(\theta \widetilde{C}_H\right)$ and $t_S(\widetilde{C}_S) = \alpha_S + (1 - \beta_S)\widetilde{C}_S$, where α_H and $\alpha_S \in \mathbb{R}$ are fixed compensations and β_H and $\beta_S \in [0, 1]$ measure the powers of the contracts.[33] When these powers are nil, the transfers fully reimburse the costs and

[33] In the healthcare sector, it is common for the government to provide full-cost coverage contracts for facility management services. However, if either hard FM or soft FM firms fail to meet all the agreed Key Performance Indicators (KPIs) outlined in the contract and incur penalties, this would be considered in our model as an instance where the government does not fully cover costs. For more information on PFI payment mechanisms and performance measurement methods under a PFI, refer to Oyedele (2013).

give no incentives to the agents to reduce their costs. When these powers equal one, the transfers do not repay for the costs and entice the agents to reduce their costs. Note that the cost structure is the same in traditional procurement and outsourcing, as FTs make the commitment to offer equal wages for equal work to employees of the FTs and outsourcing firms. The FT's problem is therefore to choose whether to outsource hard FM and soft FM activities or not and to set the contract variables $(\alpha_B, \alpha_H, \alpha_S, \beta_H, \beta_S)$ that maximize its social net benefit and entice the builder and possible outsourcing hard FM and soft FM firms to accept their contracts.

Let us denote by V the net benefit in the second stage when the builder's effort is realized. Hence, the FT solves the following maximization program:

$$W^* = \max_{\alpha_B} \mathrm{E}[V - t_B]$$

subject to the builder's participation and incentive constraints

$$\max_{e_B(\cdot)\geq 0} \mathrm{E}\left[u(t_B - \widetilde{C}_B - e_B(\cdot)^2/2)\right] \geq u(0).$$

In the second stage, the FT chooses a type of FM procurement that brings the highest net benefit level:

$$V = \max_{k,l\in\{i,o\}} V^{kl},$$

where the superscripts ^{o} and ^{i} respectively denote the outsourcing and in-house delivery of hard FM and soft FM services. First, insourcing hard FM and soft FM implies

$$V^{ii} \equiv \max_{\{e_H(\cdot),e_S(\cdot)\}} \mathrm{E}[B - \theta\widetilde{C}_H - e_H(\cdot)^2/2 - \widetilde{C}_S - e_S(\cdot)^2/2].$$

Second, outsourcing hard FM and insourcing soft FM involve

$$\begin{aligned} V^{oi} \equiv \max_{\{e_S(\cdot),\alpha_H,\beta_H\}} & \mathrm{E}[B - t_H(\widetilde{C}_H) - \widetilde{C}_S - e_S(\cdot)^2/2] \\ \text{s.t. } & \mathrm{E}[\max_{e_H(\cdot)} u(t_H(\widetilde{C}_H) - \theta\widetilde{C}_H - e_H(\cdot)^2/2)] \geq u(0). \end{aligned}$$

Third, outsourcing soft FM and insourcing hard FM imply

$$
\begin{aligned}
V^{io} \equiv & \max_{\{e_H(\cdot),\alpha_S,\beta_S\}} \mathrm{E}[B - \theta\widetilde{C}_H - \frac{e_H^2}{2} - t_S(\widetilde{C}_S)] \\
& \text{s.t. } \mathrm{E}[\max_{e_S(\cdot)} u(t_S(\widetilde{C}_S) - \widetilde{C}_S - e_S(\cdot)^2/2)] \geq u(0).
\end{aligned}
$$

Finally, outsourcing both soft FM and hard FM is defined by

$$
\begin{aligned}
V^{oo} \equiv & \max_{\{\alpha_H,\beta_H,\alpha_S,\beta_S\}} \mathrm{E}[B - t_H(\widetilde{C}_H) - t_S(\widetilde{C}_S)] \\
& \text{s.t.. } E[\max_{e_H(\cdot)} u(t_H(\widetilde{C}_H) - \theta\widetilde{C}_H - e_H(\cdot)^2/2)] \geq u(0), \\
& \qquad E[\max_{e_S(\cdot)} u(t_S(\widetilde{C}_S) - \widetilde{C}_S - e_S(\cdot)^2/2)] \geq u(0).
\end{aligned}
$$

We first solve the second stage of this program and show that in-house facility management is preferred by the FT. We then solve the first stage with the FT's agency issue with the builder.

Second stage

In the second stage, the FT maximizes the net social benefit V by choosing the procurement type of facility management services. In the case of outsourcing, the risk-neutral FT must offer a risk premium to the risk-averse outsourcing firms to entice them to participate. It also faces a moral hazard problem because it loses control of the effort levels in outsourcing firms, which shifts the cost distributions. However, the choice of contract parameters allows the FT to partly alleviate this issue. It turns out that outsourcing is not a good option. We explain this finding in the following paragraphs. The analytical details are provided in the Appendix B1 .

Under traditional procurement, the FT perfectly monitors the effort of in-house facility management services. In contrast, when the FT outsources hard FM services, it pays a risk premium to the hard FM manager, which can be shown to be equal to $\rho\beta_H^2\theta^2\sigma_H^2/2$ and therefore to increase with risk variance and contract power β_H. Considering this premium, the FT sets the contract power to $\beta_H^o = \delta_H(b_H + \theta\delta_H)/\left[\theta\left(\delta_H^2 + \rho\sigma_H^2\right)\right]$, which falls with higher risk to mitigate the risk premium. Finally, the hard FM manager chooses an effort equal to $e_H^o = \delta_H^2(b_H + \theta\delta_H)/\left(\delta_H^2 + \rho\sigma_H^2\right)$, which also decreases with risk variance. Hence, outsourcing leads to an effort level that decreases with stronger risk. Efforts and payoffs can be computed for each outsourcing configuration. The second stage payoff of the FT is given by

$$V^{kl*} = b_0 - (\theta\delta_0 + \gamma_0 + \phi_0) + (b_B + \theta\delta_B)e_B + \frac{I_H^k}{2}(b_H + \theta\delta_H)^2 + \frac{I_S^l}{2}(b_S + \gamma_S)^2$$

where

$$I_H^k = \begin{cases} 1 & \text{if} \quad k = i \\ \frac{\delta_H^2}{\delta_H^2 + \rho_H \sigma_H^2} < 1 & \text{if} \quad k = o \end{cases}$$

and

$$I_S^l = \begin{cases} 1 & \text{if} \quad l = i \\ \frac{\gamma_S^2}{\gamma_S^2 + \rho_S \sigma_S^2} < 1 & \text{if} \quad l = o \end{cases}.$$

To get intuition, assume no warranty so that the hard FM pays the full cost of its services: $\theta = 1$. Then, in the absence of risk ($\sigma_H^2 = \sigma_S^2 = 0$), the FT achieves the same net benefit from facility management services as in the first-best (see the last two terms in V^{kl*}). Outsourcing facility management yields the first-best outcome, as contracts can be set to encourage adequate efforts. However, in the presence of risk, the FT must compensate for risk-taking and therefore reduce the power of the contracts so that the net benefit falls (as I_H^k falls). The last expression shows that outsourcing is always more costly for the FT and in-house procurement is preferred. Therefore, $V^* = V^{*ii}$. To sum up, the FT's outsourcing decision depends on FM risks and their costs. The FT is unlikely to outsource given the risk premium it is obliged to grant to outside firms.

Proposition 1. *Under traditional procurement, the FT delivers the hard FM and soft FM services in-house.*

First stage

In the first stage, the FT chooses to maximize the net benefit V^* subject to the incentive and participation constraints of the builder. In equilibrium, the builder exerts the effort level $e_B^* = \delta_B(1-\theta)$. The builder indeed has an incentive to exert a positive effort because his effort decreases the hard FM cost, which in turn reduces his cost of the warranty. Finally, the FT sets the fixed compensation α_B such that the builder participates. Consequently, the FT obtains the net benefit

$$\begin{aligned} \mathrm{E}W^* = b_0 - (\delta_0 + \gamma_0 + \phi_0) + \frac{1}{2}(b_S + \gamma_S)^2 + \frac{1}{2}(b_H + \delta_H)^2 \\ + \frac{1}{2}(1-\theta)\left[2\delta_B b_B + (1+\theta)\delta_B^2 - (1-\theta)\delta_H^2\right] \end{aligned}$$

$$- \frac{1}{2}\rho\left(1-\theta\right)^{2}\sigma_{H}^{2}.$$

In the absence of a warranty ($\theta = 1$) and hard FM risk ($\sigma_H^2 = 0$), this expression matches the first-best net benefit achieved in hard FM and soft FM services (see the first line). The FT exerts adequate efforts in hard FM and soft FM but is unable to entice efforts in the building process.

In the presence of the warranty ($\theta > 0$), two effects are apparent. On the one hand, the hard FM risk decreases the net benefit because the FT must compensate the builder for the hard FM risk after construction (see the third line). On the other hand, the warranty also incentivizes the builder to internalize the cost of hard FM services (second line). However, this effect is not clear because the warranty gives the hard FM manager lower incentives to exert effort. Indeed, there exists a 'reverse' moral hazard as the warranty shifts to the builder a share of the hard FM cost that is also subject to the effort exerted by the hard FM manager. To fix ideas, suppose that the builder's effort does not impact the benefit ($b_B = 0$). In this case, the second line in the above expression simplifies to $(1-\theta)\left(\delta_B^2 - \delta_H^2\right)/2$. Accordingly, a (further) strengthening of the warranty increases the FT's net benefit if and only if $\delta_B > \delta_H$, that is, if the externality between building and hard FM services is strong enough compared to the possible cost reduction of hard FM services. Otherwise, it decreases the FT's net benefit.

2.4.3 Private finance initiative

We now study the PFI contracts in which the FT delegates hospitals' construction and operation to a consortium of building and management entities. We highlight the consortium's incentive to outsource soft FM services and the FT's incentives to use higher power contracts when quality enhancements impact the FT's benefit. We first describe the PFI's institutional and contract structures and present the FT's objective and constraints. We then solve the game by backward induction and discuss the equilibrium decisions and payoffs.

In a PFI, the project is implemented by the SPV consortium that represents the interests of both the builder and hard FM firm. The SPV collects the transfers and pays its costs. The FT observes and verifies the costs of building and facility services, $\widetilde{C}_B$, $\widetilde{C}_S$ and $\widetilde{C}_H$. It offers the SPV a contract based on reported cost; that is, $t(\widetilde{C}_B, \widetilde{C}_S, \widetilde{C}_H) = \alpha + (1-\beta)(\widetilde{C}_B + \theta\widetilde{C}_H + \widetilde{C}_S)$

where α is fixed compensation and β is the power of the contract ($\beta > 0$).[34] In turn, the SPV management supervises the construction of the hospital and runs the facility management services. Because of its structure, the SPV supervises the construction and supplies hard FM services in-house. However, it can operate soft FM services outside its structure. In this case, the contract structure between the SPV and soft FM firm is given by the transfer scheme $t_S(\widetilde{C}_S) = \alpha_S + (1 - \beta_S)\widetilde{C}_S$, where α_S and β_S represent the fixed compensation and power of this contract. Note that the cost structures of the SPV and outsourcing firms are the same as in traditional procurement because, in practice, most FTs are committed to the equal-work equal-pay principle. Additionally, cost verifiability is also identical in both the SPVs and outsourcing firms.

The FT maximizes the net benefit from the hospital project. That is,

$$W^{**} = \max_{\alpha,\beta} \mathrm{E}\left[B - t(\widetilde{C}_B, \widetilde{C}_S, \widetilde{C}_H)\right]$$

subject to the SPV's outsourcing choice

$$\max \{V^i, V^o\} \geq u(0)$$

where, under in-house soft FM, the SPV management has utility

$$V^i = \max_{e_B(\cdot), e_H(\cdot), e_S(\cdot)} \mathrm{E}\ u[t(\widetilde{C}_B, \widetilde{C}_S, \widetilde{C}_H) - \widetilde{C}_B - \frac{e_B(\cdot)^2}{2} - \theta\widetilde{C}_H - \frac{e_H(\cdot)^2}{2} - \widetilde{C}_S - \frac{e_S(\cdot)^2}{2}] \geq u(0)$$

and, under outsourced soft FM, it obtains

$$V^o = \max_{e_B(\cdot), e_{H(\cdot)}, \alpha_S, \beta_S} \mathrm{E}\ u[t(\widetilde{C}_B, \widetilde{C}_S, \widetilde{C}_H) - \widetilde{C}_B - \frac{e_B(\cdot)^2}{2} - \theta\widetilde{C}_H - \frac{e_H(\cdot)^2}{2} - t_S(\widetilde{C}_S)] \geq u(0)$$

s.t.

$$\mathrm{E}\ [\max_{e_S(\cdot)} u(t_S(\widetilde{C}_S) - \widetilde{C}_S - \frac{e_S(\cdot)^2}{2})] \geq u(0).$$

[34] In our model, we focus on PFI contracts conditioned on cost rather than quality. We justify this approach by examining the unitary charge payments made to reimburse the SPV for its operating expenses. While these payments are often linked to KPIs, we assume that contracts can be treated as cost-oriented for two main reasons. First, the penalties or deductions associated with failing KPIs tend to be small and can be reduced by renegotiation or compensation for additional services (Robinson & Scott, 2009). As an example, Pollock and Price (2008, p. 176) quote an NAO report: "Twelve of the nineteen first-wave PFI hospitals did not believe that the level of deduction that they can impose is sufficient to incentivize the contractors to provide a satisfactory level of performance". Second, the interpretation of output/performance specifications often hinders the FT from accurately assessing the agent's effort level (Robinson & Scott, 2009). Iossa and Martimort (2012, 2015) extensively discuss models with compensation conditional on KPIs.

As discussed in the literature, the advantage of the PFI is to bundle the tasks of construction and hard FM within the SPV structure. This entices its management to internalize the externality between these two tasks. However, the SPV is operated by risk-averse management, necessitating compensation for the risks it must bear. We begin by solving the second stage regarding the outsourcing choice and then solve for the transfer structure in the first stage.

Second stage

In the second stage, the SPV has the capability to perform all tasks in-house. In this scenario, the effort levels of its management are driven by the power β of the SPV contract, as indicated by $e_H^{**} = \beta\delta_H$ and $e_S^{**} = \beta\gamma_S$, while $e_B^{**} = \beta\delta_B$ (see details in the Appendix C1). The builder is incentivized to exert more effort under stronger externalities between construction and hard FM services (higher $\delta_B > 0$). The SPV management's utility is then given by

$$V^{i**} = u \left[\begin{array}{c} \alpha - \beta(\gamma_0 + \delta_0 + \phi_0) + \frac{1}{2}\beta^2\delta_B^2 + \frac{1}{2}\beta^2\delta_H^2 + \frac{1}{2}\beta^2\gamma_S^2 \\ -\frac{1}{2}\rho\beta^2\left(\sigma_H^2 + \sigma_S^2\right) \end{array} \right].$$

The SPV can also outsource soft FM services. In this situation, it can be shown that its management exerts exactly the same effort levels on the in-house tasks as $e_H^{**} = \beta\delta_H$ and $e_B^{**} = \beta\delta_B$. However, the effort for outsourced soft FM services here depends on the contract power β_S proposed to the outsourcing soft FM. It is shown that $e_S^{**} = \beta_S\gamma_S$. The SPV chooses a transfer level α_S^{**} that exactly compensates the outsourcing firm's manager for the cost of soft FM services, her effort and risk-taking. Ultimately, the SPV optimally sets the contract power to $\beta_S^{**} = \beta I_S^{**} \in [0, \beta]$ where

$$I_S^{**} = \frac{\gamma_S^2 + \rho\sigma_S^2}{\gamma_S^2 + 2\rho\sigma_S^2} \in [0, 1],$$

which is a decreasing function of risk variance. In the absence of risk, this contract power exactly matches that imposed on the SPV by the FT, i.e. $\beta_S^{**} = \beta^{**}$. In the presence of risk, the SPV benefits from sharing the soft FM service risk with the outsourcing firm. However, since higher risk augments the latter's risk premium, the SPV finds it optimal to reduce the contract power with higher risk variance (as β_S^{**} falls with σ_S^2). Ultimately, the SPV obtains the utility

$$V^{o**} = u \left[\begin{array}{c} \alpha - \beta(\gamma_0 + \delta_0 + \phi_0) + \frac{1}{2}\beta^2\delta_B^2 + \frac{1}{2}\beta^2\delta_H^2 + \frac{1}{2}\beta^2\gamma_S^2 \\ -\frac{1}{2}\rho\beta^2\left(\sigma_H^2 + \sigma_S^2\right) + \frac{1}{2}\beta^2\rho\sigma_S^2\frac{\rho\sigma_S^2}{\gamma_S^2 + 2\rho\sigma_S^2} \end{array} \right].$$

Comparing those utility levels, it can be observed that SPV management prefers to outsource soft FM services, as the inequality $V^{o**} > V^{i**}$ holds.

Proposition 2. *Under a PFI, the SPV outsources soft FM services.*

This result contrasts with the FT's choice of in-house soft FM services under traditional procurement. The main explanation lies in differences in risk preferences. The SPV, being risk-averse, prefers to transfer its exposure to soft FM risk to subcontractors, ensuring more stable operations. In contrast, the FT, being risk-neutral, is willing to bear the full risk associated with providing in-house soft FM services. As a result, when FT authorities consider taking over the management of failing PFIs, they are inclined to bring outsourced FM services back in-house. This decision aligns with the risk-neutral stance of the authorities, who can manage the soft FM services internally without the need to transfer risk to subcontractors. Consequently, in-house provision leads to greater control over operations and costs for the authorities.

First stage

In the first stage, the FT decides the contract parameters applied to the SPV. It is optimal for the FT to increase the fixed transfer α until the SPV's participation constraint binds. The expected net benefit of the FT can be written as

$$\mathrm{E}W^{**} = \begin{bmatrix} b_0 - \gamma_0 - \delta_0 \\ +\left(b_B + \delta_B\right) e_B^{**} + \left(b_H + \delta_H\right) e_H^{**} + \left(b_S + \gamma_S\right) e_S^{**} \\ -\frac{e_B^{**2}}{2} - \frac{e_H^{**2}}{2} - \frac{e_S^{**2}}{2} \\ -\frac{1}{2}\rho\sigma_H^2\beta^2 - \frac{1}{2}\rho\beta_S^2\sigma_S^2 - \frac{1}{2}\rho\sigma_S^2\left(\beta_S - \beta\right)^2 \end{bmatrix}.$$

The first three lines of this expression follow the same structure as the net benefit structure in the first-best but with distorted effort levels. The last line expresses additional distortions due to moral hazard and risk. The contract power that maximizes this expected net benefit is given by

$$\beta^{**} = \frac{\left(b_B + \delta_B\right)\delta_B + \left(b_H + \delta_H\right)\delta_H + \left(b_S + \gamma_S\right) I_S^{**}\delta_S}{\delta_B^2 + \delta_H^2 + \gamma_S^2 I_S^{**} + \rho\sigma_H^2 + \rho\sigma_S^2\left(1 - I_S^{**}\right)}. \tag{2.7}$$

The FT has only a single contract power parameter to restore efficiency in three tasks. This parameter, therefore, combines the correction for inefficiency in each task delegation. Suppose that marginal benefits from quality enhancement are absent ($b_i = 0$, $i = H, S, B$). Then, the FT sets a contract with power $\beta^{**} = 1$ if there is no risk ($\sigma_H^2 = \sigma_S^2 = 0$). That is, the SPV supports the total cost of building and facility management, thereby incentivizing the reduction of its total cost. However, an increase in hard FM risk σ_H^2 decreases this power because the FT has incentives to mitigate the risk borne by the SPV. The presence of soft FM risk is, however, ambiguous. Indeed, σ_S^2 reduces the numerator of (2.7), while it raises its denominator for strong risks when $\rho\sigma_S^2/\gamma_S^2 > 0.36$ and reduces it for lower risks.[35] Hence, an increase in soft FM risks reduces contract power only if those risks are already strong enough. If the latter are weak, the effect of stronger soft FM risk is ambiguous. Assuming away the effects in the building and hard FM ($\delta_B = \delta_H = 0$), it can further be shown that β^{**} falls with additional soft FM risk σ_S^2.[36]

Finally, in the presence of marginal benefits from quality enhancement ($b_i > 0$, $i = H, S, B$), the FT raises the contract power above 1 when there are no risks. The FT shifts more than the total cost to the SPV to entice the SPV to internalize the social benefits. In this case, risk variance decreases the contract power.

The optimal net benefit is then given by

$$\begin{aligned} \mathrm{E}W^{**} = b_0 - (\delta_0 + \gamma_0 + \phi_0) + \frac{1}{2}\left(\beta^{**}\delta_B\right)^2 + \frac{1}{2}\left(\beta^{**}\delta_H\right)^2 + \frac{1}{2}\left(\beta^{**}\gamma_S\right)^2 \\ + \frac{1}{2}\rho\sigma_H^2\left(\beta^{**}\right)^2 - \frac{1}{2}\rho\sigma_S^2\left(\beta^{**}\right)^2 \frac{\gamma_S^2 - \rho\sigma_S^2}{\gamma_S^2 + 2\rho\sigma_S^2}. \end{aligned}$$

In the absence of marginal benefits from quality enhancement and risk ($b_i = \sigma_i^2 = 0$, $i = H, S, B$), the net benefit matches the value of the first-best net benefit. As highlighted in the literature, the PFI structure makes it possible to internalize the externality between the builder and the facility management services, restoring efficiency in hospital service procurement. The SPV is given a contract with power $\beta^{**} = 1$, allowing it to fully benefit from cost reductions.

2.4.4 Structure of foundation trust

We now compare traditional procurement with the PFI. The FT chooses the PFI if $\mathrm{E}W^{**} \geq \mathrm{E}W^{*}$. Here, we discuss the preference for PFI for each type of risk included in the project and in the presence of a net benefit for quality enhancement.

First, suppose that there is no marginal benefit of quality enhancement and no risk

[35] The part of the denominator that depends on $\rho\sigma_S^2$ is given by $\left(I_S^{**}\delta_S\right)^2 + \rho\sigma_S^2\left(1 + \left(I_S^{**} - 1\right)2I_S^{**}\right)$, which can be rewritten as $\delta_S^2\left[\frac{z+z^2+1}{2z+1}\right]$, where $z = \rho\sigma_S^2/\gamma_S^2$. This can be shown to decrease for $0 \leq z \leq \left(\sqrt{3}-1\right)/2$ and increase for z above this value.

[36] If $\delta_B = \delta_H = 0$, β^{**} simplifies to $\left(\gamma_S + b_S\right)/\delta_S * (z+1)/\left(z^2+z+1\right)$ where $z = \rho\sigma_S^2$. This is decreasing in z.

$(b_i = \sigma_i^2 = 0,\ i = H, S, B)$. In this case, the choice of PFI can be summarized by its net benefit advantage

$$\mathrm{E}W^{**} - \mathrm{E}W^{*} = \frac{1}{2}\left[\delta_B^2\theta^2 + \delta_H^2(1-\theta)^2\right] > 0. \tag{2.8}$$

Hence, the PFI is always preferred. Under no warranty ($\theta = 1$), the advantage of the PFI structure is related to the importance of the externality between the builder and hard FM services (i.e. δ_B) that the PFI internalizes. Under full warranty ($\theta = 0$), the advantage lies in the importance of marginal cost reductions in hard FM services (i.e., δ_H) that are not implemented in traditional procurement. Note that the above expression is a U-shaped function of the warranty parameter θ. Thus, the advantage is maximal either for full or no warranty.

Let us add the hard FM risk ($b_i = 0$, $i = H, S, B$, $\sigma_S^2 = 0$ and $\sigma_H^2 > 0$) so that

$$\begin{aligned}\mathrm{E}W^{**} - \mathrm{E}W^{*} = &\ \frac{1}{2}\left[\delta_B^2\theta^2 + \delta_H^2\left(1-\theta\right)^2\right] \\ &- \frac{1}{2}\rho\sigma_H^2\left[1-\left(1-\theta\right)^2 - \frac{\rho\sigma_H^2}{\delta_B^2+\delta_H^2+\gamma_S^2+\rho\sigma_H^2}\right],\end{aligned} \tag{2.9}$$

where the first line replicates (2.8). It can be shown that the second line is a negative and decreasing function for $\theta = 1$, a convex function taking negative and positive values for $\theta > 1$, and a positive increasing function for $\theta = 1$ (see the Appendix D1). This yields the following proposition. Let

$$\overline{\theta} = 1/\left(1+\sqrt{1+\gamma_S^2/\delta_H^2}\right).$$

Proposition 3. *Suppose no soft FM risk. Then, in the absence of a warranty ($\theta = 1$), the FT prefers the PFI if the externality between the builder and hard FM is strong ($\delta_B > 1$). Otherwise ($\delta_B \leq 1$), it chooses PFI only for low enough hard FM risk. In the presence of weak warranty ($\theta \in (\overline{\theta}, 1)$), the FT prefers the PFI either for sufficiently low or high hard FM risks and chooses traditional procurement for intermediate hard FM risks. Finally, in the presence of a strong warranty ($\theta \in [0, \overline{\theta})$), it always prefers the PFI.*

Proof: Appendix D1.

The intuition is as follows. For small hard FM risks, the PFI is always preferred because it better internalizes the externality between the builder and hard FM. For larger risks, traditional procurement is favored because the risk-neutral FT is a better entity to bear risk. However, traditional procurement transfers hard FM risk to the builder and is exposed to reverse moral hazard in the presence of a warranty. This effect dominates, and traditional procurement is avoided when the hard FM risks become very important or the warranty is very strong.

Now, let us include only soft FM risks ($b_i = 0$, $i = H, S, B$ while $\sigma_H = 0$). Then, we can write the net benefit advantage of PFI as

$$\mathrm{E}W^{**} - \mathrm{E}W^{*} = \frac{1}{2}\left(\delta_B^2\theta^2 + \delta_H^2(1-\theta)^2\right) - \frac{1}{2}F,$$

where

$$F = \frac{1}{\dfrac{1}{\rho\sigma_S^2\left(1-I_S\right)} + \dfrac{1}{\delta_B^2 + \delta_H^2 + I_S\gamma_S^2}} + \left(1-I_S\right)\gamma_S^2 > 0.$$

The first term reflects the above trade-off resulting from the externality between the builder and hard FM services, which favors the PFI structure. The second term encapsulates the effect of the risk and moral hazard in the outsourced soft FM services. In the absence of soft FM risks ($\sigma_S^2 = 0$), we obtain $I_S = 1$ and $F = 0$, so that we find the trade-off explained in (2.8). When the externality between builder and hard FM vanishes ($\delta_B = \delta_H = 0$), only the issue of soft FM outsourcing remains. The first term vanishes, while the second term is positive. Hence, traditional procurement is preferred. Indeed, the risk-neutral FT is a better entity to manage the risk of soft FM. Then, there exists a threshold for the variance σ_S^2 such that PFI is preferred if and only if σ_S^2 is lower than this threshold.

Proposition 4. *Suppose no hard FM risk. Then, the FT prefers the PFI for sufficiently low soft FM risk and traditional procurement for higher soft FM risk.*

Proof: Appendix D2.

Fig. 2.4 displays the set of risk parameters supporting traditional procurement and PFI. Each panel is produced for a different warranty. The panels confirm the above propositions when one risk dimension is considered: when soft FM risks are nil, the PFI is preferred for low and high hard FM risks; when hard FM risks are nil, the PFI is preferred for low soft FM risks. Fig. 2.4 further shows the model properties with two risk dimensions. It indicates that, on the one hand, the PFI is preferred for low risks in both hard FM and soft FM services, and on the other hand, the PFI is preferred for high hard FM risks. Fig. 2.4 also demonstrates that the FT prefers PFI for a stronger warranty (lower θ).

In the presence of quality effects and the absence of cost reduction potential ($b_B, b_H, b_S, \sigma_H,$

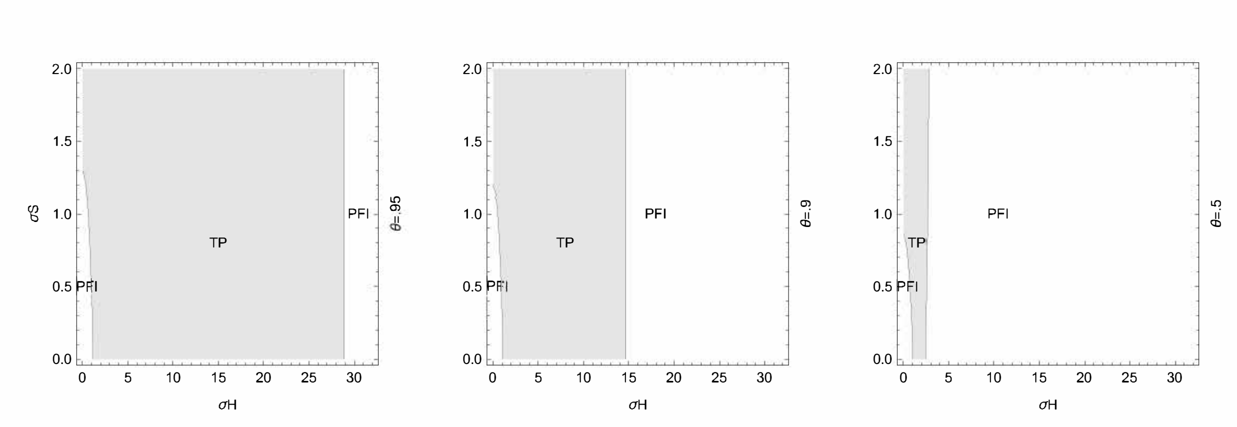


Figure 2.4: PFI vs. Traditional procurement

$\sigma_S > 0$ and $\delta_B = \gamma_H = \gamma_S = 0$), we have

$$\mathrm{E}W^{**} - \mathrm{E}W^{*} = -\frac{1}{2}b_H^2 - \frac{1}{2}b_S^2 + \frac{1}{2}\rho\sigma_H^2(1-\theta)^2.$$

Hence, traditional procurement is preferred for sufficiently small hard FM risks and a weak warranty. This result reflects the fact that the PFI is not an appropriate structure when hard FM and soft FM service quality is at stake. In this case, the FT sets the power of the SPV contract, β^{**}, to zero. The SPV has no incentive to exert effort in any quality-enhancing activities. Note that the effect of the builder's quality is not apparent in this comparison. In the presence of a warranty, stronger hard FM risk increases the net benefit of a PFI. Indeed, on the one hand, PFI is reimbursed with the risk premium. A higher risk leads to a larger risk premium paid by the authority. On the other hand, the longevity and diversity of services covered under the warranty in the contract assume higher compensation from the SPV side in the case of unforeseen circumstances, e.g. building damages and a more costly transfer from the authority side.

Proposition 5. *Suppose no cost reduction potential. Then, the FT prefers traditional procurement if the hard FM risk and warranty level are not too high.*

2.5 A calibration

The above theoretical analysis provides insight for the full set of parameter values of the model. In this section, we apply the model to reasonable parameter values that match existing projects. Toward this aim, we calibrate the model to the example of the Trafford General Hospital of the Manchester University NHS FT, which operates under traditional

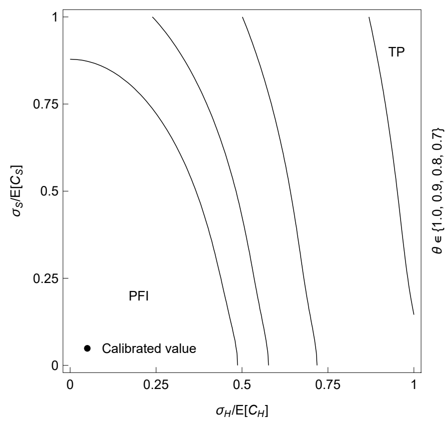


Figure 2.5: PFI vs Traditional procurement

procurement and with in-house facility management. In 2020, this FT incurred 7.0 Mo and 4.3 Mo GBP in hard FM and soft FM costs, respectively. For this calibration, we assume that the standard deviation of the cost of each facility management service is equal to 5% of its total cost and the cost reductions from management efforts are of the same order, i.e., 5% of total costs. We consider a constant absolute risk aversion coefficient of $\rho = 0.18$, which constitutes a lower bound for high-income individuals and risky assets (see Eisenhauer and Ventura, 2003). This means that hard FM and soft FM operators would require a risk premium equal to 3.1% of the cost standard deviation, which is reasonable. We assume away quality benefits in the calibration and calibrate the parameters δ_B, δ_H and γ_S to match the first-best allocation. Parameter computations and values are reported in the Appendix E1.

Fig. 2.5 displays the values of standard deviation in hard FM and soft FM costs for which the FT prefers traditional procurement or adopts PFI. Standard deviations are normalized with respect to the expected cost of each facility management service. Each curve displays the locus of standard deviation values for which the FT payoffs are equal in both situations for a specific and realistic value of the warranty $\theta \in \{1, 0.9, 0.8, 0.7\}$. The bold dot at the bottom left of Fig. 2.5 shows the values of those cost standard deviations that we use in the above calibration. Since this point lies below the curves for any θ, PFI is preferred for the considered cost uncertainties. The existence of a warranty shrinks the set of values where the PFI dominates. Fig. 2.5 nevertheless shows that PFI is preferred for cost standard deviations smaller than half of the facility management service costs. In other words, traditional procurement is preferred for risks that are far from the present calibration costs. However, Fig. 2.5 suggests a strong dominance of the PFI for the cost uncertainties as assumed in the calibration.

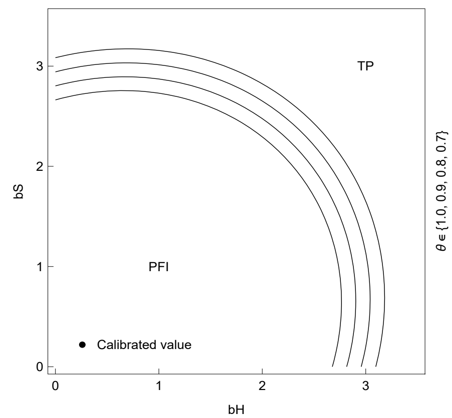


Figure 2.6: PFI vs Traditional procurement for various b_H and b_S

The cost contracts are less likely to properly monitor the operator's action in the presence of quality benefits. This makes PFI a less appropriate structure for the FT. To discuss this point, we present Fig. 2.6, which displays the set of marginal benefit parameters b_H and b_S of effort in hard FM and soft FM for which PFI is preferred to traditional procurement. Each curve displays the locus of those parameters for which PFI and traditional procurement yield the same FT net benefit for a specific warranty θ. The curves mainly reflect the elliptic structure of equation (2.9). The FT prefers PFI for parameters below each curve. We also add a bold dot (bottom left) that points to the parameter values b_H and b_S for which the quality benefits b_He_H and b_Se_S are equal to 5% of the total costs of hard FM and soft FM costs, respectively (computed in the first-best). Since this point lies largely below the curves, it is apparent that PFI implementation is a better option for the FT in such a range of parameters. In other words, quality benefits are not large enough to entice the FT to choose traditional procurement. In summary, the present calibrated example of the Trafford General Hospital supports a move to PFI.

2.6 Conclusion

This paper describes the context and structures of FTs and PFI projects in the UK health system. It focuses on the delegation of construction and hard and soft FM services to SPVs and outsourcing firms in hospitals and healthcare centers. It studies those delegation processes in the light of agency theory that includes risk and moral hazard problems among FTs, SPVs, and outsourcing firms. It considers three novel features specific to the sector: the delegation of multiple services, the outsourcing of facility services (three-tier delegation), and the possibility of a warranty by builders.

The paper shows that the choice of PFI depends on the warranty, which encompasses a "reverse" moral hazard issue. The incentives to outsource facility management services are also shown to be weaker in traditional procurement, as confirmed by some data analysis. Finally, PFIs show insufficient quality, which is a regular claim by observers in the healthcare sector.

Our stylized model abstracts from the issue of construction risk for expositional purposes. In general, construction costs are on par with maintenance costs and make up half of the total life cycle expenses. However, the role of construction risks is well discussed in many contributions so that their inclusion in this model would not enhance the paper's contribution. The paper also sets the path for new research directions about the role of economies of scope and wage advantages in outsourcing firms, quality monitoring (KPIs), and insurance contracts within PFIs. Additional discussions about the nature of economic shocks and the type of hospital procurement preferred by policymakers are also worth further investigation.

2.7 Appendix

Appendix A

A1 Certainty equivalent

In this appendix, we recall the proof of the certainty equivalent and risk premium under constant absolute risk aversion and normal risk distribution. We have that

$$E\left[u(a+b\widetilde{\varepsilon})\right]=\int e^{-\rho(a+b\widetilde{\varepsilon})}\frac{1}{\pi\sqrt{2\pi}}e^{-\frac{1}{2}(\widetilde{\varepsilon}/\sigma)^2}d\widetilde{\varepsilon}=e^{-\rho a}\int\frac{1}{\pi\sqrt{2\pi}}e^{-\rho b\widetilde{\varepsilon}-\frac{1}{2}(\widetilde{\varepsilon}/\sigma)^2}d\widetilde{\varepsilon}=$$
$$e^{-\rho a}\int\frac{1}{\pi\sqrt{2\pi}}e^{\frac{1}{2}(\rho\sigma b)^2-\frac{1}{2}\left((\widetilde{\varepsilon}/\sigma+\rho\sigma b)^2\right)}d\widetilde{\varepsilon}=e^{-\rho a+\frac{1}{2}(\rho\sigma b)^2}\int\frac{1}{\pi\sqrt{2\pi}}e^{-\frac{1}{2}\left((\widetilde{\varepsilon}/\sigma+\rho\sigma b)^2\right)}d\widetilde{\varepsilon}$$
$$=e^{-\rho\left(a-\frac{1}{2}\sigma^2b^2\right)}=u\left(a-\frac{1}{2}\sigma^2b^2\right).$$

Appendix B: Traditional procurement

B1 Computations

In this appendix, we provide a detailed analysis of the traditional procurement of the FT's hospital. We compute the FT's payoff in the four cases reported in the second stage and then analyze the first stage.

Second stage with all insourced facilities: case $(k,l)=(i,i)$

We have $V^{ii}=\max_{\{e_H(\cdot),e_S(\cdot)\}}\mathrm{E}[b_0+b_Be_B+b_He_H+b_Se_S-\theta\left(\delta_0-\delta_Be_B-\delta_He_H+\widetilde{\varepsilon}_H\right)-\frac{1}{2}e_H(\cdot)^2$ $-\left(\gamma_0-\gamma_Se_S+\widetilde{\varepsilon}_S\right)-\frac{1}{2}e_S(\cdot)^2]$, which is equivalent to $=\max_{\{e_H(\cdot),e_S(\cdot)\}}[b_0+b_Be_B+b_He_H+$ $b_Se_S-\theta\left(\delta_0-\delta_Be_B-\delta_He_H\right)-\frac{1}{2}e_H^2-\left(\gamma_0-\gamma_Se_S\right)-\frac{1}{2}e_S^2]$, where the second line takes into account the expectation of the risk-neutral FT and does not depend on the shock realization. The first order conditions are given by $b_H+\theta\delta_H-e_H=0$ and $b_S+\gamma_S-e_S=0$. Thus, $e_H^{ii*}=b_H+\theta\delta_H$ and $e_S^{ii*}=b_S+\gamma_S$. The welfare value is

$$V^{ii*}=b_0-\theta\delta_0-\gamma_0+\left(b_B+\theta\delta_B\right)e_B+\frac{1}{2}\left(b_H+\theta\delta_H\right)^2+\frac{1}{2}\left(b_S+\gamma_S\right)^2.$$

Second stage with mixed insourcing: case $(k,l)=(o,i)$

The FT has the program $V^{oi} = \max_{\{\alpha_H,\beta_H,e_S(\cdot)\}} \mathbf{E}[B - t_H(\widetilde{C}_H) - \widetilde{C}_S - \frac{1}{2}e_S(\cdot)^2]$ s.t.$U^{oi} = \mathrm{E}[\max_{e_H(\cdot)} u(t_H(\widetilde{C}_H) - \theta\widetilde{C}_H - \frac{1}{2}e_H(\cdot)^2)] \geq u(0)$. The outsourcing firm's effort is given by $e_H^*(\cdot) = \arg\max_{e_H(\cdot)} u(\alpha_H + (1-\beta_H)\theta\widetilde{C}_H - \theta\widetilde{C}_H - \frac{1}{2}e_H(\cdot)^2)$, which is also $\arg\max_{e_H(\cdot)} \alpha_H - \beta_H\theta\left(\delta_0 - \delta_B e_B - \delta_H e_H(\cdot) + \widetilde{\varepsilon}_H\right) - \frac{1}{2}e_H(\cdot)^2$. Thus, one finds that $e_H^{oi*}(\cdot) = e_H^{oi*} = \beta_H\theta\delta_H$, which does not depend on the shock realization. Then, the hard FM manager's utility is given by

$$U^{oi} = \mathrm{E}\left[u\left(\alpha_H - \beta_H\theta\left(\delta_0 - \delta_B e_B - \delta_H e_H^{oi*} + \widetilde{\varepsilon}_H\right) - \frac{1}{2}\left(e_H^{oi*}\right)^2\right)\right]$$
$$= u\left(\alpha_H - \beta_H\theta\delta_0 + \beta_H\theta\delta_B e_B + \frac{1}{2}\left(e_H^{oi*}\right)^2 - \frac{1}{2}\rho\sigma_H^2\beta_H^2\theta^2\right),$$

where we use the property $\mathbf{E}\left[u(a + b\widetilde{\varepsilon}_H)\right]$ with a and $b \in \mathbb{R}$ is given by $u\left(a - \frac{1}{2}\rho\sigma_H^2 b^2\right)$. The FT finally has the program

$$\max_{\alpha_H,\beta_H,e_S(\cdot)} V^{oi} = \mathrm{E}[B - \alpha_H - (1-\beta_H)\,\theta\widetilde{C}_H - \widetilde{C}_S - \frac{1}{2}e_S(\cdot)^2] \text{ s.t. } U^{oi} \geq u(0).$$

The FT optimally sets α_H such that the constraint is binding. Thus, the program becomes $\max \beta_H, e_S(\widetilde{\varepsilon}_S.\mathrm{E}[b_0 + b_B e_B + b_H e_H^{oi*} + b_S e_S(\widetilde{\varepsilon}_S) - \beta_H\theta\delta_0 + \beta_H\theta\delta_B e_B + \frac{1}{2}\left(e_H^{oi*}\right)^2 - \frac{1}{2}\rho\sigma_H^2\beta_H^2\theta^2 - (1-\beta_H)\theta\left(\delta_0 - \delta_B e_B - \delta_H e_H^{oi*} + \widetilde{\varepsilon}_H\right) - \left(\gamma_0 - \gamma_S e_S(\widetilde{\varepsilon}_S) + \widetilde{\varepsilon}_S\right) - \frac{1}{2}e_S(\widetilde{\varepsilon}_S)^2]$. This objective function is concave in $e_S(\cdot)$ and yields the optimal $e_S^{oi*}(\cdot) = e_S^{oi*} = b_S + \gamma_S$. Given that $e_H^{oi*} = \beta_H\theta\delta_H$, the objective is also concave in β_H. In this case, the optimal contract power is given by

$$\beta_H^* = (b_H + \theta\delta_H)\frac{\delta_H}{\theta\left(\delta_H^2 + \rho\sigma_H^2\right)}.$$

The net benefit is given by

$$V^{oi*} = b_0 - \delta_0\theta - \gamma_0 + (b_B + \delta_B\theta)e_B + \frac{1}{2}(b_S + \gamma_S)^2 + \frac{1}{2}\left(b_H + \delta_H\theta\right)^2\frac{\delta_H^2}{\delta_H^2 + \rho\sigma_H^2}.$$

Second stage with other cases $(k,l)=(i,o)$ and (o,o).

The cases (i,o) and (o,o) are obtained in the same way as above. We get

$$V^{io*} = b_0 - \delta_0\theta - \gamma_0 + (b_B + \delta_B\theta)e_B + \frac{1}{2}(b_S + \gamma_S)^2\frac{\gamma_S^2}{\gamma_S^2 + \rho\sigma_S^2} + \frac{1}{2}(b_H + \delta_H\theta)^2$$

and

$$V^{oo*} = b_0 - \delta_0\theta - \gamma_0 + (b_B + \delta_B\theta)e_B + \frac{1}{2}(b_S + \gamma_S)^2 \frac{\gamma_S^2}{\gamma_S^2 + \rho\sigma_S^2} + \frac{1}{2}\left(b_H + \delta_H\theta\right)^2 \frac{\delta_H^2}{\delta_H^2 + \rho\sigma_H^2}.$$

Comparing the payoffs V^{lk*}, $l, k \in \{i, o\}$, one can see that insourcing is preferred: $V = V^{ii*}$. This yields Proposition 1.

First stage with builder and FT

Let us denote by V the optimal net benefit in the second stage when the builder's effort is realized. The FT solves the following maximization program with $V = V^{ii*}$: $W^* = \max_{\alpha_B} \mathrm{E}[V - t_B]$ subject to the builder's participation and incentive constraints $\max_{e_B(\cdot)\geq 0} U_B = \mathrm{E}\left[u(t_B - \tilde{C}_B - \frac{1}{2}e_B(\cdot)^2)\right] \geq u(0)$. Replacing the transfer $t_B = \alpha_B$ and the builder's cost $\tilde{C}_B = \phi_0 + (1-\theta)\tilde{C}_H$, we successively obtain the builder's utility: $U_B = \mathrm{E}[u(\alpha_B - \phi_0 - (1-\theta)\widetilde{C}_H - \frac{1}{2}e_B^2)]$. Given that the $\mathrm{E}[\widetilde{\varepsilon}_H] = 0$ and $\mathrm{E}\left[u(a + b\widetilde{\varepsilon}_H)\right] = u\left(a - \frac{1}{2}\rho\sigma_H^2 b^2\right)$, this yields $U_B = u[\alpha_B - \phi_0 - (1-\theta)\left(\delta_0 - \delta_B e_B - \delta_H e_H\right) - \frac{1}{2}e_B^2 - \frac{1}{2}\rho\sigma_H^2(1-\theta)^2]$. The builder's optimal effort $e_B^* = (1-\theta)\delta_B$ maximizes this utility level.

The FT optimally sets α_B such that the builder's participation constraint is binding. Using $\mathrm{E}[\widetilde{\varepsilon}_H] = 0$ and $e_H^{ii*} = b_H + \theta\delta_H$, the FT's net benefit simplifies to $W^* = \max \mathrm{E}[V - \alpha_B] = \mathrm{E}[b_0 - \theta\delta_0 - \gamma_0 + (b_B + \theta\delta_B)e_B^* + \frac{1}{2}(b_H + \theta\delta_H)^2 + \frac{1}{2}(b_S + \gamma_S)^2 - \phi_0 - (1-\theta)\left(\delta_0 - \delta_B e_B^* - \delta_H e_H^{ii*} + \widetilde{\varepsilon}_H\right) - \frac{1}{2}e_B^{*2} - \frac{1}{2}\rho\sigma_H^2(1-\theta)^2] = b_0 - (\delta_0 + \gamma_0 + \phi_0) + \frac{1}{2}(b_S + \gamma_S)^2 + \frac{1}{2}(b_H + \delta_H)^2 + \frac{1}{2}\left(1-\theta\right)[2b_B\delta_B + \left(1+\theta\right)\delta_B^2 - \left(1-\theta\right)\delta_H^2] - \frac{1}{2}\left(1-\theta\right)^2 \rho\sigma_H^2$, which is the formula displayed in the above text.

Appendix C: Private finance initiative

C1 Computations

In this appendix, we detail the analysis of PFI structure. We begin with the second stage's structure and payoff of the SPV and then determine the net benefit for the FT.

Second stage with all in-house facility management: case (k,l)=(i,i).

Insourcing yields the following program for the SPV: $V^i = \max_{e_B,e_H,e_S} \mathrm{E}[u(\alpha + (1-\beta)(\tilde{C}_B + \theta\widetilde{C}_H + \widetilde{C}_S) - \tilde{C}_B - \frac{e_B^2}{2} - \theta\widetilde{C}_H - \frac{e_H^2}{2} - \widetilde{C}_S - \frac{e_S^2}{2})]$. Replacing the cost function and taking the certainty equivalent of the risk-averse SPV's payoff, this yields $\max_{e_B,e_H,e_S} u[\alpha - \beta(\gamma_0 + \delta_0 + \phi_0 - \delta_B e_B - \delta_H e_H - \gamma_S e_S) - \frac{e_B^2}{2} - \frac{e_H^2}{2} - \frac{e_S^2}{2} - \frac{1}{2}\rho\beta^2\left(\sigma_H^2 + \sigma_S^2\right)]$. This provides the SPV's optimal effort levels: $e_B^{**} = \beta\delta_B$, $e_H^{**} = \beta\delta_H$ and $e_S^{**} = \beta\gamma_S$.In this case, the utility of the SPV is

$$V^{i**} = u\left[\alpha - \beta(\gamma_0 + \delta_0 + \phi_0) + \frac{1}{2}\beta^2\delta_B^2 + \frac{1}{2}\beta^2\delta_H^2 + \frac{1}{2}\beta^2\gamma_S^2 - \frac{1}{2}\rho\beta^2\left(\sigma_H^2 + \sigma_S^2\right)\right].$$

Second stage with mixed outsourcing: case (k,l)=(i,o).

In this case, the SPV outsources the soft FM services. The outsourcing firm's manager has a utility defined by $U_S = \mathrm{E}\ [\max_{e_S(\cdot)} u(t_S(\widetilde{C}_S) - \widetilde{C}_S - \frac{e_S^2}{2})]$. Taking into account his risk aversion, this yields the equivalent utility $U_S = \max_{e_S} u(\alpha_S - \beta_S\left(\gamma_0 - \gamma_S e_S\right) - \frac{1}{2}e_S^2 - \frac{1}{2}\rho\beta_S^2\sigma_S^2)$. Therefore, his optimal effort level is equal to $e_S^{**} = \beta_S\gamma_S$. Her optimal utility is

$$U_S^{**} = u(\alpha_S - \beta_S\left(\gamma_0 - \beta_S\gamma_S^2\right) - \frac{1}{2}\beta_S^2\gamma_S^2 - \frac{1}{2}\rho\beta_S^2\sigma_S^2). \tag{2.10}$$

The SPV has the following program: $V^o = \max_{e_B,e_H,\alpha_S,\beta_S} E[u(\alpha + (1-\beta)\left(\tilde{C}_B + \theta\tilde{C}_H + \widetilde{C}_S\right) - \tilde{C}_B - \frac{e_B^2}{2} - \theta\widetilde{C}_H - \frac{e_H^2}{2} - \alpha_S - (1-\beta_S)\,\widetilde{C}_S)]$. The SPV diminishes the compensation α_S until the participation constraint $U_S^{**} = u(0)$ binds. After substitution of costs, the SPV then has the program $\max_{e_B,e_H,\beta_S} u[\alpha - \frac{1}{2}\beta_S^2\gamma_S^2 - \frac{1}{2}\rho\beta_S^2\sigma_S^2 - \beta\left(\delta_0 + \gamma_0 + \phi_0 - \delta_B e_B - \delta_H e_H - \beta_S\gamma_S^2\right) - \frac{e_B^2}{2} - \frac{e_H^2}{2} - \frac{1}{2}\rho\beta^2\sigma_H^2 - \frac{1}{2}\rho\sigma_S^2\left(\beta_S - \beta\right)^2]$. This yields the SPV manager's optimal efforts $e_H^{**} = \beta\delta_H$ and $e_B^{**} = \beta\delta_B$. After plugging in those values, the payoff in this utility function is concave in β_S and yields a maximum at

$$\beta_S^{**} = \beta\frac{\gamma_S^2 + \rho\sigma_S^2}{\gamma_S^2 + 2\rho\sigma_S^2}.$$

Then, after simplification, the SPV's utility is given by

$$\begin{aligned} V^{o**} = u[\alpha - \beta(\delta_0 + \gamma_0 + \phi_0) + \frac{1}{2}\beta^2\delta_B^2 + \frac{1}{2}\beta^2\delta_H^2 + \frac{1}{2}\beta^2\gamma_S^2 \\ + \frac{1}{2}\rho\beta^2(\sigma_H^2 + \sigma_S^2) + \frac{1}{2}\beta^2\rho\sigma_S^2\frac{\rho\sigma_S}{\gamma_S^2 + 2\rho\sigma_S^2}]. \end{aligned} \tag{2.11}$$

First stage with outsourced soft FM

The expected net benefit for FT is given by $\mathrm{E}W^{**} = \mathrm{E}[b_0 + b_B e_B^{**} + b_H e_H^{**} + b_S e_S^{**} - T(\widetilde{C}_B, \widetilde{C}_H, \widetilde{C}_S)]$, where the effort levels are determined above and depend on β. Plugging in the transfer, this yields

$$\begin{aligned}\mathrm{E}W^{**} = \mathrm{E}[&b_0 + b_B e_B^{**} + b_H e_H^{**} + b_S e_S^{**} - \alpha \\ &- (1-\beta)\left(\phi_0 - \theta\delta_0 - \delta_B e_B^{**} - \delta_H e_H^{**} + \gamma_0 - \gamma_S e_S^{**}\right)],\end{aligned}$$

where the two shocks can be cancelled because they have zero expectations. The FT reduces the compensation α until the SPV's participation constraint binds; i.e. $V^{o**} = u(0)$. Inserting this value into the FT's net benefit yields

$$\mathrm{E}W^{**} = \left[\begin{array}{c} b_0 - (\delta_0 + \gamma_0 + \phi_0) \\ +(b_B + \delta_B)e_B^{**} + (b_H + \delta_H)\, e_H^{**} + (b_S + \gamma_S)\, e_S^{**} \\ -\frac{e_B^{**2}}{2} - \frac{e_H^{**2}}{2} - \frac{e_S^{**2}}{2} \\ -\frac{1}{2}\rho\sigma_H^2\beta^2 - \frac{1}{2}\rho\beta_S^2\sigma_S^2 - \frac{1}{2}\rho\sigma_S^2\left(\beta_S - \beta\right)^2 \end{array}\right].$$

The first three lines of this expression correspond to the FT's expected profits in the first-best. The last line expresses the distortion due to moral hazard and risk. It can be shown that this expression is a quadratic function of β.

Let

$$I_S^{**} = \frac{\gamma_S^2 + \rho\sigma_S^2}{\gamma_S^2 + 2\rho\sigma_S^2} \in [0,1],$$

so that $\beta_S^{**} = \beta I_S^{**}$. It can be shown that $\mathrm{E}W^{**}$ has the quadratic form $C + B\beta - A\beta^2$ where $A = [\delta_B^2 + \delta_H^2 + \gamma_S^2 I_S^{**} + \rho\sigma_H^2 + \rho\sigma_S^2\left(1 - I_S^{**}\right)]/2 > 0$, $B = (b_B + \delta_B)\delta_B + (b_H + \delta_H)\,\delta_H + (b_S + \gamma_S)\, I_S^{**}\gamma_S$ and $C = b_0 - (\delta_0 + \gamma_0 + \phi_0)$. Then, the optimal β is given by

$$\beta^{**} = \frac{B}{2A} = \frac{(b_B + \delta_B)\delta_B + (b_H + \delta_H)\,\delta_H + (b_S + \gamma_S)\, I_S^{**}\gamma_S}{\delta_B^2 + \delta_H^2 + \gamma_S^2 I_S^{**} + \rho\sigma_H^2 + \rho\sigma_S^2\left(1 - I_S^{**}\right)}$$

and $\mathrm{E}W^{**} = C + 2A\left(\beta^{**}\right)^2 = C + B^2/\left(4A\right)$, which yields

$$\begin{aligned}\mathrm{E}W^{**} = b_0 - (\delta_0 + \gamma_0 + \phi_0) + \frac{1}{2}\left(\beta^{**}\delta_B\right)^2 + \frac{1}{2}\left(\beta^{**}\delta_H\right)^2 + \frac{1}{2}\left(\beta^{**}\gamma_S I_S\right)^2 \\ + \frac{1}{2}\rho\sigma_H^2(\beta^{**})^2 + (\beta^{**})^2\frac{1}{2}\rho\sigma_S^2\left[I_S^2 + \left(I_S^2 - 2I_S + 1\right)\right],\end{aligned}$$

which simplifies to the value in the text.

Appendix D: Optimal structure of foundation trust

D1 Proof of Proposition 3

We here characterize the expression (2.9). For $\theta = 1$, the second line of this expression is a convex function of σ_H^2 that decreases from 0 to $-1/2$ when hard FM risk σ_H^2 goes from zero to infinity. For $\theta \in (0,1)$, this line is also a convex function of σ_H^2 that first decreases below zero as σ_H^2 rises above zero, and reaches a minimum value $(\delta_B^2 + \delta_H^2 + \gamma_S^2)\,\theta^2$ at $\sigma_H^2 = (\delta_B^2 + \delta_H^2 + \gamma_S^2)\,\theta / [(1-\theta)\,\rho]$, then increases, crosses the zero axis and rises to positive infinity. For $\theta = 0$, this line is positive and rises to infinity as σ_H^2 increases.

This implies that, for $\theta = 1$, the above expression is always larger than zero if $\delta_B > 1$ so that PFI is always preferred. Otherwise, if $\delta_B < 1$, there exists a level of risk aversion or hard FM risk variance above which traditional procurement is preferred. For $\theta \in (0,1)$, PFI is always preferred if $\delta_B^2\theta^2 + \delta_H^2\,(1-\theta)^2 > (\delta_B^2 + \delta_H^2 + \gamma_S^2)\,\theta^2$; that is, if $(1-\theta)^2/\theta^2 > (\delta_H^2 + \gamma_S^2)/\delta_H^2$ or equivalently, $\theta < \overline{\theta}$, where

$$\overline{\theta} \equiv 1/\left(1 + \sqrt{1 + \gamma_S^2/\delta_H^2}\right).$$

Otherwise, there exist two thresholds for σ_H^2 such that traditional procurement is preferred for σ_H^2 lying within those thresholds and PFI is preferred for σ_H^2 lying outside those thresholds. Finally, if $\theta = 0$, the PFI is always preferred.

D2 Proof of Proposition 4

We want to prove the following: *Suppose no hard FM risk. Then, the FT prefers the PFI for sufficiently low soft FM risk and traditional procurement for higher soft FM risk.*

Toward this aim, we use $A = \rho\sigma_S^2$, $B = \gamma_S^2$ and $C = \delta_B^2 + \delta_H^2$ and can write

$$F = \frac{BA^3 + (B+A)\,A\,(C\,(B+2A) + B\,(B+A))}{(B+2A)\,(A^2 + C\,(B+2A) + B\,(B+A))}.$$

Then, we obtain

$$\frac{dF}{dA} = \frac{(AB + 2AC + BC + B^2)\begin{pmatrix} 3AB^3 + 2A^3B + 4A^3C + B^3C \\ +6A^2B^2 + B^4 + 4AB^2C + 6A^2BC \end{pmatrix}}{(2A+B)^2\,(AB + 2AC + BC + A^2 + B^2)^2} > 0.$$

Therefore F increases with $\rho\sigma_S^2$. Additionally,

$$\lim_{\rho\sigma_S^2\to\infty} F = \lim_{A\to\infty} F = B + C = \gamma_S^2 + \delta_B^2 + \delta_H^2.$$

Hence,

$$\lim_{\rho\sigma_S^2\to\infty} \mathrm{E}W^{**} - \mathrm{E}W^{*} = -\frac{1}{2}\delta_B^2\left(1-\theta^2\right) - \frac{1}{2}\delta_H^2\left(1-(1-\theta)^2\right) - \frac{1}{2}\gamma_S^2 < 0.$$

In summary, as $\rho\sigma_S^2$ falls from 0 to ∞, $\mathrm{E}W^{**} - \mathrm{E}W^{*}$ monotonically falls from positive to negative values. QED.

Appendix E

E1 Calibration

In the calibration, we make the following assumptions:

$$\begin{aligned}
\sigma_H &= \frac{5}{100}\mathrm{E}C_H^* = \frac{5}{100}\,\text{(annual hard FM cost of a hospital)}\\
\sigma_S &= \frac{5}{100}\mathrm{E}C_S^* = \frac{5}{100}\,\text{(annual soft FM cost of a hospital)}\\
\gamma_S e_S^* &= \frac{5}{100}\,\text{(annual soft FM cost of a hospital)}\\
\delta_B e_B^* &= \frac{1}{2}\frac{5}{100}\,\text{(annual hard FM cost of a hospital)}\\
\delta_H e_H^* &= \frac{1}{2}\frac{5}{100}\,\text{(annual hard FM cost of a hospital)}\\
e_H^{ii*} &= b_H + \theta\delta_H\\
e_S^{ii*} &= b_S + \gamma_S.\\
e_B^* &= (1-\theta)\delta_B\\
\theta &= 0.9\\
b_H &= b_S = b_B = 0
\end{aligned}$$

We consider a constant absolute risk aversion coefficient of $\rho = 0.18$, which constitutes a lower bound for high-income individuals and risky assets (see Eisenhauer and

Ventura (2003)). Alternatively, we could assume that the risk premium for the hard FM is approximately $x\%$ of the standard deviations of hard FM cost. That is,

$$\frac{1}{2}\rho\sigma_H^2 = \frac{x}{100} * \sigma_H$$

This gives $\rho = \frac{1}{\sigma_H}\frac{2x}{100} = \frac{2x}{5*(\text{annual hard FM cost of a hospital})} = \frac{2}{35}x$. To match the value in the literature, $\rho = 0.18$, we should impose $x = 3.1$. This means that hard FM and soft FM would accept a risk premium that is equal to 3.1% of the standard deviation, which is reasonable but small.

This yields

$$\begin{aligned}
\sigma_H &= \frac{5}{100}EC_H^* = \frac{5}{100}(\text{annual hard FM cost of a hospital}) = \frac{5}{100} * 7 = 0.35 \\
\sigma_S &= \frac{5}{100}EC_S^* = \frac{5}{100}(\text{annual soft FM cost of a hospital}) = \frac{5}{100} * 4.3 = 0.21 \\
\gamma_S^{\text{cal}} &= \sqrt{\frac{5}{100}(\text{annual soft FM cost of a hospital})} = \sqrt{\frac{5}{100} * 4.3} = 0.46 \\
\delta_B^{\text{cal}} &= \sqrt{\frac{1}{0.1}\frac{1}{2}\frac{5}{100}(\text{annual hard FM cost of a hospital})} = \sqrt{\frac{1}{0.1}\frac{1}{2}\frac{5}{100} * 7} = 1.32 \\
\delta_H^{\text{cal}} &= \sqrt{\frac{1}{0.9}\frac{1}{2}\frac{5}{100}(\text{annual hard FM cost of a hospital})} = \sqrt{\frac{1}{0.9}\frac{1}{2}\frac{5}{100} * 7} = 0.44
\end{aligned}$$

We also add benefits from quality enhancement that are of the same order as the cost reduction achieved in the hard FM in the above calibration setup. That is,

$$\begin{aligned}
b_B e_B^* &= \frac{1}{2}\frac{5}{100}(\text{annual hard FM cost of a hospital}) \\
b_H e_H^* &= \frac{1}{2}\frac{5}{100}(\text{annual hard FM cost of a hospital}) \\
b_S e_S^* &= \frac{5}{100}(\text{annual soft FM cost of a hospital})
\end{aligned}$$

when $e_B^* = (1-\theta)\delta_B$, $e_H^* = b_H + \theta\delta_H$ and $e_S^* = b_S + \gamma_S$ where δ_B, δ_H and γ_S take the previously calibrated values. This yields

$$\begin{aligned}
b_B(1-\theta)\delta_B^{\text{cal}} &= \frac{1}{2}\frac{5}{100}(\text{annual hard FM cost of a hospital}) \\
b_H\left(b_H + \theta\delta_H^{\text{cal}}\right) &= \frac{1}{2}\frac{5}{100}(\text{annual hard FM cost of a hospital}) \\
b_S\left(b_S + \gamma_S^{\text{cal}}\right) &= \frac{5}{100}(\text{annual soft FM cost of a hospital})
\end{aligned}$$

This yields

$$
\begin{aligned}
b_B * 0.1 * 1.32 &= \frac{1}{2}\frac{5}{100}7.0 \Longrightarrow b_B = 1.32 \\
b_H\left(b_H + 0.9 * 0.44\right) &= \frac{1}{2}\frac{5}{100}7.0 \Longrightarrow b_H = 0.26 \\
b_S\left(b_S + 0.46\right) &= \frac{5}{100}4.3 \Longrightarrow b_S = 0.287
\end{aligned}
$$

Chapter 3

Healthcare Provider Efforts vs Fees: Striking the Right Balance

3.1 Introduction

Several factors contribute to the decline in service quality when public services are outsourced. These factors include a lack of understanding of private service providers' cost structures and operations, contract incompleteness, challenges in monitoring due to high costs and employee turnover, as well as the pressure to reduce expenses. However, one factor that has not been thoroughly researched is lenient penalties for poor service quality. When mild penalties are in place, outsourcing firms may be incentivized to deliver lower-quality services without facing significant consequences. This can result in quality deterioration and potentially hinder both service providers and the government from achieving maximum payoffs. On the contrary, when penalties are low, they can act as a mechanism that encourages firms to enforce their compliance with contracts. Therefore, this study aims to determine the bonuses that the healthcare provider should pay to the outsourced firm when it surpasses or falls short of an agreed healthcare output. Their difference serves as a penalty, internally binding the parties' relationship. Consequently, the paper seeks to find an optimal balance between this internal enforcement and the government's efforts, namely the external enforcement level, to maximize the parties' joint output.

In this study, I analyze a repeated game with imperfect public monitoring. The parties involved can observe the stochastic output that arises from their interactions but can't verify it.[1] Both the principal's external enforcement effort and the agent's efforts are unverifiable and unobservable, leading to a double moral hazard (DMH) problem. I focus on the scenario where the parties' efforts are continuous. By virtue of Levin (2003), I search for an optimal relational contract. I solve the game in a stationary environment, where the principal offers a time-invariant base payment and discretionary bonus every period to the agent.

Indeed, under the DMH the first best is not possible to achieve, while to achieve second-best in static game is possible by any linear contract (Kim & Wang, 1998), or "share or noting and bonus" contract (Zhao, 2007). I explore what an optimal relational contract would be in a dynamic environment under DMH.

In static environment Cong and Zhou (2021) proves that under specific conditions hold, there always exists a "share or nothing and bonus" contract to achieve the second-best outcome. I prove in my paper that under a certain inequality, there always exists a share-or-nothing contract to achieve the second-best outcome in a dynamic environment simplified to a stationary environment, following Levin (2003) approach. The dynamic model was chosen to determine the optimal maximum and minimum contracts, $\bar{W}$ and $\underline{W}$, which bind the parties' relationship. The objective of the paper is to find a balance between the difference in these contracts (internal enforcement) and the efforts of the healthcare provider (external enforcement). The existence of at least one share-or-nothing contract under the second-best scenario enables me to achieve this dynamic trade-off.

The main contribution of this study is twofold. First, I extend the Levin (2003)'s model to the DMH scenario. Thus, I incorporate an external enforcement variable into my model by considering the principal's unobservable efforts. Second, I conduct a simulation of the model using Spaeter (1998)'s distribution. The simulation allows me to examine how variations in the distribution impact the optimal level of the principal's effort, which then exogenously influences the variation in contingent payments. This study aims to establish how parties can achieve more efficient outcomes by making use of internal enforcement and external enforcement in the optimal relational contract.[2]

The main result of this study is that with the increase in healthcare output sensitivity

[1]Seminal contributions include Bull (1987), Gibbons and Roberts (2013), Klein and Leffler (1981), and Levin (2003). See also Gibbons and Roberts (2013) for a review.

[2]To identify violations of contract terms, the authority engages in contract enforcement - a process aimed at compelling the involved parties to fulfil the actions outlined in the agreed-upon contract. The mechanisms for contract enforcement differ according to their applicability, type of contract and formality. For instance, contract enforcement can be formal and informal, public or private, internal (self-enforceable) or external (attracting a third party, public institution, regulatory authority, or law court).

to the government's external enforcement and supplier's efforts (from delivery of facility management services to surgery equipment), external enforcement should increase along with the internal enforcement in order to encourage parties to sustain the relationship under optimal relational contract.

The remainder of this paper is organized as follows. Section 3.2 provides an extensive literature review. Section 3.3 discusses the model's relevance to real-world scenarios. The model is described in Section 3.4. Section 3.5 provides simulations. Section 3.6 concludes.

3.2 Literature review

This study is related to two strands of contract theory literature: relational contract modelling within a stationary environment and with persistent types of players (Levin, 2003; MacLeod, 2003; Malcomson, 2016; Pearce & Stacchetti, 1998), and the complementary nature of external and internal enforcement from a theoretical perspective (Dumav et al., 2022; Watson, 2021; Watson et al., 2020).

Relational contracts have emerged as a result of developments in repeated game theory applied to principal-agent modelling.[3] This concept is derived from the dynamic enforcement constraint for the equilibria in repeated games. Rubinstein (1979) is the first to examine a repeated-game model of a principal-agent relationship with binary choices for both parties. Radner (1985) expands on this by considering the model in discrete time and studying equilibria that involve "review strategies". Spear and Srivastava (1987) further explore these equilibria within a larger context, analysing them as part of a dynamic program that incorporated continuation values.

Meanwhile, MacLeod and Malcomson (1989) extend the study of Radner (1985) by incorporating continuous effort. They demonstrate that when output measures are not verifiable and performance is commonly known, continuation values in long-term relationships can be utilised to incentivise individuals. Pearce and Stacchetti (1998) explore how both verifiable and non-verifiable performance measures could be combined in optimal contracts, providing a foundational framework for the recursive approach in contract theory. Levin (2003) develops a model on Pearce and Stacchetti (1998)'s work by introducing a nonpersistent and observable outcome that cannot be verified. Additionally, Levin (2003) includes the shock to the cost of effort, while the environment in MacLeod and Malcomson

[3]See MacLeod (2007) and MacLeod and Malcomson (2023) for a comprehensive review of the relational contracts theoretical literature. For empirics, follow Macchiavello (2022).

(1989) does not involve any uncertainty.[4]

Theories in microeconomics have been developed based on certain contract enforcement assumptions. Hereafter, incentive theory focuses on how agents attempt to resolve information asymmetry, allowing for a perfect enforcement agreement by an external mechanism. In contrast, transaction cost theory eliminates this binding assumption. It establishes how economic agents in the real world solve contracting problems under incomplete contracts, where contractual breach penalties and/or supervising authorities can punish the present. In the late 1980s, incomplete contract theory was developed, focusing on the information asymmetry between parties interacting within hierarchical relationships. This theory focuses on imperfections in institutional systems, aimed at making contracts enforceable and allowing for the unverifiability of key variables. Recently, game theorists have modeled relational contracts as long-term contractual relationships encompassing both formal (externally enforced) and informal (self-enforcing) contracts. Notably, a commonality across these theories is the mutual exclusion of either self-enforcing or externally enforced contracts, with a limited number of studies considering their combined application. Nevertheless, the relational contract literature has made a step further, and recently written papers prove that external enforcement complements internal enforcement.

The concept of self-enforcement and external enforcement in finite period models was first distinguished by Bull (1987). Recently, other studies built on the Levin (2003) model have considered the complementarity of external and internal enforcement in infinite-period models. Notably, Dumav et al. (2022) study a repeated principal-agent game coupling that limited external enforcement with persistent productivity shocks. Watson et al. (2020) demonstrate that in more realistic setting where players can successfully renegotiate every period both components of their long-term contract every following any history, the external-enforcement technology always complements self-enforcement in an optimal contract. This can be achieved even after deviation. Watson (2021) congregates relational incentive contracts on a class of repeated-game style models of ongoing relationships with moral hazard. He establishes external enforcement through an external contract that prescribes contractual provisions to the external enforcer on how to intervene in a relationship. This contract is introduced by compelling monetary transfers as a function of verifiable information. The internal part of the contract records how the contracting parties agree to act. In comparison to the aforementioned studies, I introduce external enforcement into the model through the principal's external enforcement effort and establish a link to the self-enforcement constraint through the tightness of the dynamic enforcement constraint.

[4] Similar to Levin (2003) but with a risk-averse agent, there is a study by MacLeod (2003).

This study also contributes to existing research on DMH. DMH has been applied in various applications to determine optimal contract conditions, including franchising (Bhattacharyya & Lafontaine, 1995), warranty contracts (Cooper & Ross, 1985), supply chains (Corbett & DeCroix, 2001; Corbett et al., 2005), collaborative services such as financial planning, consulting, and IT outsourcing (Roels et al., 2010), joint product improvement by client and customer support centers (Bhattacharya et al., 2014), repair and restoration services (Jain et al., 2013), and justice production (Roussey & Soubeyran, 2018). These studies share the common assumption that the parties' efforts contribute to a joint outcome. In the healthcare sector, any relationship should, in my view, be considered within the double-sided framework since all actors obtain a common output, joint production of health, and improvement of patient care.

Nevertheless, there is limited research on the interrelationships between different actors in healthcare services from the perspective of double-sided asymmetric information. Those that exist are mainly focused on adverse selection due to common problems with health insurance, where individuals have private health risk information, and doctors have private patient health condition information. Classical problems within this framework are: lack of coverage, overtreatment and undertreatment, inappropriate referral to a specialist.[5] This paper focuses on the less covered in the healthcare literature asymmetric information problem, DMH, leaving aside adverse selection.[6]

There have been trials by other authors to solve for an optimal contract within patient-physician and hospital-physician relationships under a DMH in a static environment. Specifically, Schneider (2004) covers the DMH problem in patient-physician relationship based on the Cooper and Ross (1985)'s paper, while Leonard and Zivin (2005) introduce a regulator as a third party to the problem, who observes physician effort and forces him to provide its particular level. Wang (2015) describes hospital and physician relationship under a double-sided model.[7] Finally, Bhattacharya et al. (2015) solve for an optimal contract within the research and development partnerships of a provider that conducts research and

[5]For example, optimal contract establishment between the National Health Service (NHS) (public, or private insurer) and a healthcare provider (such as a hospital or GP) for a specific health service (De Fraja, 2000) or when there are multiple treatments available for a given diagnosis (Siciliani, 2006); between health planner and patients (Frank et al., 2000); between hospitals varying in terms of doctor abilities and unit mass of patients (Makris & Siciliani, 2013).

[6]Major (2019) widely covers various combinations of asymmetric information among different actors involved in providing healthcare services including patient-physician relationships, physicians working within medical institutions, government interactions with medical institutions, and patients dealing with governmental or state agencies.

[7]Follow McCullough and Snir (2010) and Culyer and Newhouse (2000) for moral hazard problem in between hospital and physician relationship.

a client that provides activities in the pharmaceutical industry. Thus, they simultaneously resolve the holdup, DMH, and risk-aversion problems. All these studies assume that one of the actors is risk-averse, that is, the patient, physician, or service provider. In contrast, I focus on the interaction of parties in the healthcare industry who are indifferent to risk over time.

My research also adds to the existing knowledge on contract enforcement. In the following subsections, I provide a comprehensive review of recent literature on contract enforcement in economics, covering theoretical frameworks and empirical findings. To enhance clarity, I organize the discussion into separate subsections for public and private contract enforcement.

3.2.1 Public enforcement by law court

Enforcing a contract may require engaging a third party, such as a court, to serve as an overseer in situations in which the parties violate the agreement.

Theoretical approach

According to the literature on principal-agent contracts under unverifiable performance measures, contractual terms may not be enforced by a third party or could involve excessively high enforcement costs (Baker et al., 1994; Fuchs, 2007; Levin, 2003; MacLeod, 2003; MacLeod & Malcomson, 1989). Doornik (2010) explores an intermediate scenario where parties need to bear some cost for contract enforcement, but the costs are not prohibitive that external enforcement becomes impossible, e.g. liquidated damages clauses. He demonstrates that the structure of principal-agent contracts can impact the likelihood of incurring enforcement costs, which has implications for determining the optimal contract choice. In this context, the two parties are able to draft contracts detailing payments based on output. However, unlike a standard principal-agent model, verifying output and enforcing payments comes with associated expenses.

Under incomplete contract theory, enforcement can be viewed from an ex-ante versus ex-post perspective. In a principal-agent model with adverse selection, costly enforcement technology (Guasch et al., 2008) and lack of enforcement (Chong et al., 2006; Estache, 2006; Guasch, 2004; Saussier et al., 2009) lead to renegotiation occurrences. However, an efficient judicial system may attract more renegotiation because of the court's ability to force a solution (Domingues & Sarmento, 2016; Guasch et al., 2008). Al-Najjar et al. (2002) focus on incomplete contracts leading judges to void clauses and initiate renegotiation. The procurement and regulation models proposed by Laffont (2003) and Laffont and Meleu (2000) integrate the concept of adverse selection, in which enforcement of penalties may be influenced by enforcement expenditures. These models align with the perspectives of the Chicago school. Although modern contract theory recognizes the importance of law enforcement, it has not yet fully addressed this specific aspect.

Empirical approach

There is a growing body of empirical research on enforcement of public contracts. For example, studies by Girth (2014) and Coviello et al. (2018) examine the impact of external factors on the enforceability of public contracts, while Coviello et al. (2018) also discusses a strategy that is not only within the discretion of public managers but also aligns with the theoretical literature on internal verifiability (Kvaløy & Olsen, 2009, 2010). Using an extensive dataset on Italian public procurement, Coviello et al. (2018) empirically analyze the effects of court inefficiency on the performance of public works. They observe that in situations where courts are inefficient, there are longer delays in delivering public works, and these delays increase for more valuable contracts. In contrast to this focus on accountability, private agreements emphasize self-enforcement through mutually binding pacts, where reputation plays a crucial role. Giacomelli and Menon (2017) demonstrate how inadequate contract enforcement can significantly influence firms' incentives for expansion - their findings suggest that reducing judicial proceedings duration by 10% leads to a 2% growth in local firms' average size.

3.2.2 Public enforcement through institutions

Contracts can also be enforced by institutions. This subsection explores how legal frameworks and institutions adhere to contractual agreements.

Theoretical approach

The study by Laffont and Meleu (2000) examines the concept of incentive regulation in developing nations, where inadequate institutions lead to contracts that cannot be fully enforced. In this framework, the agent must decide whether to accept a regulatory contract based on the menu before knowing its cost implications. The effort made by the agent is not visible, which reduces the apparent costs. Therefore, contracts that reward agents based on observed costs are more likely to be enforced when the principal's expenditure level increases. The effective enforcement of regulatory contracts means that high-cost agents encounter reduced benefits.

Laffont (2003) analyses the structure of incentives and defines the most effective regulatory agreements and enforcement expenses. By contrast, Garcia et al. (2005) proposes that an agent's legal costs impact the likelihood of successfully enforcing the original contract. The effort put forth by an agent in carrying out a project is influenced by its ability to pursue litigation over contract terms to recoup any cost overruns. Garcia et al. (2005) focuses on how an agent's motivation for reducing project costs is impacted by their option to engage in expensive litigation. Their model illustrates that, when large-scale public projects are procured through contracts with strong incentives for private firms, excessive litigation may occur in weak institutional settings. They demonstrate that committing to a predetermined level of government-led litigation alongside weaker incentive contracts serves as a more efficient procurement method. Guccio et al. (2017) discover that the quality of local conditions can influence public officials' motivations to act efficiently.

Empirical approach

The role of institutional weaknesses in infrastructure procurement has been discussed widely. The general result of the studies mentioned below is that the quality of the institutional environment matters in infrastructure procurement. For example, Estache et al. (2015) demonstrate that "weak institutions" do not uniformly advocate for or oppose private finance. Instead, different weaknesses push in different directions. If a regulator is weak and faces significant information asymmetry, there could be potential cost reductions on which the government may fail to capitalize through pricing. This situation leads to private finance as a means of increasing the likelihood of cost reduction and taking advantage of lower expected costs.

Cavalieri et al. (2020) empirically demonstrate that certain dimensions of institutional quality have a more significant impact on performance in contract execution within the transport infrastructure. Other studies (Baldi et al., 2016; Coviello & Gagliarducci, 2017; Finocchiaro Castro et al., 2014, 2018) focusing on corruption in the institutional environment find an association between the characteristics of the local area and outcomes in public procurement, impacting measures such as price differentials, cost overruns, and execution time (Bandiera et al., 2009; Coviello & Gagliarducci, 2017; Finocchiaro Castro et al., 2014).

3.2.3 Private enforcement: self-enforcing agreements

Self-enforcement is often overlooked in the literature as a possible mechanism for maintaining future partnerships and preventing breach of contracts. Telser (1980) is one of the first to develop the theory of self-enforcing agreements. One crucial assumption in his paper is that parties only consider uncertain future outcomes, without taking into account their past relationship history. In other words, an agreement is self-enforcing, as long as both parties expect greater utility from continuing the relationship than from breaking the present contract. Noorderhaven (1992) argues that under this assumption, as in agency theory, only transactions with an immediate and simultaneous performance exchange can occur. Nevertheless, it is impossible to examine agency theory for these exchanges. Further theoretical models have been developed to address contract self-enforcement when cooperation is optimal. In supply contracts, the long-term returns from the current relationship must be equivalent to the present value of returns from the spot market for the product involved in order for both parties to continue trading with each other.

Watson (2021) explains that self-enforcement involves coordinated actions by the parties involved, aligned with their individual motivations. Self-enforcing agreements allow one party (the principal) to end a contract with the other party (the agent) if undesirable actions are identified. The threat of contract termination serves as a deterrent for the agent's misbehavior, particularly when they derive greater benefits from the relationship compared to outside it. Despite enforceable legal contracts, various aspects of parties' conduct and performance remain uncontracted due to multiple uncertainties and information imbalances. Consequently, self-enforcing agreements are widespread in business relationships (Gil & Zanarone, 2014; Gil & Marion, 2013) whether through informal arrangements alone (Levin, 2003) or in conjunction with formal contracts (Zanarone, 2013). There is also extensive literature on purely self-enforcing contracts that can be found in studies such as those by Bull (1987), Levin (2003), and MacLeod and Malcomson (1989).

A significant breach in the incentive contract literature comes from the impossibility of considering both public and private enforcement mechanisms. However, these are typically excluded. One way to deal with contract complexity and incomplete contracts and eliminate possible hold-up problems is to rely on informal commitments, such as relational contracting (Macaulay, 2018). Reliance on relational contracts in the public domain is unfeasible, owing to their uniqueness and contract longevity. Therefore, using relational contracts, I investigate internal and external contract enforcement within public services procurement in the healthcare industry.

3.3 Real-world scenario relevance of the model

The model analysed in this study can be used to describe relationships between a pharmaceutical company and a healthcare provider, as well as between a medical equipment maintaining firm and a hospital, and other actors providing healthcare services.[8] The choice to focus on the healthcare sector was based on the feasibility of applying risk-neutral parties' interaction to numerous different relations within this industry.[9] In general, the model is suitable to describe various relationships in other industries, like franchiser-franchisee interactions, that satisfy particular criteria:

- risk-neutral parties;
- presence of double-sided moral hazard problem in the parties relationships;
- contract is of the type: fixed fee and contingent on the output bonus or fee;
- parties interact every period with the possibility to continue relationships endlessly;
- one's party prevarication ends the relationship forever;
- introduction of external contract enforcement in the relationship through the principal's effort level complements or substitutes for the agent's efforts without directly affecting their efficiency.

Below, there is a detailed example of a scenario within the healthcare industry that fulfills these criteria. Specifically, medical equipment maintaining firm and a hospital.

Parties risk-neutrality and external contract enforcement efforts: a healthcare organisation offers a contract to a provider for maintenance services on medical equipment to perform preventive maintenance and repairs on medical devices. The risk-neutrality of the provider is influenced by their reputation and long-term relationships with hospitals, which are more important than short-term risk-taking behaviour. Both parties' actions impact the chance of failure, leading to a DMH problem where both the hospital and service provider may have incentives to neglect proper care for the equipment. To address this issue, the healthcare organization employs various forms of external enforcement, such as performance

[8] New technology development, like telemedicine devices, may not fit this model because the developer could be a monopolist. This might lead to the government being pressured to extend the contract even if the service is unsatisfactory. In such cases, even though there may be penalties for the supplier, the contract will not be terminated, which does not align with the grim-trigger strategy examined in this study.

[9] In the healthcare sector, any firm that focuses on preventive measures, optimizing healthcare delivery, or enhancing patient outcomes instead of prioritizing revenue generation exhibits the behaviour of a risk-neutral firm.

benchmarks, contractual penalties, and quality assurance measures.

Contract: a hospital offers a contract to a maintenance firm that includes fixed payment and possible fees or bonuses. The firm can be fined or have the contract terminated if it does not respond promptly to equipment breakdowns, leading to potential issues with critical medical devices. In contrast, a hospital or equipment manufacturer covers the costs associated with replacements or major repairs, and the maintenance firm earns an additional bonus for coordinating and facilitating the repair or replacement process.

Parties interaction: multiple firms can maintain healthcare medical equipment because the market is not monopolistic. Since service failure directly impacts patient health, there is a high probability of contract termination for unsatisfactory maintenance. A possibility of renewing or extending the contract between parties due to the new equipment maintenance can be equalized to a newly offered contract by the principal.

Principal's contract enforcement effort level

Efforts of the principal in the principal-agent model, particularly in the context of external contract enforcement, can take various forms beyond direct monitoring. These efforts are designed to incentivize and ensure compliance from the agent without necessarily incurring additional monitoring costs. Here are some examples:

- Clear contractual terms and incentive structures: the principal can invest effort in designing clear and comprehensive contractual terms, including performance metrics, standards, and incentive structures. By clearly defining expectations and rewards for achieving desired outcomes, the principal creates a framework that aligns the agent's incentives with organizational objectives, reducing the need for extensive monitoring.
- Regular communication and feedback mechanisms: the principal can establish channels for regular communication and feedback between the principal and the agent. By providing timely feedback on performance and addressing any concerns or issues promptly, the principal fosters transparency, trust, and accountability, which can motivate the agent to adhere to contractual obligations without the need for constant monitoring.
- Training and capacity building: the principal can invest in training programs and capacity-building initiatives to enhance the agent's skills, knowledge, and capabilities. By providing the agent with the necessary resources and support to perform their duties effectively, the principal empowers the agent to fulfill their contractual obli-

gations autonomously, reducing the likelihood of non-compliance and the need for continuous monitoring.

- Performance reviews and recognition: the principal can conduct periodic performance reviews and provide recognition or rewards for exemplary performance. By acknowledging and rewarding the agent's achievements, the principal reinforces desired behaviors and outcomes, motivating the agent to maintain high levels of performance and compliance with contractual obligations.
- Escalation mechanisms and dispute resolution processes: the principal can establish escalation mechanisms and dispute resolution processes to address any disagreements or disputes that may arise during the contract period. By providing a structured framework for resolving conflicts and addressing grievances, the principal ensures that issues are addressed promptly and fairly, mitigating the risk of non-compliance and minimizing the need for external monitoring.

Overall, these efforts by the principal contribute to effective contract enforcement and compliance without imposing significant additional monitoring costs. By investing in clear communication, training, feedback mechanisms, and performance incentives, the principal can incentivize the agent to fulfill their contractual obligations autonomously, fostering a mutually beneficial relationship that maximizes value creation and minimizes the need for external oversight.

3.4 The Model

This section describes an applied model of this study. Initially, I provide the timing of the game. Then, I discuss how agents interact in the stage game. Finally, I extend the stage game to the infinitely-repeated version, where I solve for the optimal relational contract that can be achieved by the parties in equilibrium under certain constraints.

I examine the dynamic relationship between two long-lived parties ($i = P, A$): a risk-neutral principal, referred to as "she", and a risk-neutral agent, "he", responsible for providing services on behalf of the principal. To illustrate this relationship, I consider the context of contracting healthcare-oriented services (the detailed example provided in the previous section 3.3). Interactions occur at regular intervals over periods $t = 0, 1, 2, \ldots$. In the vein of MacLeod and Malcomson (1989) and Levin (2003), I assume that the parties' commitment to the relationship is observable, ensuring that identical promised payments in every period are honoured.[10] The physical environment remains unchanged at each date.

3.4.1 Timing

In each period t, the parties play the following stage game, as depicted in Fig. 3.1.

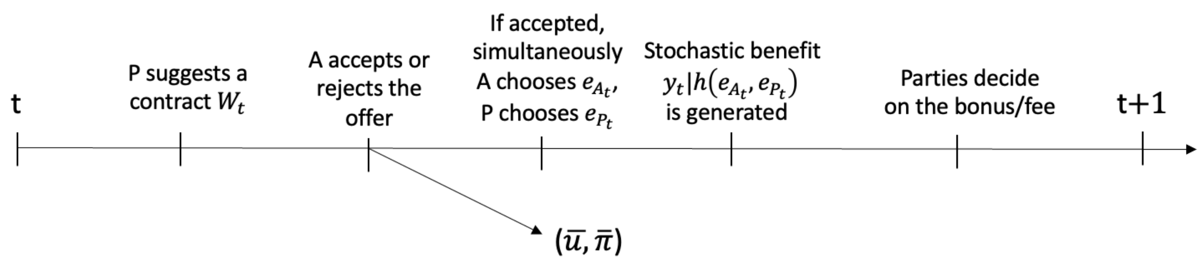


Figure 3.1: Timing

The principal makes a take-or-leave-it offer to the agent. Upon receiving the offer, he decides whether to accept or reject it. If declined, the agent gains $\overline{u} \in \mathbb{R}$ (by signing a contract with another principal) in the current period and for all subsequent periods, while the principal earns $\overline{\pi} \in \mathbb{R}$ (by providing services in-house or outsourcing to an alternative supplier).[11] If accepted, both the agent and the principal simultaneously choose their respective effort levels, e_{A_t} and e_{P_t}.

The agent exerts effort $e_{A_t} \in E_A \subseteq [0, \overline{e}_A]$, incurring cost $c(e_{A_t})$, where $c_e, c_{ee} > 0, c(0) = 0$, and $\lim_{e \to \overline{e}_A} c_e = \infty$.[12] His nonpersistent level of effort is unobservable and noncontractible.[13] Simultaneously, the principal chooses efforts to incentivize and ensure compliance from the agent without necessarily incurring additional monitoring costs, $e_{P_t} \in E_P \subseteq [0, \overline{e}_P]$. She bears a cost of effort $\phi(e_{P_t})$, where $\phi_e, \phi_{ee} > 0, \phi(0) = 0$, and $\lim_{e \to \overline{e}_P} \phi_e = \infty$. The choice of a cost function with increasing marginal cost for the principal aligns with risk-neutral decision-making and reflects the realistic cost structure of her activities. In particular, the principal's external enforcement effort incurs increasing costs as it becomes more intensive. Similarly, her nonpersistent effort is unobservable and nonverifiable for the agent. Thus, I face a DMH problem.

[10] See Halac (2012) for relaxing the assumption that commitment to the relationship is certain.

[11] This reflects a traditional grim-trigger strategy.

[12] The limit $\lim_{e \to \overline{e}_A} \phi_e = \infty$ indicates that the model acknowledges the infeasibility of extremely high effort levels. In particular, the marginal cost of effort becomes prohibitively high or approaches infinity when the agent attempts to exert effort beyond the maximum level.

[13] The assumption that the agent's effort, and the principal's later, is not persistent means that their choice of effort in one period does not provide any information about their effort level in the next period.

The parties' actions yield a stochastic output y_t, which is a random variable conditional on e_{A_t} and e_{P_t} through a composite effort function $h(e_{A_t}, e_{P_t}) : \mathbb{R}_+^2 \to \mathbb{R}$, where $h_{e_A}(e_{A_t}, e_{P_t}), h_{e_P}(e_{A_t}, e_{P_t}) > 0$ and $h_{e_A e_A}(e_{A_t}, e_{P_t}), h_{e_P e_P}(e_{A_t}, e_{P_t}) \leq 0$.[14] The output is distributed as $F(y_t|h(e_{A_t}, e_{P_t}))$ with the corresponding twice continuously differentiable density function $f(y_t|h(e_{A_t}, e_{P_t}))$ on the support $Y = [\underline{y}, \overline{y}]$.[15] This is a repeated game with imperfect public monitoring, where the output y is publicly observed by both the agent and the principal, but is non-verifiable by a third party. To allow for the validity of the first-order approach (Cong & Zhou, 2021; Jewitt, 1988; Milgrom, 1981; Rogerson, 1985), I assume that $\forall h \in \mathbb{R}$, $\frac{d}{dy}\left(\frac{f_h(y_t|h(e_{A_t}, e_{P_t}))}{f(y_t|h(e_{A_t}, e_{P_t}))}\right) > 0$ and $F(y_t|h(e_{A_t}, e_{P_t}))$ is convex in h for any $y \in [\underline{y}, \overline{y}]$.[16]

Finally, upon the realization of the output y_t, the principal compensates the agent with an agreed fixed payment $w_t \geq 0$. Additionally, adjusting this payment with a promised, but not guaranteed, output-contingent bonus $b_t : Y \to \mathbb{R}$. Consequently, I examine an asymmetric information scenario, where both parties' efforts are unobservable, and they have equal levels of moral hazard. The scenario where the parties' hidden actions vary is beyond the scope of this study.

When $b_t(y_t) \geq 0$, the principal decides whether to fulfill or withdraw the bonus payment at the end of period t. Conversely, when $b_t(y_t) < 0$, the decision belongs to the agent. Allowing for a negative bonus payment removes limited liability from the model. Let W_t denote the total compensation, where $W_t = w_t + b_t(y_t)$ if the contingent payment is honored, and $W_t = w_t$ otherwise.

To streamline notations within a dynamic environment, henceforth in this paper, I define: $h = h(e_{A_t}, e_{P_t})$, $h_{e_P} = h_{e_P}(e_{A_t}, e_{P_t})$, $h_{e_A} = h_{e_A}(e_{A_t}, e_{P_t})$, $h_{e_P e_P} = h_{e_P e_P}(e_{A_t}, e_{P_t})$ and $h_{e_A e_A} = h_{e_A e_A}(e_{A_t}, e_{P_t})$. Hence, $f(y_t|h) = f(y_t|h(e_{A_t}, e_{P_t}))$, $f_h(y_t|h) = f_h(y_t|h(e_{A_t}, e_{P_t}))$, $F(y_t|h) = F(y_t|h(e_{A_t}, e_{P_t}))$ and $F_h(y_t|h) = F_h(y_t|h(e_{A_t}, e_{P_t}))$. In a static environment, the time subscripts will be omitted.

[14] I employ a composite effort function to simplify the analysis in the vein of Bhattacharyya and Lafontaine (1995), Cong and Zhou (2021), and Kim and Wang (1998). The conditions for the first and second order derivatives of the joint production function justify complementary efforts by parties that correspond to reality.

[15] A restriction on the finite continuum of outputs is essential for the existence of an optimal contract. Without such a limitation, continuous efforts allow the principal's payoff decrease in output, potentially incentivizing her to sabotage strong performance. For more details on this issue, follow Innes (1990).

[16] These assumptions make the Mirrlees-Rogerson conditions, the monotone likelihood ratio property (MLRP) and the convexity of the distribution function condition (CDFC), valid and allow for the first-order conditions to bind. Follow the Appendix A1 for more details.

3.4.2 Stage game

A discussion of the stage game in this section serves as a preliminary step towards addressing the DMH problem within a dynamic framework, which constitutes the central focus of this paper.

I denote a stage game as G. The stage game G determines the optimal contract $W(\cdot)$, when parties interact only during one period. Following Kim and Wang (1998) and Zhu and Wang (2005), under the binding first order approach (FOA) and combination of the parties' incentive constraints, the relaxed problem that solves for the optimal linear contract is as follows:

$$\max_{e_P, e_A} \int_{\underline{y}}^{\overline{y}} yf(y|h)dy - \phi(e_P) - c(e_A) - \overline{u}, \tag{3.1}$$

$$\int_{\underline{y}}^{\overline{y}} yf(y|h)dy = \frac{c'(e_A)}{h_{e_A}} + \frac{\phi'(e_P)}{h_{e_P}}. \tag{3.2}$$

Defining the solution of the problem by (e_A^*, e_P^*) that is independent of any specific contract and slightly rearranging (3.2), it is clear that $\int_{\underline{y}}^{\overline{y}} yf_h(y|h(e_A^*, e_P^*))h_{e_A}dy > c'(e_A^*)$. More precisely, given e_P^*, the expected marginal payoff from e_A^* is strictly larger than its marginal cost, and vice versa. This inequality explains why (e_A^*, e_P^*) is the second-best effort choice. An impossibility of achieving first-best outcome within this problem is related to the balancing-budget problem, i.e. despite the output, the sum of parties payment is always equal to the whole output (Holmstrom, 1982).

Kim and Wang (1998) and Zhu and Wang (2005) have proved that under the DMH problem without limited liability the linear sharing contract that can always achieve second-best outcome is of the form $W^*(y) = \frac{c'(e_A^*)}{R_{e_A}(e_A^*, e_P^*)}[y - R(e_A^*, e_P^*)] + \overline{u} + c(e_A^*)$, where $R(e_A^*, e_P^*) = \int_{\underline{y}}^{\overline{y}} yf(y|h)dy$. Cong and Zhou (2021) simplify the optimal linear sharing contract to the form $W^*(y) = \gamma^*(y - \hat{y}^*)$, where $\hat{y}^*$ and γ^* are defined below:

$$W^*(y) = \underbrace{\frac{c'(e_A^*)}{\int_{\underline{y}}^{\overline{y}} yf_h(y|h)h_{e_A}dy}}_{\gamma^*} \left(y - \underbrace{\int_{\underline{y}}^{\overline{y}} yf(y|h)dy + \frac{c(e_A^*) + \overline{u}}{\gamma^*}}_{\hat{y}^*} \right).$$

3.4.3 Multiple-periods contracting problem

Let consider $G^{\infty}(\delta)$ as an infinitely repeated version of the two players stage game G, where parties maximize their discounted payoff streams. Specifically, parties care about the future of their interactions, so from date t onward, their expected payoffs are discounted by the same factor $\delta \in (0,1)$. δ corresponds to the probability that the interaction will continue until the next date, i.e. after each stage, there is a probability $(1-\delta)$ that the game will end. In essence, the game will end in finite time but just randomly. Expected lifetime payoffs are normalized by $(1-\delta)$ to show them as per-period averages.

Principal's expected payoff:

$$\pi_t \equiv (1-\delta)E\sum_{\tau=t}^{\infty}\delta^{\tau-t}[\Lambda_\tau[y_\tau - W_\tau - \phi(e_{P_\tau})] + (1-\Lambda_\tau)\overline{\pi}]. \tag{3.3}$$

Agent's expected payoff:

$$u_t \equiv (1-\delta)E\sum_{\tau=t}^{\infty}\delta^{\tau-t}[\Lambda_\tau[W_\tau - c(e_{A_\tau})] + (1-\Lambda_\tau)\overline{u}]. \tag{3.4}$$

In both equations, (3.3) and (3.4), $\Lambda_\tau \in [0,1]$ is a probability that determines the agent's response to the take-or-leave-it offer. When $\Lambda_\tau = 1$, he accepts the offer, whereas a value of $\Lambda_\tau = 0$ means rejection. Once Λ_τ is zero, it remains zero forever, indicating a strict punishment rule as in Abreu (1988). Then, the expected surplus is $s_t = u_t + \pi_t$. In a dynamic environment, the principal's offer in period t depends on the information she obtains when she makes an offer. The information available at the beginning of period t is denoted as $h^t = (w_0, \Lambda_0, b_0, y_0, e_{A_0}, e_{P_0} \cdots w_{t-1}, \Lambda_{t-1}, b_{t-1}, y_{t-1}, e_{A_{t-1}}, e_{P_{t-1}})$ as a public history up to period t, and H^t is a set of all possible period-t public histories.

The principal's strategy σ_P specifies a decision whether or not to offer a contract to the agent, a fixed payment $w_t(h^t)$, a contingent bonus $b_t(h^t, y_t)$, and an effort level $e_{P_t}(h^t, w_t)$. The agent's strategy σ_A specifies a decision whether or not to accept an offer from the principal, and an effort level $e_{A_t}(h^t, w_t)$. Let ζ_w is a flow payoff from a verifiable fixed compensation, while ζ_b is a flow payoff from non-verifiable contingent bonus payment.

Hence, $(\sigma_P, \sigma_A, \zeta_w, \zeta_b)$ is a *relational contract* that is a complete plan of the relationship. It identifies for each period t and every history $h^t \in H^t$ a fixed compensation the principal offers w_t, the agent's participation decision Λ_t, in the event of acceptance, the principal's effort level e_{P_t} along with the agent's effort level e_{A_t}, and the variable bonus payment

$b_t(y_t)$ given the output observable realization. A relational contract is *self-enforcing* if the players' strategies constitute a perfect public equilibrium (PPE) of the repeated game that describes the behavior on and off the equilibrium path (Fudenberg & Levine, 1994). In the PPE, players' decisions are based solely on publicly available information in equilibrium. Specifically, they can not base their actions on their previous efforts, while both parties can consider past payments and outcomes. This analysis focuses on optimal relational contracts, which are defined as PPEs that achieve Pareto efficiency within the set of PPE payoffs.

Further, I first describe the constraints that must be satisfied for the payoff pair (π, u) to be within the PPE payoff set. Then, in Proposition 1, I characterize the parties' efforts that can be sustained in a PPE. Next, I define an optimal relational contract under a specific scenario in Proposition 2.

Constraints

I denote the set of PPE payoffs by Φ. Each payoff pair $(\pi, u) \in \Phi$ is associated with the profile of actions $(e_A, e_P, w, b(y))$ and continuation payoffs $(\pi(y), u(y))$ as functions of observable but unverifiable output y, where $\pi(y)$ is the principal's continuation payoff and $u(y)$ is the agent's continuation payoff.[17] The continuation payoffs $(\pi(y), u(y))$ are generated by the continuation contract $W(y) \equiv w + b(y)$ imposition.

Parties' expected payoffs under the continuation contract $W(y)$ that are equal to the weighted sum of current and future payoffs, i.e.,

$$\pi \equiv (1-\delta) \int_{\underline{y}}^{\overline{y}} [y - W(y) - \phi(e_P)]\, f(y|h)dy + \delta \int_{\underline{y}}^{\overline{y}} \pi(y) f(y|h)dy,$$

$$u \equiv (1-\delta) \int_{\underline{y}}^{\overline{y}} [W(y) - c(e_A)]\, f(y|h)dy + \delta \int_{\underline{y}}^{\overline{y}} u(y) f(y|h)dy,$$

with the followed expected contract surplus $s \equiv u + \pi$, i.e.,

$$s \equiv (1-\delta) \int_{\underline{y}}^{\overline{y}} [y - \phi(e_P) - c(e_A)] f(y|h)dy + \delta \int_{\underline{y}}^{\overline{y}} s(y) f(y|h)dy,$$

where $s(y) \equiv \pi(y) + u(y)$ is the continuation surplus.

[17] A continuation payoff refers to the expected payoff that a player anticipates receiving in future periods of a repeated game, based on the strategies and actions chosen by all players in preceding periods.

For this paper, there are five constraints, four as in Levin (2003) and one more, principal's incentive constraint, that identify whether the continuation contract $W(y) \equiv w + b(y)$ is self-enforcing and ensure the viability of the PPE payoff pair (π, u) through pure actions. In particular,

(i) individual rationality constraints that ensure the wiliness of parties to initiate the contract: $u \geq \bar{u}$ and $\pi \geq \bar{\pi}$ for the agent and the principal, respectively. These constraints are defined as (IR_A) and (IR_P);

(ii) agent's incentive constraint that guarantees a choice by the agent of a certain level of effort e_A:

$$e_A \in \arg \max_{e_A \in E_A} \left\{ \int_{\underline{y}}^{\overline{y}} \left[W(y) + \frac{\delta}{1-\delta} u(y) \right] f(y|h)dy - c(e_A) \right\};$$

(iii) principal's incentive constraint that guarantees a choice by the principal of a certain level of effort e_P:

$$e_P \in \arg \max_{e_P \in E_P} \left\{ \int_{\underline{y}}^{\overline{y}} \left[y - W(y) - \frac{\delta}{1-\delta} \pi(y) \right] f(y|h)dy - \phi(e_P) \right\};$$

(iv) self-enforcement constraints (called by J. Li and Matouschek (2013) as truth-telling) that ensure wiliness of parties to make the variable payment for all output $y \in Y$. I define them as the agent's dynamic-enforcement constraint (DEC_A) and the principal's dynamic-enforcement constraint (DEC_A). Specifically, for the agent, it is preferable to set $e_A = 0$ rather than commit to any agreement with $e_A > 0$ unless the following condition is met:

$$(DEC_A) \qquad \delta\{\text{future gain to the agent}\} \equiv \delta(u(y) - \overline{u}) \geq -(1-\delta)b(y),$$

which stipulates that the agent will adhere to the relationship with the principal if the agent's future gain, $u(y) - \overline{u}$, is equal to or exceeds the variable payment that he can receive. Similarly, the principal prefers not to exert any effort, $e_P = 0$, and maintains relationships with the agent only if the following condition holds:

$$(DEC_P) \qquad \delta\{\text{future gain to principal}\} \equiv \delta(\pi(y) - \overline{\pi}) \geq (1-\delta)b(y),$$

which stipulates that her future gains from interacting with him, $\pi(y) - \overline{\pi}$, must be greater than or equal to the highest possible variable payment that she should make to the agent. It is important to note that when (DEC_A) and (DEC_P) are satisfied, constraints (IR_A) and (IR_P) are implicitly met. More precisely, the imposition of (DEC_A) and (DEC_P) eliminates the necessity of applying (IR_A) and (IR_P).

(v) feasibility constraints that are met by the stage game G settings. Namely, the sequence of nonnegativity constraints: $e_A, e_P, w, b(y) \geq 0$. Furthermore, each continuation contract should be self-enforcing (i.e. self-generating). In particular, for each y, the pair of continuation payoffs $(u(y), \pi(y))$ should correspond to a self-enforcing contract that will be initiated in the next period.

It follows from Theorem 1 of Levin (2003) that an existence of self-enforcing contract that generates an expected surplus s that is strictly larger than an outside option $\bar{s}$ guarantees an existence of a pair (u, π) that gives the same expected payoff, where $u \geq \bar{u}$, $\pi \geq \bar{\pi}$ and $s + \pi$. Hence, I focus on contracts that maximize the parties joint surplus subject to the constraint that each continuation contract is self-enforcing. If there is a self-enforcing contract (or PPE) that achieves a joint surplus s, there are also self-enforcing contracts that achieve any individually rational split of this surplus.

Given the mentioned above constraints, I formulate the problem:

$$s = \max_{e_A, e_P} \left\{ (1-\delta) \int_{\underline{y}}^{\overline{y}} [y - \phi(e_P) - c(e_A)] f(y|h) dy + \delta \int_{\underline{y}}^{\overline{y}} s(y) f(y|h) dy \right\}$$

s.t.

$$(IC_A) \qquad e_A \in \arg\max_{e_A \in E_A} \left\{ \int_{\underline{y}}^{\overline{y}} \left[W(y) + \frac{\delta}{1-\delta} u(y) \right] f(y|h) dy - c(e_A) \right\},$$

$$(IC_P) \qquad e_P \in \arg\max_{e_P \in E_P} \left\{ \int_{\underline{y}}^{\overline{y}} \left[y - W(y) - \frac{\delta}{1-\delta} \pi(y) \right] f(y|h) dy - \phi(e_P) \right\},$$

$$(DEC_A) \qquad W(y) + \frac{\delta}{1-\delta} \int_{\underline{y}}^{\overline{y}} [W(y) - c(e_A)] f(y|h) dy \geq 0 + \frac{\delta}{1-\delta} \bar{u},$$

$$(DEC_P) \qquad -W(y) + \frac{\delta}{1-\delta} \int_{\underline{y}}^{\overline{y}} [y - W(y) - \phi(e_P)] f(y|h) dy \geq 0 + \frac{\delta}{1-\delta} \overline{\pi},$$

where incentive constraints, (IC_A) and (IC_P), ensure that parties choose the efforts that maximize their utility. (DEC_A) and (DEC_P) constraints guarantee that the parties' expected payoff from the interaction in the contractual relationship is higher than what they would receive from pursuing their individual reservation utility or outside options.

To characterize a PPE, I employ a factorization technique, as called by Abreu et al. (1986, 1990), or a decomposition to stationary contracts, as termed by Levin (2003). This approach involves a characterization of a PPE in terms of payoffs rather than strategies. The idea is that in any Perfect Bayesian Equilibrium, the rewards can be delineated into current and future payoffs. Within a PPE, all continuation payoffs must align with the PPE scenarios. These payoffs can then be further decomposed, creating a recursive structure. The concept is akin to a principal-agent problem, where the principal motivates the agent by offering certain incentives or penalties linked to future rewards. The challenge lies in ensuring that these promised incentives and penalties correspond to payoffs within a PPE of the continuation game, rather than being monetary payoffs specified in an enforceable court contract. Thus, I rely on Theorem 2 from Levin (2003), which asserts that "if an optimal contract exists, there is a stationary contract that is optimal." This theorem allows to simplify the problem and find an optimal relational contract by focusing on stationary contracts.

The optimal relational contract

It is well known from Thomas and Worrall (1988) that once the participation constraints are hit in all states, the contract is determined only by the current state and no longer by the history. To decompose the relational contract into a stationary one I need to impose additional constraints. These constraints ensure that the parties' efforts sustain in a PPE. Therefore, I develop Proposition 1 based on Levin (2003)'s Theorem 3. Proposition 1 delineates these conditions. It adds (IC_P) as an additional constraint to Levin (2003)'s Theorem 3 due to the unobservability of principal's efforts.

The proof follows a similar approach to that of Theorem 3 in Levin (2003), as the additional principal's effort does not affect the necessity and sufficiency of the dynamic enforcement constraint (DEC) that binds the parties' variation in contingent payments by the future gains from the relationship. Thus, I confirm one of Levin (2003)'s key findings, that there exists a stationary contract with identical payoffs for any set of non-stationary actions and transfers. Moreover, I demonstrate that this finding holds true when both parties' efforts are unobservable.

Proposition 1. *Parties efforts, e_P and e_A, that generate expected surplus s can be implemented* *with a stationary contract if and only if there is a payment schedule $W : Y \to \mathbb{R}$ satisfying:*

$$(IC_A) \qquad e_A \in \arg\max_{e_A \in E_A} \mathbb{E}_y \left[W(y)|h\right] - c(e_A),$$

$$(IC_P) \qquad e_P \in \arg\max_{e_P \in E_P} \mathbb{E}_y \left[y - W(y)|h\right] - \phi(e_P),$$

$$(DEC) \qquad \frac{\delta}{1-\delta}(s - \bar{s}) \geq \sup_{y \in y} W(y) - \inf_{y \in y} W(y).$$

Proof. Consider a self-enforcing contract with efforts, e_P and e_A, payments $W(y) = w + b(y)$, and per-period payoffs (u, π). My aim is to prove that (IC_A), (IC_P), and (DEC) are necessary conditions to make the continuation contract $W(y)$ self-enforcing and the payoff pair (u, π) capable of sustaining PPE. To achieve this, I must prove that the parties' efforts satisfy conditions (i) - (v).

First, feasibility constraint (v) is met by the stage game setting. Second, each period the principal and the agent can choose any $e_P \in E_P$ and $e_A \in E_A$ respectively. Therefore, the (IC_A) and (IC_P) constraints serve as necessary conditions for self-enforcement, encouraging parties to choose efforts that facilitate the continuation of their relationship into the future. Thus, constraints (ii) and (iii) are met. Third, as either party can renege on discretionary payment and exit the relationship, (iv) must be satisfied:

$$(DEC_A) \qquad \delta(u - \overline{u}) \geq -(1-\delta)b(y), \qquad \text{and} \qquad (DEC_P) \qquad \delta(\pi - \overline{\pi}) \geq (1-\delta)b(y).$$

This is the constraint (iv) in stationary environment since $u(y) = u$ and $\pi(y) = \pi$. If (iv) is satisfied, then (i) is satisfied implicitly. Because the output varies, the bonus fluctuates accordingly. As a result, there exists a maximum value of the bonus that the principal is willing to pay ($\sup_{y \in Y} b(y)$), as well as a minimum value that the agent is willing to accept to refrain from quitting ($\inf_{y \in Y} b(y)$). Combining (DEC_P) and (DEC_A), in a stationary contract, I obtain (DEC):

$$(DEC) \qquad \frac{\delta}{1-\delta}(s - \bar{s}) \geq \sup_{y \in Y} b(y) - \inf_{y \in Y} b(y).$$

Without loss of generality, since $W(y) = w + b(y)$ I rewrite the constraint as:

$$\frac{\delta}{1-\delta}(s - \bar{s}) \geq \sup_{y \in Y} W(y) - \inf_{y \in Y} W(y).$$

Suppose there is a payment schedule $W(y)$ and efforts that satisfy (IC_A), (IC_P) and (DEC). Let define a fixed payment as $w \equiv \bar{u} - \mathbb{E}_y [b(y) - c(e_A)]$ and bonus payment as $b(y) \equiv W(y) - \inf_{y \in y} b(y)$. In a stationary contract with w and $b(y)$, and efforts e_P and e_A, and deviations punished with a reversion to the static equilibrium. This contract gives per-period payoffs $\bar{u}$ to the agent and $\pi \equiv s - \bar{u}$ to the principal. By (DEC), $s \geq \bar{s}$ and, therefore, $\pi \geq \bar{\pi}$, meaning both parties are willing to initiate the contract. Moreover (IC_P) and (IC_A) imply that the principal and the agent prefer e_P and e_A respectively to any other $e_P \in E_P$ and $e_A \in E_A$. Defining a fixed payment differently through the principal's reservation utility would provide the same results. □

By the definition of stationary relational contract, in every period $e_{A_t} = e_A$, $e_{P_t} = e_P$, $b_t = b(y)$ and $w_t = w$ on the equilibrium path. That is, parties effort rules, the fixed wage and the output contingent bonus do not change over time. In other words, I fix a relational contract $(\sigma_A, \sigma_P, \zeta_A, \zeta_P)$, letting all other variables be also fixed, i.e. w is the wage under this contract, $b(y)$ is the bonus under this contract, e_A, e_P - parties efforts, and u- agent's payoff π - principal's payoff under this contract and s - parties common joint value. Thus, following Proposition 1, the highest and the lowest contract or payment that would refrain parties can be expressed numerically, i.e. $\bar{W}$ and $\underline{W}$, namely,

$$(DEC) \qquad \frac{\delta}{1-\delta}(s - \bar{s}) \geq \bar{W} - \underline{W}.$$

Hence, given Proposition 1, under DMH I am able to rewrite the problem in a stationary environment. Particularly, a stationary optimal contract $\{e_P^*, e_A^*, W^*((y) = w + b(y)\}$ is the solution to the problem:

$$\max_{W(y)} s = \int_{\underline{y}}^{\overline{y}} [y - c(e_A^*) - \phi(e_P^*)] f(y|h) dy$$

s.t.

$$(IC_A) \qquad e_A^* \in \arg\max_{e_A} \int_{\underline{y}}^{\overline{y}} [W(y) - c(e_A)] f(y|h) dy,$$

$$(IC_P) \qquad e_P^* \in \arg\max_{e_P} \int_{\underline{y}}^{\overline{y}} [y - W(y) - \phi(e_P)] f(y|h) dy,$$

$$(DEC) \qquad \frac{\delta}{1-\delta}(s - \bar{s}) - \left(\bar{W} - \underline{W}\right) \geq 0,$$

Where (DEC) enforces the condition that the parties' mutual future gains outweigh their temptation to break the contract. Equation (DEC), along with (IC_P) and (IC_A), guarantees the existence of a perfect Bayesian equilibrium by safeguarding against reneging temptations.

Due to the FOA validity, the agent's incentive constraint (IC_A) and the principal's incentive constraint (IC_P) can be rewritten as follows:

$$\begin{aligned} e_A^* \in \arg\max_{e_A} \int_{\underline{y}}^{\overline{y}} \left[W(y) - c(e_A)\right] f(y|h)dy \iff \\ 0 = \frac{d}{de_A} \int_{\underline{y}}^{\overline{y}} \left[W(y) - c(e_A)\right] f(y|h)dy \iff \\ c'(e_A^*) = \frac{d}{de_A} \int_{\underline{y}}^{\overline{y}} W(y) f(y|h)dy; \end{aligned}$$

$$\begin{aligned} e_P^* \in \arg\max_{e_P} \int_{\underline{y}}^{\overline{y}} \left[y - W(y) - \phi(e_P)\right] f(y|h)dy \iff \\ 0 = \frac{d}{de_P} \int_{\underline{y}}^{\overline{y}} \left[y - W(y) - \phi(e_P)\right] f(y|h)dy \iff \\ \phi'(e_P^*) = \frac{d}{de_P} \int_{\underline{y}}^{\overline{y}} \left[y - W(y)\right] f(y|h)dy. \end{aligned}$$

Without loss of generality, since (IC_P) and (IC_A) bind, I combine them to obtain a common incentive constraint (CIC). (CIC) is satisfied, i.e. necessary and sufficient for the solution. Refer to Cong and Zhou (2021) for detailed explanations. This approach facilitates the solution for μ, the moral hazard rate of parties, and allows for the straightforward computation of parties' optimal efforts.[18] In contrast, having different incentive constraints for parties would result in their moral hazard levels depending on each other. I note that this issue does not arise when solving for the DMH in a static environment, as shown in Kim and Wang (1998). Hence, the combined (CIC) constraint can be expressed as follows:

$$(CIC) \qquad c'(e_A^*) + \phi'(e_P^*) = \frac{d}{de_A} \int_{\underline{y}}^{\overline{y}} W(y) f(y|h)dy + \frac{d}{de_P} \int_{\underline{y}}^{\overline{y}} \left[y - W(y)\right] f(y|h)dy.$$

Then, the optimal stationary contract $\{e_A^*, e_P^*, W^*(y) = w + b(y)\}$ solves the following

[18] Here, I refer to the solution of the Lagrangian introduced in Appendix B2.

problem:

$$\max_{W(\cdot)} s = \int_{\underline{y}}^{\overline{y}} [y - c(e_A^*) - \phi(e_P^*)] f(y|h) dy$$

s.t.

$$(CIC) \qquad c'(e_A^*) + \phi'(e_P^*) = \frac{d}{de_A} \int_{\underline{y}}^{\overline{y}} W(y) f(y|h) dy + \frac{d}{de_P} \int_{\underline{y}}^{\overline{y}} [y - W(y)] f(y|h) dy,$$

$$(DEC) \qquad \frac{\delta}{1-\delta} (s^* - \overline{s}) \geq \left(\bar{W} - \underline{W}\right).$$

Since $W(y)$ is a continuous function from $\mathbb{R}$ to $[\underline{W}, \bar{W}]$, this problem is linear in W. Therefore, I consider the Lagrangian function for the problem. Let L be the Lagrange function of the problem. Then,

$$L(W, e_A, e_P, \mu, \lambda) = \int_{\underline{y}}^{\overline{y}} [y - c(e_A^*) - \phi(e_P^*)] f(y|h) dy$$
$$+\mu[-c'(e_A^*) - \phi'(e_P^*) + \frac{d}{de_A} \int_{\underline{y}}^{\overline{y}} W(y) f(y|h) dy + \frac{d}{de_P} \int_{\underline{y}}^{\overline{y}} [y - W(y)] f(y|h) dy]$$
$$+ \lambda[\frac{\delta}{1-\delta}(s^* - \overline{s}) - \left(\overline{W} - \underline{W}\right)],$$

where μ and λ are Kuhn-Tucker multipliers. μ represents the moral hazard degree of the parties. The pointwise differentiation yields necessary conditions for a solution to the problem:

$$\begin{aligned} \frac{\partial L}{\partial W} =& \mu h_{e_A} f_h(y|h) - \mu h_{e_P} f_h(y|h) \iff \\ =& \underbrace{\mu(h_{e_A} - h_{e_P}) f_h(y|h)}_{z(y, e_A, e_P)} = 0. \end{aligned} \tag{3.5}$$

Since we are in a scenario where both parties have equal moral hazard degrees, μ is always nonnegative. Given the assumption that the marginal rates are always greater than zero and never equal to each other ($h_{e_A} - h_{e_P} \neq 0$), the marginal effects of the agent's and principal's efforts on the output cannot be the same. Hence, there are four possible scenarios:

Scenario 1: when $h_{e_A} > h_{e_P}$ and $f_h(y|h)$ is increasing in y,

Scenario 2: when $h_{e_A} < h_{e_P}$ and $f_h(y|h)$ is increasing in y,

Scenario 3: when $h_{e_A} > h_{e_P}$ and $f_h(y|h)$ is decreasing in y, Scenario 4: when $h_{e_A} < h_{e_P}$ and $f_h(y|h)$ is decreasing in y.

The hint, MLRP assumption, provided by Innes (1990) in the problem of moral hazard with limited liability, similar to the one utilized by Levin (2003) in the moral hazard scenario within a dynamic environment decomposed into a stationary one would not work here. MLRP posits that the density function is always increasing in y for a fixed e. In my case, with the joint production function MLRP is: $\forall h \in \mathbb{R}, \frac{\partial}{\partial y}\left(\frac{f_h(y|h)}{f(y|h)}\right) > 0$, hence it does not guarantee that $f_h(y|h)$ is always increasing.

Under the same degree of moral hazard problem on the parties' sides, when FOA is valid, the optimal contract that generates a second-best optimal parties' efforts, e_P and e_A, depends on the trade-off between the marginal effect of parties' efforts on the output $(h_{e_A} \lesseqgtr h_{e_P})$ and the behavior of the density function $f_h(y|h) \lesseqgtr 0$.

Scenario 1 Under *Scenario 1*, equation (3.5) yields:

$$\begin{aligned}
&z(y, e_A, e_P) = \mu(h_{e_A} - h_{e_P}) f_h(y|h) \\
&z(y, e_A, e_P) > 0 \to W(y) = \bar{W} = \underline{W} + \frac{\delta}{1-\delta}(s - \bar{s}) \\
&z(y, e_A, e_P) = 0 \to W(y) \in [\underline{W}, \bar{W}] \\
&z(y, e_A, e_P) < 0 \to W(y) = \underline{W}
\end{aligned} \tag{3.6}$$

In (3.6), one expects to have the proper value of surplus s. In this study, I prioritize the assumption $h_{e_A} > h_{e_P}$ due to its alignment with existing literature on moral hazard, where only the effort of the agent impacts the payoff distribution; its correspondence to the specific real-world scenario detailed in section 3.3; and its plausibility supported by the assumptions $F_h < 0$, indicating that greater joint effort h results in higher payoffs, and $f_h > 0$, suggesting a diminishing impact of joint effort h on higher payoffs. Nevertheless, I plan future extensions to encompass *Scenario 2* through *Scenario 4*.

Proposition 2. *When $h_{e_A} > h_{e_P}$ and $f_h(y|h(e_A, e_P)) > 0$, an optimal contract is "one-step", i.e. there is some $\hat{y}$ with $W(y) = \underline{W}$ if $y \leq \hat{y}$ and $W(y) = \bar{W}$ if $y \geq \hat{y}$.*

The proof of Proposition 2 is similar to Levin (2003)'s Theorem 5, where the optimal contract is a "one-step" contract. Follow the discussion below for the solution. A "one-step" contract allows to rewrite the problem with a step function as follows:[19]

$$\max_{\underline{W},\bar{W},\hat{y}} s = \int_{\underline{y}}^{\bar{y}} \left[y - c(e_A^*) - \phi(e_P^*)\right] f(y|h)dy$$

s.t.

$$(CIC) \qquad c'\left(e_A^*\right) + \phi'\left(e_P^*\right) = h_{e_P} \int_{\underline{y}}^{\bar{y}} y f_h(y|h)dy + m(h_{e_P} - h_{e_A})F_h\left(\hat{y}|h\right),$$

$$(DEC) \qquad \frac{\delta}{1-\delta}\left(s^* - \overline{s}\right) \geq m,$$

where $m = \bar{W} - \underline{W}$.

Let L_1 be the Lagrange function of the problem under *Scenario 1*:

$$L_1(\underline{W}, \bar{W}, \hat{y}, e_A^*, e_P^*, \mu, \lambda) = \int_{\underline{y}}^{\bar{y}} \left[y - c(e_A^*) - \phi(e_P^*)\right] f\left(y|h\right) dy$$

$$+\mu[-c'\left(e_A^*\right) - \phi'\left(e_P^*\right) + h_{e_P} \int_{\underline{y}}^{\bar{y}} y f_h(y|h)dy + m(h_{e_P} - h_{e_A})F_h\left(\hat{y}|h\right)]$$

$$+ \lambda[\frac{\delta}{1-\delta}(s^* - \overline{s}) - m],$$

Refer to Appendix B2 for the solution of the Lagrangian. Therefore, the final program consists of four equations and four unknowns:

$$(I) \ f_h(\hat{y}|h) = 0,$$

$$(II) \ c'(e_A) + \phi'(e_P) = h_{e_P} \int_{\underline{y}}^{\bar{y}} y f_h(y|h)dy + mF_h(\hat{y}|h)(h_{e_P} - h_{e_A}),$$

$$(III) \ h_{e_A} \int_{\underline{y}}^{\bar{y}} y f_h(y|h)dy - c'(e_A) + \frac{1-\delta}{\delta(h_{e_P} - h_{e_A})F_h(\hat{y}|h)}$$

$$\times \Bigg[-c''(e_A) + h_{e_P} h_{e_A} \int_{\underline{y}}^{\bar{y}} y f_{hh}(y|h)dy$$

$$+ m\left(F_{hh}(\hat{y}|h)h_{e_A}(h_{e_P} - h_{e_A}) - F_h(\hat{y}|h)h_{e_A e_A}\right)\Bigg] = 0,$$

$$(IV) \ h_{e_P} \int_{\underline{y}}^{\bar{y}} y f_h\left(y|h\right) dy - \phi'(e_P) + \frac{1-\delta}{\delta(h_{e_P} - h_{e_A})F_h(\hat{y}|h)}$$

$$\times \Bigg[-\phi''(e_P) + h_{e_P e_P} \int_{\underline{y}}^{\bar{y}} y f_h(y|h)dy + h_{e_P} h_{e_P} \int_{\underline{y}}^{\bar{y}} y f_{hh}(y|h)dy$$

[19]Refer to Appendix B1 for the detailed simplification of (CIC) constraint.

$$+ m\left(F_{hh}(\hat{y}|h)h_{e_P}(h_{e_P} - h_{e_A}) + F_h(\hat{y}|h)h_{e_Pe_P}\right)\Big] = 0.$$

3.5 Comparative statistics

In this section, I provide a numerical example of the optimal contracts as outlined in Proposition 2, where $h_{e_A} > h_{e_P}$ and $f_h(y|h) > 0$. I utilize the distribution function from Spaeter (1998), which satisfies FOA.[20] I transform the distribution in two ways: multiplying it by a variable parameter $\eta > 0$ to understand the changes in the optimal contract with variations in the distribution sensitivity of the outcome to changes in parties' effort; using a joint production function instead of the effort level of a party.

Namely, I employ the distribution function, where $\underline{y} = 0$ and $\overline{y} = 1$,

$$F(y|h) = y\left(\frac{\eta(1-y)}{h+1} + 1\right),$$

and thus, the density function becomes

$$f(y|h) = \frac{d}{dy}F(y|h) = \frac{h + 1 + \eta(1-2y)}{h+1}.$$

With the aforementioned distribution, equation (I) provides the threshold level $\hat{y}$, where the density function changes its direction: the marginal benefit is negative for all $y < \hat{y}$ and positive for all $y > \hat{y}$. Thus,

$$(I)\ f_h(\hat{y}|h) = 0 \Leftrightarrow \frac{(2\hat{y}-1)\,\eta}{(h+1)^2} = 0 \Leftrightarrow \hat{y} = \frac{1}{2}.$$

Given $\hat{y} = \frac{1}{2}$ and using equations (II), (III), and (IV), I compute the optimal difference between the highest and lowest wages m^*, the agent's optimal effort e_A^* and the principal's optimal effort e_P^*:[21]

$$m^* = \frac{2(\eta h_{e_P} - 6(e_A^* + e_P^*)(h+1)^2)}{3\eta(h_{e_P} - h_{e_A})}, \tag{3.7}$$

$$e_A^* = \frac{\eta h_{e_A}}{6(h+1)^2} + \frac{1-\delta}{\delta}\times$$

[20] Refer to the Appendix C1 for details on the FOA validity of the distribution and density function from Spaeter (1998).

[21] Appendix C2 provides a detailed derivation of equations for the chosen distribution.

$$\left[\frac{12(h+1)^3+4\eta h_{e_P}h_{e_A}-3m^*(h_{e_Ae_A}\eta(h+1)+(h_{e_P}-h_{e_A})2\eta h_{e_A})}{3(h+1)\eta(h_{e_P}-h_{e_A})}\right], \tag{3.8}$$

$$e_P^* = \frac{\eta h_{e_P}}{6(h+1)^2}+\frac{1-\delta}{\delta}\times$$
$$\left[\frac{12(h+1)^3-2\eta h_{e_Pe_P}+4\eta h_{e_P}h_{e_P}-3m^*(h_{e_Pe_P}\eta(h+1)+(h_{e_P}-h_{e_A})2\eta h_{e_P})}{3(h+1)\eta(h_{e_P}-h_{e_A})}\right]. \tag{3.9}$$

Since m^* depends on δ through e_A^* or e_P^*, I discuss the sign of m^* for $\forall\delta$. By definition $\eta, e_A^*, e_P^*, h_{e_P}, h_{e_A} > 0$, and from Proposition 2 $h_{e_A} > h_{e_P}$, hence, from the equality (3.7), the sign of m^* depends on the trade-off between ηh_{e_P} and $6(e_A^*+e_P^*)(h+1)^2$. Thus, $m^* < 0$ if and only if $\eta^{-1}6(e_A^*+e_P^*)(h+1)^2 < h_{e_P} < h_{e_A}$. In contrast, $m^* > 0$ if and only if $h_{e_P} < h_{e_A}$ and $h_{e_P} < \eta^{-1}6(e_A^*+e_P^*)(h+1)^2$.

When the output's responsiveness to the parties' efforts is sufficiently high and the principal's contribution to the output is relatively small, it is advantageous to opt for a contract where the agent primarily receives the output and reimburses the principal with a designated bonus. Conversely, when the principal's contribution rate is comparatively low in relation to the sensitivity of the output, it is favorable for the principal to be the primary recipient of the output and share the bonus with the agent.

Further, I investigate the variation of (3.8) and (3.9) with respect to δ. Let consider two cases: A) theoretically, when the parties are very patient ($\delta \to 1$), and B) using simulations for all other scenarios due to the complexity of the equations.

Case A: $\delta \to 1$

As $\delta \to 1$, e_A^*, and e_P^* can be simplified as follows:

$$e_A^* = \frac{\eta h_{e_A}}{6\left(h+1\right)^2} \qquad \text{and} \qquad e_P^* = \frac{\eta h_{e_P}}{6\left(h+1\right)^2}. \tag{3.10}$$

I conclude that when parties are highly patient, their optimal effort levels, aimed at sustaining the relationship, vary in tandem with the sensitivity of the healthcare output to parties' efforts, i.e. as η enlarges, both e_A^* and e_P^* increase in the equilibrium. More precisely, with growth in output sensitivity, the optimum is reached at a higher level of parties' efforts. Nevertheless, I can not make any conclusion about the relation between the parties' optimal efforts and the marginal rate of their contribution. For example, if $h = ae_A^* + be_P^*$, where a and b are positive, that correspond to the complimentary of the parties efforts covered in this paper, an increase in either h_{e_A} or h_{e_P} leads to a decrease in the effort level of the respective party at the optimum. However, this is not always true, if the sign for a or b changes or a different function is introduced, the dependency can differ. Moreover, straightforward computations of optimal effort complicate the equations without producing reliable results.[22]

Case B: $\forall\delta$

For $\forall\delta$ and a linear joint production function $h = ae_A^* + be_P^*$, equations (III) and (IV) are as follows:

$$
\begin{aligned}
m^* &= \frac{2(\eta b - 6(e_A^* + e_P^*)(ae_A^* + be_P^* + 1)^2)}{3\eta(b-a)},\\
e_A^* &= \frac{a\eta}{6(ae_A^* + be_P^* + 1)^2} + \frac{1-\delta}{\delta}\left[\frac{12(ae_A^* + be_P^* + 1)^3 + 4\eta ab - 3m^*(b-a)2a\eta}{3(ae_A^* + be_P^* + 1)\eta(b-a)}\right],\\
e_P^* &= \frac{b\eta}{6(ae_A^* + be_P^* + 1)^2} + \frac{1-\delta}{\delta}\left[\frac{12(ae_A^* + be_P^* + 1)^3 + 4\eta b^2 - 3m^*(b-a)2b\eta}{3(ae_A^* + be_P^* + 1)\eta(b-a)}\right].
\end{aligned}
$$

Based on simulations conducted in Mathematica, I am able to provide the conclusions below. The figures in the Appendix (Fig. E1 and Fig. E2) correspond to the model discussed above. They reveal that the sign of m^*, which determines the party receiving the main output and deciding on bonus payment, depends not only on its marginal contribution (a classical interpretation in the trade where the principal's marginal contribution to output is higher than that of the agent results in $m^* > 0$, and vice versa for $m^* < 0$) but also on the inequality sign in the condition $\eta h_{e_P} \lesseqgtr 6(e_A^* + e_P^*)(h+1)^2$.

Both Fig. E1 and Fig. E2 in the Appendix yield $m^* > 0$. Therefore, I examine a scenario in which the principal determines the agent's bonus, where $h_{e_A} > h_{e_P}$ and $h_{e_P} < \eta^{-1}6(e_A^* + e_P^*)(h+1)^2$.

Let consider a numerical example from Fig. E1 in the Appendix, where the agent's contribution to the output is ten times higher than the principal's ($h = 50e_A^* + 5e_P^*$), parties are very patient ($\delta = 0.9$), and the sensitivity of the output to parties' efforts (η) varies. When the distribution sensitivity equals 10, the optimal relational contract establishes that the principal should exert 0.31 of her effort unit and pay to the agent either 13.56 wage units or 12.83 wage units, depending on whether the jointly generated output exceeds $1/2$. Increasing the sensitivity to 60 alters the requirements of the optimal relational contract. It now specifies that the principal should exert more effort in the optimum ($e_P^* = 0.57$)

[22] Follow the Appendix C3 for a trial.

because, with increased sensitivity, the achieved output level is even more dependent on her efforts. The payment also changes: she would now pay 13.72 units if the output exceeds the threshold, and she should pay 12.98 units if it does not exceed. An interpretation is as follows, since the agent is the main contributor to the output, with the growth of output sensitivity to parties' efforts, the principal needs to motivate even more the agent, otherwise, his deviation will be very costly. It is important to note that the upper wage bound increases faster than the minimum wage bound, leading to a positive m^*. Since the agent is very valuable, the principal wants to pay a higher upper wage bound as the agent's contribution increases.

In other words, when an additional unit of external enforcement by the principal results in a lower healthcare output value than an additional unit of effort by the agent, in an environment where healthcare output does not react sensitively to the parties' efforts (such as facility management services supply), both external and internal enforcement should not be intense. In contrast, in more sensitive environments (such as surgery equipment supply), where outcomes directly impact people's lives and healthcare output, both types of enforcement should be increased.[23]

Nevertheless, the surplus achieved in equilibrium in a more sensitive environment is seven times lower than the surplus achieved in a less sensitive environment. This difference primarily relates to the fact that additional parties' efforts necessitate higher costs, thus decreasing the surplus.

Furthermore, Fig. E2 shows what happens as parties' patience changes when the agent's contribution to the output is ten times higher than the principal's ($h = 50e_A^* + 5e_P^*$), and parties' sensitivity to the output is fixed ($\eta = 50$). The result corresponds to the behavior of the dynamic enforcement constraint in Levin (2003). Specifically, the tightness of the restriction (m) depends on the discount factor (δ): as $\delta \to 1$, the range of payments (m) is unbounded, and as $\delta \to 0$, the m is limited but also cannot even be provided. This is what Fig. E2 produces. As δ increases, m^* enlarges, becoming indeed unbounded for δ approaching one. The relationship can only be sustained by very patient parties. The equilibrium does not exist for non-patient parties, i.e., Mathematica provides negative efforts. For example, for $\eta = 50$, $\delta = 0.95$ is the minimum patience level that sustains the relationship (Fig. E2 in the Appendix).

Fig. E2 also illustrates that as parties become more patient, both the principal's external enforcement level and internal enforcement increase, while the wage level paid to the

[23] Follow the Appendix D1 for the detailed real-world scenarios.

agent, both over and below the threshold, decreases. Understanding that the agent values this relationship and is engaged in a long-term collaboration, the principal refrains from providing additional motivation, considering the agent's intrinsic motivation. Similarly, as parties exhibit more patience, they are rewarded more. Consequently, s^* increases with the parties' growing patience.

3.6 Conclusion

This study relates economic theory to real-world scenarios in the healthcare industry. In particular, it describes the trade-off between the principal's external enforcement effort level and internal enforcement in the environment, varying by healthcare output sensitivity to parties' efforts and parties' patience. Moreover, it computes the bonus rates paid above and below the agreed output threshold, which should be determined by the optimal relational contract in the equilibrium.

I establish that for highly patient parties, in an environment where parties' efforts are not very sensitive to the output, both external and internal enforcement can be less pressing. In contrast, in a very sensitive environment, the principal should intensify external and internal enforcement. I plan to expand the paper by adding three more scenarios, incorporating a decreasing density function in healthcare output and varying parties' contribution to the healthcare output. Additionally, I aim to compare the simulation results of DMH with those of moral hazard computed from Levin (2003)'s model.

The findings of this study can be useful for governments or healthcare providers when choosing contracts for their relationships with suppliers. It can also be an effective tool to correctly motivate the agent to maximize the joint surplus and reach equilibrium, establishing the agent's motivation depending on his contribution to output.

Nevertheless, the model has two strong assumptions, the levelling of which could impact the results: first, an identical moral hazard degree on both parties' sides, and second, the Grimm-trigger strategy. Relaxation of the first assumption, for example, could accelerate the necessity of external enforcement efforts from the principal with the growth of the agent's hidden actions, leveraging it with a downgrade on internal enforcement. Relaxation of the second assumption would allow to examine what happens when, with the deviation of one party, the relationship does not end, but continues with possible contract renegotiation.

Furthermore, improving the model involves solving it in a dynamic environment without simplifying it to stationarity. The solution of the model with simplification to a stationary environment, as examined in this study, fixes a relational contract within a specific time period and allows all other variables to remain unchanged over time. Finally, another point to note is that the principal's effort complements the agent's effort rather than impacting it. Considering the opposite could lead to a more realistic discussion but would require a completely different theoretical model to develop.

3.7 Appendix

Appendix A

A1 Validity of the first order approach

The MLRP and the CDFC are known as the Mirrlees-Rogerson conditions. These conditions should be satisfied to make the FOA valid.[24] Levin (2003) uses this approach to simplify the solution of the program, allowing for the agent's incentive constraint to bind, i.e. equalise it to zero.[25]

MLRP property: given any two effort levels, $e, e' \in E$ with $e > e'$, the ratio $\frac{f(y|e)}{f(y|e')}$ is increasing in y, i.e. higher output is more indicative of the higher effort (Milgrom, 1981). Given continuous output y, continues effort e and twice continuously differentiable distribution $F(\cdot)$, which satisfies MLRP in e if

$$\frac{\partial}{\partial y}\frac{f_e(y|e)}{f(y|e)} = \frac{\partial}{\partial e}\ln f(y|e) \geq 0$$

for all $e > 0$ and $y \geq 0$, where $E\{y|e = 0\}$.[26] The condition says that for any outcomes $y' > y$, enlarges effort increases the log density at y' more than at y. Roughly, more effort makes low outcomes more likely. MLRP states that the likelihood ratio $f_e(y|e)/f(y|e)$ must be non-decreasing in the output y: it is more likely to observe large revenues for a high level of effort.

CDFC property: A distribution $F(y|e)$ satisfies CDFC condition if

$$F_{ee}(y|e) \geq 0$$

for all (y, e). CDFC requires the distribution function to be convex in effort.

[24]Follow Rogerson (1985) for the proofs on FOA validity.

[25]Jewitt (1988) suggests an alternative set of conditions that should be satisfied to make FOA valid. Compared to Levin (2003), these conditions do not require strong output distributional assumption while leaving the agent's utility unconstrained. Instead, they allow for milder restrictions on output distribution and the utility function.

[26]MLRP implies First Order Stochastic Dominance (FOSD) property, $F_e(y|e) \leq 0$, that tells that higher effort makes the higher output more likely, and it guarantees that there is always a benefit of higher effort levels, gross of effort costs.

Appendix B: Proposition 2

B1 Detailed simplification of (CIC) constraint

$$
\begin{aligned}
(CIC) \qquad c'(e_A^*) + \phi'(e_P^*) &= \frac{d}{de_A}\int_{\underline{y}}^{\overline{y}} W(y) f(y|h) dy \\
&+ \frac{d}{de_P}\int_{\underline{y}}^{\overline{y}} \left[y - W(y)\right] f(y|h) dy \iff \\
c'(e_A^*) + \phi'(e_P^*) &= \frac{d}{de_A}\int_{\underline{y}}^{\hat{y}} \underline{W} f dy + \frac{d}{de_A}\int_{\hat{y}}^{\overline{y}} \bar{W} f dy \\
&+ \frac{d}{de_P}\int_{\underline{y}}^{\hat{y}} (y - \underline{W}) f dy + \frac{d}{de_P}\int_{\hat{y}}^{\overline{y}} (y - \bar{W}) f dy.
\end{aligned}
$$

Detailed simplification of the two parts of (CIC) constraint:

$\frac{d}{de_A}\int_{\underline{y}}^{\hat{y}} \underline{W} f(y|h) dy + \frac{d}{de_A}\int_{\hat{y}}^{\overline{y}} \overline{W} f(y|h) dy = \frac{d}{de_A}[\underline{W} F(\hat{y}|h)] + \frac{d}{de_A}[\overline{W}(1 - F(\hat{y}|h))] =$ $\underline{W} h_{e_A} F_h(\hat{y}|h) - \overline{W} h_{e_A} F_h(\hat{y}|h) = [\underline{W} - \overline{W}] h_{e_A} F_h(\hat{y}|h)$. Given that $m = \overline{W} - \underline{W},$ then $[\underline{W} - \overline{W}] h_{e_A} F_h(\hat{y}|h) = -m h_{e_A} F_h(\hat{y}|h);$

$\frac{d}{de_P}\int_{\underline{y}}^{\hat{y}} [y - \underline{W}] f(y|h) dy + \frac{d}{de_P}\int_{\hat{y}}^{\overline{y}} [y - \overline{W}] f(y|h) dy = \frac{d}{de_P}\int_{\underline{y}}^{\hat{y}} y f(y|h) dy +$ $\frac{d}{de_P}\int_{\hat{y}}^{\overline{y}} y f(y|h) dy - \left[\frac{d}{de_P}[\underline{W} F(\hat{y}|h)] + \frac{d}{de_P}[\overline{W}(1 - F(\hat{y}|h))]\right] = h_{e_P}\int_{\underline{y}}^{\overline{y}} y f_h(y|h) dy -$ $\left[\underline{W} h_{e_P} F_h(\hat{y}|h) - \overline{W} h_{e_P} F_h(\hat{y}|h)\right] = h_{e_P}\int_{\underline{y}}^{\overline{y}} y f_h(y|h) dy - [\underline{W} - \overline{W}] h_{e_P} F_h(\hat{y}|h)$. Given that $m = \overline{W} - \underline{W},$ then $h_{e_P}\int_{\underline{y}}^{\overline{y}} y f_h(y|h) dy + m h_{e_P} F_h(\hat{y}|h).$

Thus, (CIC) constraint can be rewritten as:

$$
c'\left(e_A^*\right) + \phi'\left(e_P^*\right) = h_{e_P}\int_{\underline{y}}^{\bar{y}} y f_h(y|h) dy + m(h_{e_P} - h_{e_A}) F_h\left(\hat{y}|h\right).
$$

B2 Solution of the Lagrangian

$$L_1(\underline{W}, \bar{W}, \hat{y}, e_A^*, e_P^*, \mu, \lambda) = \int_{\underline{y}}^{\overline{y}} [y - c(e_A^*) - \phi(e_P^*)] f(y|h) \, dy$$
$$+\mu[-c'(e_A^*) - \phi'(e_P^*) + h_{e_P} \int_{\underline{y}}^{\bar{y}} y f_h(y|h) dy + m(h_{e_P} - h_{e_A}) F_h(\hat{y}|h)]$$
$$+ \lambda[\frac{\delta}{1-\delta}(s^* - \overline{s}) - m],$$

From the Envelop theorem on s^*,

$$\frac{\partial L}{\partial s^*} = \lambda \frac{\delta}{1-\delta} = 1. \tag{3.11}$$

Pointwise differentiation provides the following equations:

$$\frac{\partial L}{\partial m} = \mu F_h(\hat{y}|h)(h_{e_P} - h_{e_A}) - \lambda = 0, \tag{3.12}$$

$$\frac{\partial L}{\partial \hat{y}} = \mu m f_h(\hat{y}|h)(h_{e_P} - h_{e_A}) = 0. \tag{3.13}$$

$$\begin{aligned} \frac{\partial L}{\partial e_A} &= h_{e_A} \int_{\underline{y}}^{\overline{y}} y f_h(y|h) dy - c'(e_A) - \mu c''(e_A) \\ &+ \mu(h_{e_P} \frac{\partial \int_{\underline{y}}^{\overline{y}} y f_h(y|h) dy}{\partial e_A} \\ &+ m(\frac{\partial F_h(\hat{y}|h)}{\partial e_A}(h_{e_P} - h_{e_A}) + F_h(\hat{y}|h) \frac{\partial(-h_{e_A})}{\partial e_A})) = 0, \end{aligned} \tag{3.14}$$

$$\begin{aligned} \frac{\partial L}{\partial e_P} &= h_{e_P} \int_{\underline{y}}^{\overline{y}} y f_h(y|h) \, dy - \phi'(e_P) - \mu \phi''(e_P) \\ &+ \mu(h_{e_P e_P} \int_{\underline{y}}^{\overline{y}} y f_h(y|h) dy + h_{e_P} \frac{\partial \int_{\underline{y}}^{\overline{y}} y f_h(y|h) dy}{\partial e_P} \\ &+ m(\frac{\partial F_h(\hat{y}|h)}{\partial e_P}(h_{e_P} - h_{e_A}) + F_h(\hat{y}|h) \frac{\partial h_{e_P}}{\partial e_P})) = 0, \end{aligned} \tag{3.15}$$

From (3.11) $\lambda = \frac{1-\delta}{\delta}$. Therefore,

$$(3.12) \Rightarrow \mu = \frac{1-\delta}{\delta(h_{e_P} - h_{e_A})F_h(\hat{y}|h)} \tag{3.16}$$

$$\begin{aligned}
&(3.14) \text{ and } (3.16) \Rightarrow \\
&h_{e_A}\int_{\underline{y}}^{\overline{y}} yf_h(y|h)dy - c'(e_A) + \frac{1-\delta}{\delta(h_{e_P} - h_{e_A})F_h(\hat{y}|h)} \\
&\times [-c''(e_A) + h_{e_P}h_{e_A}\int_{\underline{y}}^{\overline{y}} yf_{hh}(y|h)dy \\
&+ m\left(F_{hh}(\hat{y}|h)h_{e_A}(h_{e_P} - h_{e_A}) - F_h(\hat{y}|h)h_{e_Ae_A}\right)] = 0
\end{aligned} \tag{3.17}$$

$$\begin{aligned}
&(3.15) \text{ and } (3.16) \Rightarrow \\
&h_{e_P}\int_{\underline{y}}^{\overline{y}} yf_h\left(y|h\right)dy - \phi'(e_P) + \frac{1-\delta}{\delta(h_{e_P} - h_{e_A})F_h(\hat{y}|h)} \\
&\times [-\phi''(e_P) + h_{e_Pe_P}\int_{\underline{y}}^{\overline{y}} yf_h(y|h)dy + h_{e_P}h_{e_P}\int_{\underline{y}}^{\overline{y}} yf_{hh}(y|h)dy \\
&+ m\left(F_{hh}(\hat{y}|h)h_{e_P}(h_{e_P} - h_{e_A}) + F_h(\hat{y}|h)h_{e_Pe_P}\right)] = 0
\end{aligned} \tag{3.18}$$

$$\text{From } (3.13) \Rightarrow \text{ either } \mu = 0, \text{ or } m = 0,\ h_{e_P} - h_{e_A} = 0, \text{ or } f_h(\hat{y}|h) = 0. \tag{3.19}$$

Therefore, I have the final program with four equations and four unknowns:

$$\begin{aligned}
&(I)\ f_h(\hat{y}|h) = 0, \\
&(II)\ c'(e_A) + \phi'(e_P) = h_{e_P}\int_{\underline{y}}^{\overline{y}} yf_h(y|h)dy + mF_h(\hat{y}|h)(h_{e_P} - h_{e_A}), \\
&(III)\ h_{e_A}\int_{\underline{y}}^{\overline{y}} yf_h(y|h)dy - c'(e_A) + \frac{1-\delta}{\delta(h_{e_P} - h_{e_A})F_h(\hat{y}|h)} \\
&\times [-c''(e_A) + h_{e_P}h_{e_A}\int_{\underline{y}}^{\overline{y}} yf_{hh}(y|h)dy \\
&+ m\left(F_{hh}(\hat{y}|h)h_{e_A}(h_{e_P} - h_{e_A}) - F_h(\hat{y}|h)h_{e_Ae_A}\right)] = 0, \\
&(IV)\ h_{e_P}\int_{\underline{y}}^{\overline{y}} yf_h\left(y|h\right)dy - \phi'(e_P) + \frac{1-\delta}{\delta(h_{e_P} - h_{e_A})F_h(\hat{y}|h)} \\
&\times [-\phi''(e_P) + h_{e_Pe_P}\int_{\underline{y}}^{\overline{y}} yf_h(y|h)dy + h_{e_P}h_{e_P}\int_{\underline{y}}^{\overline{y}} yf_{hh}(y|h)dy
\end{aligned}$$

$$+ m\left(F_{hh}(\hat{y}|h)h_{e_P}(h_{e_P} - h_{e_A}) + F_h(\hat{y}|h)h_{e_Pe_P})\right] = 0.$$

Appendix C: Comparative statistics

C1 FOA validity with a modified Spaeter (1998)'s distribution

The FOA is valid if the CDFC and MLRP conditions are satisfied (Rogerson, 1985).

1) CDFC:

$$F_h(y|h) = \frac{d}{dh}\left(y\left(\frac{\eta(1-y)}{(h+1)} + 1\right)\right) = \frac{\eta y\,(y-1)}{(h+1)^2},$$
$$F_{hh}(y|h) = \frac{d}{dh}\left(\frac{\eta y\,(y-1)}{(h+1)^2}\right) = \frac{2\eta y\,(1-y)}{(h+1)^3},$$

where $\eta > 0$, $y \in [0,1]$, and $h \in \mathbb{R}$. However, $h = ae_A + be_P$, where a and b are positive constants ($a, b > 0$), leading to $h > 0$. Therefore, $F_{hh}(y|h) \geq 0$, and CDFC is satisfied.

2) MLRP:

$$f_h(y|h) = \frac{d}{dh}\left(\frac{h+1+\eta(1-2y)}{h+1}\right) = \frac{\eta\,(2y-1)}{(h+1)^2},$$
$$\frac{f_h(y|h)}{f(y|h)} = \left(\frac{\eta(2y-1)}{(h+1)^2}\right) \times \left(\frac{h+1}{h+1+\eta(1-2y)}\right) = \frac{\eta(2y-1)}{(h+1)(1+h+\eta-2\eta y)},$$
$$\frac{d}{dy}\left(\frac{f_h(y|h)}{f(y|h)}\right) = \frac{d}{dy}\left(\frac{\eta(2y-1)}{(h+1)(1+h+\eta-2\eta y)}\right) = \frac{2\eta}{(1+h+\eta-2\eta y)^2},$$

where $\eta > 0$, $y \in [0,1]$ and $h > 0$. Hence, $\frac{d}{dy}\left(\frac{f_h(y|h)}{f(y|h)}\right) > 0$, and MLRP is satisfied.

C2 Derivation of Equations (II), (III), and (IV) with a modified Spaeter (1998)'s distribution

Given the distribution function $F(y|h) = y\left(\frac{\eta(1-y)}{h+1} + 1\right)$ and the density function $f(y|h) = \frac{h+1+\eta(1-2y)}{h+1}$, I compute:

$$F_h(y|h) = \frac{\eta y(y-1)}{(h+1)^2}$$

$$F_h(\hat{y}|h) = -\frac{\eta}{4(h+1)^2}$$

$$F_{hh}(y|h) = \frac{\eta 2y(1-y)}{(h+1)^3}$$

$$F_{hh}(\hat{y}|h) = \frac{\eta}{2(h+1)^3}$$

$$f_h(y|h) = \frac{\eta(2y-1)}{(h+1)^2}$$

$$f_{hh}(y|h) = -\frac{2\eta(2y-1)}{(h+1)^3}$$

$$\int_{\underline{y}}^{\overline{y}} y f_h(y|h)dy = \int_0^1 y\frac{\eta(2y-1)}{(h+1)^2}dy = \frac{\eta}{6(h+1)^2}$$

$$\int_{\underline{y}}^{\overline{y}} y f_{hh}(y|h)dy = \int_0^1 -\frac{y2\eta(2y-1)}{(h+1)^3}dy = -\frac{\eta}{3(h+1)^3}$$

$$\int_{\underline{y}}^{\overline{y}} y f(y|h)dy = \int_0^1 y\frac{h+1+\eta(1-2y)}{h+1}dy = \frac{3h-\eta+3}{6(h+1)}$$

Therefore, Equations (II), (III), and (IV) transform as follows:

$$(II)\ c'(e_A) + \phi'(e_P) = h_{e_P}\int_{\underline{y}}^{\overline{y}} y f_h(y|h)dy + mF_h(\hat{y}|h)(h_{e_P} - h_{e_A}) \Leftrightarrow$$

$$e_A + e_P = h_{e_P}\frac{\eta}{6\left(h+1\right)^2} - m\frac{\eta}{4\left(h+1\right)^2}(h_{e_P} - h_{e_A}) \Leftrightarrow$$

$$m\frac{\eta}{4\left(h+1\right)^2}(h_{e_P} - h_{e_A}) = -e_A - e_P + h_{e_P}\frac{\eta}{6\left(h+1\right)^2} \Leftrightarrow$$

$$m\frac{\eta\left(h_{e_P} - h_{e_A}\right)}{4(h+1)^2} = \frac{-(e_A+e_P)6(h+1)^2 + \eta h_{e_P}}{6(h+1)^2} \Leftrightarrow$$

$$m = \frac{2(\eta h_{e_P} - 6(e_A+e_P)(h+1)^2)}{3\eta\left(h_{e_P} - h_{e_A}\right)}.$$

$$(III)\ h_{e_A}\int_{\underline{y}}^{\overline{y}} y f_h(y|h)dy - c'(e_A) + \frac{1-\delta}{\delta(h_{e_P}-h_{e_A})F_h(\hat{y}|h)}\times$$

$$\left[-c''(e_A) + h_{e_P}h_{e_A}\int_{\underline{y}}^{\overline{y}} y f_{hh}(y|h)dy + m\left(F_{hh}(\hat{y}|h)h_{e_A}(h_{e_P}-h_{e_A}) - F_h(\hat{y}|h)h_{e_A e_A}\right)\right] = 0 \Leftrightarrow$$

$$0 = h_{e_A}\frac{\eta}{6\left(h+1\right)^2} - e_A - \frac{1-\delta}{\delta\left(h_{e_P}-h_{e_A}\right)}\frac{4(h+1)^2}{\eta}\times$$

$$\left[-1 - \frac{\eta h_{e_P}h_{e_A}}{3\left(h+1\right)^3} + m\left(\frac{\left(h_{e_P}-h_{e_A}\right)\eta h_{e_A}}{2\left(h+1\right)^3} + \frac{h_{e_A e_A}\eta}{4\left(h+1\right)^2}\right)\right] \Leftrightarrow$$

$$0 = h_{e_A}\frac{\eta}{6\left(h+1\right)^2} - e_A + \frac{1-\delta}{\delta\left(h_{e_P}-h_{e_A}\right)}\frac{4(h+1)^2}{\eta}\times$$

$$\left[1 + \frac{\eta h_{e_P}h_{e_A}}{3\left(h+1\right)^3} - m\left(\frac{\left(h_{e_P}-h_{e_A}\right)\eta h_{e_A}}{2\left(h+1\right)^3} + \frac{h_{e_A e_A}\eta}{4\left(h+1\right)^2}\right)\right] \Leftrightarrow$$

$$0 = h_{e_A}\frac{\eta}{6\left(h+1\right)^2} - e_A + \frac{1-\delta}{\delta\left(h_{e_P}-h_{e_A}\right)}\frac{4(h+1)^2}{\eta}\times$$

$$\left[1 + \frac{\eta h_{e_P}h_{e_A}}{3\left(h+1\right)^3} - m\left(\frac{h_{e_A e_A}\eta\left(h+1\right) + \left(h_{e_P}-h_{e_A}\right)2\eta h_{e_A}}{4\left(h+1\right)^3}\right)\right] \Leftrightarrow$$

$$0 = h_{e_A}\frac{\eta}{6\left(h+1\right)^2} - e_A + \frac{1-\delta}{\delta\left(h_{e_P}-h_{e_A}\right)}\frac{4(h+1)^2}{\eta}\times$$

$$\left[1 + \frac{4\eta h_{e_P}h_{e_A}}{12\left(h+1\right)^3} - \frac{3m(h_{e_A e_A}\eta\left(h+1\right) + \left(h_{e_P}-h_{e_A}\right)2\eta h_{e_A})}{12\left(h+1\right)^3}\right] \Leftrightarrow$$

$$0 = h_{e_A}\frac{\eta}{6\left(h+1\right)^2} - e_A + \frac{1-\delta}{\delta\left(h_{e_P}-h_{e_A}\right)}\frac{4(h+1)^2}{\eta}\times$$

$$\left[1 + \frac{4\eta h_{e_P}h_{e_A} - 3m(h_{e_A e_A}\eta\left(h+1\right) + \left(h_{e_P}-h_{e_A}\right)2\eta h_{e_A})}{12\left(h+1\right)^3}\right] \Leftrightarrow$$

$$0 = h_{e_A}\frac{\eta}{6\left(h+1\right)^2} - e_A + \frac{1-\delta}{\delta\left(h_{e_P}-h_{e_A}\right)}\frac{4(h+1)^2}{\eta}\times$$

$$\left[\frac{12(h+1)^3 + 4\eta h_{e_P}h_{e_A} - 3m(h_{e_A e_A}\eta\left(h+1\right) + \left(h_{e_P}-h_{e_A}\right)2\eta h_{e_A})}{12\left(h+1\right)^3}\right] \Leftrightarrow$$

$$0 = h_{e_A}\frac{\eta}{6\left(h+1\right)^2} - e_A + \frac{1-\delta}{\delta\eta\left(h_{e_P}-h_{e_A}\right)}\times$$

$$\left[\frac{12(h+1)^3 + 4\eta h_{e_P}h_{e_A} - 3m(h_{e_A e_A}\eta\left(h+1\right) + \left(h_{e_P}-h_{e_A}\right)2\eta h_{e_A})}{3\left(h+1\right)}\right] \Leftrightarrow$$

$$0 = \frac{\eta h_{e_A}}{6\left(h+1\right)^2} - e_A + \frac{1-\delta}{\delta}\left[\frac{12(h+1)^3 + 4\eta h_{e_P}h_{e_A} - 3m(h_{e_A e_A}\eta\left(h+1\right) + \left(h_{e_P}-h_{e_A}\right)2\eta h_{e_A})}{3\left(h+1\right)\eta\left(h_{e_P}-h_{e_A}\right)}\right].$$

$$
\begin{aligned}
&(IV)\ h_{e_P}\int_{\underline{y}}^{\overline{y}} yf_h\left(y|h\right)dy-\phi'(e_P)+\frac{1-\delta}{\delta(h_{e_P}-h_{e_A})F_h(\hat{y}|h)}\\
&\times\left[-\phi''(e_P)+h_{e_Pe_P}\int_{\underline{y}}^{\overline{y}} yf_h(y|h)dy+h_{e_P}h_{e_P}\int_{\underline{y}}^{\overline{y}} yf_{hh}(y|h)dy\right.\\
&\left.+\,m\left(F_{hh}(\hat{y}|h)h_{e_P}(h_{e_P}-h_{e_A})+F_h(\hat{y}|h)h_{e_Pe_P}\right)\right]=0\Leftrightarrow\\
&0=h_{e_P}\frac{\eta}{6(h+1)^2}-e_P+\frac{1-\delta}{\delta}\frac{1}{(h_{e_P}-h_{e_A})F_h(\hat{y},h)}\times\\
&\quad\left[-1+\frac{\eta h_{e_Pe_P}}{6(h+1)^2}-\frac{\eta h_{e_P}h_{e_P}}{3(h+1)^3}+m\left(\frac{\eta h_{e_P}}{2(h+1)^3}(h_{e_P}-h_{e_A})-\frac{\eta h_{e_Pe_P}}{4(h+1)^2}\right)\right]\Leftrightarrow\\
&0=h_{e_P}\frac{\eta}{6(h+1)^2}-e_P-\frac{1-\delta}{\delta(h_{e_P}-h_{e_A})}\frac{4(h+1)^2}{\eta}\times\\
&\quad\left[-1+\frac{\eta h_{e_Pe_P}}{6(h+1)^3}-\frac{\eta h_{e_P}h_{e_P}}{3(h+1)^3}+m\left(\frac{(h_{e_P}-h_{e_A})\eta h_{e_P}}{2(h+1)^3}+\frac{h_{e_Pe_P}\eta}{4(h+1)^2}\right)\right]\Leftrightarrow\\
&0=h_{e_P}\frac{\eta}{6(h+1)^2}-e_P+\frac{1-\delta}{\delta(h_{e_P}-h_{e_A})}\frac{4(h+1)^2}{\eta}\times\\
&\quad\left[1-\frac{\eta h_{e_Pe_P}}{6(h+1)^3}+\frac{\eta h_{e_P}h_{e_P}}{3(h+1)^3}-m\left(\frac{h_{e_Pe_P}\eta(h+1)+(h_{e_P}-h_{e_A})2\eta h_{e_P}}{4(h+1)^3}\right)\right]\Leftrightarrow\\
&0=h_{e_P}\frac{\eta}{6(h+1)^2}-e_P+\frac{1-\delta}{\delta(h_{e_P}-h_{e_A})}\frac{4(h+1)^2}{\eta}\times\\
&\quad\left[1-\frac{2\eta h_{e_Pe_P}}{12(h+1)^3}+\frac{4\eta h_{e_P}h_{e_P}}{12(h+1)^3}-\frac{3m(h_{e_Pe_P}\eta(h+1)+(h_{e_P}-h_{e_A})2\eta h_{e_P})}{12(h+1)^3}\right]\Leftrightarrow\\
&0=h_{e_P}\frac{\eta}{6(h+1)^2}-e_P+\frac{1-\delta}{\delta(h_{e_P}-h_{e_A})}\frac{4(h+1)^2}{\eta}\times\\
&\quad\left[\frac{12(h+1)^3-2\eta h_{e_Pe_P}+4\eta h_{e_P}h_{e_P}-3m(h_{e_Pe_P}\eta(h+1)+(h_{e_P}-h_{e_A})2\eta h_{e_P})}{12(h+1)^3}\right]\Leftrightarrow\\
&0=h_{e_P}\frac{\eta}{6(h+1)^2}-e_P+\frac{1-\delta}{\delta\eta(h_{e_P}-h_{e_A})}\times\\
&\quad\left[\frac{12(h+1)^3-2\eta h_{e_Pe_P}+4\eta h_{e_P}h_{e_P}-3m(h_{e_Pe_P}\eta(h+1)+(h_{e_P}-h_{e_A})2\eta h_{e_P})}{3(h+1)}\right]\Leftrightarrow\\
&0=\frac{\eta h_{e_P}}{6(h+1)^2}-e_P+\frac{1-\delta}{\delta}\times\\
&\quad\left[\frac{12(h+1)^3-2\eta h_{e_Pe_P}+4\eta h_{e_P}h_{e_P}-3m(h_{e_Pe_P}\eta(h+1)+(h_{e_P}-h_{e_A})2\eta h_{e_P})}{3(h+1)\eta(h_{e_P}-h_{e_A})}\right].
\end{aligned}
$$

C3 Derivation of e_A^* and e_P^*

For instance, let consider a linear joint production function $h = ae_A^* + be_P^*$ that satisfies the conditions in the setup ($h_e > 0, h_{ee} \leq 0$). For $e_A^*, e_P^*, h > 0$, from (3.8), the patient principal's optimal effort level is $e_P^* = \frac{\sqrt{\eta a} - (2 + ae_A^*)\sqrt{6e_A^*}}{\sqrt{6e_A^*}b}$. Hence, inserting this equation into (3.9) provides

$$
\begin{aligned}
e_A^* &= \frac{\sqrt{\eta b} - (1 + be_P^*)\sqrt{6e_P^*}}{a\sqrt{6e_P^*}} = \frac{\sqrt{\eta b} - \left(1 + b\frac{\sqrt{\eta a} - (2+ae_A^*)\sqrt{6e_A^*}}{\sqrt{6e_A^*}b}\right)\sqrt{6\frac{\sqrt{\eta a} - (2+ae_A^*)\sqrt{6e_A^*}}{\sqrt{6e_A^*}b}}}{a\sqrt{6\frac{\sqrt{\eta a} - (2+ae_A^*)\sqrt{6e_A^*}}{\sqrt{6e_A^*}b}}} \\
&= e_A^* + \frac{1 - \frac{\sqrt{a\eta}}{\sqrt{6}\sqrt{e_A^*}} + \frac{b\sqrt{e_A^*}\sqrt{b\eta}\sqrt{\frac{-2\sqrt{6} - \sqrt{6}ae_A^* + \frac{\sqrt{a\eta}}{\sqrt{e_A^*}}}{b}}}{6^{1/4}\left(-2\sqrt{6}\sqrt{e_A^*} - \sqrt{6}ae_A^{3/2} + \sqrt{a\eta}\right)}}{a} \iff \\
0 &= \frac{1 - \frac{\sqrt{a\eta}}{\sqrt{6}\sqrt{e_A^*}} + \frac{b\sqrt{e_A^*}\sqrt{b\eta}\sqrt{\frac{-2\sqrt{6} - \sqrt{6}ae_A^* + \frac{\sqrt{a\eta}}{\sqrt{e_A^*}}}{b}}}{6^{1/4}\left(-2\sqrt{6}\sqrt{e_A^*} - \sqrt{6}ae_A^{3/2} + \sqrt{a\eta}\right)}}{a}.
\end{aligned}
$$

Appendix D

D1 Applying conclusions to reality

In this Appendix, I relate the findings to real-world scenarios. Let $(\eta_1, \eta_2) \in \eta$, where $\eta_1 < \eta_2$.

$h_{e_A} > h_{e_P}$, $h_{e_P} < \eta^{-1}6(e_A^* + e_P^*)(h+1)^2$ **and** η_2

In this example, the sensitivity of the distribution is higher, indicating that the parties' deviations from average output have a greater impact. Moreover, the pharmaceutical company's (agent's) effort contributes more to the output than the hospital's (principal's) effort.

Real-world example: A pharmaceutical company, operating without monopolistic control in the market, provides drugs to hospitals. The company's endeavors to maintain quality, ensure availability, and facilitate timely delivery have a substantial influence on healthcare output. Although government regulations and external enforcement efforts also contribute, the direct impact of the pharmaceutical company's efforts is more pronounced, owing to the intricacies and particularities of drug production and delivery.

$h_{e_A} > h_{e_P}$**,** $h_{e_P} < \eta^{-1}6(e_A^* + e_P^*)(h+1)^2$ **and** η_1

In this example, the sensitivity of the distribution is lower than that of the previous scenario. However, the facility management company (agent) contributes more to the output than the facility administration (principal).

Real-world example: Healthcare facility administration frequently outsources facility management tasks, including cleaning, maintenance, and security, to specialized companies. While the efforts of the facility administration to oversee these tasks are crucial, the cleanliness of the healthcare facility primarily hinges on the quality and frequency of the efforts made by the facility management company.

Appendix E: Graphs

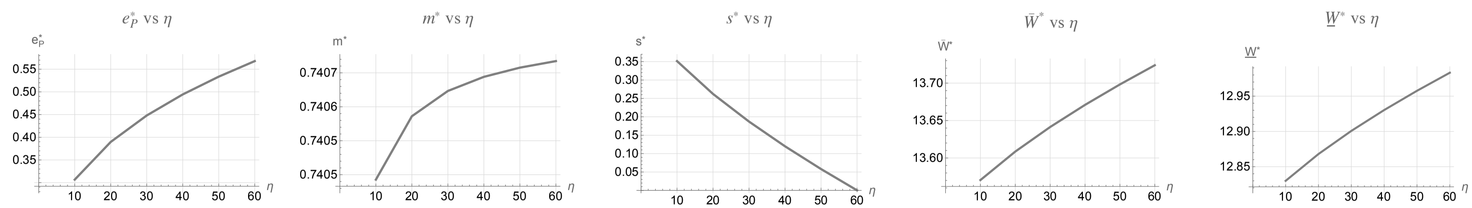


Figure E1: Changes of the distribution sensitivity η for very patient parties, where $\delta = 0.9$ and $h = 50e_A^* + 5e_P^*$

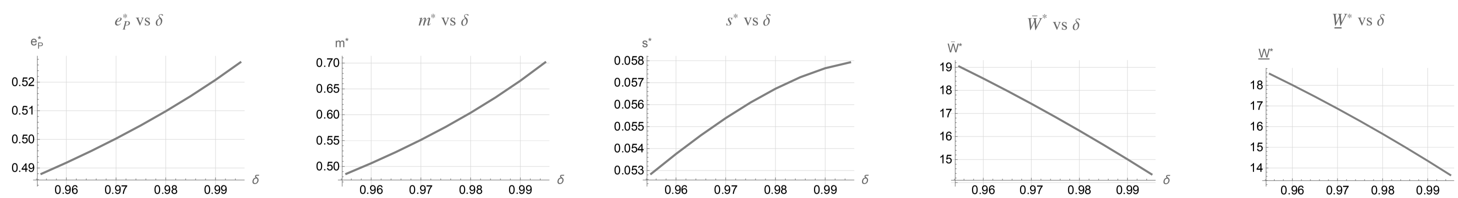


Figure E2: Changes of parties' patience δ, where $\eta = 50$ and $h = 50e_A^* + 5e_P^*$

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