Bail out the money printer?

The impact of fiscal indemnity on central bank profitability

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Abstract

Since 2022, central bank losses have been prevalent in advanced economies due to previous quantitative easing and recent inflationary pressures. This paper focuses on the unique case of the United Kingdom, where the government promised in advance to cover any central bank losses arising from quantitative easing. This promise is known as the indemnity. A game-theoretical model is proposed to explain the causes and effects of such indemnity. The model's predictions about the indemnity's effect on central bank profitability are empirically examined. Using the novel Dynamic Multilevel Latent Factor Model (DM-LFM), the indemnity is found to have significantly boosted the Bank of England's profits in the deflationary environment after 2008, but exacerbated its losses under the recent inflationary pressure since 2022. The theoretical model suggests the pronounced effects are due to the Bank of England's high sensitivity to losses and the UK government's moderate fiscal liberalism. Therefore, the British experience should not be generalised. Nevertheless, the theoretical and empirical lessons can inform policy-makers about future institutional designs concerning the fiscal-monetary interactions and the public finance-price stability trade-off.

Keywords— Central Bank Losses, Fiscal-Monetary Interaction, Public Finance

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1. Introduction

Large financial losses incurred by central banks were once considered theoretically improbable in advanced economies due to the stable profit generated from the monopolistic supply of currency, known as the seigniorage (Cukierman, 2011, pp. 44–45; Downes & Vaez-Zadeh, 1991; Stella, 2005). Nevertheless, since 2022, central bank losses have become more common due to the compound effect of

1. higher interest rates implemented to tackle the inflationary pressure following COVID-19 and the Russo-Ukrainian War, and
2. the large central bank balance sheets resulting from previous Quantitative Easing (QE) (Cecchetti & Hilscher, 2024).

Major Western economies such as the US, Eurozone and UK introduced QE as a novel form of monetary policy to combat the deflationary pressure from the recession following the 2007-2008 Global Financial Crisis (GFC) (Joyce et al., 2012). Traditionally, central banks aim to achieve low and stable inflation (typically 2%) by setting short-term interest rates. Nevertheless, one obvious drawback of this instrument is that the market interest rates cannot possibly approach zero - this limitation is known as the zero lower bound. After the GFC, inflation was so low that the problem of zero lower bound materialised. Consequently, central banks initiated massive asset purchases (primarily long-term government bonds), aiming to reduce *long-term* interest rates. The scale and pace of such purchases are *ex ante* decided by Monetary Policy Committees, hence the term Quantitative Easing (QE).

Due to the lack of any material inflationary threat and the sluggish recovery from the recession, the assets purchased during QE were not actively sold and interest rates were rarely raised. The returns on these assets financed by cheap credit generated substantial profits for central banks. These profits are usually remitted to their respective governments (Chaboud & Leahy, 2013). At this point, central bank capital and profitability received little attention from researchers and policymakers (Cecchetti & Hilscher, 2024). However, this euphoria ended in 2022 when the major central banks acknowledged the long-term inflationary prospects arising from the COVID-19 supply chain bottlenecks and the Russian invasion of Ukraine (Blanchard & Bernanke, 2023). Monetary policy was subsequently tightened: central banks raised the interest rates they paid on commercial banks reserves and sold their assets at discounted prices, turning previous profits into losses.

This paper seeks to explain the *national variation* in central bank losses (profits). Despite other determinants of central bank financial stability such as sovereign defaults, exchange rates (Hall & Reis, 2015) and accounting rules (Cecchetti & Hilscher, 2024), this paper focuses specifically on one political and institutional factor: the government's fiscal indemnity against QE-related losses of the central bank.

The United Kingdom is unique among the advanced economies which adopted QE after the GFC due to the indemnity arrangements between its treasury and central bank, the Bank of England (BoE). In a letter from 29 January 2009[1], the UK Treasury authorised the BoE to create the Asset Purchase Facility (APF) which served as the central bank's QE vehicle. The letter stipulates the size of the fund (initially £50 billion), the eligible sterling assets to be purchased and the *explicit* guarantee that any financial losses incurred by the facility would be compensated for by the government. This guarantee, henceforth referred to as the *indemnity*, forecloses the possibility of a *quid pro quo,* where the government leverages the recapitalisation of a loss-making central bank for favourable monetary policy (Stella, 1997), a potential source of political pressure faced by central banks under implicit loss-coverage rules. In a subsequent exchange of letters in 2012[2], the Conservative government reaffirmed the indemnity granted by their Labour predecessor and it was agreed that the profit (losses) of the APF would be regularly transferred to (from) the Treasury in cash.

As a result, the growing fiscal burden of the indemnity has become a *political* issue unique to the UK: since the Treasury began compensating the APF for losses in 2022 (Financial Times, 2023b), the expected total bill faced by the Treasury was repeatedly revised upwards from £50 billion to a startling £150 billion (Financial Times, 2023a). More worryingly, the UK taxpayers are liable for these losses without the right to know. In early 2024, the House of Lords Economic Affairs Committee demanded that the full details of the indemnity agreement be published. The request was *refused* by the Treasury due to 'market sensitivities' (Bloomberg, 2024). The House of Commons Treasury Committee (2024, para. 64) concluded in a report that "there is no [*ex post*] reason to think that

[1]The letter was originally available at the UK Treasury and BoE websites but was later removed. It is only accessible from the National Archives at the time of writing.

[2]The exchange of letters are available from the BoE website.

the indemnity and cashflow arrangements devised in 2009 and 2012 are the most suitable available." A group of Conservative backbenchers went so far as to demand a review of the BoE's independence. (The Independent, 2024).

Thus far, the British experience may resemble a familar story of *moral hazard*, defined as a situation where an agent adopts riskier behaviour if the risk can be entirely or partially transferred to another party (Landes, 2013). Indeed, even Michael Saunders, a former member of the of the BoE Monetary Policy Committee admitted that the Bank is incurring larger losses on QE than other non-indemnified counterparts, because it has been taking *higher risks* by buying and selling longer-dated bonds (Financial Times, 2023c).

Nevertheless, this paper argues that the moral hazard rationale does not depict a full picture of the story, because many important questions remain unanswered. If the indemnity arrangements were so unwise, why did the UK government agree to it in the first place? Does a naive loss comparison constitute a valid causal inference, free from selection bias? Is the indemnity a necessary condition for stable inflation, as the conventional economic theory prescribes (Hall & Reis, 2015)? More importantly, do higher risks necessarily lead to higher losses and is the UK case generalisable to other countries?

To address these difficult questions, this paper proposes a game-theoretical model to examine post-2008 fiscal-monetary interactions in the Theory section. Key theoretical implications are as follows:

- The UK introduced the indemnity because of its government's relatively low fiscal conservatism.
- Naive profit and loss comparisons likely *underestimate* the impact of indemnity on BoE financials.
- The model confirms the benefits of indemnity for price stability, but highlights the *heterogeneity* in such benefits across contexts.
- Indemnity leads to higher risk-taking by central banks, but higher risks only translate into higher losses
    1. under inflationary pressure, and
    2. when the central bank's sensitivity to losses is not too low.

Thus, the UK experience should *not* be directly extrapolated to other contexts.

- The effects of indemnity on profits under deflationary and inflationary pressures can be in *opposite* directions.

Therefore, the impact of the indemnity on the BoE profits is estimated separately for the deflationary (2009-2021) and inflationary (2022-2023) periods. The findings indicate the indemnity boosted the profits in the former, and exacerbated the losses in the latter for the British case. These results are robust to additional checks.

The remainder of this paper is organised as follows: Section 2 reviews the existing literature; Section 3 sets out the game-theoretical framework to be tested. Section 4 describes the data used for empirical analysis. Section 5 introduces the main estimator (DM-lFM) for causal inference. The main empirical results are presented in Section 6, with their robustness examined in Section 7. This is followed by a discussion on the mapping of the countries to the theoretical domain (Section 8) and the conclusion (Section 9).

2. Literature Review

Prior to 2008, the profits of central banks in mature economies tended to be small and stable, which rarely intrigued scholars or were typically discussed only as a secondary point. Downes & Vaez-Zadeh (1991) provide a great summary of *pre-QE* central bank financials. Downes & Vaez-Zadeh (1991) indicate that, when excluding the impact of exchange rate fluctuations, as per the conventional accounting standards for current profits, central bank profitability is mainly attributable to *seigniorage,* profits of the central bank "resulting from its ability to purchase interest-bearing assets by issuing non-interest-bearing high-powered money[3]" (p.78). More importantly, Downes & Vaez-Zadeh (1991) point out that part of the seigniorage is an *inflation tax.* This highlights the possibility that a non-indemnified central bank may connive in higher inflation to finance its losses, a result echoed with our model in Section 3.

Due to the novelty of losses associated with QE, the existing empirical literature centres on pre-QE central bank losses, which mostly occurred in the *developing and transition* economies (Beckerman, 1997); this contributes little to the understanding of the recent

[3]Molho (1989) reviews the debate around the exact measurement of seigniorage.

QE-related losses in the advanced economies. Dalton & Dziobek (2005) attribute such losses to monetary operations under extreme conditions and financial sector restructuring, while others blame them on central banks' engagement in *quasi-fiscal* activities, which increases central banks' expenditures (Lonnberg & Stella, 2008; Mackenzie & Stella, 1996; Markiewicz, 2001; Muñoz, 2007; Sweidan, 2011). Despite these cases of losses, most central banks did not have specific rules to cover losses (Downes & Vaez-Zadeh, 1991; Pringle & Turner, 1999). This situation improved after the GFC when specific rules such as the use of particular buffers, claims on future profits, direct capitalisation and losses carried forward have become more common (Bunea et al., 2016).

This paper thus contributes to the growing body of literature on *advanced* economies that has flourished since the GFC. After the GFC, unconventional monetary policies such as QE were introduced and fundamentally changed the financial stability of central banks. In the post-QE era, the threats to central bank profitability in mature economies have shifted to the interest rate, default and exchange rate risks (Hall & Reis, 2015). Furthermore, since the GFC the literature has converged on a new definition of central bank *solvency*, namely the present value of the central bank's *dividends* to the treasury being non-negative, without which hyper-inflation may result (Bassetto & Messer, 2013; Del Negro & Sims, 2015; Hilscher et al., 2015; Reis, 2013, 2015)[4]. This is in stark contrast to the traditional emphasis on positive *equity* as the criterion for solvency, which inappropriately treats central banks as commercial banks. The fact that central banks[5] have historically fulfilled their duties withstanding extended periods of losses and negative equity may *mislead* the public into thinking the financial performance of central banks does not matter at all (Bell et al., 2023).

According to this new definition, the only guarantee of central bank's solvency and consequently, effective monetary policy, is a dividend rule that requires the treasury to pay the central bank a "negative dividend" (Hall & Reis, 2015). This "negative dividend rule" is perfectly epitomised by the indemnity agreements between the UK Treasury and the Bank of England. Therefore, there is a theoretical foundation for the UK indemnity arrangement as a *sufficient* condition for central bank solvency, which is in turn a *necessary* condition for achieving inflation targets. This inflation-stabilising effect is also confirmed

[4]This definition is named "intertemporal insolvency" as the most accepted definition of the three definitions provided by Reis (2015).

[5]For example, Chile, Czechia, Hungary, Israel and Mexico.

by our theoretical analysis (see Proposition 2). However, the UK's negative dividend rule is only one among many possible arrangements. Chaboud & Leahy (2013) provide case studies into central banks losses in advanced economies; Bunea et al. (2016) categorize the profit distribution, loss coverage and recapitalisation arrangements of central banks around the world, while Long & Fisher (2024) provide the most detailed summary of such arrangements for *most* countries. Nevertheless, for simplicity we do not distinguish between the non-indemnity arrangements in this paper, as central banks are still more or less subject to loss-related pressure under these rules.

More importantly, the literature has identified central bank losses and their coverage as *political economy* problems. Hall & Reis (2015) notice that a payment from the treasury to the central bank involves the appropriation of government funds, subject to the political process. Similarly, indemnity as an *unconditional commitment* to such appropriation is ultimately a *political* decision. Goncharov et al. (2023) document the central banks' tendency to report small profits rather than losses, driven by political factors such as public opinion and governor reappointability. Diessner (2023) explore the case studies of the UK, Japan and Eurozone, and reach a similar conclusion - that central bankers' aversion to losses despite their ability to create currency is associated with their pursuit of *independence* from political interference, which is itself a political phenomenon.

This links the sub-field of central bank losses (including this paper), to a broader literature on central bank independence (CBI) in the discipline of comparative/international political economy. The political economy approach to the topic differs from the purely economic accounts in that the latter highlights the benefits of *apolitical* central banks in achieving sound economic outcomes such as stable inflation (Alesina & Stella, 2010; Barro & Gordon, 1983; Kydland & Prescott, 1977; Lohmann, 2008; Rogoff, 1985), while the former explains the delegation outcome as a result of political bargaining rather than the promotion of the economic ideal (Alesina, 1997; Bernhard, 1998; Bernhard et al., 2002; Fernández-Albertos, 2015; Hallerberg, 2002; Lohmann, 1997; Woodruff, 2019). This paper adopts the political economy approach by assuming that indemnity decisions are *endogenous* to preferences of the government and central bank in theoretical and empirical analyses.

This literature review reveals that, despite the current literature's acknowledgement of central bank losses and their coverage as political economy issues, there has not yet been a formal theoretical framework that treats the indemnity agreement as an *endogenous* decision to the fiscal-monetary interaction or guides empirical effort on quantitatively evaluating the causal impact of indemnity on central bank financial strength. This paper aims to contribute to the literature by providing such theoretical framework and empirical analysis. The theoretical and empirical results can be used for the cost-benefit analysis of the indemnity and future institutional designs, as sought by the House of Commons Treasury Committee (2024).

3. Theory

The section first lays out the Model Setup of the game theoretical model, then presents the key analytical and Numerical Evaluation results, omitting the tedious mathematical analysis.

3.1. Model Setup

Consider a two-period game ($t \in \{1, 2\}$) between a government G and a central bank B.

Indemnity. The concept of indemnity is central to this theoretical model. In this model, the indemnity is denoted by x and is an *endogenous* decision by the government at the start of period 1, which will be explained further. In either period $t \in \{1, 2\}$, if profits are made $p_t \geq 0$, all profits are transferred to the government. In case of losses $p_t < 0$, an indemnified central bank ($x = 1$) receives a payment of $|p_t|$ from the government to cover the losses. An non-indemnified central bank ($x = 0$) bears the losses itself. This setting is in line with the real-world distribution arrangements where profits are mostly transferred to the treasury (Long & Fisher, 2024).

Central Bank's (B) actions and preferences.

In each period $t \in \{1, 2\}$, B chooses a level of monetary policy i_t and a level of risk-taking $r_t \geq 0$. Its period utility (U_{Bt}) is determined by the level of inflation ($\pi_t\%$) and the size of losses when it is not indemnified. For simplicity it is assumed that there is no discounting between the two period ($U_B = U_{B1} + U_{B2}$). It is worth noting that the level of risk-taking r_2 can only be increased and not decreased in the second period, reflecting the difficulty of active Quantitative Tightening (QT) in the reality. Throughout this model, we assume that B chooses the *minimum* level of risk when it is indifferent to eliminate multiple equilibria. The central bank's period utility function is given by:

$$U_{Bt} = -(\pi_t - 2)^2 + \alpha(1 - x_t)\min\{p_t, 0\}$$

The first term is the quadratic loss function of inflation. This follows the inflation target of 2% across the developed world. The second term reflects the fear of losses for a *non-indemnified* central bank. As for a indemnified central bank ($x = 1$), all profits and losses are due to/from the government and the term is eliminated from the utility function. As for a non-indemnified central bank, additional *profits* do not increase its utility since they are transferred to the government G ($\frac{\partial}{\partial p_t} U_{Bt} = 0$ when $p_t \geq 0$). Nevertheless, additional *losses* linearly reduce its utility by α:

$$\frac{\partial}{\partial p_t} U_{Bt} = \alpha \text{ when } p_t < 0$$

α denotes the central bank's sensitivity toward losses, it is assumed that all central banks are more or less sensitive to losses ($\alpha > 0$), as argued by Goncharov et al. (2023) and Diessner (2023). This sensitivity is also known to the other player, the government G.

Government's (G) actions and preferences. The government chooses to indemnify the central bank ($x = 0$) or not ($x = 1$) at the start of period 1. In both periods, the government chooses level of fiscal surplus net of the transferred profit (f_t) simultaneously with the central bank's monetary policy decisions (i_t and r_t). A higher f_t means higher fiscal surplus or lower fiscal deficit in the period. F_t denotes the *total* budget surplus (deficit), including the profit remittance from the central bank. The government's period utility function given by:

$$\begin{aligned} U_{Gt} &= C(F_t) + g_t \\ &= C(\max\{p_t, p_t x\} + f_t) + g_t \\ &= \begin{cases} C(p_t + f_t) + g_t \text{ if } x = 1 \\ C(\max\{p_t, 0\} + f) + g_t \text{ if } x = 0 \end{cases} \end{aligned}$$

$C(F)$ is a function that represents the component of total fiscal surplus/deficit in G's utility. A greater fiscal surplus or a smaller budget deficit increases G's utility ($\frac{\partial}{\partial F}C(F) > 0$) at a decreasing rate ($\frac{\partial^2}{\partial F^2}C(F) < 0$). The justification for the diminishing marginal utility of fiscal surplus is the increasing marginal loss of popularity from higher taxes and lower public good provision. This function is also known to the other player, the central bank B.

In case of indemnity ($x = 1$), the first term collapses into $C(p_t + f_t)$, which implies that government bears the full benefits (costs) of central bank profits (losses). In case of no indemnity ($x = 0$), the maximisation reduces to $\max\{p, 0\}$ so the government only enjoys the profits and does not bear the losses.

The second term (g_t) is the real GDP growth of the period in percentage points. The government prefers higher real GDP growth. Here a linear function of growth is assumed for simplicity.

Hence, one can compare different government's sensitivity to overall fiscal surplus (deficit) by comparing the level of F required to achieve the same level of marginal utility, as in Figure 1:

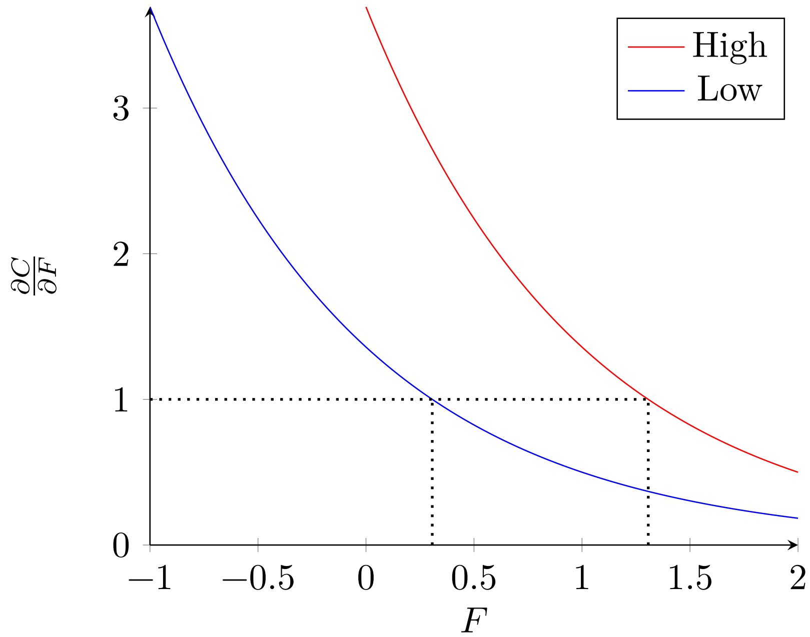


Figure 1: Illustration of the marginal utilities of fiscal surplus/deficit with high/low fiscal conservatism

It can be seen in Figure 1 that a government with a higher sensitivity to fiscal surplus/deficit requires a larger total fiscal surplus (F) to achieve the same level of marginal utility as a government with a lower sensitivity. Therefore, we can measure a government's fiscal sensitivity by the level of fiscal surplus/deficit required to achieve any arbitrary level of marginal utility. For convenience of later analysis, we choose this level to be 1. Therefore, we can denote the government's fiscal sensitivity by an exogenous parameter ρ which measures fiscally conservatism:

$$\rho = \left(\frac{\partial C}{\partial F}\right)^{-1} \quad (1)$$

Simplified macro-economic setting. In a simplified macro-economic setting, the inflation (π_t) and real growth rate (g_t) are both determined by the fiscal (f_t) and monetary (i_t) policies, a demand shock (ϵ_{dt}) and a supply-side shock (ϵ_{st}), where $\epsilon_{st} < 0$ denotes a negative shock (e.g. supply-chain interruption) that leads to lower growth and higher inflation.

$$g_t = 4 - f_t - i_t + \epsilon_{dt} + \epsilon_{st}$$
$$\pi_t = 4 - f_t - i_t + \epsilon_{dt} - \epsilon_{st}$$

We assume a common belief between the government and central bank that the second period demand shock is drawn from a uniform distribution and there will be no second period supply shock. The anticipation of no supply shock echoes the rarity of such shocks in reality (1973 oil crisis and 2021-23 global energy crisis). The uniform distribution for the demand shock is chosen for its simplicity in the later analysis. The support for the demand shock is set to be $[-2, 2]$ to ensure that both quantitative easing and monetary tightening are possibly needed (although not necessarily implemented) in the second period - this requires a support width of at least 2. An additional 2 units of support width is added to expand the policy space and to avoid corner solutions.

$$\tilde{\epsilon}_{d2} \sim U(-2, 2)$$
$$\tilde{\epsilon}_{s2} = 0$$

To reflect the zero lower bound of monetary policy and the necessity of quantitative easing, the lower bound of monetary policy is determined by r_t:

$$i_t \geq -r_t$$

When no additional risk is taken by the central bank ($r_t = 0$), the monetary policy cannot go beyond zero ($i_t \geq 0$). One can conceive of the level of risk-taking r_t as reflecting the scale of QE and the maturity of the bond assets purchased during QE. Larger scales of QE and the longer maturity of the purchased bonds translate into higher risks borne by B.

The profit (p) is determined by monetary policy (i) and the level of risk-taking (r):

$$p_t = -\psi(i_t - 2)r_t$$

Here $\psi > 0$ denotes the sensitivity of profits to monetary policy and risk-taking. A higher ψ implies higher losses/profits given the same level of risk-taking and monetary policy. One can conceive of $i = 2$ as the "neutral" interest rate at which no profits/losses are made. Monetary policies above (below) this level lead to losses (profits).

Timing. The sequence of the game is as follows:

1. The types of the central bank (α) and the government (ρ) are exogenously determined and known to both players.
2. Global Financial Crisis occurs; first period shocks are revealed ($\epsilon_{d1} = -1$, $\epsilon_{s1} = 0$). The government decides whether to indemnify the central bank ($x = 1$) or not ($x = 0$).

3. The central bank chooses the level of monetary policy and risk-taking (i_1 and r_1). Simultaneously, the government determines the level of fiscal policy (f_1).

4. First period payoffs are realized.

5. COVID-19 and the full-scale Russian invasion of Ukraine occur; second period shocks are revealed ($\epsilon_{d2} = 0$, $\epsilon_{s2} = -2$).

6. The central bank chooses the level of monetary policy and risk-taking (i_2 and r_2). Simultaneously, the government determines the level of fiscal policy (f_2).

7. Second period payoffs are realized. Game ends.

The solution concept is Subgame Perfect Nash Equilibrium (SPNE).

3.2. Analytical Results

The game is solved by backward induction. This section analyses the two subgames with indemnity ($x = 1$) and without indemnity ($x = 0$). The solution to the indemnity decision (x) is evaluated numerically in Section 3.3.1. Full model derivation and analysis are available in Appendix A.

3.2.1. Subgame with Indemnity ($x = 1$)

Complete analysis of this subgame is available in Appendix A.1. This section summarises the main findings of the subgame equilibrium and explains the intuition.

As for the government G, its first period fiscal policy f_1 does not affect the second period. Consequently, the government simply plays a dominant strategy in each stage game which satisfies:

$$f_t^*(x = 1) = \rho - p_t$$

This implies that the fiscal policy f_t is determined by the fiscal sensitivity of government (ρ) and the profit (losses) transferred from (to) the central bank B. Additional profits received from B are immediately spent by G and losses by B would incur a fiscal contraction of the same size. This result is summarised by Proposition 1 of *monetary dominance*.

Proposition 1 (Monetary Dominance)**.** *Under fiscal indemnity for central bank losses, the fiscal policy of the government is constrained by the size of the profit (indemnity) payment from (to) the central bank.*

The term "monetary dominance" is coined as a mirroring concept to *fiscal dominance*, which refers to the possibility that the government's excessive fiscal deficits "dominate" central bank efforts to keep inflation low (Calomiris, 2023). Nevertheless, monetary dominance defined in this paper departs from that in the existing literature (Barwell, 2016; Bonam et al., 2024; Hinterlang & Hollmayr, 2022) which highlights the constraints of *interest rates* on fiscal borrowing. In contrast, this paper emphasizes the indemnity payments as a *forced expenditure* by the government.

As a result of the monetary dominance under the indemnity, the central bank is able to achieve the inflation target (which is assumed to be 2% in the model) in both periods. This is known as Proposition 2.

Proposition 2 (Stable inflation under indemnity)**.** *The inflation target can always be achieved when the central bank is indemnified by the government against losses.*

$$\pi_t(x = 1) = 2$$

This confirms the mainstream economic literature's support of indemnity for stable inflation.

3.2.2. Subgame without Indemnity ($x = 0$)

Complete analysis of this subgame is available in Appendix A.2. This section merely discusses the main analytical findings of the subgame equilibrium.

Intuitively, a central bank without indemnity has to bear its own risks and would not choose a higher risk level than in an indemnified counterfactual scenario. This result is formally proven in Proposition 3.

Proposition 3 (Central bank prudence without indemnity)**.** *Indemnity against losses never reduces a central bank's risk level.*

$$r_t^*(x=0) \leq r_t^*(x=1)$$

Proposition 3 can be understood as moral hazard, where the risk of the central bank is *completely* transferred to the government under the indemnity agreement (Landes, 2013). It is therefore not surprising to find central banks without indemnity tend to choose lower risk-levels.

As a result of this *prudence*, the central bank cannot choose i low enough to boost inflation back to target (2%) in period 1. As a result. inflation is *below* the target in period 1 under deflationary pressure. It is worth noting that the *deflationary bias* increases with the extent of *prudence* ($r_1^*(x=1) - r_1^*(x=0)$), as stated in Proposition 4.

Proposition 4 (Deflationary bias without indemnity)**.** *If the central bank chose a lower risk level due to no indemnity, there would be a deflationary bias negatively correlated with the chosen risk level in the aftermath of the GFC.*

$$\pi_1(x=0) - 2 = r_1^2(x=0) - r_1^2(x=1) + 3r_1(x=0) - 3r_1(x=1) \leq 0$$

Moreover, due to the fear of losses, the central bank hesitates to adopt contractionary monetary policy (high i_2) in the second period that is required to suppress inflation to the 2% target in period 2. Notice that this *inflationary bias* increases with the chosen risk level ($r_1(x=0)$) and central bank sensitivity (α), as stated in Proposition 5.

Proposition 5 (Inflationary bias without indemnity)**.** *If the central bank decided to implement QE ($r_1 > 0$) without indemnity ($x = 0$), there would be an inflationary bias under inflationary pressure. The extent of this bias is proportional to the first period risk level (r_1) and the central bank's financial sensitivity (α)*

$$\max \tilde{\pi}_2 - 2 = \frac{\alpha \psi r_1(x=0)}{2}$$

As later shown in Numerical Evaluation, the deflationary and inflationary biases depend on the preferences of the government and central bank (ρ and α). This information is useful for assessing the public finance-price stability trade-off in future policy making, which will be discussed in Conclusion.

3.3. Numerical Evaluation

Due to the piece-wise nature of the solution to risk-taking without indemnity ($r^*(x = 0)$), which can be seen in Figure 3 and Appendix A.2, full analytical solutions are unnecessarily long and unintuitive to understand. Therefore, the SPNE outcomes are numerically evaluated and visualised with different values of ρ (goverment's fiscal conservatism) and α (central bank's loss sensitivity). As justified in Equation (3) of Appendix A.2, ρ is set such that $\rho \in (1, 2)$ to ensure both deflationary and inflationary pressures were expected by the players in period 2. ψ (profit coefficient) is set to 1 for convenience, other values of ψ show a similar pattern. The range for α is set to $\alpha \in (0, 4\sqrt{3}]$ to ensure concavity of the utility function[6].

[6]It requires that $\alpha \leq \frac{\sqrt{\frac{8(4\psi+2)}{2-\rho}}}{\psi} \leq \frac{\sqrt{\frac{8(4+2)}{2-\rho_{\min}}}}{1} = \sqrt{\frac{48}{1}} = 4\sqrt{3}$

3.3.1. Government's Indemnity Decision (x)

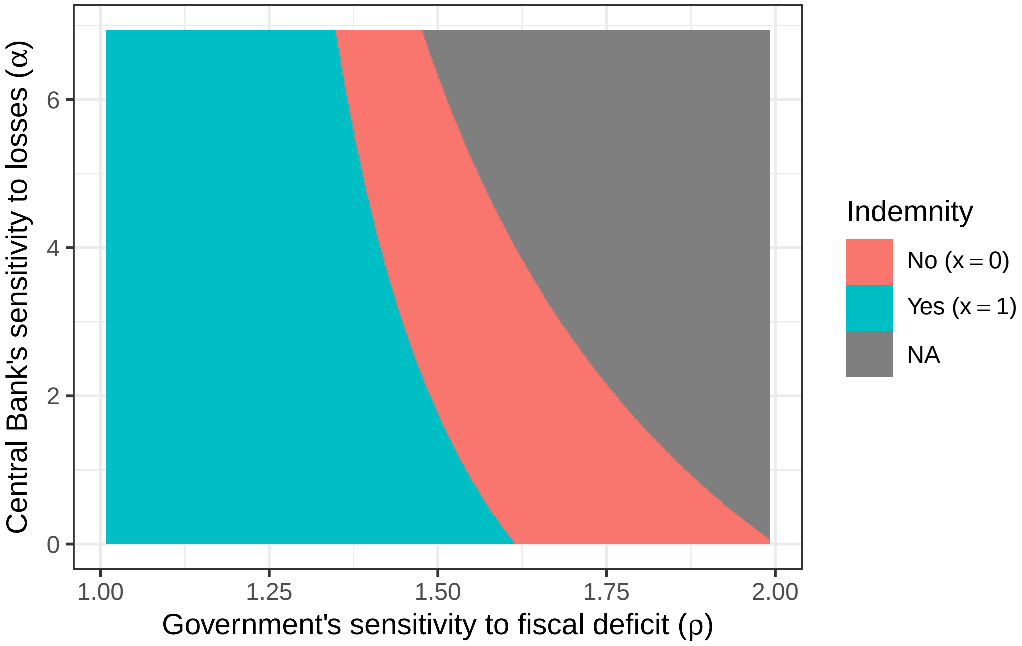


Figure 2: Indemnity decision with respect to ρ and α

Figure 2 shows the indemnity outcome with respect to the government's fiscal conservatism (ρ) and the central bank's sensitivity to losses (α). The blue area represents the values of ρ and α where the central bank is indemnified; no indemnity is granted in the red and grey areas. The grey area denotes values for which the central bank does not adopt contrationary monetary policy even in cases of extreme inflationary pressure such as COVID-19 without indemnity, which are not representative of the control group in our empirical analysis and are thus excluded to avoid confusion.

We define domain D to denote combinations of α and ρ in the blue or red areas that are relevant to our empirical analysis:

$$D = \{(\alpha, \rho)|0 < \alpha \leq 4\sqrt{3}, 1 < \rho < 2, \alpha \leq \frac{4 - 2\rho}{r(x = 1)}\}$$

Figure 2 suggests that the indemnity decision (x) depends primarily on the government fiscal conservatism (ρ), and to a lesser extent, the central bank's sensitivity to losses (α).

A fiscally liberal government (low ρ) is more likely to indemnify the central bank (in blue area). When the government's sensitivity (ρ) is low, inflationary pressure is more likely in the second period and the central bank would only be willing to take zero or low risk without indemnification. As such, the government expects to gain more from indemnification because of higher benefits in the first period and lower opportunity cost in the second period. In the first period, the indemnification has a greater impact on QE for a fiscally liberal government, which implies higher positive impact on first-period growth rate. In the second period, the low risk level in the non-indemnified counterfactual scenario means that even an non-indemnified central bank would be more determined to suppress inflation and growth in an inflationary scenario, just as an indemnified central bank would. This implies that the opportunity cost of indemnification is lower for a fiscally liberal government.

On the other hand, the impact of the central bank's sensitivity to losses (α) on the indemnity decision is less pronounced. Counter-intuitively, a less sensitive bank (α) is more likely to receive indemnity, although a highly sensitive bank may also be indemnifed. When α is low, the bank (B) is more determined to suppress inflation and growth in the second period, which implies that the opportunity cost of indemnification is lower, hence indemnity is more likely. Nevertheless, part of this impact is offset by the fact that a less sensitive non-indemnified central bank is almost as likely to take high risks in the first period as an indemnified bank would, which implies that the government's benefits from indemnification are lower in the first period.

Nevertheless, it will be shown in the Section 8 that the UK is likely a combination of relative fiscal liberalism (low ρ) and high central bank financial sensitivity (α), due to the lack of independence of the BoE.

3.3.2. Central Bank's Optimal Risk Levels (r^*)

In our setting, an inflationary shock is realised in period 2; the second-period risk levels are kept constant. Therefore, we only need one plot for $r^* = r_1^* = r_2^*$.

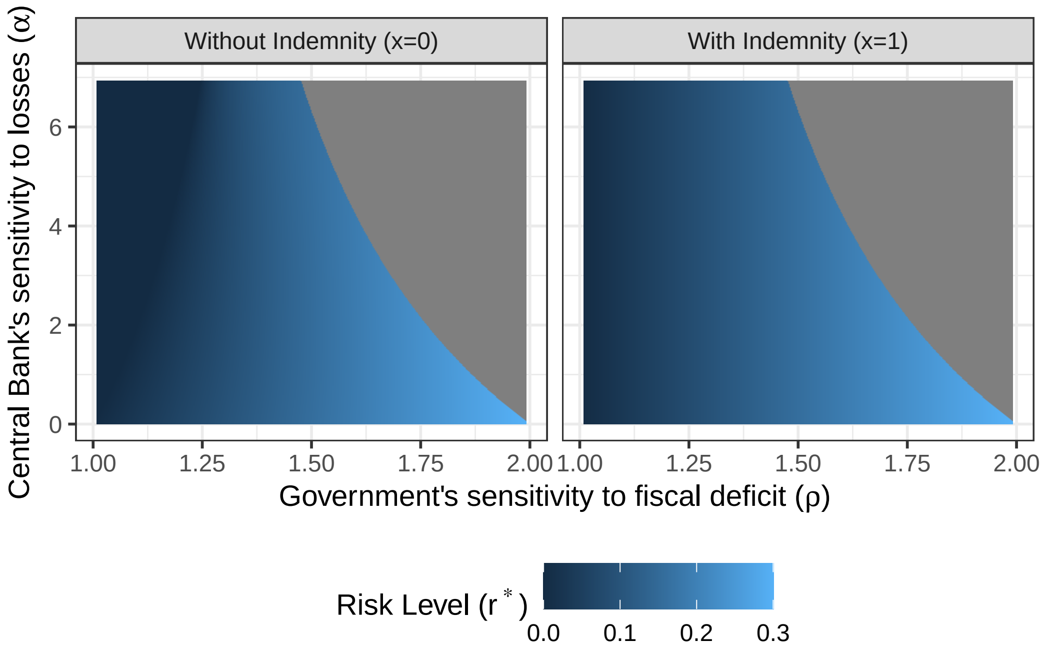


Figure 3: Central bank's optimal risk levels (r^*) with respect to ρ and α

As shown in Figure 3, when the bank is indemnified ($x = 1$), the chosen risk level (r^*) increases with the government's fiscal conservatism (ρ). This is because when the government is more fiscally conservative, more expansionary monetary policy is needed to stimulate the economy, hence higher risks needed.

On the other hand, when the central bank is not indemnified ($x = 0$), the risk level chosen by the central bank (r^*) is irregular. When the government's fiscal conservatism (ρ) is low but the bank's sensitivity to losses (α) is high, the central bank is reluctant to take any risks (denoted by the dark blue area) due to the bank's risk aversion and second-period inflationary pressure resulting from the government's fiscal liberalism. Note that when the bank is more risk-averse (higher α), the government needs to be more fiscally conservative (higher ρ) for the bank to trigger QE (adopt a positive r) without indemnity. This is referred to as Proposition 6. Proposition 6 provides basis for Proposition 7.

Proposition 6 (Reluctance to QE driven by central bank loss sensitivity)**.** *Without indemnity ($x = 0$), the central bank B is reluctant to engage in QE ($r = 0$) unless the government's fiscal conservatism (ρ) is sufficiently high. This reluctance increases with the central bank's sensitivity to losses (α), i.e. the level of ρ needed to trigger QE without indemnity increases with α.*

We then explore the effect of the indemnity (x) on risk taking (r^*) by subtracting the untreated from the treated potential outcomes, as in Figure 4.

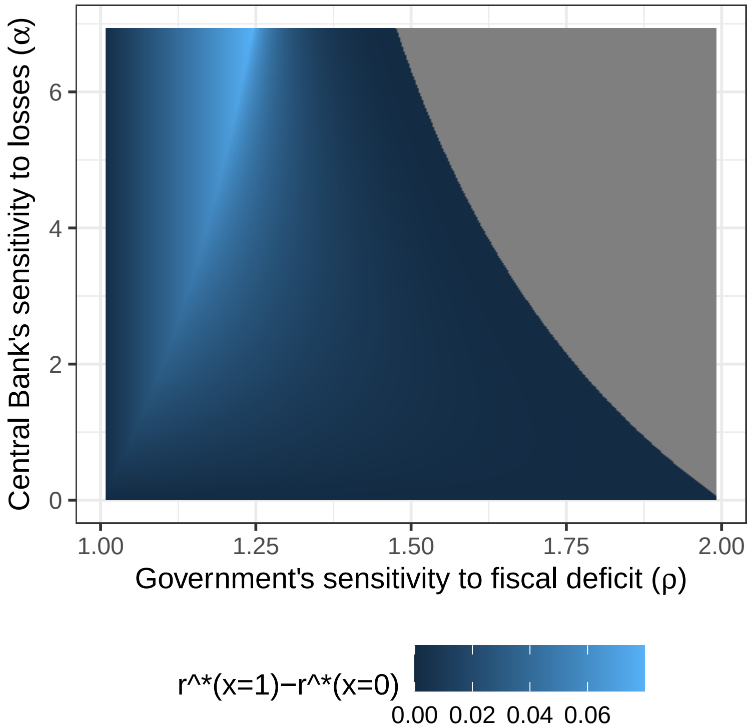


Figure 4: Predicted effects of the indemnity on risk taking (r) with respect to ρ and α

The results show that, for the domain of α and ρ in this numerical evaluation (D), the indemnity strictly increases risk-taking (i.e. positive effect of indemnity on the scale/depth of QE):

$$r^*(x = 0, \alpha, \rho) < r^*(x = 1, \alpha, \rho)\ \forall(\alpha, \rho) \in D$$

Moreover, note that the positive effect is strongest when α is proportional to ρ, shown as a "belt" in light blue in Figure 4. This corresponds to the *boundary* of the area of parameters where the central bank would not engage in QE without indemnity ($r^*(x = 0) = 0$), which has been discussed in Proposition 6. Note that within the belt, the effect is highest when α is high. This is because a high α requires a sufficiently high ρ to trigger QE without indemnity (Proposition 6). A relatively high ρ implies the government is reluctant to stimulate the economy with fiscal policy and more QE (r) is needed to restore growth and inflation in period 1. When indemnified ($x = 1$), the bank B would be willing to take such high risks (r); nevertheless, no risk would be taken at all without indemnity ($r^*(x = 0) = 0$). Hence the highest effect of the indemnity on risk-levels when both α and ρ are high on the "belt".

The "belt" pattern of the effect of indemnity drives similar patterns for below-target inflation in period 1 (see Figure 5), and the effect of indemnity on central bank profits (see Proposition 7).

3.3.3. Period 1 - Deflationary Episode Following GFC

We first examine the potential outcomes in period 1, which features the deflationary pressure following the GFC. We first look at the growth and inflation rates which are identical in the first period. Figure 5 shows that indemnity stabilises the growth/inflation rates at 2% in the first period (as predicted by Proposition 2), whereas growth and inflation can be lower in the non-indemnified scenario. Note that in the non-indemnified scenario, the 2% inflation target is sometimes *almost* achieved, especially for countries which do not self-select into indemnity. This implies that naive comparisons of inflation outcomes are likely not informative. The results confirm our conclusion in Section 3.3.1 that the gain from indemnity in the first period growth rate is higher for a *relatively* low-sensitivity (ρ) government with a highly sensitive (α) central bank. The pattern where the inflation target is severely under-achieved (in dark blue) again resembles the "belt" in Figure 4 and Figure 12. It will be shown that the UK is located on the belt.

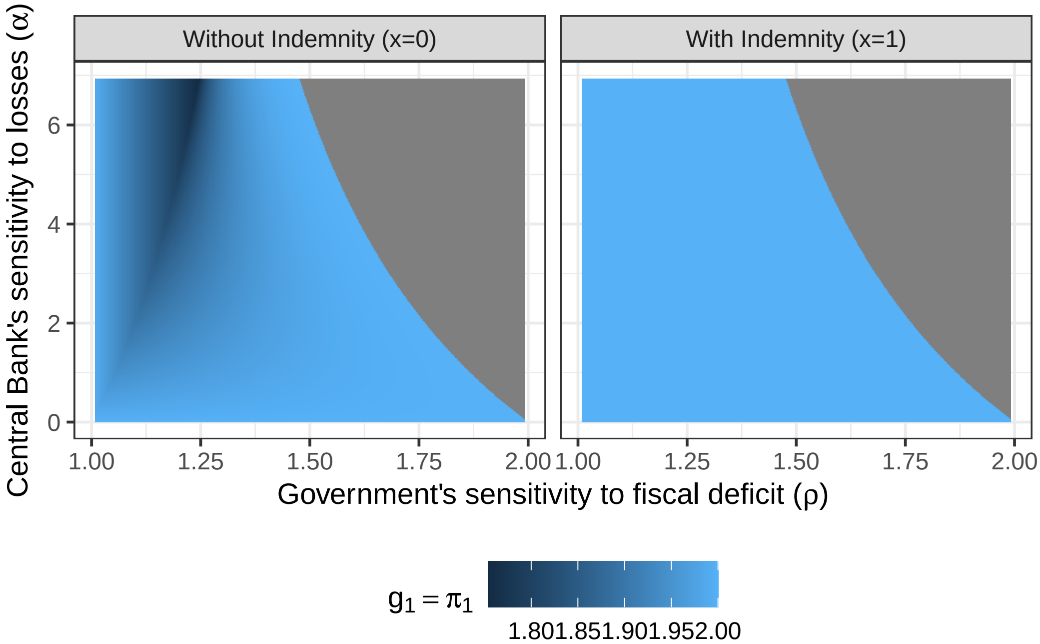


Figure 5: First period growth and inflation rates ($g_1 = \pi_1$) with respect to ρ and α

As for the potential outcomes of central bank profit in period 1 (p_1), results in Figure 6 looks highly similar to risk-taking (r^*) results in Figure 3. This should not be surprising as in period 1, the interest rates are determined by the risk levels ($i_1^* = -r_1^*$) as in Figure 7. Therefore, the first period profits are a function of risk levels only. Because of the greater risks taken under indemnity, the indemnity is expected to have a *positive* impact on the central bank profits. It will be shown in Section 3.3.5 that the effect is most prominent on the same "belt" as in Figure 4.

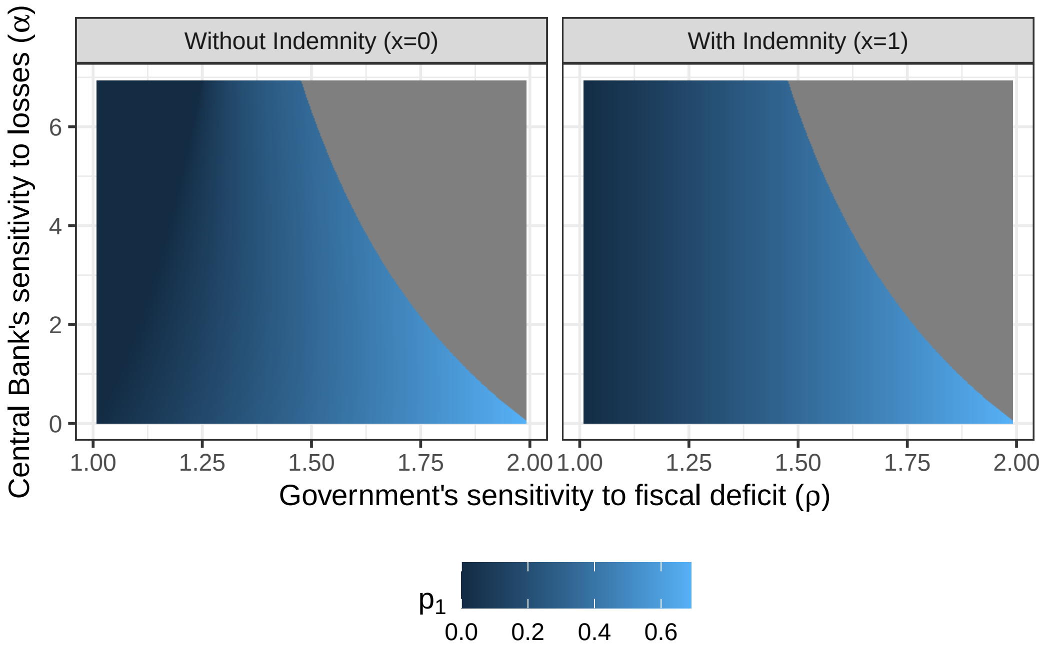


Figure 6: First period central bank profit (p_1) with respect to ρ and α

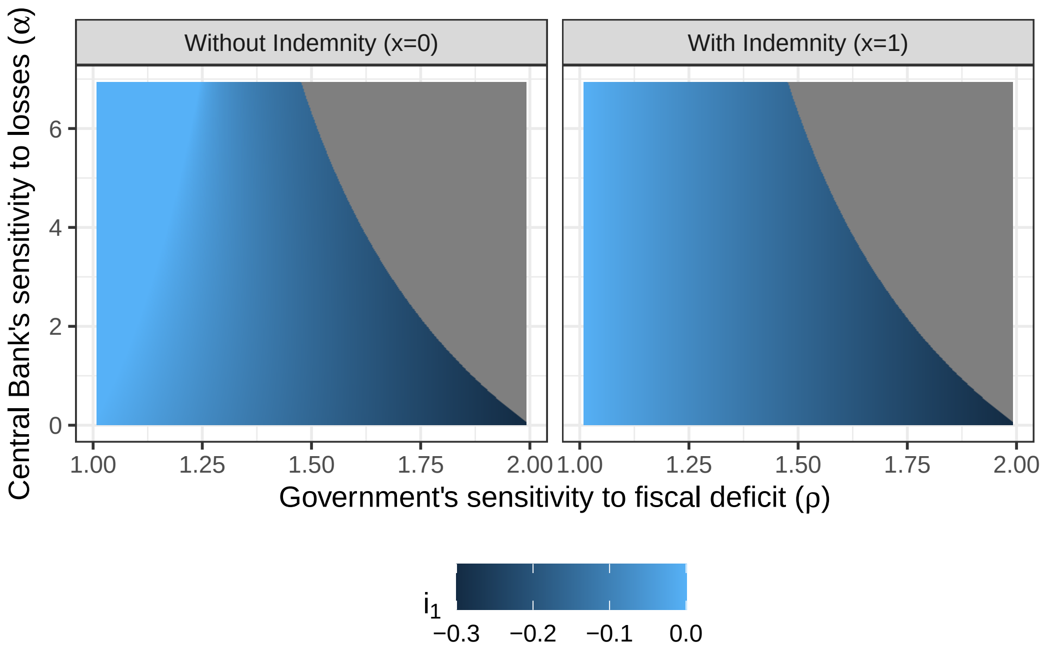


Figure 7: First period monetary policy (i_1) with respect to ρ and α

3.3.4. Period 2 - Inflationary Crisis of COVID-19

We model the impact of COVID-19 (and the contemporaneous full scale Russian invasion of Ukraine) as an unexpected negative supply shock ($\epsilon_{d2} = 0$, $\epsilon_{s2} = -2$) that is outside the government and central bank's belief ($\tilde{\epsilon}_{s2} = 0$).

The potential outcomes of monetary policy (i_2) are presented in Figure 8. Results show that the interest rates with indemnity ($x = 1$) tend to be lower than those without indemnity ($x = 0$) when either ρ or α is low, and higher otherwise.

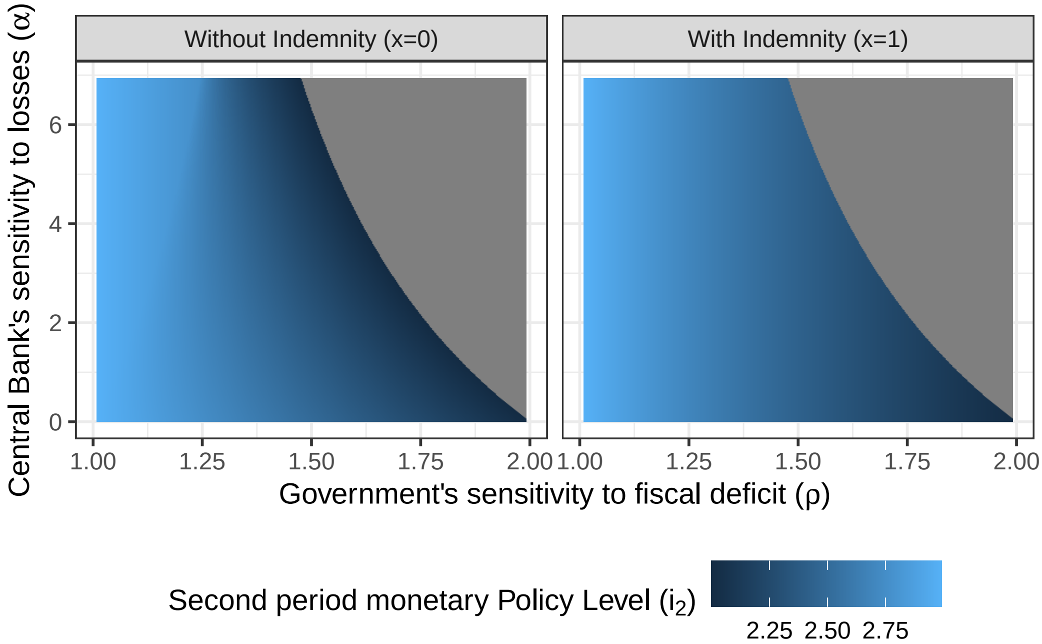


Figure 8: Second period monetary policy (i_2) with respect to ρ and α

The results on inflation and growth outcomes in period 2 are more important, because a key argument for central bank independence and indemnity is the central bank's ability to suppress inflation against the government's preference for growth. Results in Figure 9 confirms our proposition 2 that the inflation target is always achieved under indemnity.

Interestingly, the beneficial impact of indemnity on price stability is only substantial for countries with high ρ and α, which *do not* self-select into the indemnity treatment. This is because the central banks which received indemnity would have taken no/low risks in a non-indemnified counterfactual and therefore not be constrained to tackle inflation in the second period. This means naive comparisons of inflation outcomes in countries with and without indemnity *overestimate* the importance of indemnity on stable price levels. On the contrary, the trade-off between inflation and public finance should be rethinked.

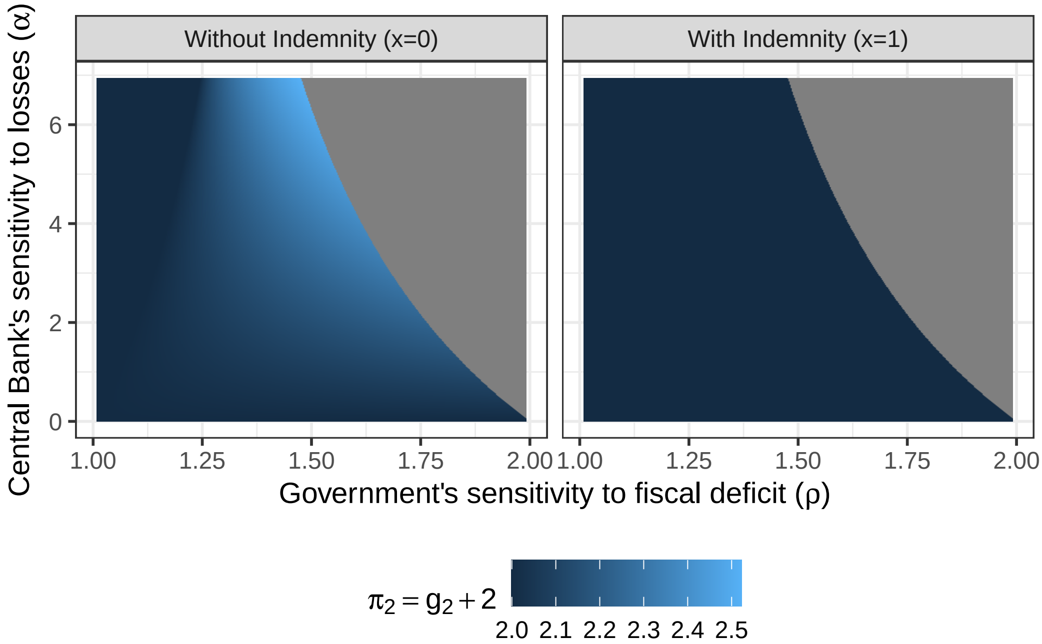


Figure 9: Second period inflation and growth ($\pi_2 = g_2 + 2$) with respect to ρ and α

We finally look at the results for second-period profits (p_2) in Figure 10, which is the main hypothesis tested in the empirical section. Counterintuitively, central banks which receive indemnity *do not necessarily* make higher losses compared with a non-indemnified counterfactual. This observation is presented in a clearer way in Figure 11. It can be seen that the indemnity may *save* losses when α is low but increase losses when α is moderate or high. This is because when α is low, a non-indemnified bank is also determined to keep inflation in control despite losses, and adopts much tighter monetary policy in the inflationary episode to account for the unconstrained fiscal policy. This combination of high risk and high interest rate means the losses in the non-indeminified case are even higher than the indemnified case. This is at odds with the conventional idea of moral hazard.

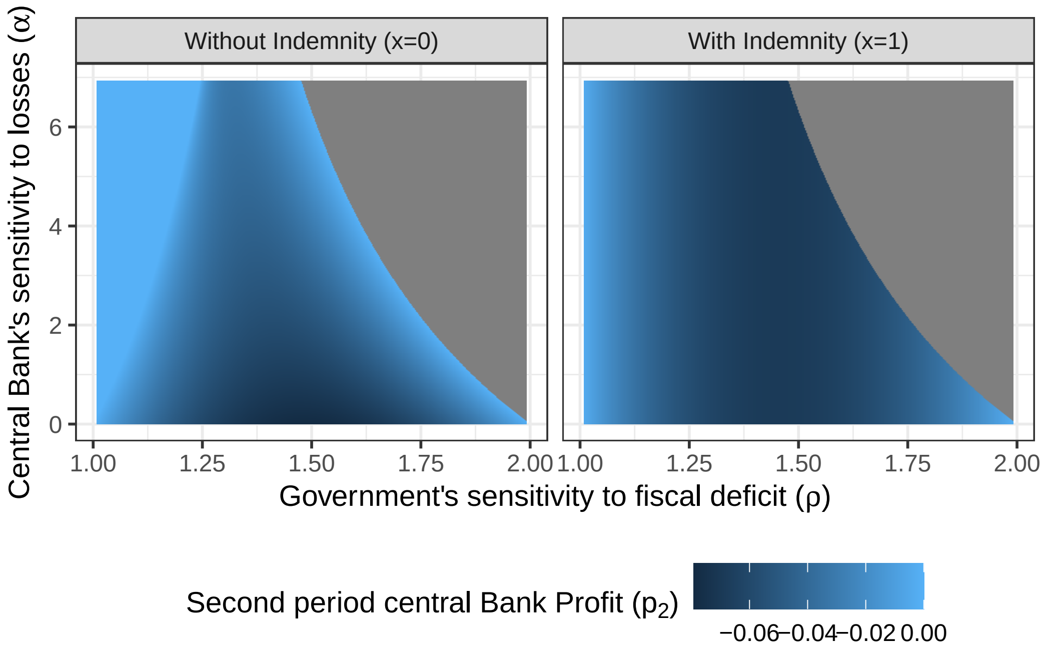


Figure 10: Central bank profit (p_2) with respect to ρ and α

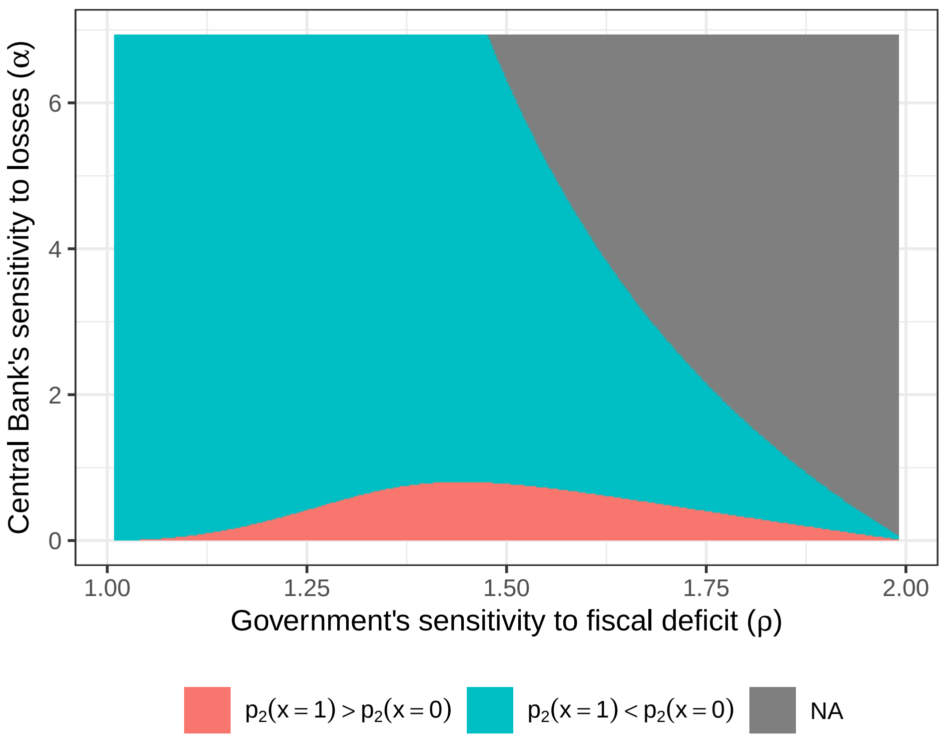


Figure 11: Central bank profit comparison (p) with respect to ρ and α

3.3.5. Belt of Effect

In Figure 6 and Figure 10, the numerical evaluations of the potential outcomes of profits under the treatment (indemnity) and control conditions are presented. By subtracting the untreated from the treated outcomes, we can calculate the predicted treatment effects, which are presented in Figure 12.

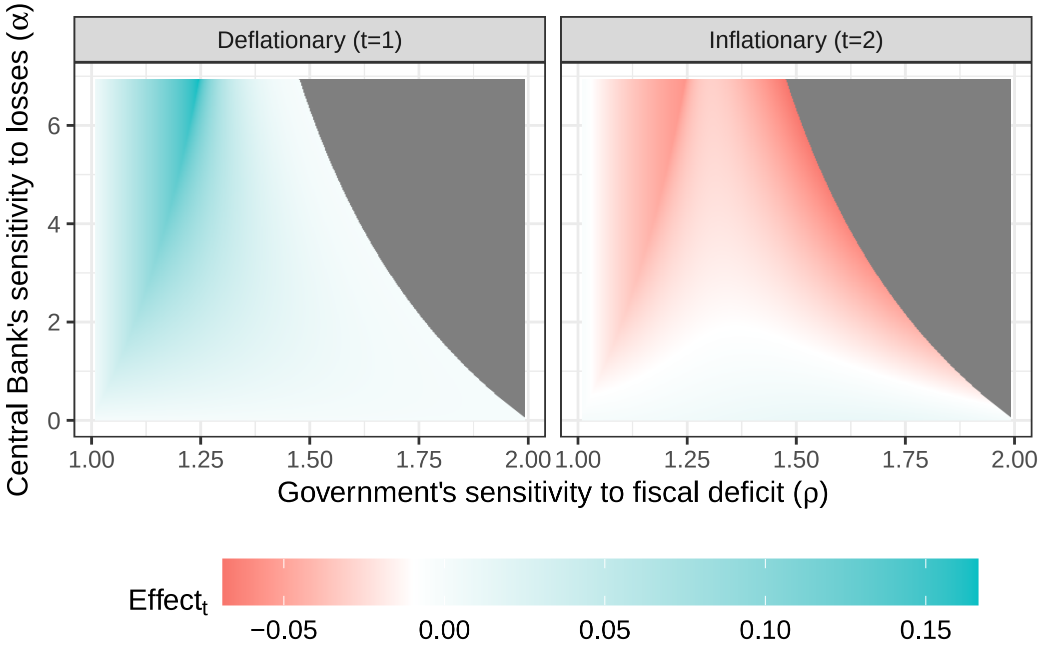


Figure 12: Predicted effects of indemnity on profits with respect to ρ and α

The indemnity's effects are largest (denoted by dark blue/red) along a "belt" where α is proportional to ρ, where ρ is moderately low. Although for period 2, the effect is also strong when both α and ρ are high (top right), this is ignored by this paper as countries in this area do not self-select into treatment and the empirical section focuses on the treatment effect *on the treated* (UK) only.

The "belt" patterns are similar to and driven by the "belt" of effect of the indemnity on risk levels in Figure 4, which is in turn driven by Proposition 6. The intuition is that, along this belt, the central bank (B) would not engage in QE ($r^*(x = 0) = 0$) at all without indemnity and therefore would not generate any abnormal profits/losses in both periods ($p_t(x = 0) = 0$). Nevertheless, along the belt the government is sufficiently averse to fiscal deficit (ρ is sufficiently high) such that the bank (B) would bear high risks in QE under indemnity to stimulate growth and inflation in period 1 (relatively high r), which results in profits and losses in periods 1 and 2, respectively. The stark difference in the potential outcomes implies strong effects of the indemnity:

Proposition 7 (Belt of effect)**.** *The effect of the indemnity on profits are strongest in size along a belt where α is proportiontal to ρ for countries which self-select into indemnity. Along the belt, the effects are stronger when both α and ρ are high.*

In the Discussion section we will try to locate the UK on this belt of effect.

3.4. Testable Hypotheses

While the theoretical model sheds light on the effects of indemnity on economic outcomes, and describes conditions under which a government indemnifies its central bank, it crucially refines the hypothesis to be tested. The main empirical hypothesis is:

Hypothesis 1 (H_1)**.** The UK Treasury's indemnity against QE losses has affected the BoE profitability.

Nevertheless, the theoretical model reveals that the direction of the impact depends on the demand and supply shocks at the time. Under the deflationary shock after of the GFC, which corresponds to period 1 of the theoretical model, the indemnity is expected to have *increased* the central bank profits. However, under the inflationary shocks since 2022, which corresponds to period 2 of the theoretical model, the impact of the indemnity on profitability can be *positive or negative* depending on the value of α. When α is moderate or high, the indemnity is expected to have increased the losses, hence a *negative* impact. This implies that the impacts in the two periods can be in *opposite* directions and thus *offsetting* each other if estimated in a combined analysis. It is therefore more appropriate to break the main hypothesis into two sub-hypotheses:

Hypothesis 1a (H_{1a})**.** The UK Treasury's indemnity against QE losses increased the BoE profits in the deflationary environment following GFC.

$$p_1^{UK}(x=1) - p_1^{UK}(x=0) > 0$$

Hypothesis 1b (H_{1b}). The UK Treasury's indemnity against QE losses has affected the BoE losses in the inflationary environment since 2022.

$$p_2^{UK}(x=1) - p_2^{UK}(x=0) \neq 0$$

4. Data

For empirical analysis, panel data on 24 countries across 25 years (1999-2023) are used. There are missing data for some countries, resulting in 586 observations available. Countries are selected into the sample if they 1) are members of the OECD or EU as proxies for advanced economies and 2) introduced QE soon after the 2007-2008 GFC to exclude countries which never introduced QE or introduced QE after COVID-19, which are not comparable to the UK. More information on sample selection and justification is provided in Appendix B. 1999 is chosen as the start date because the euro (€) was introduced in that year, which constituted a major monetary change. The data availability information is summarised in Figure 13. Treatment is assigned to the UK from 2009 onward, when the Asset Purchase Faciliy (APF) was created under the UK Treasury's indemnity.

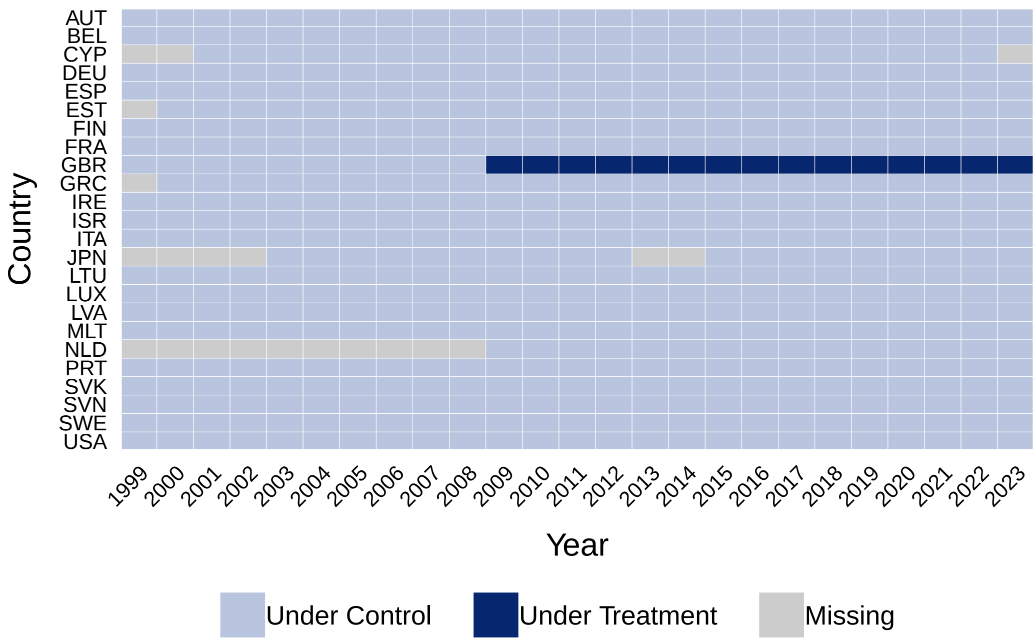


Figure 13: Overview of the panel data availability

4.1. Dependent Variable

The dependent variable of the main analysis is *central bank profit as a percentage of GDP*:

$$Y_{it} = \frac{\text{Profit}_{it}}{\text{GDP}_{it}} \times 100\%$$

The central bank profit data (profit_{it}) are mainly sourced from S&P Capital IQ Pro (2024) as "Net Income Before Taxes", where data for most central banks in the sample are available from 2010 onward[7]. They are supplemented by data hand-collected from central bank websites, using the same calculation as S&P Capital IQ Pro (2024). A complete list of financial statement sources for hand-collected data are given in Appendix C. For the UK, the net cash transfers from the BoE APF to HM Treasury[8] are added to the BoE net income to make the profit accounts comparable. This is because, any profits made from QE by the APF are transferred to the Treasury and not recorded as profits of the BoE or APF. Table 1 provides an example of such calculation for 2014 and 2023 and reveals that the indemnity transfers are very large relative to the reported profits of the BoE. The data for UK indemnity cash transfers can be found from the Office for National Statistics (2024)[9].

Table 1: Example of BoE Profit calculation (£mn)

Year	Indemnity Transfer	Net Income	Total Profit
2014	10,898	198	11,096
2023	-37,378	33	-37,345

The GDP data (GDP_{it}) are provided by the World Bank Open Data (2024). For most countries, the current GDP in the local currency (LCU) is used. For countries which changed their currency (to the euro) during the time span, GDP (current US$) is used

[7]For consistency, the SNP Financial source is used within the S&P Capital IQ Pro dataset.

[8]From 2010 to 2012, no transfers were made and the profits accumulated until the 2013 transfer. To reflect the true profitability, the net interest receivable is used for 2010-12 and their sum is deducted from the 2013 transfer.

[9]See Worksheet PSA9B of the ONS dataset.

and converted to their local currency using the year-average official exchange rate, which is also sourced from World Bank Open Data (2024).

In the supplementary analysis, the policy interest rates and central bank liabilities (as a percentage of GDP) are used as dependent variables. The policy interest rate data are primarily from FRED (2024)[10]. Data on central bank liabilities are obtained from same sources as profit, primarily from S&P Capital IQ Pro (2024).

4.2. Covariates

Inspired by Goncharov et al. (2023), the empirical analysis includes as covariates central bank governor reappointability and whether the central bank is publicly traded, because they may impact central bank financial results and the self-selection into indemnity. Reappointability data are borrowed from Goncharov et al. (2023); the binary variable is coded to 1 if at least one central bank governor served more than one legal term during the sample period in the Dreher et al. (2008) dataset. Three central banks in the dataset (Japan, Belgium and Greece) are publicly traded and they are coded as 1 in this variable. In addition, we control for the Euro Area membership to account for the effect of the monetary union.

Commonly used macroeconomic indicators such as unemployment, growth and inflation are *intentionally excluded* as covariates because they are endogenously affected by the treatment (indemnity).

Summary statistics of the variables in the dataset are shown in Table 2.

Table 2: Summary statistics of the data

	Mean	SD	Min	Q1	Median	Q3	Max	N
Profit (% of GDP)	0.18	0.42	−2.15	0.04	0.14	0.29	3.35	579
Liabilities (% of GDP)	43.72	55.58	0.92	16.95	28.66	51.62	509.86	580
Interest rate	1.17	1.74	−0.50	0.00	0.50	2.21	12.78	414
Publicly traded	0.13	0.33	0.00	0.00	0.00	0.00	1.00	586
Euro Area	0.65	0.48	0.00	0.00	1.00	1.00	1.00	586
Govenor reappointability	0.48	0.50	0.00	0.00	0.00	1.00	1.00	586

[10]Under the name of “Immediate Rates (<24 hours)”. The only exception is the UK policy rates, which are directly sourced from the BoE website.

5. Empirical Strategy

This paper uses the Dynamic Multilevel Latent Factor Model (DM-LFM) proposed by Pang et al. (2021) as the main estimator for the empirical analysis. The DM-LFM is described as a "Bayesian Alternative to Synthetic Control" by the inventors and is applicable to scenarios where the Difference-in-Differences (DID) and Synthetic Control (SCM) estimators are applied, namely the estimation of *binary* treatment effects with Time-Series Cross-Sectional (TSCS) data. Since in our case, the indemnity is a binary treatment and country-year panel data are used, the DM-LFM estimator perfectly suits our empirical purpose.

Similar to a growing family of SCM-like estimators for comparative case studies, the DM-LFM estimates the causal impact by first predicting the *treated counterfactuals* (Pang et al., 2021, p. 269) and then calculating the *difference* between the observed outcomes and predicted counterfactuals as the estimate for the Average Treatment Effect on the Treated (ATT). The basic idea behind the DM-LFM is to "perform a low-rank approximation of the observed untreated outcome matrix so as to predict treated counterfactuals in the $(T \times N)$ rectangular outcome matrix." (p.270) This can be seen in the functional form for *untreated potential outcomes*, which is given by:

$$Y_{it}(c) = \mathbf{X}'_{it}\beta_{it} + \gamma'_i\mathbf{f}_t + \epsilon_{it}$$

Where $\mathbf{X}_{it}$ is a matrix of observed covariates and β_{it} are their their effects that can be *heterogeneous across units and over time*. $\mathbf{f}_t$ is vector of *latent factors* which commonly affect all units, but their effects are allowed to be *heterogeneous across units* as suggested by the subscript i of their coefficients γ_i. This *latent factor term* $(\gamma'_i\mathbf{f}_t)$ correct for biases arising from the "potential correlation between the timing of the treatment and the time-varying latent variables." (p.271) Bayesian stochastic model searching is performed to search and estimate the parameters via an MCMC algorithm[11]. As a result, the empirical *posterior distribution* of the treated counterfactuals and ATT estimates are formed, with *95% credible intervals* given for inference.

[11]MCMC diagnostics are provided in Appendix E.

The DM-LFM is particularly more suited for this paper compared to traditional estimators such as DID and SCM: There is only one treated unit (UK) and none of the existing standard errors produces valid inference in this case for the Two-way Fixed Effects (TWFE) difference-in-differences (DID) design (Conley & Taber, 2011; MacKinnon et al., 2023a, 2023b; MacKinnon & Webb, 2016, 2018). The SCM relies on placebo permutation tests for inference (Abadie, 2021) which cannot quantify uncertainty in traditional ways (as confidence intervals) (Pang et al., 2021). This is in contrast to the DM-LFM, which is tailor-made for single (and few) treated unit(s) and provides built-in uncertainty measures (credibility intervals) that are easy to interpret.

The key assumption of the DM-LFM is *latent ignorability* (Pang et al., 2021, p. 274):

Assumption 1 (Latent ignorability)**.** *Conditional on the observed pre-treatment covariates* $\mathbf{X}_i$ *and latent variables* $\mathbf{U}_i$ *(approximated by* $\mathbf{f}_t$ *and* γ_i*), the assignment mechanism is independent from the untreated potential outcomes for each unit* i*.*

This is a *relaxed* version of the parallel-trends assumption in the conventional DID design. The difference is that, the TWFE-DID design assumes a unit-specific *constant* $\mathbf{U}_i$ while the DM-LFM also allows for heterogeneous treatment effects of common time-varying factors. Similar to the parallel-trends, this assumption *cannot be tested directly*, but a placebo test of pre-trends can serve as diagnostics. The results for the placebo test of pre-trends are provided in Appendix D. Moreover, one may legitimately critique that information about central banks' loss sensitivity (α) cannot be extracted from pre-treatment outcomes, which may constitute a threat to internal validity. Section 7.3 shows that, by indirect tests guided by Theory, this bias is *downward* (i.e making our empirical results more conservative).

Another assumption of the DM-LFM that is potentially violated is no anticipation (Pang et al., 2021, p. 273):

Assumption 2 (No anticipation)**.** *The current untreated potential outcome does not depend on whether the unit gets the treatment in the future.*

As early as 2004, the then governor of BoE Mervyn King and Monetary Policy Committee member Paul Tucker emphasised in public that effective monetary policy might require further cooperation with the Treasury, in an attempt to hint at the potential need for indemnity (Diessner, 2023). If the BoE anticipated that it would later receive indemnity and adjusted its behaviour accordingly, Assumption 2 would be violated. To address this concern, an early treatment of 2004 is adopted as a robustness check to the results with treatment in 2009.

6. Results

Recall that our main hypothesis (Hypothesis 1) is broken into two sub-hypotheses:

Hypothesis 1a (H_{1a})**.** The UK Treasury's indemnity against QE losses increased the BoE profits in the deflationary environment following GFC.

$$p_1^{UK}(x=1) - p_1^{UK}(x=0) > 0$$

Hypothesis 1b (H_{1b})**.** The UK Treasury's indemnity against QE losses has affected the BoE losses in the inflationary environment since 2022.

$$p_2^{UK}(x=1) - p_2^{UK}(x=0) \neq 0$$

It is therefore necessary to divide the post-treatment period (2009-2023) into a deflationary period (2009-2021) and an inflationary period (2022-2023) and estimate the ATT in these periods separately. Thanks to the DM-LFM, this can be achieved by averaging the posterior distributions across years. The DM-LFM estimation results without covariates are presented in Columns (1) and (3) in Table 3 for the deflationary and inflationary periods, respectively; the corresponding ATT estimates are visualised as red bars in Figure 14. Those with covariates are presented in Columns (2) and (4) in Table 3 and the ATT estimates are visualised as blue bars in Figure 14. Note that the DM-LFM assumes that the covariates' effects vary over time. Therefore, covariate coefficients in (2) and (4) are different, albeit from the same estimation.

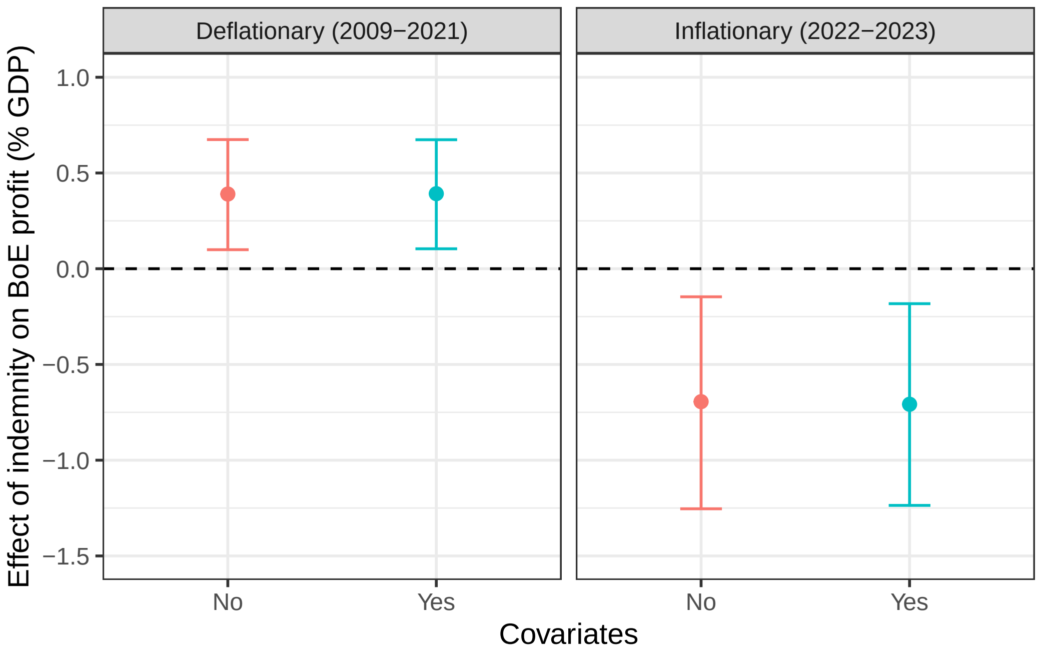


Figure 14: Estimated ATT of indemnity on BoE profits (% of UK GDP)

Table 3: Main DM-LFM analysis results table for impact of indemnity on BoE profits

	Deflationary (2009-2021)		Inflationary (2022-2023)	
	(1)	(2)	(3)	(4)
ATT	0.390**	0.392**	−0.694*	−0.708*
	[0.099, 0.674]	[0.104, 0.674]	[−1.254, −0.147]	[−1.236, −0.183]
Publicly traded		0.001		−0.004
		[−0.006, 0.011]		[−0.032, 0.013]
Euro Area		0.000		−0.003
		[−0.006, 0.009]		[−0.024, 0.013]
Reappointability		0.000		0.000
		[−0.004, 0.006]		[−0.012, 0.009]
Observations	586	586	586	586
Treated Units	1	1	1	1
Control Units	23	23	23	23

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

95% equal-tailed Credible Intervals in square brackets.

Figure 14 and Table 3 show that the covariates do not substantively change the results. The indemnity is estimated to have increased BoE profits in the deflationary period (2009-2021) by 0.39% of the UK GDP and decreased them in the inflationary period (2022-2023) by 0.7% of the UK GDP, on average. The effects are statistically significant at the 1% and 5% significance levels, respectively.

Such effects are also *substantively* significant in context: In the 2014 budget, corporation tax accounted for 2.44% of UK GDP (HM Treasury, 2014), this means extra revenue of 0.39% of GDP arising from the indemnity in the deflationary period would have substituted 16% of corporation tax of the year. The extra loss arising from the indemnity in the inflationary period is even more prominent: the average loss of 0.7% of GDP is approximately twice as large as the extra revenue gain in the deflationary period.

The results are even more alarming if one zooms into specific years such as 2023. Figure 15 gives the most intuitive overview of the results by visually comparing the actual trend of BoE profits as a percentage of GDP and the counterfactual path predicted by the DM-LFM estimator with covariates. The solid and dashed lines represent the treatment (indemnity agreement in 2009) and the inflationary shock (2022), respectively. The shaded area denotes the 95% credible interval which can be used for inference at the 5% significance level. It can be seen that the BoE profits were *substantively lower in 2023* than the estimated untreated counterfactual. In fact, in 2023 the extra loss from the indemnity amounted to 1.5% of GDP ($p < 0.01$). This is comparable to the size of the unfunded tax cuts (£45 billion) announced in the controversial mini-budget of September 2022, which was 1.8% of the 2022 GDP (BBC, 2022).

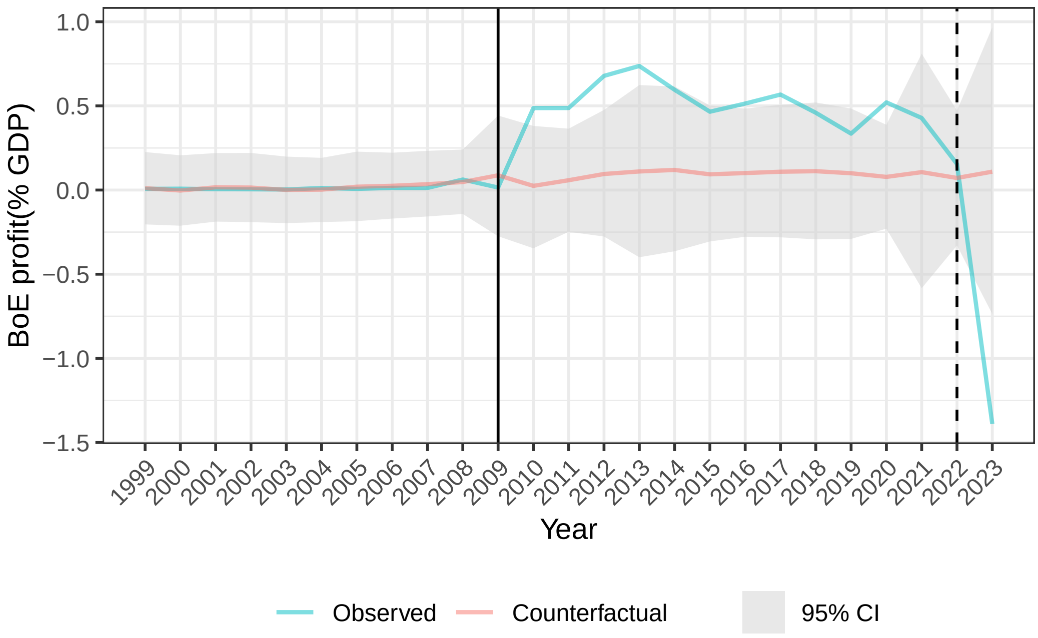


Figure 15: Estimated counterfactual and actual trends of BoE profits as % of UK GDP

The empirical evidence above is sufficient to support Hypotheses 1a and 1b that the indemnity significantly increased the BoE profits in the deflationary period, and affected them in the inflationary period. Furthermore, evidence indicates that the impact in the inflationary period is *negative*, i.e., the indemnity incurred extra losses to the BoE during monetary tightening.

7. Robustness Checks

Besides the placebo tests of pre-trends in Appendix D, other checks are conducted to ensure the robustness of the main results.

7.1. Alternative Estimators

Alternative estimators such as the difference-in-differences (DiD), synthetic control (SCM) and synthetic difference-in-differences (SDiD)[12] are used to cross-check the DM-LFM results in the main analysis. The results using these alternative estimators are reported in Appendix F alongside the main results using the DM-LFM. Although the alternative

[12]A novel estimator proposed by Arkhangelsky et al. (2021) that combines the DiD and SCM.

estimators cannot produce valid inference as discussed in the Empirical Strategy, they provide comparable ATT estimates to the DM-LFM results. This suggests our results are robust.

7.2. Re-estimation with Earlier Treatment Time

One may suspect that the BoE might have anticipated the indemnity, in which case Assumption 2 would be violated. Therefore, the main analysis is replicated with an earlier treatment time of 2004 to test the main results' sensitivity to the possible anticipation effect. The results are presented in Appendix G. It can be seen that the point estimates are stable, which indicates good robustness of our results, despite lower statistical significance resulting from the short pre-treatment period.

7.3. Identification of Selection Bias - a Parameter Location Problem

As explained in the Empirical Strategy, although the DM-LFM estimator overcomes many shortcomings of other estimators, its estimates are still prone to *selection bias* due to the little information about central bank's sensitivity to losses (α) that can be extracted from the *pre-treatment* outcomes, despite the attempt to address it by controlling for relevant covariates.

Recall from the Model Setup, the period utility function for central bank (B):

$$U_{Bt} = -(\pi_t - 2)^2 + \alpha(1 - x_t)\min\{p_t, 0\}$$

where

$$p_t = -\psi(i_t - 2)r_t$$

Before QE in 2009, the risk level chosen by B was always 0 ($r_0 = 0$). This means that abnormal profit before QE would also be 0 and the central bank's sensitivity (α) would be eliminated from the utility function U_{Bt}:

$$
\begin{aligned}
p_t &= -\psi(i_t - 2) \times 0 = 0 \\
U_{Bt} &= -(\pi_t - 2)^2 + \alpha(1 - x_t)\min\{0, 0\} \\
&= -(\pi_t - 2)^2
\end{aligned}
$$

More importantly, α *only* affects the system through the central bank's utility function (U_B). This means that information about α is not extractable from pre-treatment outcomes. Unfortunately, the fact that central bank sensitivity (α) determines the *direction* of the selection bias makes it a problem impossible to circumvent empirically.

We first define selection bias:

Definition 1 (Selection bias)**.** Selection bias is defined as the baseline difference between the control and treatment units in the untreated potential outcome of profits.

$$
\text{Bias}_t(\alpha, \rho) = p_t(x = 0 | x = 1, \alpha, \rho) - \mathbb{E}[p_t(x = 0) | x = 0]
$$

According to this definition, we can plot the direction (in Figure 16) and size (in Figure 17) of selection bias with respect to α and ρ by comparing their untreated potential outcomes of treated units to the mean outcome of the control group (red area in Figure 2). Figure 16 and Figure 17 suggest that, in the deflationary period ($t = 1$), the selection bias is relatively large but primarily *negative*, which makes our estimates more *conservative*; in the inflationary period ($t = 2$), the selection bias is relatively small, but varies in direction. Figure 16 shows, that when α is high and ρ is low (as in the *blue* area of the right panel), the bias is *positive and conservative*, since the effect is expected to be negative (see Figure 11).

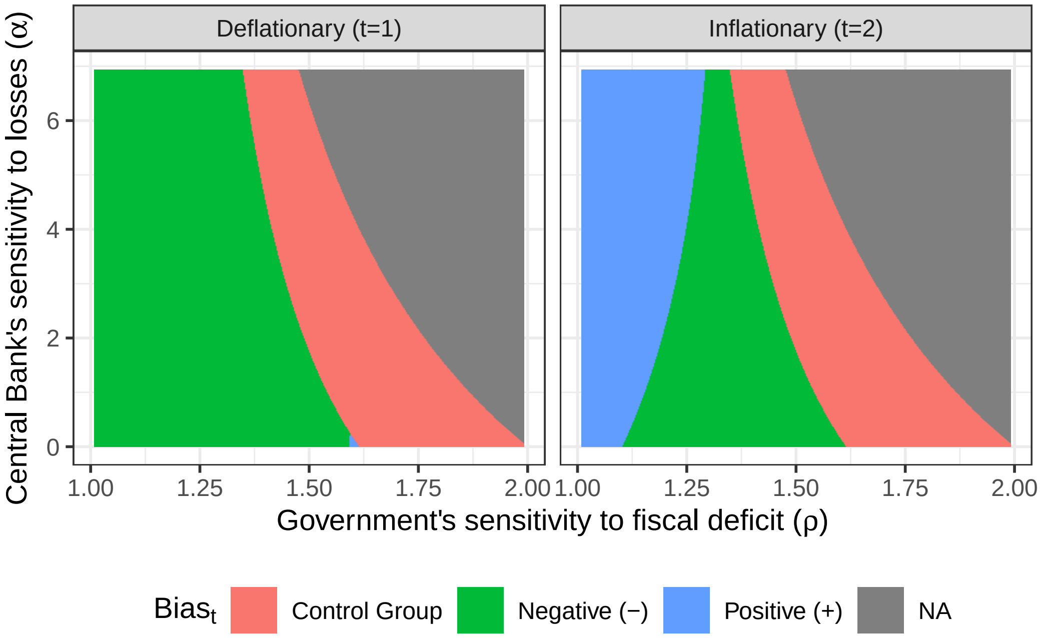


Figure 16: Sign of selection bias with respect to ρ and α

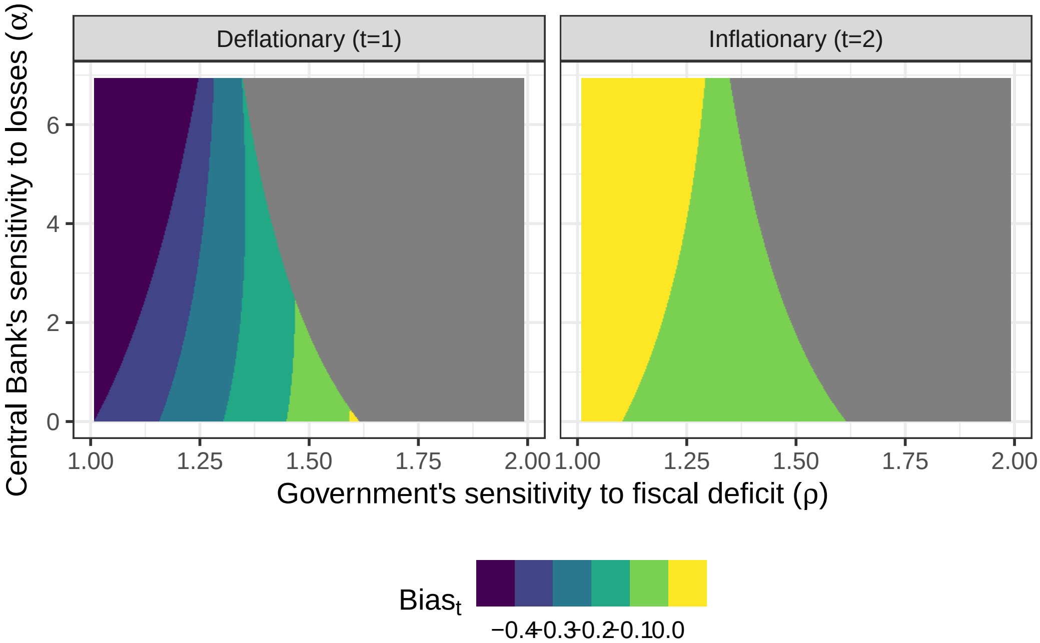
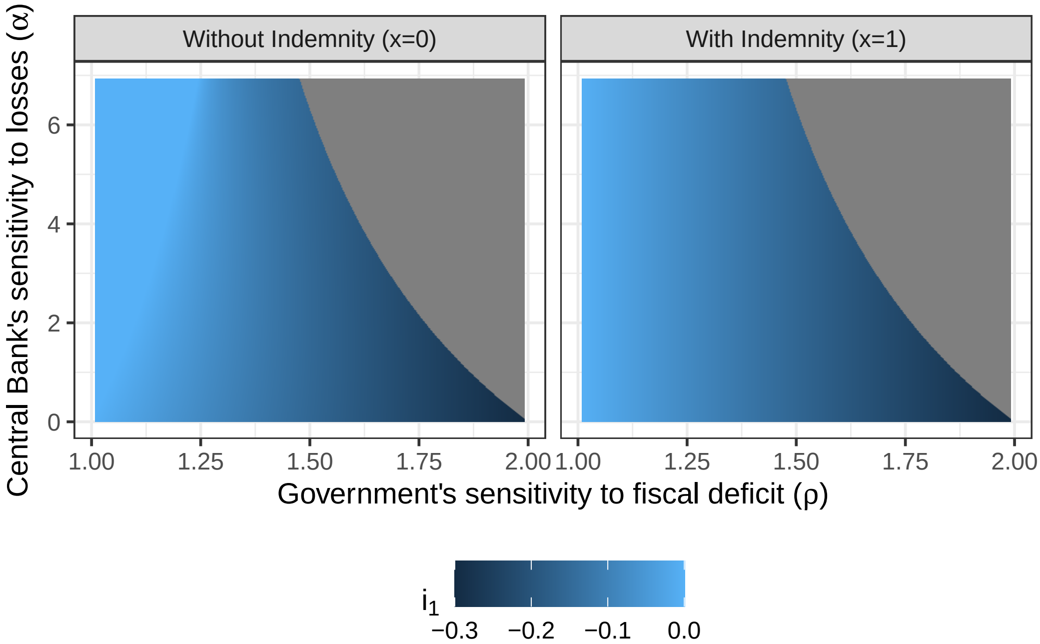


Figure 17: Size of selection bias with respect to ρ and α

Thanks to the theoretical model, there is an *indirect* test that is sufficient to prove that the UK locates in this blue area of conservative bias. Figure 7 (restated below) shows that *only* for the area where $i_1(x = 0) = 0$ (light blue in left panel), a significantly *negative* impact of indemnity on monetary policy is expected. More importantly, this estimate is convincingly *downward/conservatively* biased because the control group (on the right of each panel) is expected to have lower i_1 (denoted by darker blue) at the baseline.



Therefore, it is true that:

Proposition 8 (Supplementary test of downward bias)**.** *An empirical supplementary test that suggests the UK adopted a significantly more expansionary monetary policy due to the indemnity in the deflationary period is sufficient to prove that the estimates of the indemnity's impact on profits are conservative.*

Therefore, additional DM-LFM analyses are conducted as supplementary tests. The supplementary tests use two outcome variables to measure monetary policy: central bank policy interest rate as a direct measurement, and the central bank liabilities as an indirect measurement. Central bank liabilities (as percentage of GDP) are used as a good approximation of the *monetary base*, a tool that central banks use to affect market interest rates (Rule, 2015). Moreover, central bank liabilities are solely decided by central bank themselves, unaffected by commercial bank lending decisions (unlike other indicators of money supply such as M2) or asset price fluctuations (unlike central bank assets). Hence, higher (lower) liabilities relative to GDP are a good indicator of expansionary (contractionary) monetary policy.

The results for supplementary tests are shown in Table 4[13]. Additional plots are available in Appendix H. Recall that the estimates from these supplementary tests are *conservatively* biased. This implies that the indemnity is estimated to have significantly reduced the BoE policy interest rate by at least 2.7 percentage points in the deflationary period (2009-2021); this suggests the UK adopted a significantly more expansionary monetary policy due to the indemnity. Moreover, the indemnity is also estimated to have increased the size of the BoE liabilities (interpreted as UK monetary base) by at least 11% of GDP, albeit statistically insignificant. Nevertheless, the positive coefficient can be interpreted as complementary to the interest rate results.

Table 4: Supplementary DM-LFM results for impact of indemnity on monetary policy in the deflationary period (2009-2021)

	Interest Rate	BoE Liabilities
ATT	−2.718***	11.036
	[−3.013, −2.402]	[−20.052, 43.912]
Publicly traded	0.000	−0.208
	[0.000, 0.000]	[−1.272, 0.605]
Euro Area	−0.221***	0.117
	[−0.319, −0.117]	[−0.593, 0.968]
Reappointability	0.000	0.037
	[0.000, 0.000]	[−0.196, 0.384]
Observations	414	586
Treated Units	1	1
Control Units	16	23

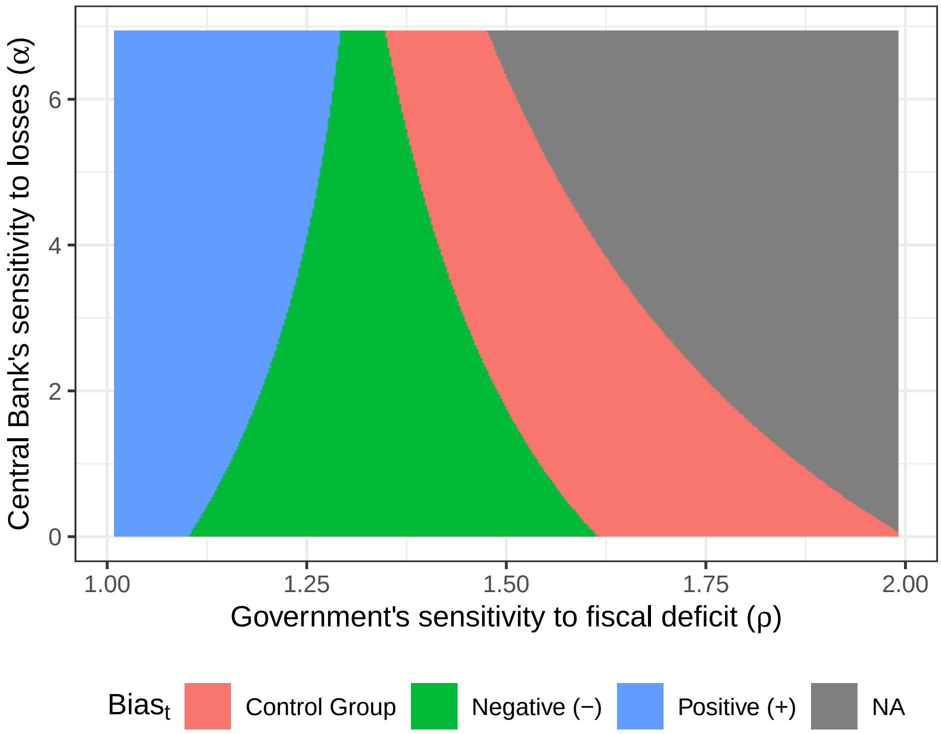
+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

95% equal-tailed Credible Intervals in square brackets.

Therefore, evidence suggests that the potential selection bias in the main results from miss-

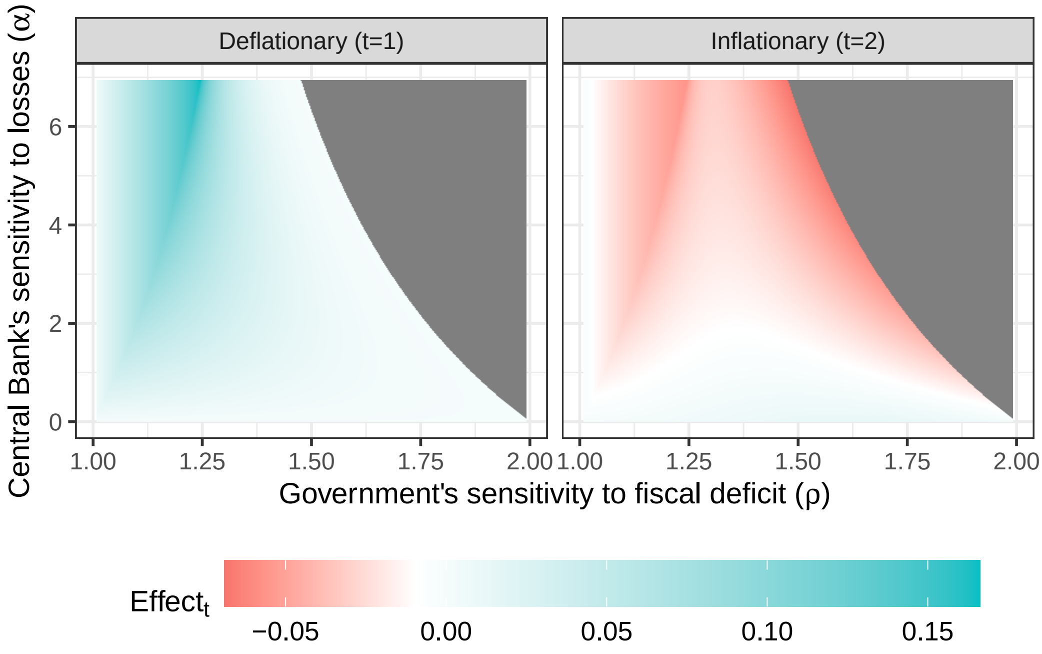
[13] Note the observations for the interest rate estimation are fewer because the data for new Euro Area members are not available from FRED (2024).

ing information about the central bank's sensitivity to losses (α) is *conservative.* Moreover, this means that the UK locates in the *blue* area in the right panel of Figure 17 (restated below), where the government (G) is relatively insensitive to fiscal deficit (low ρ) but the central bank (α) is relatively sensitive to financial losses high (α).



8. Discussion - Where Are Countries Located?

Recall Proposition 7 that, the effects of the indemnity on profits are strongest along a belt of effects as shown in Figure 12 (restated below). The empirical results suggest that the indemnity against QE losses received by the BoE has substantively increased its profits during the deflationary period (2009-2021) when expansionary monetary policy was concerned, and exacerbated its losses during the inflationary period (2022-23) when contractionary monetary policy was implemented. This means the UK is likely located on the belt of effect.



This paper further argues that the UK is located in the *upper* part of the belt, where α is high and ρ is not too low, and the approximate locations of the UK, US and Euro Area countries are shown in Figure 18.

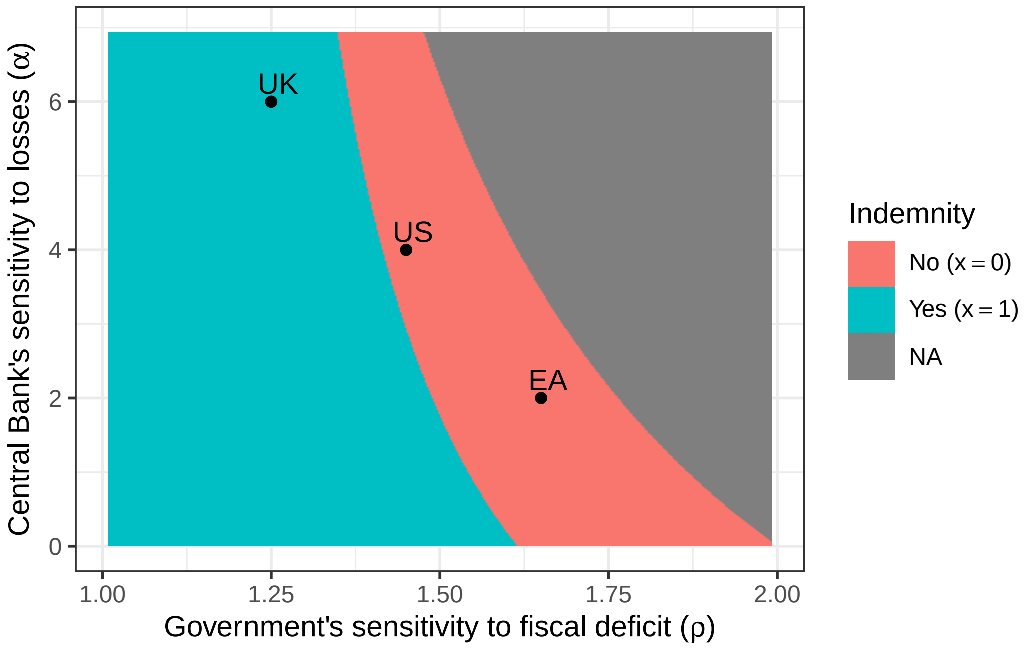


Figure 18: Approximate locations of the UK, US and Euro Area countries

There are qualitative accounts for why the BoE is likely the most sensitive to losses (highest

α), and why Euro Area is the least sensitive among the three. Diessner (2023) documents that the BoE is the *least* independent from the Treasury among the mentioned central banks, for two reasons. First, the inflation target of the BoE is set by the Treasury, whereas that of the Fed and ECB are set by themselves (Svensson, 2010). Second, the BoE only enjoys a small capital base and lacks any capacity to strengthen its capital position (Diessner, 2023). As such, the BoE is both politically and financially dependent on the Treasury, which results in high sensitivity to losses. This high sensitivity is also revealed by the fact that the BoE would have *not implemented QE at all* without indemnity according to interviews of former MPC members (Diessner, 2023). This confirms our location of the BoE in the upper part of the "belt of effect" where no QE would be implemented without indemnity, and considerable QE was carried out under treatment. On the contrary, the Euro Area central banks are the least financially sensitive because their monetary policy is dictated by the European Central Bank (ECB), which is among the most independent central banks (Diessner, 2023). The ECB makes monetary decisions free of political pressure from national governments or a non-existent Eurozone treasury (Goodhart, 1998). This independence is exemplified by the ECB's discretionary doubling of its capital base as a signal to national governments that it would not "[embark] on a quid pro quo" in monetary decision making (Diessner, 2023). Therefore, it is convincing to conclude that the BoE is the most sensitive to losses, followed by the Federal Reserve and the Euro Area central banks.

The order of fiscal conservatism (ρ) in Figure 18 is supported by indirect evidence of historical budget records in Figure 19. While it is commonsensical that the Euro Area has historically run the smallest budget deficit due to 1) strict EU fiscal rules and 2) impossibility of national-level monetary financing of deficits (Frieden & Walter, 2017; Pisani-Ferry, 2012), it may be surprising before seeing the evidence that the UK is *less* fiscally conservative than the US, despite the advertisement of austerity under the Conservative government from 2010 onward (Reeves et al., 2013). In fact, the UK consistently ran a larger budget deficit than the US before the indemnity was agreed in 2009, and continued to maintain a larger deficit than the US as a proportion of GDP until 2016, with the exception of 2011. Therefore, the UK is believed to be the most fiscally liberal, followed by the US and Euro Area countries.

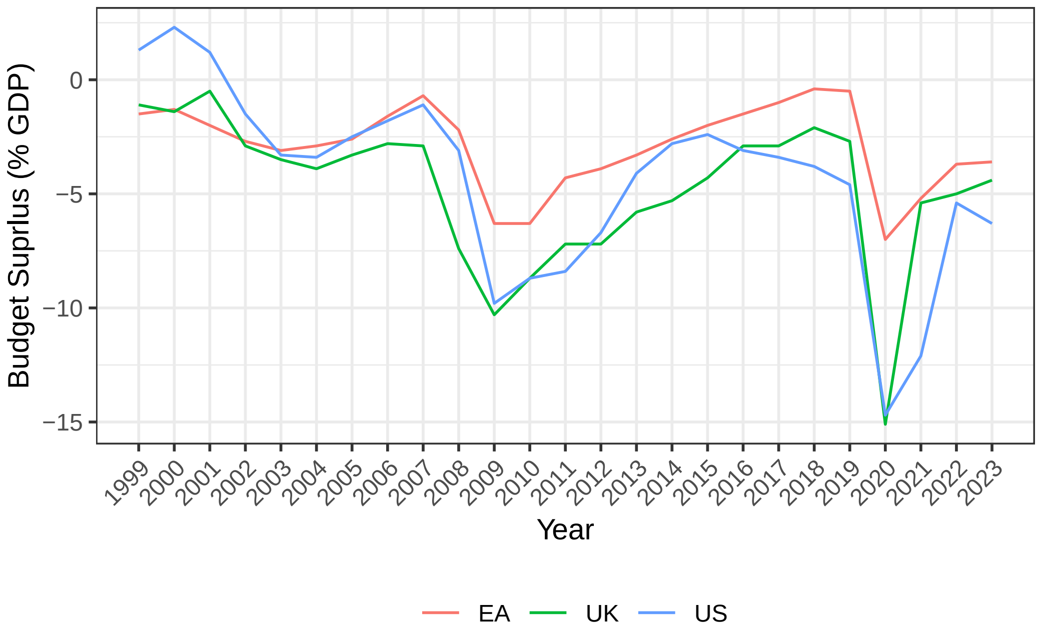


Figure 19: Budget surplus (deficit) of the UK, US and Euro Area over time (Source: Trading Economics)

9. Conclusion

This paper presents a theoretical framework to analyse the causes and impacts of fiscal indemnity for central banks' quantitative easing-related losses. The predicted impact of indemnity on central bank profitability is empirically tested with the UK case study. Findings indicate that the indemnity granted by the UK government significantly boosted the Bank of England's profits during the deflationary period following the 2007-08 Global Financial Crisis. However, since inflationary pressures emerged in 2022, the indemnity has exacerbated the Bank's losses. The theoretical and empirical findings fill relevant gaps in the literature on central bank loss coverage.

Nonetheless, the British experience should not be generalised. The theoretical model suggests that the pronounced effects in the British case are likely due to the Bank of England's high sensitivity to losses and the UK government's moderate fiscal liberalism. For countries that did not adopt indemnity due to stronger fiscal conservatism, the profit gains during the deflationary period would have been weaker, and the impact during the inflationary period would depend on the central bank's sensitivity to losses. For central banks with lower sensitivity to losses, the indemnity might have even mitigated losses under inflationary pressure.

Furthermore, this paper contributes to future policy evaluation and institutional design by highlighting the *heterogeneity* in the public finance-price stability trade-off. While the theoretical model aligns with the mainstream economic literature in recognising the benefits of indemnity for price stability, these benefits vary significantly between countries that self-select into indemnity and those that do not. While the indemnity may help tackle deflationary pressures in cases like the UK, it contributes little to suppressing inflation. The reverse is true for countries that do not adopt indemnity.

There are several limitations to this paper that future research could address. First, the empirical analysis is limited to a single treated case (the UK). Future studies could examine similar cases, such as Canada and New Zealand, which have recently adopted QE and similar indemnity agreements, as more data become available. Secondly, the central bank-held bond maturity is a good, if not better, measurement for monetary policy in the supplementary test evaluating the effect of indemnity on the depth of QE. However, its inclusion in this study was beyond the scope due to time constraints in data collection. Future research could explore these aspects more thoroughly.

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A. Complete Model Derivation and Analysis

This appendix presents the full subgame analysis for when the central bank receives indemnity ($x = 1$) or not ($x = 0$) as a supplement to the Theory section.

A.1. Subgame with Indemnity ($x = 1$)

We start with the simpler case when the government indemnifies the central bank ($x = 1$). With backward induction, we first solve for the second period with the constraint of first period risk level r_1.

The government's second period payoff function is given by:

$$U_{G2}(x = 1) = C(p_2 + f_2) + 4 - f_2 - i_2 + \epsilon_{d2} + \epsilon_{s2}$$

The government maximises its expected payoff in the second period by:

$$\begin{aligned}
\frac{\partial}{\partial f_2} EU_{G2}(x = 1) &= \frac{\partial C}{\partial (p_2 + f_2)} - 1 = 0 \\
p_2 + f_2 &= \left(\frac{\partial C}{\partial (p_2 + f_2)} \right)^{-1} (1) = \rho \\
f_2^* &= \rho - p_2 \\
&= \rho + \psi(i_2 - 2) r_2
\end{aligned}$$

When the central bank is indemnified ($x = 1$), the central bank's second period payoff function is given by:

$$\begin{aligned}
U_{B2}(x = 1) &= -(\pi_2 - 2)^2 \\
&= -(2 - f_2 - i_2 + \epsilon_{d2} - \epsilon_{s2})^2
\end{aligned}$$

Deciding on the level of monetary policy (i_2) and risk-taking (r_2), we take the first order conditions:

w.r.t monetary policy (i_2):

$$\begin{aligned}
\frac{\partial}{\partial i_2} U_{B2}(x=1) &= 2(2 - f_2 - i_2 + \epsilon_{d2} - \epsilon_{s2}) = 0 \\
2 - f_2 - i_2 + \epsilon_{d2} - \epsilon_{s2} &= 0 \qquad (1) \\
i_2^*(x=1) &= 2 - f_2 + \epsilon_{d2} - \epsilon_{s2}
\end{aligned}$$

Note Equation (1) implies that the indemnified central bank can always achieve the inflation target at 2% by adjusting the monetary policy to the fiscal policy and the shocks.

Substituting $f_2^*(x=1)$ into $i_2^*(x=1)$:

$$\begin{aligned}
i_2^*(x=1) &= 2 - (\rho + \psi(i_2 - 2)r_2) + \epsilon_{d2} - \epsilon_{s2} \\
&= 2 - \rho - \psi i_2 r_2 + 2\psi r_2 + \epsilon_{d2} - \epsilon_{s2} \\
(1 + \psi r_2) i_2^*(x=1) &= 2 - \rho + 2\psi r_2 + \epsilon_{d2} - \epsilon_{s2} \\
i_2^*(x=1) &= \frac{2 - \rho + 2\psi r_2 + \epsilon_{d2} - \epsilon_{s2}}{\psi r_2 + 1}
\end{aligned}$$

For convenience, we denote the frequently used expression $2 - \rho + \epsilon_{d2} - \epsilon_{s2}$ as u. u can be conceived of as the inflationary pressure perceived by the central bank B after taking into account fiscal policy. Therefore,

$$i_2^*(x=1) = \frac{u + 2\psi r_2}{\psi r_2 + 1}$$

Accordingly, the risk level is either kept the same by central bank B or increased to the minimum level that optimal monetary policy i_2 requires:

$$
\begin{aligned}
r_2^*(x=1) &= \max\{r_1, -i_2^*\} = \max\{r_1, \frac{-u + 2\psi r_2}{\psi r_2 + 1}\} \\
&= \max\{r_1, \frac{-(2\psi+1) + \sqrt{(2\psi+1)^2 - 4\psi u}}{2\psi}\}
\end{aligned}
$$

Recall from Equation (1) that, in the second period (we will show it is also true for the first period), an indemnified bank can maintain the inflation on target by adjusting the monetary policy according to the fiscal policy. The central bank's utility is at the maximum of 0 in this case:

$$
\begin{aligned}
\pi_2^*(x=1) &= 4 - (f_2^*(x=1) + i_2^*(x=1)) + \epsilon_{d2} - \epsilon_{s2} \\
&= 4 - (2 + \epsilon_{d2} - \epsilon_{s2}) + \epsilon_{d2} - \epsilon_{s2} \\
&= 2 \\
U_{B2}(x=1) &= -(\pi_2^*(x=1) - 2)^2 \\
&= -(2-2)^2 \\
&= 0
\end{aligned}
$$

We now turn to the first period of the subgame. Since the government's first period fiscal policy (f_1) does not affect the second period, the government maximises its expected payoff in the first period in a similar way to the second period:

$$
\begin{aligned}
U_{G1}(x=1) &= C(p_1+f_1)+4-f_1-i_1+\epsilon_{d1}+\epsilon_{s1} \\
&= C(p_1+f_1)+4-f_1-i_1-1+0 \\
&= C(p_1+f_1)+3-f_1-i_1 \\
\frac{\partial}{\partial f_1}U_{G1}(x=1) &= \frac{\partial C}{\partial(p_1+f_1)}-1=0 \\
p_1+f_1 &= \left(\frac{\partial C}{\partial(p_1+f_1)}\right)^{-1}(1)=\rho \\
f_1^* &= \rho-p_1 \\
&= \rho+\psi(i_1-2)r_1
\end{aligned}
$$

It can be seen that, for both periods, it is true that

$$f_t(x=1)=\rho-p_t$$

This is property is known as Proposition 1 of monetary dominance:

Proposition 1 (Monetary Dominance)**.** *Under fiscal indemnity for central bank losses, the fiscal policy of the government is constrained by the size of the profit (indemnity) payment from (to) the central bank.*

As for the central bank (B), the first period monetary policy and risk level do not affect its ability to maintain the inflation target in the second period since it is indemnified. Therefore, the central bank also maximises its first period utility by setting the monetary policy and risk-taking to the optimal level that aims for the 2% target. Recall that first period shocks ($\epsilon_{d1}=-1$, $\epsilon_{s1}=0$) are known to players at the beginning of the game:

$$
\begin{aligned}
U_{B1}(x=1) &= -(\pi_1 - 2)^2 \\
&= -(2 - f_1 - i_1 + \epsilon_{d1} - \epsilon_{s1})^2 \\
&= -(1 - f_1 - i_1)^2 \\
\frac{\partial}{\partial i_1} U_{B1}(x=1) &= 2(1 - f_1 - i_1) = 0 \\
1 - f_1 - i_1 &= 0 \\
i_2^*(x=1) &= 1 - f_1
\end{aligned}
$$

Substituting f_1^* into i_1^*, we have the optimal monetary policy in the first period:

$$
\begin{aligned}
i_1^*(x=1) &= 1 - (\rho + \psi(i_1 - 2)r_1) \\
&= 1 - \rho - \psi i_1 r_1 + 2\psi r_1 \\
(1 + \psi r_1) i_1^*(x=1) &= 1 - \rho + 2\psi r_1 \\
i_1^*(x=1) &= \frac{1 - \rho + 2\psi r_1}{1 + \psi r_1}
\end{aligned}
$$

When $i_1^*(x=1) \geq 0$ and $r_1^* = 0$, i.e. $1 - \rho \geq 0$, quantitative easing is not required whatsoever in the first period and is hence not of interest in this case. We only consider the case when $i_1^*(x=1) < 0$ and $r_1^* > 0$, i.e. $1 - \rho < 0$ and $\rho > 1$. In this case, $r_1^* = -i_1^*$:

$$
\begin{aligned}
i_1^*(x=1) &= \frac{1 - \rho - 2\psi i_1^*}{1 - \psi i_1^*} \\
-\psi i_1^{*2} + i_1^* &= 1 - \rho - 2\psi i_1^* \\
-\psi i_1^{*2} + (2\psi + 1) i_1^* &= 1 - \rho \\
i_1^* &= \frac{2\psi + 1 - \sqrt{(2\psi + 1)^2 - 4\psi(1 - \rho)}}{2\psi} < 0
\end{aligned}
$$

In this case:

$$
r_1^* = \frac{-(2\psi + 1) + \sqrt{(2\psi + 1)^2 - 4\psi(1 - \rho)}}{2\psi} > 0
$$

This implies that the central bank can also achieve the 2% inflation target in the first period by taking on risk in the first period. Hence, the central bank's utility in the first period is also 0.

$$\begin{aligned}\pi_1^*(x=1) &= 2\\ U_{B1}(x=1) &= 0\end{aligned}$$

Hence the second major conclusion of the model:

Proposition 2 (Stable inflation under indemnity)**.** *The inflation target can always be achieved when the central bank is indemnified by the government against losses.*

$$\pi_t(x=1) = 2$$

We can now calculate the Government's (G) (expected) utility from indemnifying the central bank.

For the first period:

$$\begin{aligned}U_{G1}(x=1) &= C(p_1+f_1)+g_1\\ &= C(\rho)+\pi_1+2\epsilon_{s1}\\ &= C(\rho)+2\end{aligned}$$

For the second period:

$$\begin{aligned}EU_{G2}(x=1) &= \mathbb{E}[(C(p_2+f_2)+g_1]\\ &= C(\rho)+\mathbb{E}(\pi_2+2\tilde{\epsilon}_{s2})\\ &= C(\rho)+2\end{aligned}$$

Hence, the Government's two-period expected utility from indemnifying the central bank is:

$$\begin{aligned} EU_G(x=1) &= U_{G1}(x=1) + EU_{G2}(x=1) \\ &= 2C(\rho) + 4 \end{aligned}$$

A.2. Subgame without Indemnity ($x = 0$)

We now consider the more complex case when the government chooses not to indemnify the central bank ($x = 0$). With backward induction, we first solve for the second period with the constraint of first period risk level r_0.

When the government does not indemnify the central bank ($x = 0$), the government's second-period utility function is given by:

$$U_{G2}(x=0) = C(\max\{p_2, 0\} + f_2) + 4 - f_1 - i_1 + \epsilon_{d2} + \epsilon_{s2}$$

The government maximises its expected utility by:

$$\begin{aligned} \frac{\partial}{\partial f_2} EU_{G2}(x=0) &= \frac{\partial C}{\partial(\max\{p_2, 0\} + f_2)} - 1 = 0 \\ \max\{p_2, 0\} + f_2 &= \rho \\ f_2^* &= \rho - \max\{p_2, 0\} \\ &= \rho + \min\{\psi(i_2 - 2)r_2, 0\} \end{aligned}$$

When the central bank is not indemnified ($x = 0$), the central bank's utility function is given by:

$$\begin{aligned} U_{B2}(x=0) &= -(\pi_2-2)^2+\alpha\min\{p_2,0\} \\ &= -(2-f_2-i_2+\epsilon_{d2}-\epsilon_{s2})^2-\alpha\psi\max\{(i-2)r_2,0\} \end{aligned}$$

When $p>0$ and $i_2<2$:

The same solution as in the case where $x=1$ applies.

$$\begin{aligned} i_2^*(x=0) &= \frac{2-\rho+2\psi r_2+\epsilon_{d2}-\epsilon_{s2}}{\psi r_2+1} = \frac{u+2\psi r_2}{\psi r_2+1} < 2 \\ r_2^*(x=0) &= \max\{r_1,-i_2^*\} \\ &= \max\{r_1, \frac{-(2\psi+1)+\sqrt{(2\psi+1)^2-4\psi(1-\rho)}}{2\psi}\} > 0 \end{aligned}$$

This implies the 2% inflation target is met and $U_{B2}(x=0, i_2<2)=0$. This requires $u<2$.

When $p<0$ and $i_2>2$:

$$f_2^*(x=0;i_2>2) = \left(\frac{\partial C}{\partial f_2}\right)^{-1}(1) = \rho$$

$$U_{B2}(x=0;i_2>2) = -(2-f_2-i_2+\epsilon_{d2}-\epsilon_{s2})^2-\alpha\psi(i-2)r_2$$

It can be shown that, the central bank (B) prefers a lower level of risk in the second period r_2 as a higher risk level would increase the financial loss and no longer help with monetary policy:

$$\frac{\partial}{\partial r_2}U_{B_2}(x=0,i_2>2) = -\alpha\psi(i_2-2)r_2 < 0$$

Therefore, the central bank (B) chooses the lowest level of risk in the second period:

$$r_2(x=0, i_2>2) = r_1$$

w.r.t monetary policy (i):

$$\begin{aligned}
&\frac{\partial}{\partial i_2}U_{B_2}(x=0, i_2>2) = 2(2-f_2-i_2+\epsilon_{d2}-\epsilon_{s2}) - \alpha\psi r_1 = 0\\
&f_2+i_2-\epsilon_{d2}+\epsilon_{s2}-2 = -\frac{\alpha\psi r_1}{2}\\
&\qquad\qquad i_2^*(x=0) = -f_2+\epsilon_{d2}-\epsilon_{s2}-\frac{\alpha\psi r_1}{2}+2>2
\end{aligned} \tag{2}$$

Substituting $f_2^*(x=0)$ and r_2 into $i_2^*(x=0)$:

$$\begin{aligned}
i_2^* &= -f_2^* + \epsilon_{d2} - \epsilon_{s2} - \frac{\alpha\psi r_1}{2} + 2\\
&= 2 - \rho + \epsilon_{d2} - \epsilon_{s2} - \frac{\alpha\psi r_1}{2}\\
&= u - \frac{\alpha\psi r_1}{2}
\end{aligned}$$

This requires $u > 2 + \frac{\alpha\psi r_1}{2}$. In this case, the second-period utility of the central bank is:

$$U_{B2}(x=0, i_2>2) = -(2-f_2^*-i_2^*+\epsilon_{d2}-\epsilon_{s2})^2 - \alpha\psi(i_2^*-2)r_1$$

Recall Equation (2), the equation above can be rewritten as:

$$\begin{aligned}
U_{B2}(x=0, i>2) &= -(2-f_2^*-(-f_2^*+\epsilon_{d2}-\epsilon_{s2}-\frac{\alpha\psi r_1}{2}+2)+\epsilon_{d2}-\epsilon_{s2})^2 - \alpha\psi(i_2^*-2)r_1\\
&= -(\frac{\alpha\psi r_1}{2})^2 - \alpha\psi r_1(u-\frac{\alpha\psi r_1}{2}-2)
\end{aligned}$$

Therefore, when $2 < u < 2 + \frac{\alpha\psi r_1}{2}$, $i_2^*(x=0) = 2$. In other words, there is a range of u where the central bank (B) prefers to keep the interest rate neutral in the second period and not respond to inflationary pressure. In this case, the second-period utility of the central bank is:

$$
\begin{aligned}
U_{B2}(x=0, i_2=2) &= -(2 - f^* - 2 + \epsilon_{d2} - \epsilon_{s2})^2 - \alpha\psi(2-2)r_1 \\
&= -(-\rho + \epsilon_{d2} - \epsilon_{s2})^2 \\
&= -(u-2)^2
\end{aligned}
$$

The relationship between the second period interest rate (r_2^*) and u is summarised and visualised in Figure 20. It can be seen that, when the central bank is not indemnified ($x = 0$) as in shown by the red line, the function is four-fold: in case of deflationary pressure ($u < 2$), the monetary policy linearly decreases with lower u, until a higher r_2 is required to enable even lower i. In case of inflationary pressure ($u > 2$), i is briefly stuck at 2 to avoid losses until further inflationary pressure (higher u) forces the central bank to embrace tighter monetary policy ($i > 2$).

Interest rates for an indemnified counterfactual (blue line) are also provided for comparison. It is realistically assumed in this graph that the first period risk level is high when the bank is indemnified ($r_1(x = 1) > r_1(x = 0)$), which is later proven in Proposition 3. When this is the case, the interest rates are higher when the bank is indemnified ($x = 0$) under deflationary pressure ($U < 2$), until a higher r_2 is required, at which point the two potential outcomes converge. In case of inflationary pressure ($u > 2$), the indemnified bank adopts a higher interest rate than the non-indemnified counterpart, but can be overtaken in the extreme cases when the inflationary pressure is too high, as further demonstrated in the simulation.

We now turn to the first period of this subgame so that we can calculate the intertemporal optimisation for the central bank's actions.

In the first period, the government's (G) strategy is the same as in the second period because its first-period fiscal policy does not affect the second period:

$$
f_1^*(x=0) = \rho + \min\{\psi(i_1-2)r_1, 0\}
$$

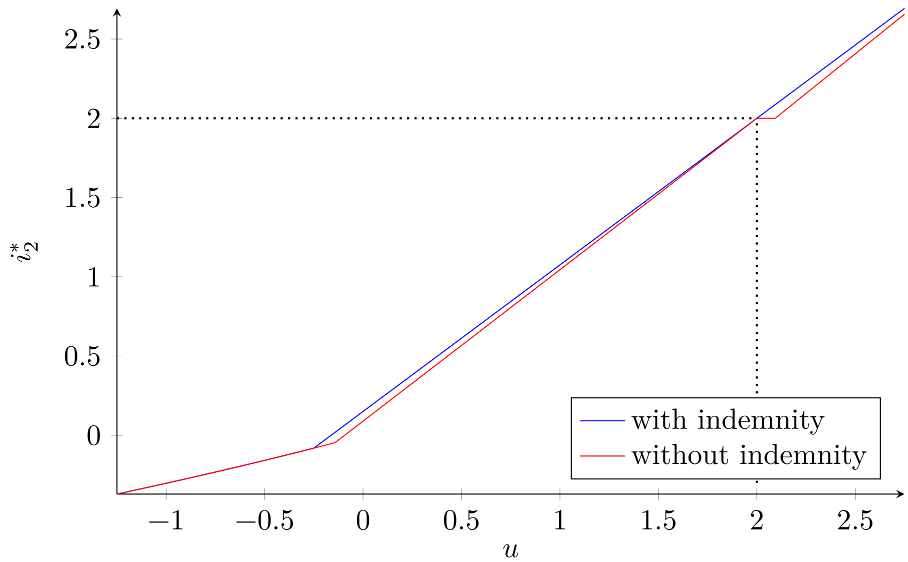

Figure 20: Illustration of the optimal second-period interest rate (i_2^*) with respect to u ($\alpha = 4$, $\rho = 1.25$)

However, as we discussed in the previous section, we only consider the case where the deflationary pressure in the first period is so severe that the 2% inflation target cannot be met without quantitative easing, it must be that $\rho > 1$ and $i_1^*(x = 0) \leq 0$. This means that no loss would be made in the first period. Therefore, the first period fiscal policy can be relaxed to:

$$f_1^*(x = 0) = \rho + \psi(i_1 - 2)r_1$$

For the same reason, the central bank's (B) first period utility is:

$$\begin{aligned} U_{B1}(x = 0) &= -(\pi_1 - 2)^2 \\ &= -(1 - f_1 - i_1)^2 \\ &= -(1 - f_1 + r_1)^2 \end{aligned}$$

It's partial derivative with respect to r_1 is:

$$\frac{\partial}{\partial r_1} U_{B1}(x=0) = -2(1 - f_1 + r_1)$$
$$= -2(1 - (\rho + \psi(i_1 - 2)r_1) + r_1)$$

One may notice that, when this first order condition is set to zero, the solution is exactly the same as $r_1^*(x = 1)$. This means that, when not considering the second period, an unindemnified central bank (B) would choose the same level of risk in the first period as an indemnified central bank (B). Choosing a higher level of risk would not offer the central bank (B) a higher utility in the first period.

Moreover, a higher level of risk in the first period would not offer the central bank (B) a higher utility in the second period either. Recall that the central bank (B) is indifferent to the level of risk (r_2) when there is a deflationary pressure in the second period ($u < 2$), as a profit is made in this case and thus excluded from B's utility function; the unindemnified central bank (B) simply chooses the optimal monetary policy (i_2) and the minimum level of risk required (r_2). Furthermore, the central bank (B) strictly prefers a lower level of risk in the second period when there is an inflationary pressure in the second period ($u > 2$). Therefore, the central bank (B) never prefers a higher level of risk in the second period.

Knowing that choosing a higher level of risk in the first period (r_1) would not offer the central bank (B) a higher utility in either period, and a similar reasoning can be applied to the second period risk level (r_2), we have reached the third major finding of the model:

Proposition 3 (Central bank prudence without indemnity)**.** *Indemnity against losses never reduces a central bank's risk level.*

$$r_t^*(x = 0) \leq r_t^*(x = 1)$$

Recall the determinants of inflation in period 1:

$$\begin{aligned}\pi_1 &= 3 - f_1^* - i_1^* \\ &= 3 - (\rho - p_1^*) + r_1^* \\ &= 3 - \rho + r_1^*(r_1^* + 2) + r_1^* \\ &= 3 - \rho + r_1^{*2} + 3r_1^*\end{aligned}$$

Also, recall that, under indemnity the inflation is 2% in the first period. This means we can calculate the potential *deflationary bias* in the first period without indemnity.

$$\begin{aligned}\pi_1(x=1) &= 2 \\ \pi_1(x=0) - 2 &= \pi_1(x=0) - \pi_1(x=1) \\ &= r_1^{*2}(x=0) - r_1^{*2}(x=1) + 3r_1^*(x=0) - 3r_1^*(x=1)\end{aligned}$$

This is another major conclusion of this model:

Proposition 4 (Deflationary bias without indemnity)**.** *If the central bank chose a lower risk level due to no indemnity, there would be a deflationary bias negatively correlated with the chosen risk level in the aftermath of the GFC.*

$$\pi_1(x=0) - 2 = r_1^2(x=0) - r_1^2(x=1) + 3r_1(x=0) - 3r_1(x=1) \leq 0$$

Knowing the belief about distributions of ϵ_{d2} and ϵ_{s2}, we can calculate the believed distribution of u:

$$\begin{aligned}\tilde{\epsilon}_{d2} &\sim U(-2, 2) \\ \tilde{\epsilon}_{s2} &= 0 \\ u &= 2 - \rho + \epsilon_{d2} - \epsilon_{s2} \\ &\sim U(-\rho, 4 - \rho)\end{aligned}$$

This means the probability density u is $\frac{1}{(4-\rho)-(\rho)} = \frac{1}{4}$. Moreover, for an inflationary pressure to be possible, an upper limit for ρ must also be set:

$$
\begin{aligned}
4-\rho &> 2 \\
\rho &< 2 \\
\rho &\in (1,2)
\end{aligned}
\tag{3}
$$

Furthermore, in reality, the major central banks, even if they were not indemnified, chose to adopt contractionary monetary policy amid inflationary pressure, rather than maintaining a neutral stance to avoid financial losses. In our model, this corresponds to the case where the interest rate at the upper limit of u must be greater than 2:

$$
\begin{aligned}
i^*(x=0, u=4-\rho) &> 2 \\
2+\frac{\alpha\psi r_1}{2} &\leq 4-\rho \\
\alpha\psi r_1 &\leq 4-2\rho \\
\alpha &\leq \frac{4-2\rho}{\psi r_1}
\end{aligned}
$$

Since the values of $r_1^*(x=0)$ is not yet known, we have to further restrict this constraint by setting $r_1^*(x=0)$ to its theoretical maximum of $r_1^*(x=1)$, as per Proposition 3:

$$
\alpha \leq \frac{4-2\rho}{\psi r_1^*(x=1)}
$$

With this constraint, we can now calculate the expected utility of the central bank for the second period (EU_{B2}):

$$
\begin{aligned}
&EU_{B2}(x=0)\\
=&\int_{-\rho}^{2} U_{B2}(x=0,i_2<2)\cdot\frac{1}{4}\,du+\int_{2}^{2+\frac{\alpha\psi r_1}{2}} U_{B2}(x=0,i_2=2)\cdot\frac{1}{4}\,du\\
&+\int_{2+\frac{\alpha\psi r_1}{2}}^{4-\rho} U_{B2}(x=0,i_2>2)\cdot\frac{1}{4}\,du\\
=&\int_{-\rho}^{2} 0\cdot\frac{1}{4}\,du+\int_{2}^{2+\frac{\alpha\psi r_1}{2}} -(u-2)^2\cdot\frac{1}{4}\,du\\
&+\int_{2+\frac{\alpha\psi r_1}{2}}^{4-\rho} [-(\frac{\alpha\psi r_1}{2})^2-\alpha\psi r_1(u-\frac{\alpha\psi r_1}{2}-2)]\cdot\frac{1}{4}\,du\\
=&\int_{-\rho}^{2} 0\cdot\frac{1}{4}\,du+\int_{2}^{2+\frac{\alpha\psi r_1}{2}} -(u-2)^2\cdot\frac{1}{4}\,du\\
&+\int_{2+\frac{\alpha\psi r_1}{2}}^{4-\rho} [\frac{(\alpha\psi r_1)^2}{4}-\alpha\psi r_1(u-2)]\cdot\frac{1}{4}\,du\\
=&[-\frac{(u-2)^3}{12}]_2^{2+\frac{\alpha\psi r_1}{2}}+[\frac{(\alpha\psi r_1)^2}{16}u-\alpha\psi r_1(\frac{u^2}{8}-\frac{u}{2})]_{2+\frac{\alpha\psi r_1}{2}}^{4-\rho}\\
=&-\frac{(\frac{\alpha\psi r_1}{2})^3}{12}+[\frac{(\alpha\psi r_1)^2}{16}u-\frac{\alpha\psi r_1 u}{8}(u-4)]_{2+\frac{\alpha\psi r_1}{2}}^{4-\rho}\\
=&-\frac{(\alpha\psi r_1)^3}{96}-[\frac{(\alpha\psi r_1)^2}{16}(2+\frac{\alpha\psi r_1}{2})-\frac{\alpha\psi r_1(2+\frac{\alpha\psi r_1}{2})}{8}(-2+\frac{\alpha\psi r_1}{2})]+[\frac{(\alpha\psi r_1)^2}{16}(4-\rho)+\frac{\alpha\psi r_1(4-\rho)}{8}\rho]\\
=&-\frac{(\alpha\psi r_1)^3}{96}-[\frac{(\alpha\psi r_1)^2}{16}(2+\frac{\alpha\psi r_1}{2})-\frac{\alpha\psi r_1(\frac{(\alpha\psi r_1)^2}{4}-4)}{8}]+[\frac{(\alpha\psi r_1)^2}{4}-\frac{(\alpha\psi r_1)^2}{16}\rho+\frac{\alpha\psi r_1\rho}{2}-\frac{\alpha\psi r_1\rho^2}{8}]\\
=&-\frac{(\alpha\psi r_1)^3}{96}-\frac{(\alpha\psi r_1)^2}{8}-\frac{(\alpha\psi r_1)^3}{32}+\frac{(\alpha\psi r_1)^3}{32}-\frac{\alpha\psi r_1}{2}+\frac{(\alpha\psi r_1)^2}{4}-\frac{(\alpha\psi r_1)^2}{16}\rho+\frac{\alpha\psi r_1\rho}{2}-\frac{\alpha\psi r_1\rho^2}{8}\\
=&-\frac{(\alpha\psi r_1)^3}{96}-\frac{(\alpha\psi r_1)^2}{8}+\frac{(\alpha\psi r_1)^2}{4}-\frac{(\alpha\psi r_1)^2}{16}\rho-\frac{\alpha\psi r_1}{2}+\frac{\alpha\psi r_1\rho}{2}-\frac{\alpha\psi r_1\rho^2}{8}\\
=&-\frac{(\alpha\psi r_1)^3}{96}+\frac{2-\rho}{16}(\alpha\psi r_1)^2+\frac{-4+4\rho-\rho^2}{8}\alpha\psi r_1
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial}{\partial r_1}EU_{B2}(x=0)=&-\frac{(\alpha\psi)^3 r_1^2}{32}+\frac{2-\rho}{8}(\alpha\psi)^2 r_1+\frac{-4+4\rho-\rho^2}{8}\alpha\psi\\
\frac{\partial}{\partial r_1}EU_{B}(x=0)=&-\frac{(\alpha\psi)^3 r_1^2}{32}+\frac{2-\rho}{8}(\alpha\psi)^2 r_1+\frac{-4+4\rho-\rho^2}{8}\alpha\psi-2(1-\rho+\psi(r_1+2)r_1+r_1)=0\\
=&-\frac{(\alpha\psi)^3 r_1^2}{32}+\frac{2-\rho}{8}(\alpha\psi)^2 r_1+\frac{-(2-\rho)^2}{8}\alpha\psi-2+2\rho-2\psi r_1^2-4\psi r_1-2r_1=0\\
0=&(-\frac{(\alpha\psi)^3}{32}-2\psi)r_1^2+(\frac{2-\rho}{8}(\alpha\psi)^2-4\psi-2)r_1-\frac{(2-\rho)^2}{8}\alpha\psi-2+2\rho
\end{aligned}
$$

For the convenience of analytical results and to set a justifiable domain for α in later simulation, we constrain α so that the the expected utility of the bank (B) without indemnity is concave in r_1. This is equivalent to the condition that the partial derivative above is decreasing in $r_1 \geq 0$:

$$\begin{aligned}\frac{2-\rho}{8}(\alpha\psi)^2 - 4\psi - 2 \leq 0\\ \frac{2-\rho}{8}(\alpha\psi)^2 \leq 4\psi + 2\\ (\alpha\psi)^2 \leq \frac{8(4\psi+2)}{2-\rho}\\ 0 < \alpha \leq \frac{\sqrt{\frac{8(4\psi+2)}{2-\rho}}}{\psi}\end{aligned}$$

This means that we can find an analytical solution for r_1:

$$\bar{r}_1^*(x=0) = \frac{(\frac{2-\rho}{8}(\alpha\psi)^2 - 4\psi - 2) + \sqrt{(\frac{2-\rho}{8}(\alpha\psi)^2 - 4\psi - 2)^2 - 2(\frac{(\alpha\psi)^3}{16} + 4\psi)(\frac{(2-\rho)^2}{8}\alpha\psi + 2 - 2\rho)}}{\frac{(\alpha\psi)^3}{16} + 4\psi}$$

$$r_1^*(x=0) = \begin{cases} 0 \text{ if } \bar{r}_1^*(x=0) \leq 0 \\ \bar{r}_1^*(x=0) \text{ if } 0 < \bar{r}_1^*(x=0) < r_1^*(x=1) \\ r_1^*(x=1) \text{ if } \bar{r}_1^*(x=0) \geq r_1^*(x=1) \end{cases}$$

Now we can calculate the utility of government (G) without indemnity in period 1 (U_{G1}):

$$\begin{aligned}U_{G1} &= g_1 = \pi_1\\ &= 3 - f_1 - i_1\\ &= 3 - \rho + p_1 + r_1\\ &= 3 - \rho + r_1 - \psi(i_1 - 2)r_1\\ &= 3 - \rho + r_1 + \psi(r_1 + 2)r_1\end{aligned}$$

We now calculate the expected utility of government (G) without indemnity in period 2 (EU_{G2}). As previously demonstrated, the government always chooses the same level of total fiscal surplus ($F = \rho$). The variation in its utility therefore depends on the level of real growth (g_2), which in our simplified model is believed to equal the level of inflation ($\tilde{g}_2 = \tilde{\pi}_2$).

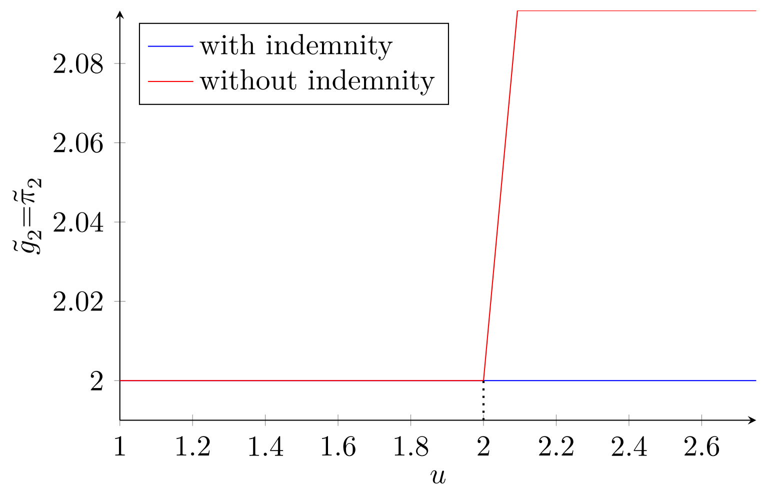

Figure 21: Illustration of the perceived second-period inflation and growth ($\tilde{g}_2 = \tilde{\pi}_2$) with respect to u ($\alpha = 4$, $\rho = 1.25$)

As shown in Figure 21, the growth and inflation rates are kept at 2% in the second period in case of deflationary pressure ($u \leq 2$). They rise with u when inflationary pressure is low $2 < u \leq 2 + \frac{\alpha\psi r_1}{2}$; this corresponds to the scenario when monetary policy (i) kept at 2 in Figure 20. When $u > 2 + \frac{\alpha\psi r_1}{2}$, the growth and inflation rates are kept at a constant level of $2 + \frac{\alpha\psi r_1}{2}$; this corresponds to the scenario when monetary policy (i) rises up again to tackle high inflationary pressure in Figure 20.

This is referred to as the *inflationary bias* in this paper.

Proposition 5 (Inflationary bias without indemnity)**.** *If the central bank decided to implement QE ($r_1 > 0$) without indemnity ($x = 0$), there would be an inflationary bias under inflationary pressure. The extent of this bias is proportional to the first period risk level (r_1) and the central bank's financial sensitivity (α)*

$$\max \tilde{\pi}_2 - 2 = \frac{\alpha\psi r_1(x = 0)}{2}$$

As such, we can calculate the expected utility of government (G) without indemnity in period 2 (EU_{G2}):

$$\begin{aligned}
EU_{G2} =& \int_{-s}^{2} 2 \cdot \frac{1}{4} du + \int_{2}^{2+\frac{\alpha\psi r_1}{2}} u \cdot \frac{1}{4} du + \int_{2+\frac{\alpha\psi r_1}{2}}^{4-\rho} (2 + \frac{\alpha\psi r_1}{2}) \cdot \frac{1}{4} du \\
=& (1 + \frac{1}{2}\rho) + [\frac{1}{8}u^2]_2^{2+\frac{\alpha\psi r_1}{2}} + [\frac{1}{2}u + \frac{\alpha\psi r_1 u}{8}]_{2+\frac{\alpha\psi r_1}{2}}^{4-\rho} \\
=& (1 + \frac{1}{2}\rho) + (\frac{1}{2} + \frac{\alpha\psi r_1}{4} + \frac{(\alpha\psi r_1)^2}{32} - \frac{1}{2}) - (1 + \frac{\alpha\psi r_1}{4} + \frac{\alpha\psi r_1}{4} + \frac{(\alpha\psi r_1)^2}{16}) \\
& + (2 - \frac{\rho}{2} + \frac{\alpha\psi r_1}{2} - \frac{\alpha\psi r_1}{8}\rho) \\
=& (1 + \frac{1}{2}\rho) + (\frac{\alpha\psi r_1}{4} + \frac{(\alpha\psi r_1)^2}{32}) - (1 + \frac{\alpha\psi r_1}{2} + \frac{(\alpha\psi r_1)^2}{16}) + (2 - \frac{\rho}{2} + \frac{\alpha\psi r_1}{2} - \frac{\alpha\psi r_1}{8}\rho) \\
=& \frac{(\alpha\psi r_1)^2}{32} - \frac{(\alpha\psi r_1)^2}{16} + \frac{\alpha\psi r_1}{4} - \frac{\alpha\psi r_1}{2} + \frac{\alpha\psi r_1}{2} - \frac{\alpha\psi r_1}{8}\rho + 1 - 1 + 2 + \frac{1}{2}\rho - \frac{1}{2}\rho \\
=& - \frac{(\alpha\psi r_1)^2}{32} + \frac{\alpha\psi r_1}{4} - \frac{\alpha\psi r_1}{8}\rho + 2
\end{aligned}$$

Hence, the expected utility of government (G) without indemnity is:

$$\begin{aligned}
EU_G(x = 0) &= U_{G1} + EU_{G2} \\
&= 3 - \rho + r_1 + \psi(r_1 + 2)r_1 - \frac{(\alpha\psi r_1)^2}{32} + \frac{\alpha\psi r_1}{4} - \frac{\alpha\psi r_1}{8}\rho + 2 \\
&= 5 - \rho + r_1 + \psi(r_1 + 2)r_1 - \frac{(\alpha\psi r_1)^2}{32} + \frac{\alpha\psi r_1}{4} - \frac{\alpha\psi r_1}{8}\rho
\end{aligned}$$

A.3. Decision to Indemnify

The government will indemnify if the expected utility of government with indemnity is greater than the expected utility of government without indemnity:

$$x = \begin{cases} 1 \text{ if } EU_G(x = 1) > EU_G(x = 0) \\ 0 \text{ otherwise} \end{cases}$$

A.4. Further Details on Numerical Evalutaion

This section describes the Numerical Evaluation process in detail. Note that we use $\psi = 1$ throughout the evaluation.

We first calculate the risk levels under indemnity:

$$\begin{aligned} &r^*(x=1) = r_1^*(x=1) = r_2^*(x=1) \\ =&\frac{-(2\psi+1)+\sqrt{(2\psi+1)^2-4\psi(1-\rho)}}{2\psi} \end{aligned}$$

We then calculate the risk levels without indemnity:

$$\bar{r}_1^*(x=0) = \frac{(\frac{2-\rho}{8}(\alpha\psi)^2-4\psi-2)+\sqrt{(\frac{2-\rho}{8}(\alpha\psi)^2-4\psi-2)^2-2(\frac{(\alpha\psi)^3}{16}+4\psi)(\frac{(2-\rho)^2}{8}\alpha\psi+2-2\rho)}}{\frac{(\alpha\psi)^3}{16}+4\psi}$$

$$r_1^*(x=0) = \begin{cases} 0 \text{ if } \bar{r}_1^*(x=0) \leq 0 \\ \bar{r}_1^*(x=0) \text{ if } 0 < \bar{r}_1^*(x=0) < r_1^*(x=1) \\ r_1^*(x=1) \text{ if } \bar{r}_1^*(x=0) \geq r_1^*(x=1) \end{cases}$$

With this information, we are able to calculate the expected utilities of the government with and without indemnity:

$$\begin{aligned} &EU_G(x=1) = 4 \\ &EU_G(x=0) = 5-\rho+r_1+\psi(r_1+2)r_1-\frac{(\alpha\psi r_1)^2}{32}+\frac{\alpha\psi r_1}{4}-\frac{\alpha\psi r_1}{8}\rho \end{aligned}$$

The government indemnifies the central bank if the expected utility from doing so is greater:

$$x = \begin{cases} 1 \text{ if } EU_G(x=1) > EU_G(x=0) \\ 0 \text{ otherwise} \end{cases}$$

We then calculate the relevant economic outcomes in period 1:

$$i_1(x=0) = -r(x=0)$$
$$i_1(x=1) = -r(x=1)$$
$$p_1(x=0) = -\psi(i_1(x=0)-2)r(x=0)$$
$$p_1(x=1) = -\psi(i_1(x=1)-2)r(x=1)$$
$$\pi_1(x=0) = g_1(x=0) = 3-(\rho - p_1(x=0)) - i_1(x=0)$$
$$\pi_1(x=1) = g_1(x=1) = 2$$

We then calculate the relevant economic outcomes in period 2:

$$i_2(x=0) = \begin{cases} 2 \text{ if } 4-\rho \leq 2+\frac{\alpha\psi r(x=0)}{2} \\ 4-\rho+\frac{\alpha\psi r(x=0)}{2} \text{ if } 4-\rho > 2+\frac{\alpha\psi r(x=0)}{2} \end{cases}$$
$$i_2(x=1) = \frac{4-\rho+2\psi r(x=1)}{\psi r(x=1)+1}$$
$$p_2(x=0) = -\psi(i_2(x=0)-2)r(x=0)$$
$$p_2(x=1) = -\psi(i_2(x=1)-2)r(x=1)$$
$$\pi_2(x=0) = 6-\rho-i_2(x=0)$$
$$\pi_2(x=1) = 2$$
$$g_2(x=0) = \pi_2(x=0)-2$$
$$g_2(x=1) = \pi_2(x=1)-2$$

B. More Information on Sample Selection

The following table discusses all countries in the European Union (EU) and the Organisation for Economic Co-operation and Development (OECD), which constitute the potential pool for the sample. The table provides justification for the exclusion of certain countries from the sample of the dataset.

Table 5: List of EU and OECD countries and the reasons for exclusion

Country	Inclusion	Reason for exclusion
Australia	No	Late QE (2020)
Austria	Yes	
Belgium	Yes	
Bulgaria	No	No QE
Canada	No	Late QE (2020)
Chile	No	Late QE (2020)
Colombia	No	Late QE (2020)
Costa Rica	No	No QE
Croatia	No	Late QE (2020)
Cyprus	Yes	
Czech Republic	No	No QE
Denmark	No	No QE
Estonia	Yes	
Finland	Yes	
France	Yes	
Germany	Yes	
Greece	Yes	
Hungary	No	Late QE (2017)
Iceland	No	No QE
Ireland	Yes	
Israel	Yes	
Italy	Yes	
Japan	Yes	

Country	Inclusion	Reason for exclusion
Korea (Republic of)	No	No QE
Latvia	Yes	
Lithuania	Yes	
Luxembourg	Yes	
Malta	Yes	
Mexico	No	No QE
Netherlands	Yes	
New Zealand	No	Late QE (2020)
Norway	No	No QE
Poland	No	Late QE (2020)
Portugal	Yes	
Romania	No	Late QE (2020)
Slovak Republic	Yes	
Slovenia	Yes	
Spain	Yes	
Sweden	Yes	
Switzerland	No	Extreme effect of exchange rate on central bank profit. See Reis (2015).
Turkiye	No	Hyperinflation
United Kingdom	Yes	
United States	Yes	

C. List of Central Bank Financial Statement Data Sources

Country	Financial statement source(s) for manual collection
Austria	https://www.oenb.at/en/Publications/Oesterreichische-Nationalbank/Annual-Report.html
Belgium	https://www.nbb.be/en/publications-and-research/economic-and-financial-publications/annual-reports
Cyprus	https://www.centralbank.cy/en/publications/annual-report
Estonia	https://www.eestipank.ee/en/publications/annual-report
Finland	https://www.suomenpankki.fi/en/media-and-publications/publications/annual-report/
France	https://www.banque-france.fr/en/publications-and-research/our-main-publications/annual-reports
Germany	https://www.bundesbank.de/en/publications/reports/annual-reports
Greece	https://www.bankofgreece.gr/en/news-and-media/financial-statements/annual-accounts
Ireland	https://www.centralbank.ie/publication/corporate-reports/annual-reports
Israel	https://www.boi.org.il/en/communication-and-publications/regular-publications/bank-of-israel-annual-report/
Italy	https://www.bancaditalia.it/pubblicazioni/relazione-annuale/index.html?com.dotmarketing.htmlpage.language=1
Japan	None (all data are from S&P Capital IQ Pro)
Latvia	https://www.bank.lv/en/about-us/operations/annual-reports
Lithuania	https://www.lb.lt/en/reviews-and-publications/category.38/series.204

Country	Financial statement source(s) for manual collection
Luxembourg	https://www.bcl.lu/en/publications/Annual-reports/index.html
Malta	https://www.centralbankmalta.org/annual-reports
Netherlands	None (the data from the DNB website are even more incomplete than S&P Capital IQ Pro)
Portugal	https://www.bportugal.pt/en/page/list-publications-banco-de-portugal
Slovak Republic	https://nbs.sk/en/publications/annual-report/
Slovenia	https://www.bsi.si/en/publications/annual-reports/banka-slovenijes-annual-report
Spain	https://www.bde.es/wbe/en/publicaciones/informes-memorias-anuales/informe-anual/informe-anual-2010.html
Sweden	https://www.riksbank.se/en-gb/press-and-published/publications/annual-report/
United Kingdom	https://www.bankofengland.co.uk/news/publications
United States	https://www.federalreserve.gov/aboutthefed/audited-annual-financial-statements.htm

D. Placebo Test of Pre-treatment Trends

As mentioned in the Empirical Strategy section, a placebo test of pre-treatment trends commonly serves as diagnostics for potential violation of assumptions among the family of SCM-inspired estimators. The idea is akin to the test of parallel pre-treatment trends for the difference-in-differences (DiD) design.

To this end, the pre-treatment period (1999-2008) is divided into two parts by the *placebo* treatment date of 2004. The DM-LFM is trained on data before 2004 and expected to predict the outcomes (BoE profit as percentage of UK GDP) between 2004 and 2008. A null result should be found for the placebo ATT, otherwise violations of the DM-LFM model assumptions are likely which would invalidate our main results.

Similar to the main results, results for estimations with and without covariates are reported in Table 7. The predicted and actual trends of BoE profits from the placebo estimation with covariates are visualised in Figure 22. It can be seen that the placebo ATT is close to zero (-0.05) and statistically very insignificant ($p = 0.58$). We should therefore be more confident in the validity of our main analysis results.

Table 7: Results for DM-LFM analysis of placebo impact of indemnity on BoE profits

	(1)	(2)
ATT	−0.035	−0.049
	[−0.215, 0.145]	[−0.236, 0.137]
Publicly traded		0.000
		[−0.009, 0.011]
Euro Area		−0.003
		[−0.020, 0.008]
Reappointability		0.001
		[−0.014, 0.017]
Observations	226	226
Treated Units	1	1
Control Units	22	22

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

95% equal-tailed Credible Intervals in square brackets.

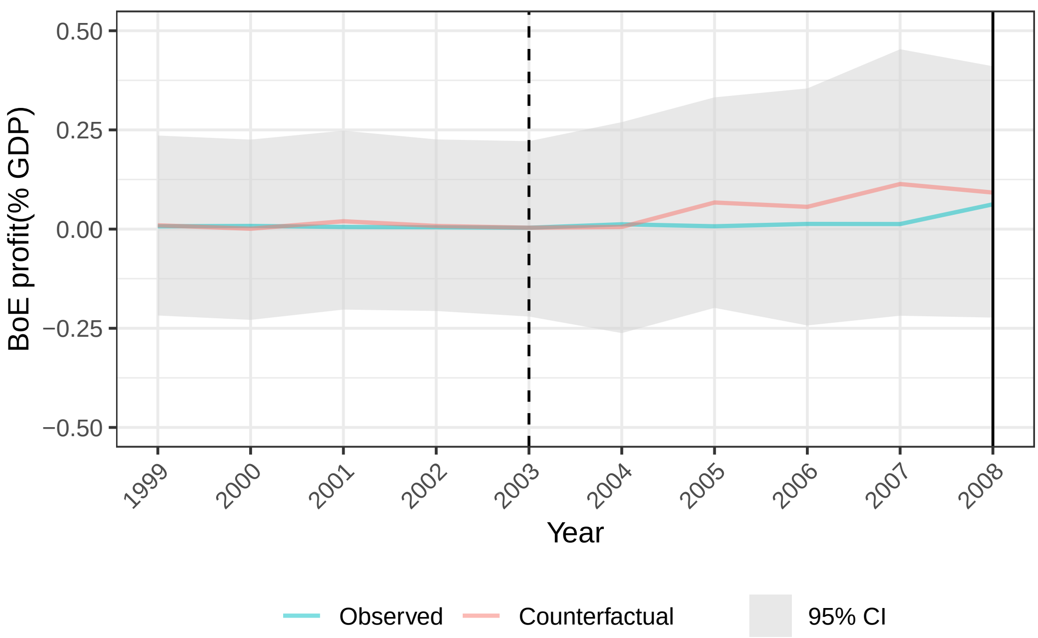

Figure 22: Estimated counterfactual and actual trends of BoE profits as % of UK GDP (placebo treatment at 2004)

E. DM-LFM MCMC Diagnostics

Due to the complexity of the Bayesian estimation of the DM-LFM, the estimator relies on Markov Chain Monte Carlo (MCMC) algorithm to approximate the posterior distribution of the ATT for inference. This appendix provides diagnostic information on the Maokov Chain Monte Carlo draws. Table 8 shows the summary statistics for the ATTs in the deflationary and inflationary periods; Table 9 show the corresponding quantiles. Figure 23 and Figure 24 trace the simulation draws. It can be seen from these figures that there is no serious serial correlation that concerns further thinning. Figure 25 and Figure 26 plot the distribution density of such draws. It can be seen that the draws are normally shaped, which implies that we can be confident that they are good approximations of the target distributions.

Table 8: Summary table of DM-LFM MCMC draws for ATT

Period	Start year	End year	Mean	SD	Naive SE	Time-series SE
Deflationary	2009	2021	0.391988	0.144423	0.001444	0.002835
Inflationary	2022	2023	-0.707911	0.266830	0.002668	0.004027

Table 9: Quantiles of DM-LFM MCMC draws for ATT

Period	Start year	End year	2.5%	25%	50%	75%	97.5%
Deflationary	2009	2021	0.104079	0.295288	0.391682	0.489288	0.673773
Inflationary	2022	2023	-1.236136	-0.881064	-0.706616	-0.533039	-0.182563

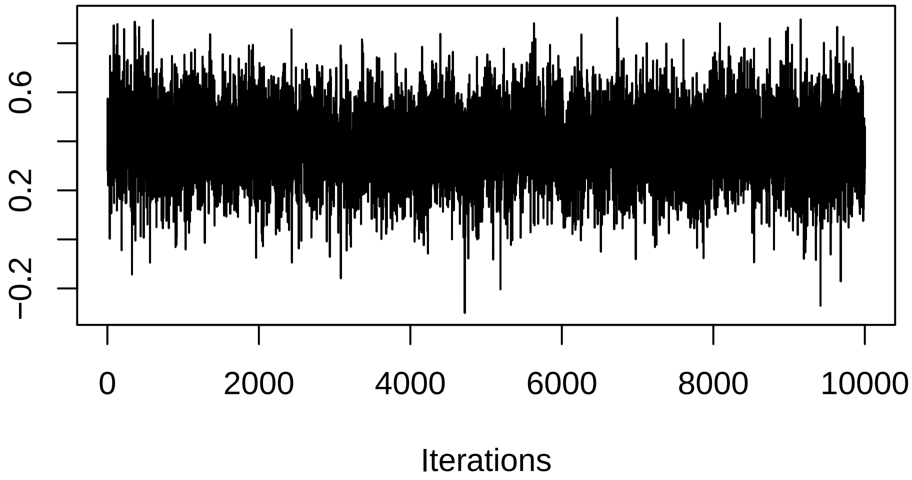

Figure 23: Trace plot for ATT MCMC simulations (Deflationary period 2009-2021).

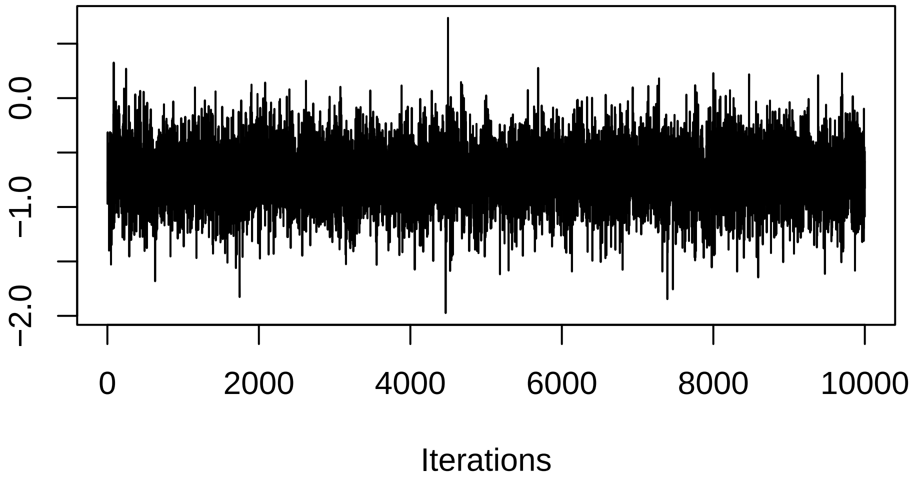

Figure 24: Trace plot for ATT MCMC simulations (Inflationary period 2022-2023).

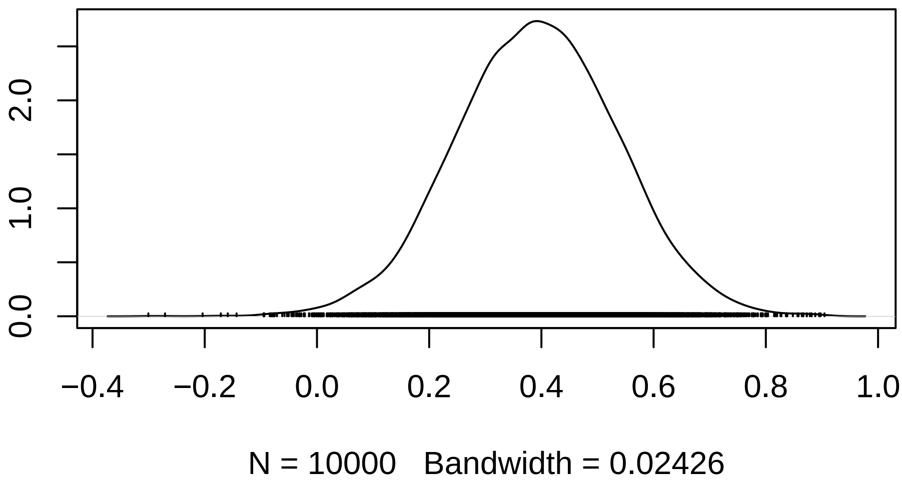

Figure 25: Density plot for ATT MCMC simulations (Deflationary period 2009-2021).

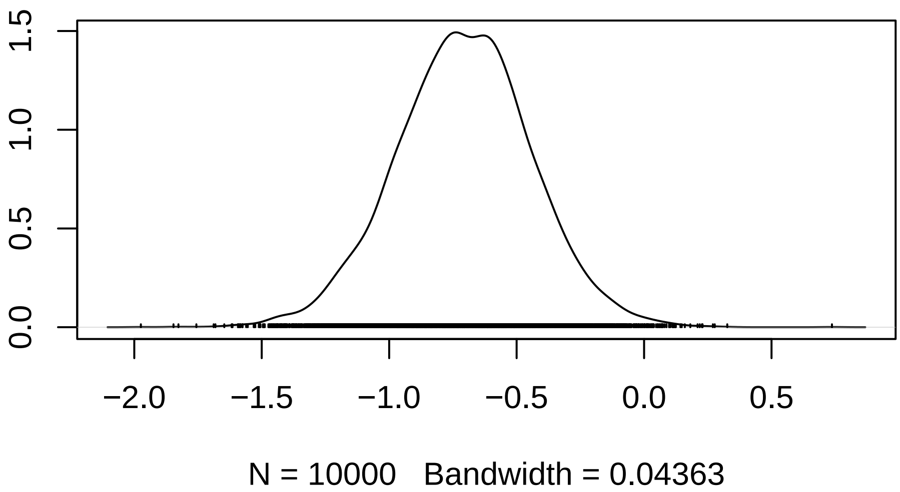

Figure 26: Density plot for ATT MCMC simulations (Inflationary period 2022-2023).

F. Results with Alternative Estimators

This section replicates the main results with alternative estimators as robustness checks. The selected estimators are all designed for estimating the effect of a binary treatment with panel data, hence potential alternatives to the DM-LFM. In addition to the familiar difference-in-differences (DiD) estimator first employed by Card & Krueger (2000) and the Synthetic Control Method (SCM) proposed by Abadie & Gardeazabal (2003), we also use the synthetic difference-in-differences estimator that combines the desirable characteristics of the two (Arkhangelsky et al., 2021). However, none of the three estimators provides valid inference as pointed out by Pang et al. (2021). Therefore, one should pay more attention to the point estimates of the Average Treatment Effect on the Treated (ATT) rather than the *p* values. The results are shown in Table 10 alongside the main DM-LFM results with covariates from Columns (2) and (4) of Table 3. A comparison of the estimated treatment effects over time by estimator is visualised in Figure 27.

Please note that the three alternative estimators have smaller observations and do not include covariates because the R package[14] used for their estimations do not support such features. For the SDiD estimates, *p* values are generated using the placebo variance estimation[15], which tend to under-reject the null hypothesis. For the DiD estimates, *p* values are calculated using clustered standard errors, which tend to over-reject. For the SCM, the permutation test *p* values are reported[16].

[14] see Arkhangelsky (2023).
[15] See Algorithm 4 of Arkhangelsky et al. (2021).
[16] see Abadie (2021) for further details on the permutation inferential procedure.

Table 10: Results with alternative estimators for the impact of indemnity on BoE profits

	SDiD	DiD	SCM	DM-LFM
ATT^{def}	0.419	0.409***	0.435	0.392**
	(0.189)	(<0.001)	(0.143)	(0.009)
ATT^{inf}	−0.559	−0.516**	−0.653+	−0.708*
	(0.331)	(0.003)	(0.095)	(0.011)
Observations	504	504	504	586
Treated Units	1	1	1	1
Control Units	20	20	20	23

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

p values are reported in parentheses.

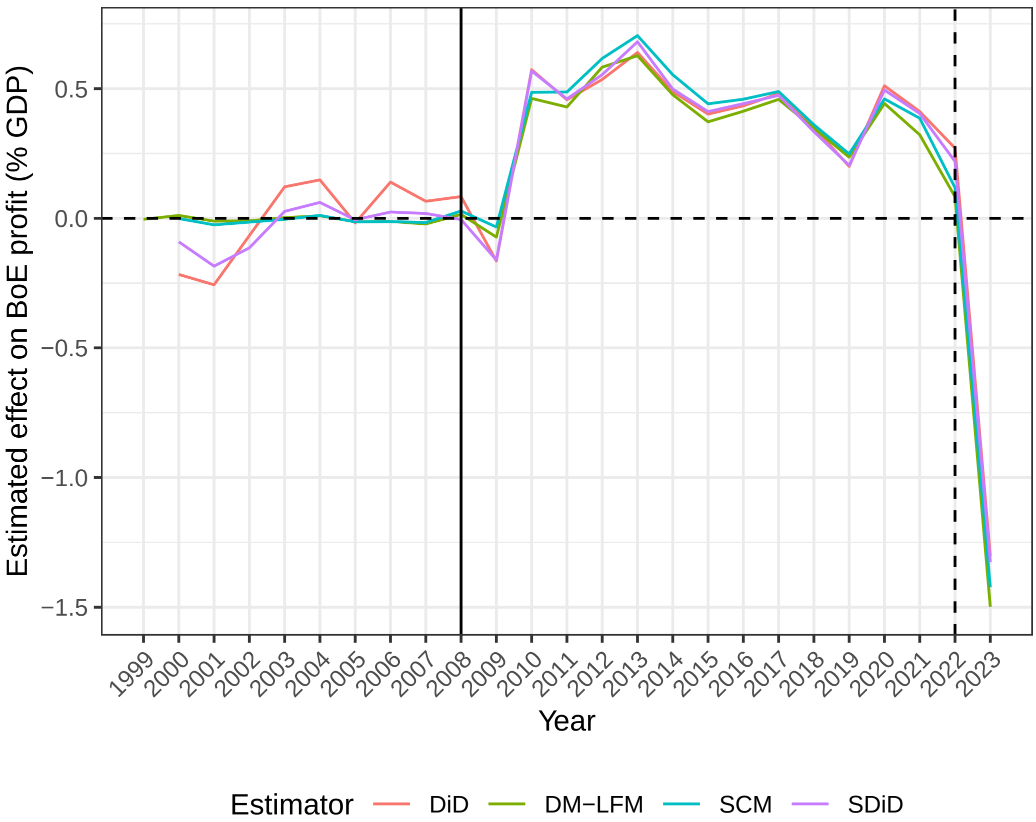

Figure 27: Estimated effects of indemnity on BoE profits by estimator

G. Results with Early Treatment

This appendix replicates the main results but bring forwards the time of treatment from 2009 to 2004 to examine the sensitivity of the results to potential anticipation effects and the GFC. The results are shown in contrast to the original in Table 11. It can be seen that the point estimates remain largely the same but the estimated effects of the indemnity on profits lose their statistical significance at 5%. This is likely due to the lost information between 2006 and 2008 and a short pre-treatment period of 5 years (1999-2003), which limit the precision of the estimates. The stable point estimates should be sufficient to prove the robustness of our main results.

Table 11: Results with early treatment (2005) for the impact of indemnity on BoE profits

	Deflationary (2009-2021)		Inflationary (2022-2023)	
	Early	Original	Early	Original
ATT	0.345+	0.392**	−0.765+	−0.708*
	[−0.039, 0.731]	[0.104, 0.674]	[−1.556, 0.018]	[−1.236, −0.183]
Publicly traded	0.001	0.001	−0.003	−0.004
	[−0.007, 0.010]	[−0.006, 0.011]	[−0.031, 0.013]	[−0.032, 0.013]
Euro Area	0.000	0.000	−0.003	−0.003
	[−0.006, 0.008]	[−0.006, 0.009]	[−0.025, 0.012]	[−0.024, 0.013]
Reappointability	0.000	0.000	−0.001	0.000
	[−0.004, 0.006]	[−0.004, 0.006]	[−0.013, 0.010]	[−0.012, 0.009]
Observations	586	586	586	586
Treated Units	1	1	1	1
Control Units	23	23	23	23

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

95% equal-tailed Credible Intervals in square brackets.

H. Additional Plots for the Supplementary Tests

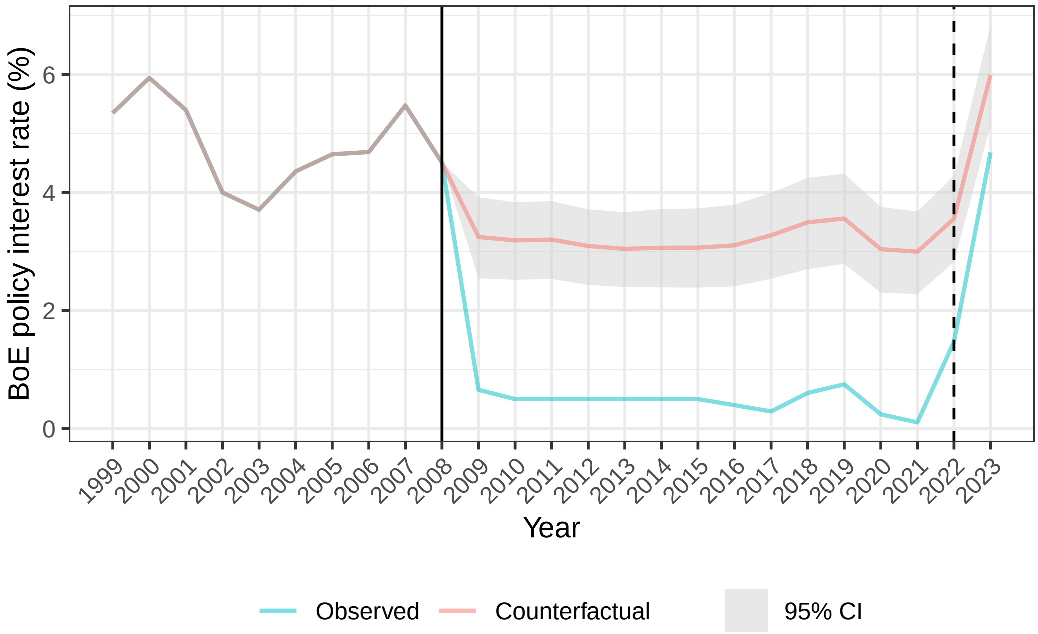

Figure 28: Estimated counterfactual and actual trends of BoE policy interest rate

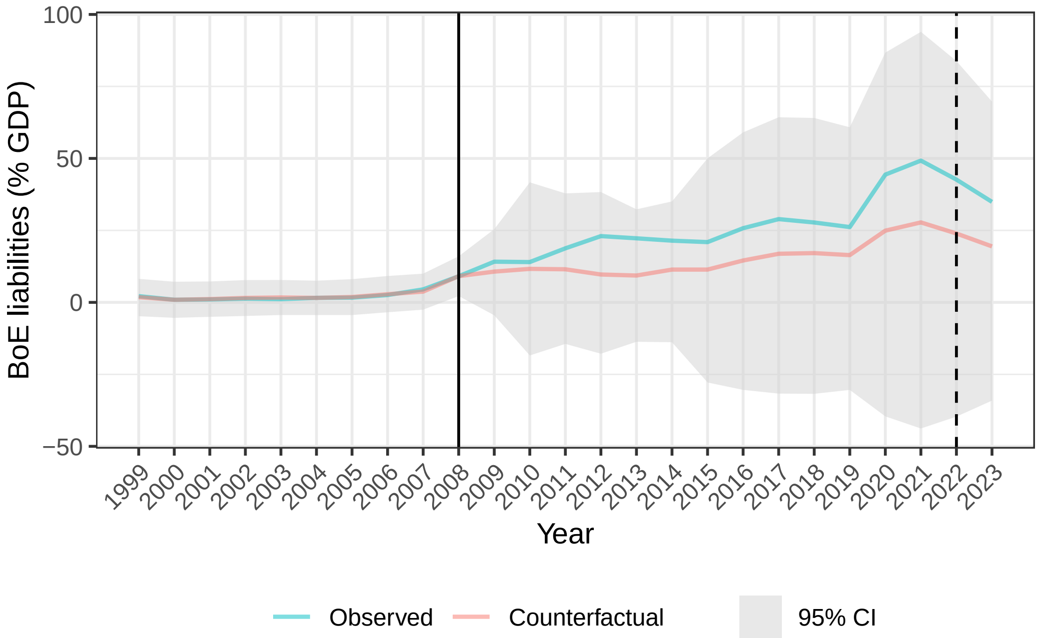

Figure 29: Estimated counterfactual and actual trends of BoE liabilities