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ENHANCING THE PUBLIC INVESTMENT IN PUBLIC-PRIVATE PARTNERSHIPS USING SYSTEM DYNAMICS MODELING

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ABSTRACT

Public-Private Partnership (PPP) programs have been adopted to leverage private funding for the development of public infrastructure and services, thereby relieving public fiscal pressure. However, the complexity and length of PPP contracts can lead to higher costs for the public sector. Using data from more than 700 PPPs that integrate the UK Private Finance Initiative and Private Finance 2 programs, this study analyzes the long-term financial implications of these programs using System Dynamics. Causal-loop diagrams were developed to illustrate the causal structures that generate the long-term financial effects of PPPs on the public sector. The paper offers potential strategies to enhance the performance of PPP programs. This study contributes to closing the research gap identified in previous research for more efficient PPP programs by uncovering their dynamics and offering suitable policies for governments to improve their outcomes.

1 INTRODUCTION

Public-Private Partnerships (PPPs) have been adopted as a procurement mechanism to alleviate financial pressure on the public sector and shift responsibilities to the private sector (Rojas et al. 2023). PPPs programs can be described as the development of public infrastructure and services through leveraging on private funding within long-term arrangements that incorporate design, construction, operation, and maintenance (Castelblanco et al. 2023b). PPPs allow the private sector to finance, design, build, operate, and operate public infrastructure (Lakshmanan 2008). PPP projects are contracts signed between public authorities and private sectors for almost all infrastructure types, such as health, education, and transport (Castelblanco and Guevara 2022). These contracts usually last between 25 and 30 years (El Kawam et al. 2024; HM Treasury 2018). PFI contracts are signed between public authorities and Special Purpose Vehicles (SPVs), made by multiple private companies, including construction firms and facility management companies, among others (Marcellino et al. 2022). The revenues cover the cost of construction, maintenance, and operation, financing costs, and the SPV’s long-term profitability (Guevara et al. 2023; Zhang et al. 2020). The private sector company is also responsible for managing most of the risks associated with the project (Ortiz-Mendez et al. 2023), especially construction and operation risks (Castelblanco et al. 2023a). In return, the private sector company receives long-term revenues from the government and/or users (Oloruntobi Dada 2013).

One of the countries that have led the implementation of PPPs in the world is the United Kingdom (UK) (Pagoni et al. 2019). In the UK two PPP programs have been procured between 1992 and 2018 allowing the development of over 700 projects. The former and larger program was the Private Finance Initiative (PFI) and the latter was Private Finance 2 (PF2). The magnitude of PFI and PF2 programs is reflected in 704 PPP projects procured as of 31st March 2018, with a capital value estimated at £57 billion and an estimated payment of £188.35 billion over 30 years (HM Treasury 2020). PFI was introduced in 1992 (Hodges and Mellett 2012) to enable cooperation between the public and private sectors, allowing the public sector to benefit from private sector expertise in managing projects (Froud 2003; Villalba-Romero and Liyanage 2016). On the other hand, PF2 was introduced in 2012 as a replacement for PFI aiming to enhance the Value for Money of the projects (HMT 2016).

Despite the multiple benefits of PPPs, emblematic PPP developers such as the UK have decided to conclude the PFI and PF2 programs mostly due to the perception of excessive costs for the public sector under this project delivery. The closure of PFI projects was announced by public authorities in 2018 (HM Treasury 2020). In fact, PPP contracts are often very long and complex, involving many different stakeholders and contractual arrangements (Salazar et al. 2024). This can make it difficult for public sector organizations to manage the contracts effectively and ensure that the private sector company is delivering the required services at an acceptable cost. In addition, PPP projects can be highly risky, with the private sector company bearing most of the financial risk associated with the project (HM Treasury 2018). This can result in higher costs to the public sector over the life of the project, as the private sector company will typically charge a premium for taking on the risk (Castelblanco et al. 2024).

System Dynamics (SD) has been widely employed as a methodological approach within the PPP body of knowledge. Previous models in this field have primarily focused on analyzing construction costs (Leon et al. 2018); financial performance (Castelblanco et al. 2022); infrastructure deterioration (Páez-Pérez and Sánchez-Silva 2016); concession pricing (Xu et al. 2012); construction risks (De Marco et al. 2016); construction risk allocation (Nasirzadeh et al. 2013); concession period (Khanzadi et al. 2012); and demand forecast (Alasad and Motawa 2016) at the project level. However, there is a notable gap in the PPP literature regarding the application of SD to analyze PPPs at the portfolio level.

To offer potential strategies to enhance the performance of PPP programs, this paper develops a SD analysis to unravel the complex relationships behind PPP programs and conduct scenario analysis to explore possible enhancements that could lead to more efficient programs. Using data from the UK PFI and PF2 programs, this paper analyzes the impact of the concession period on the efficiency of public investment in large PPP infrastructure projects. The study examines the long-term financial implications of these programs using SD modeling techniques. This study contributes to close the research gap identified in previous research for more efficient PPP programs. In fact, the International Monetary Fund emphasized the importance of developing robust financial structures and government support mechanisms to ensure the long-term viability of PPP programs (International Monetary Fund 2018). Overall, this paper aims to contribute to the ongoing debate on how to improve PPP programs and make them more effective and efficient.

2 METHODOLOGY

2.1 System Dynamics

The initial step involved defining the SD model based on the established goal, followed by creating the Casual Loop and Stock and Flow Diagrams using system dynamics-based software - Vensim to address the research questions. SD is a modeling and simulation methodology introduced by Forrester in the 1960s for dynamic management problems (Forester 1961). The SD model comprises Causal Loop Diagrams (CLD) that depict qualitative relationships and cycles between variables, which are later transformed into equations in the Stock and Flow Diagram (Sterman 2000). CLDs have the form of an oriented graph and are intended to explain the causal structures within the system, with arrows representing links between variables (Ottaviani et al. 2023). The effects among the variables can be positive (denoted by "+") or negative (denoted by "-") (Delgado-Maciel et al. 2018). CLDs have two types of loops: reinforcing ones that strengthen a behavior, and balancing ones that counteract the effect of a change (Haraldsson 2004). Stock and Flow diagrams consist of four main components: stocks, flows, auxiliary variables, and connectors (Cagliano et al. 2015). Stocks represent tangible quantities, and these are modeled quantitatively as integrals that accumulate quantities given by inflows and outflows (Khallaf et al. 2024). Auxiliary variables may be constant over time or may be changeable, and connectors represent the relationships between all the other components, which could either positively or negatively influence the system (Cagliano et al. 2015).

2.2 Casual Loop Diagram

CLD explains the causal relationships within the system and is used in this paper to estimate the long-term financial effects of PPPs on the government and society. The CLD shown in Figure 1 includes two reinforcing loops (R1 and R2) and one balancing loop (B1). The first reinforcing loop (R1) shows that as more projects are initiated in the PFI and PF2 programs, the number of projects in construction and operating PFI also increases. This results in more transferred PFI to the public sector after the operation period has concluded. An increase in PFI supply also leads to a higher number of projects that may be procured a second time, resulting in a higher number of PFI initiated. The second reinforcing loop (R2) shows that the relationship between PFI initiated and unitary charges is key. An increase in PFI initiated results in an increase in unitary charges paid by the government, which leads to a higher average IRR and Interest Rate Gap. This favors investors, resulting in an increasing number of PFI initiated, but it will lead to decreasing number of PFI initiated from the government perspective. The balancing loop (B1) focuses on limiting the number of PFI initiated. The more operating projects, the higher the unitary charges paid by the public sector to the concessionaires, resulting in a higher Average IRR and Interest Rates Gap. The higher the Interest Rates Gap, the lower the number of PFI initiated due to higher social and political opposition. This leads to lower numbers of PFI under construction and operating PFI.

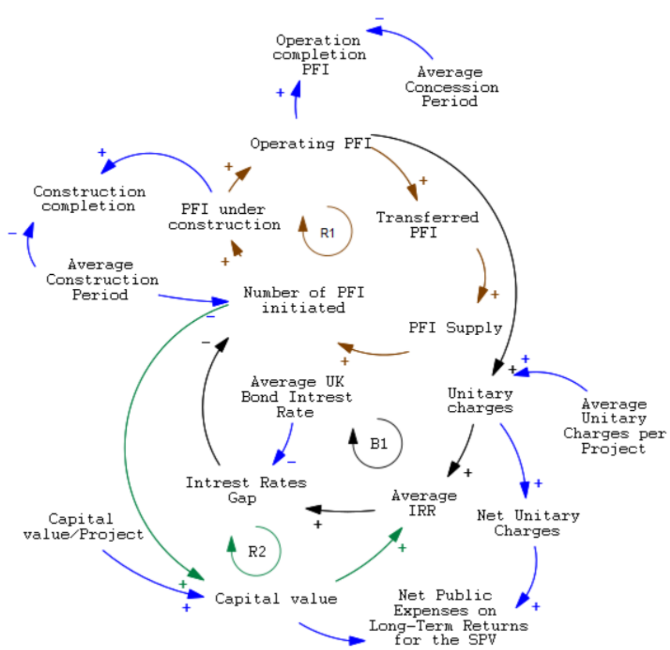

Figure 1: Causal Loop Diagram.

2.3 Stock and Flow Diagram

Figure 2 depicts the Stock and Flow Diagram developed based on the CLD. The unit of time for this model is a "year," and it begins in 1993, which is the year of the first project and the model runs for a time period of 50 years. The model comprises four stocks: PFI under construction, Operating PFI, Transferred PFI, and Net Public Expenses on Long-Term Returns for the SPV. PFI under construction decreases with Construction completion, which is subject to the Average construction period. Operating PFI increases with Construction completion, whereas Transferred PFI increases with the Operation completion PFI. These stocks contribute to the variable PFI Supply, which represents the total number of projects regardless of their stage. The Stock named Net Public Expenses on Long-Term Returns for the SPV has been created in order to calculate the impact of the public sector on financing the PFI/PF2 programs. The inflow for this stock is Net Unitary Charges, and the outflow is the Capital Value. The Average IRR is calculated based on the Capital Value and Unitary Charges to determine the profitability for the private investor. As can be noticed, Average IRR depends on Net Unitary Charges and Net capital value. The Interest Rates Gap shows the difference between the Average IRR and the Average UK Bond Interest, where a positive gap represents a higher detrimental effect on public finance. Table 1 presents all the exogenous parameters utilized for Stock and Flow diagram modeling. The quantitative results obtained from the SD model were validated using data obtained from the UK government.

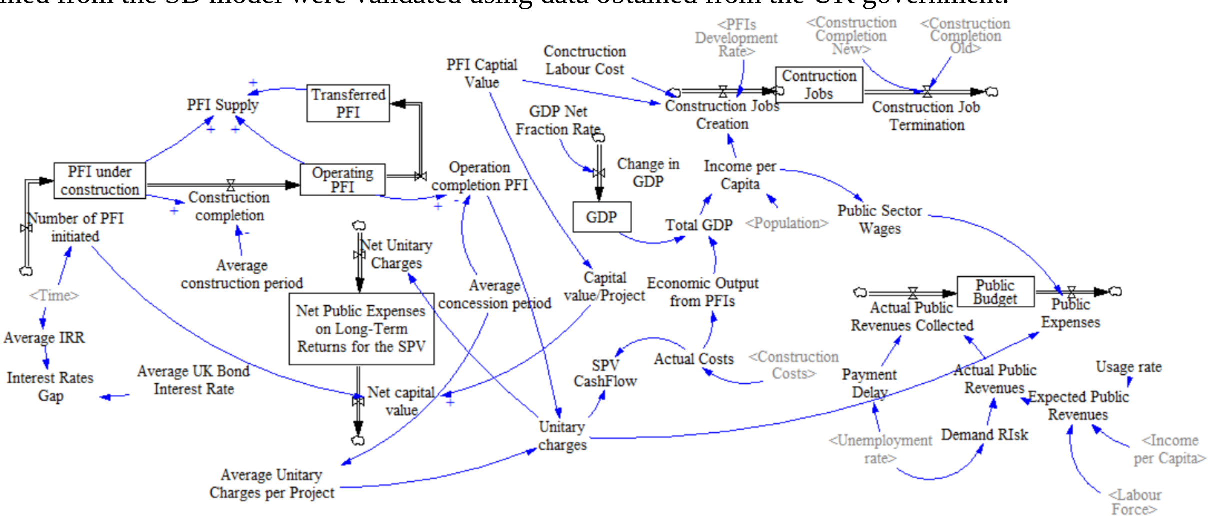

Figure 2: Stock and Flow Diagram.

Table 1: Exogenous parameters for the Baseline Scenario.

NAME	Constant	Units
Capital Value/Project	81.1065	mln £
Average construction period	3	years
Average concession period	28	years

The Stock and Flow Diagram consists of four subsystems: GDP, PFI Supply, Labor Generation, and Public Budget.

The GDP subsystem (Figure 3) shows that Unitary Charges have a positive influence on the SPV CashFlow. The more the government pays to the SPV, the larger the CashFlow. On the other hand, Actual Costs (i.e., construction and maintenance costs) have a negative impact on the CashFlow. However, the SPV must be cautious about decreasing costs excessively, as it can lead to lower project quality, which in the long term will result in lower CashFlow. The Actual Costs also affect the Economic Output from the PPPs, which, in turn, influences the Total GDP. A higher Economic Output from PPPs leads to a higher

Total GDP. Complementary, a larger Population can lower the Income per Capita. The GDP subsystem also includes a stock of GDP, which cumulate according to the rate of Change of GDP.

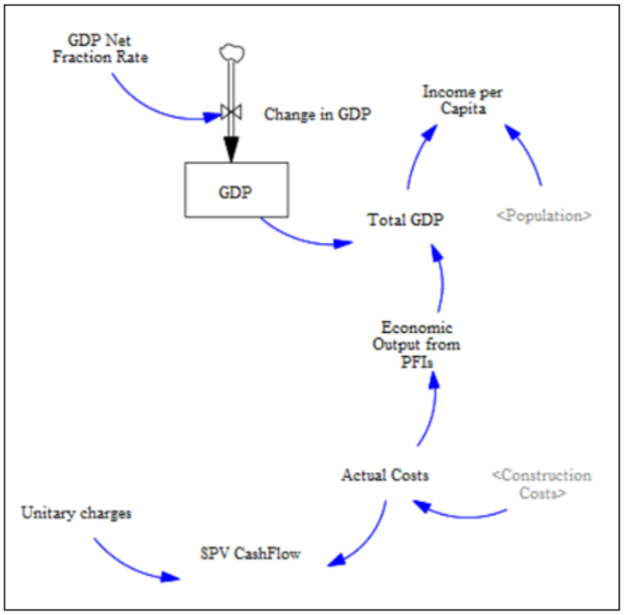

Figure 3: GDP subsystem.

Figure 4 represents the PFI Supply subsystem. It begins with the Number of PFI initiated, which flows into the PFI under Construction stock. Once construction starts, the Construction Completion rate determines the inflow rate, and the projects enter the Operating PFI stock. After the concession period ends, the projects are transferred to the government, represented by Transferred PFI stock. The sum of ongoing projects represents the total PFI Supply available.

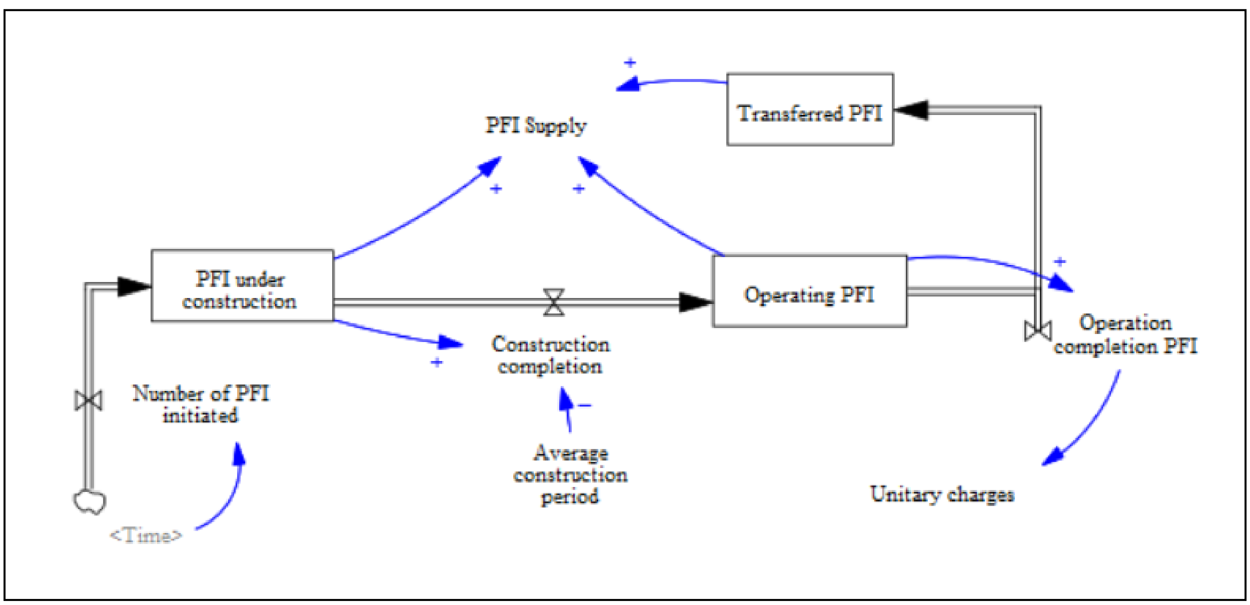

Figure 4: PFI Supply subsystem.

The Labor Generation subsystem (Figure 5) is closely linked to the Income per Capita mentioned earlier. The stock of Construction Jobs is influenced by the flow of Construction Job Creation, which, in turn, is influenced by Income per Capita, PFI Capital Value, Construction Labor Cost, and PFIs Development Rate. Higher Income per Capita leads to more Construction Job as more projects are initiated. PFI Capital Value, which indicates project complexity and size, has a positive influence on this stock, along with the PFIs Development Rate. On the contrary, higher Construction Labor Cost negatively affects Construction Job Creation, as it decreases project revenue. After a project is completed, Construction Job Termination occurs influenced by Completion Construction Old and Construction Completion New, which determine the flow of Construction Job Termination.

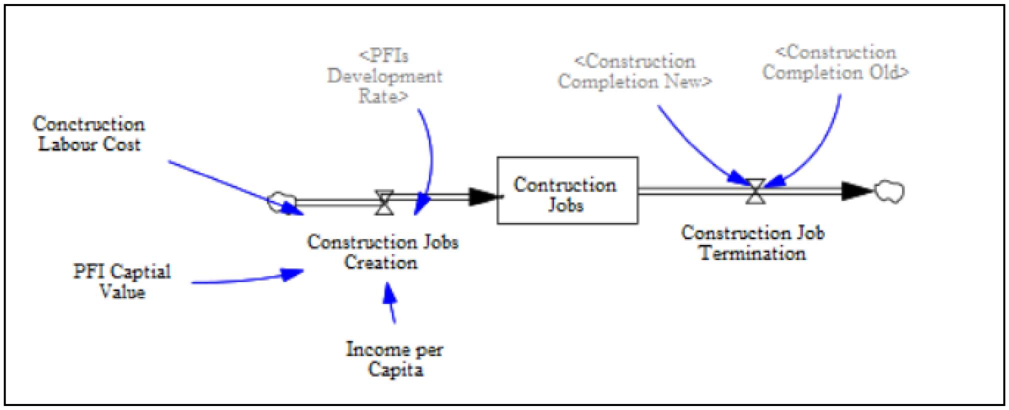

Figure 5: Labor generation subsystem.

The Public Budget subsystem (Figure 6) is influenced by the PFI projects, with inflows representing the Actual Public Revenues Collected and outflows representing the Public Expenses. The Actual Public Revenues Collected are influenced by Payment Delay, which in turn is influenced by the Unemployment Rate. Actual Public Revenues also depend on the Demand Risk for the PFI. Expected Public Revenues, on the other hand, are influenced by Labor Force, as taxes are collected from them. Additionally, Expected Public Revenues are based on Income per Capita and Usage rate, which generate income, such as in the case of roads and other infrastructure types. On the outflow side of the Public Budget stock, Public Expenses are influenced by Unitary Charges that must be paid by the government to the SPV.

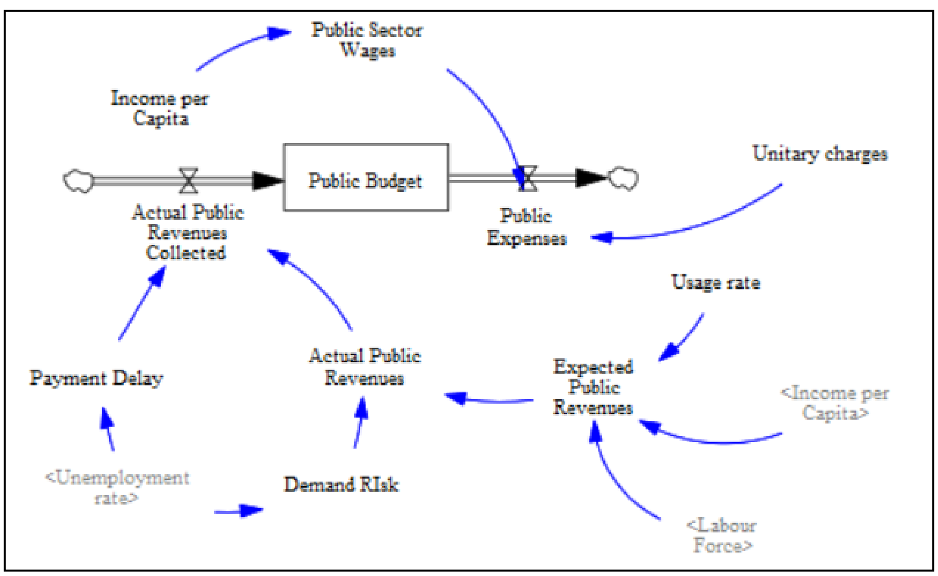

Figure 6: Public Budget subsystem.

2.4 Model Validation

This SD model is a simplification of the real-world scenario, as is the case with all models. However, to ensure the model's reliability, it underwent a rigorous validation process, incorporating various recommended confidence tests. These tests included behavior reproduction, which examined the accuracy of the model in replicating the real system's behavior, sensitivity analysis to assess the impact of parameter changes on the model's outputs, integration error to evaluate the numerical solution's accuracy, extreme conditions to observe the model's behavior under extreme inputs, parameter assessment to ensure consistency with the real system, dimensional consistency to maintain uniform units across variables, structure assessment to ensure internal consistency, and boundary adequacy to validate the model's assumptions and boundaries (Sterman 2000).

Sensitivity analysis was conducted to comprehensively evaluate the model's robustness and account for uncertainty by assessing the impact of changes in input variables following different statistical distributions (Eker et al. 2014). Furthermore, behavior reproduction focused on both the stocks of the system aiming to verify whether the model accurately reproduced the behavior observed in the real system.

3 FINDINGS AND DISCUSSION

3.1 Scenario Analysis

In order to analyze the long-term effects on the public budget of the PPP program, the simulation considered a time span of 50 years. In order to assess the impact of the concession period on the Net Public Expenses on Long-Term Returns for the SPV, multiple scenarios were established. Specifically, five scenarios were established to assess the changes in the Average Concession Period, as follows:

1. Baseline scenario
2. Baseline Concession Period + 5 years
3. Baseline Concession Period - 5 years
4. Baseline Concession Period + 10 years
5. Baseline Concession Period - 10 years.

The first outcome to assess was the Net Unitary Charges, which refer to the periodic payments that the public sector disburses to the SPV. Figure 3 shows that the more the Average Concession Period, the higher the Net Unitary Charges in the long term. This can be understood because of the impact of any additional year on the cost of the project. Moreover, the model considers that any additional year in the Concession period will increase the total cost of the projects by 2% and vice versa. Conversely, the shorter the Concession Period the more Unitary Charges are required in the middle term for the PPP program.

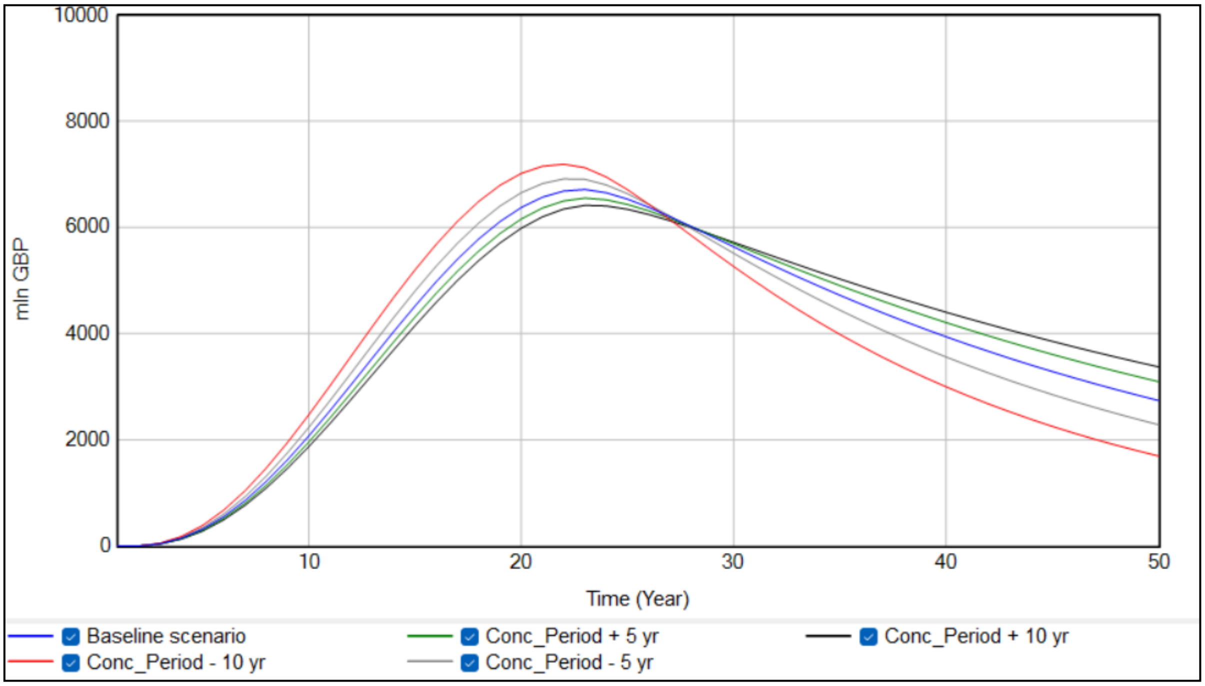

Figure 7: Net Unitary Charges.

The analysis of the Net Public Expenses on Long-Term Returns for the SPV (Figure 8). The primary purpose of this Stock is to calculate the cumulative impact for the public sector of financing a long-term PPP program, where payments are distributed over the long run during the operation phase compared to alternative project deliveries, such as Design Build, where payments are distributed over the short term during the construction phase. In general, during the first 20 years, the capital value invested by the private sector results in negative cumulative Net Public Expenses, resulting in benefits on the public budget because this private investment is leveraging the capital expenditures required for building the facilities. Conversely, after 20 years, the Net Unitary Charges are higher than the Net Capital Value and the public sector must reimburse the SPVs and provide for their profitability. Figure 8 shows that the longer period of the concession, the higher the cumulated Net Public Expenses on Long-Term Return for the SPV and vice-versa. The difference in this outcome between opposite scenarios is almost £10 billion. The main reason behind this behavior is that the Average SPV's IRR is much higher than the Average UK Bond Interest Rate, resulting in a detrimental effect of longer Concession Periods for the public budget.

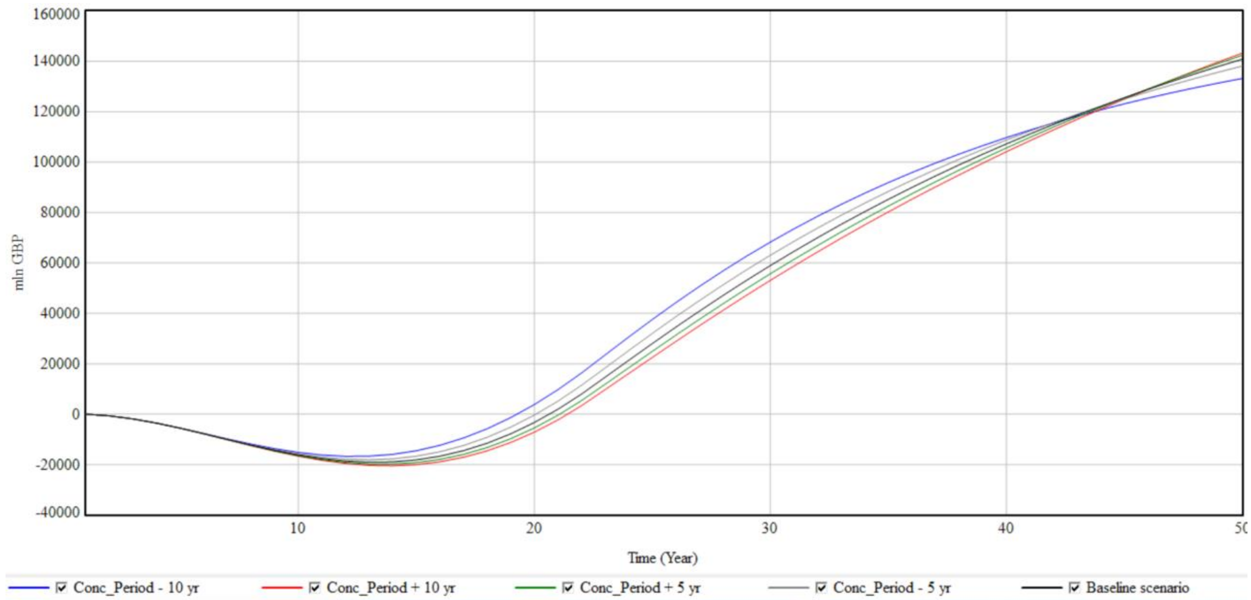

Figure 8: Net Public Expenses on Long-Term Returns for the SPV.

4 CONCLUSIONS

PPPs have been implemented globally as a means to develop public infrastructure and services through leveraging private funding while shifting responsibilities to the private sector. The UK has been one of the leading countries in implementing PPP programs, including the PFI and PF2, which have allowed for the development of over 700 projects. However, the excessive costs and complex contractual arrangements of PPP programs have raised concerns, leading to the closure of PFI and PF2 in 2018.

To enhance the performance of PPP programs, this study utilized SD modeling techniques to evaluate the impact of the concession period on the efficiency of public investment in large PPP infrastructure projects. Using data from the UK PFI and PF2 programs, this study examined the long-term financial implications of these programs. The results showed that increasing the concession period is detrimental to the public budget in the long term from a portfolio perspective.

The study contributes to closing the research gap in previous research for more efficient PPP programs. The findings suggest that policymakers and project managers should consider limiting the concession period in PPP projects to enhance the efficiency of public investment in large infrastructure projects. Furthermore, the study highlights the importance of developing robust financial structures and government support mechanisms to ensure the long-term viability of PPP programs, as emphasized by the International Monetary Fund in 2018.

The practical implications of the study are that policymakers and project managers should consider the potential benefits of limiting the concession period when planning PPP projects. By doing so, PPP programs can achieve greater efficiency in public investment and long-term value for money. The findings also suggest the importance of effective contract management and risk allocation between the public and private sectors to minimize costs and ensure the long-term success of PPP programs. Overall, the study highlights the potential benefits of PPP programs, while also emphasizing the importance of careful planning, implementation, and management to ensure their success.

Future research should focus on investigating other factors that may influence the efficiency of PPP programs, beyond the concession period. One potential area for future research is to examine the impact of different risk allocation strategies on the efficiency of PPP programs. This research could analyze how different risk allocation models, such as the transfer of operational risk to the private sector or the allocation of construction risk to a third party, can affect the overall cost and performance of PPP programs. Moreover, future research could explore how PPP programs can be better integrated with other public sector procurement methods, such as design-build procurement, to achieve greater efficiency in infrastructure delivery. Overall, future research should aim to provide a more comprehensive understanding of the factors that influence the efficiency of PPP programs and offer insights into how PPP programs can be improved to achieve greater value for money for public sector investment.

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