Listed Real Estate as an Inflation Hedge across Regimes

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Abstract

This paper investigates the inflation hedging capability of listed real estate (LRE) companies from 1990 to 2021 in four economies: the US, the UK, Australia, and Japan. By using a Markov switching vector error correction model (MS-VECM), we identify that the short-term hedging ability moves towards being negative or zero during crisis periods. In non-crisis periods, LRE provides good protection against inflation. In the long term, LRE provides a good hedge against expected inflation, and shows a superior inflation hedging ability than stocks. Additionally, we propose inflation-hedging portfolios by minimizing the expected shortfall. This inflation-hedging portfolio allocation methodology suggests that listed real estate stocks should play a significant role in investor portfolios.

Keywords: Inflation Hedging, Listed Real Estate Companies, Markov-Switching, VECM, Inflation-Hedging Portfolio

JEL Codes: G11, G15

1. Introduction

Due to central banks' response to the COVID-19 pandemic and a huge stimulus that increased levels of money supply, together with the subsequent consequences of military confrontations, the world is experiencing large price swings in energy and commodity markets and a possibility of a global recession. In September 2022, the year-on-year US inflation rose to 8.2%. In response, Central banks, such as the Federal Reserve or the Bank of England, quickly tightened their monetary policy, attempting to curb the massive inflation by imposing higher interest rates. As of the end of 2022, the engaged policy does not appear to be adequate in terms of curbing inflationary pressure; hence further tightening of the policy is likely. With those inflationary pressures, it becomes more important to take a fresh look at real estate's inflation hedging capability by using state-of-the-art estimation techniques. Against this background, this paper aims to broaden our understanding of the inflation-hedging characteristics of real estate relative to other asset classes. Such properties should particularly benefit long-term institutional investors (especially pension funds, which usually operate under inflation-linked liability constraints) and individual investors, for whom real-term capital preservation is a minimal objective.

Some assets are more suited to hedging inflation than others, depending on the country, sector, or time horizon. Real estate has often been perceived as the asset class which can deliver an adequate inflation hedge due to its two mechanisms: (1) Rent or lease payments (tenant leases contain rent escalation clauses and/or pass expense increases through to tenants) and (2) Land values and building costs typically rise with inflation (Ruhmann and Woolston, 2011). However, empirical evidence, especially for listed real estate, is mixed. Gyourko and Linneman (1988) find that REITs may protect against expected inflation but not against unexpected inflation. In contrast, Park et al. (1990) find that equity REITs are negatively associated with expected and unexpected inflation. Titman and Warga (1989) argue that REITs act as a paradoxical hedge against inflation because they are catalysts rather than reactants to a change in inflation rates. In particular, the contemporaneous return on equity REITs anticipates future inflation rates. According to Glascock et al. (2002), the observed negative relationships between REIT returns and inflation are a result of changes in monetary policies.

This paper extends the existing literature in two ways. First, we allow for non-linear inflation-hedging characteristics. Most previous literature combines the Fama and Schwert (1977) framework (which distinguishes the expected and unexpected inflation components) and the cointegration technique (which differentiates long-term equilibrium and short-term dynamics) (e.g., Hoesli and Hamelink, 1997; Liu et al., 1997; Hoesli et al., 2008; and many others). However, all these studies assume a stable equilibrium, which may be violated by the change in monetary policy and business cycles. For instance, Glascock et al. (2002) show that the relation between REIT returns and inflation can be influenced by monetary policies. Demary and Voigtländer (2009) argue that the office sector partially protects against inflation because worsening economic perspectives (inflation) alleviate the demand for office space. National and Low (2000) find that the inflation-hedging characteristics of assets differ in different inflationary environments, indicating time-varying inflation-hedging characteristics. Given the long-lasting low-interest-rate environment and the increased uncertainty in the global economy, the inflation-hedging characteristics of real estate may differ from previous periods.

Second, this project compares the hedging characteristics across asset classes, including real estate, stocks, silver, and gold, using an inflation-hedging portfolio. The hedging ability of other assets, such as infrastructure (Bitsch et al., 2010; Wurstbauer and Schäfers, 2015), stocks (Bodie, 1976), gold (Lucey et al., 2017), and white precious metals (Bampinas and Panagiotidis, 2015; Bilgin et al., 2018) has been intensively studied in the literature. Regarding real estate, many studies also exist, as highlighted above, and the literature has often focused on whether differences exist across property types (Hoesli, 1994; Ganesan and Chiang, 1998; National and Low, 2000). However, there is still a lack of conclusive evidence regarding the inflation-hedging capabilities across different asset classes, i.e., in a diversified portfolio. Most of the research has been done within a mean-variance framework. However, using variance as the risk measure may not be what corresponds best to investors' objectives, as variance treats both upside and downside risk as the same. Because investors usually consider the upside risk to be favorable, the use of variance appears to be unsuitable (Sukcharoen and Leatham, 2016). In reality, listed real estate returns are non-normal (Hutson and Stevenson, 2010; Giannotti and Mattarocci, 2013). Using listed real estate (LRE) performance in the EU area, Lizieri et al. (2022) also show that the mean-variance approach often yields extreme and unrealistic asset allocations to listed real estate. Given that investors may only consider downside risk, we use a more realistic measurement of risk – the expected shortfall, which focuses on the risk of being far below the expected real return (i.e., the downside risk). A shortfall probability risk measure for portfolio optimizations has been conducted before, for example, by Leibowitz and Henriksson (1989), Leibowitz and Kogelman (1991), Lucas and Klaassen (1998), Smith and Gould (2007), and Brière and Signori (2012). In this paper, we apply this measurement to construct an inflation-hedging portfolio.

Using 1990 to 2021 monthly return data for LRE companies for four economies, our paper confirms the effectiveness of listed real estate to hedge against inflation. LRE assets provide a reliable hedge against inflation in the long term, but mainly against its expected component. One of the reasons for this can perhaps be attributed to the fact that commercial leases are often inflation-adjusted, resulting in a positive adjustment in the capital value. In all four regions, listed real estate shows long-term positive inflation-hedging capability against expected inflation. In Japan, we also see long-term positive inflation hedging effectiveness against unexpected inflation. Further, in non-crisis periods, LRE may provide an adequate level of protection against inflation in the short term. However, the level of protection decreases during periods of economic turmoil. Finally, we demonstrate that LRE can play a significant role in the inflation-hedging portfolio of an investor. The average allocations for the US, UK, Australia, and Japan over the entire period are 6.35%, 19.21%, 48.81%, and 16.02%, respectively. The inflation-hedging portfolio also provides a higher risk-adjusted return than the mean-variance approach for the US, UK, and Japan.

The remainder of the paper is organized as follows. Section 2 discusses the literature. We next discuss the data and methods that we use to test the inflation-hedging ability of the various asset classes, followed by the presentation of our results. The subsequent section discusses inflation-hedging portfolios and compares those with traditional mean-variance portfolios. A final section concludes.

2. Literature Review

There have been numerous studies examining various aspects of LRE's ability to serve as an inflation hedge. One strand of research focuses on protecting against expected and unexpected inflation in the short run (e.g., Chen and Tzang, 1988; Gyourko and Linneman, 1998; Murphy and Kleiman, 1989; Titman and Warga, 1989; Chan et al., 1990; Park et al., 1990; Yobaccio et al., 1995; Hardin et al., 2012; Fang et al., 2022; and Connolly and Stivers, 2022), while others investigate the long-term relationship using cointegration techniques (e.g., Chatrath and Liang, 1998; Glascock et al., 2002; Bahram et al., 2004; Hoesli et al., 2008; Lee and Lee, 2012; Lee et al., 2011; and Fehrle, 2022).[1] The findings are quite mixed. For instance, Chen and Tzang (1988) show that REITs can protect against inflation expectations up to some extent. Using

[1] A comprehensive summary of the existing literature can be found in Arnold and Auer (2015).

equity REITs, Chan et al. (1990) observed that real estate is less risky than stocks but that it does not offer a superior risk-adjusted return and is not a protection against inflation.

Considering the structural break in the US, Hardin et al. (2012) split the sample period into two subperiods (1980–1992 and 1993–2008). Based on dividend yield composition, the authors demonstrate, that although inflation illusion and hedging effects exist in REITs, inflation illusion appears to predominate throughout the entire sample period. The study by Fang et al. (2022) decomposes inflation into energy, food, and core components and finds that these components have markedly different properties concerning asset pricing. They demonstrate that traditional inflation hedging instruments such as stocks, currencies, commodities, and REITs only succeed in hedging energy inflation, while in the case of core inflation they tend to be less successful. Following Fang et al. (2022), Connolly and Stivers (2022) find the existence of a complex relationship between REIT equity returns. The authors establish a strongly negative relationship during phases of weaker economic growth, such as periods in the 1980s and early 1990s when stagflation was more of a concern. Similar to Hardin et al. (2012), Lee and Lee (2012) demonstrate that REITs act as a hedge against expected inflation only after a structural break in 1993, where a tax reform made large-scale investments in REITs more desirable to institutional investors. Moreover, they emphasize that the hedging capability of REITs is driven by large capitalization which implies that small-cap REITs fail to hedge against inflation once isolated from the influence of large REITs.

Glascock et al. (2002) find significant negative coefficients for general and expected inflation and a negative but non-significant coefficient for unexpected inflation. They find evidence of cointegration between REIT returns and the generic CPI as well as with its expected and unexpected components. Innovations in REIT returns lead to negative changes to both expected and unexpected inflation (which would be consistent with a real output model for a given level of money). In contrast to this, Chatrath and Liang (1998) and Bahram et al. (2004) support the traditional notion that REITs do not hedge against inflation (in contrast to direct real estate). Lee et al. (2011) investigate the long-run inflation-hedging properties of real estate stocks in East Asian developing countries. They report that LRE was not capable of hedging inflation in the long run. Fehrle (2021) investigates the hedging ability of equity and housing against inflation. He concludes that hedging ability is strongly time-dependent. Further, he notes that housing, even if marginally, is superior to equity in terms of hedging against inflation capability.

Our paper extends the existing literature by combining short-and long-run analysis with a Markov-regime switching process, which ensures that changes in monetary policies are captured over crisis and non-crisis regimes. Beckmann and Czudaj (2013) analyze whether gold possesses the ability to hedge against inflation but from a new perspective. By using data from four major global economies, they allow for non-linearities while they as well discriminate between long-run and time-varying short-run dynamics. Thus, they conduct a Markov-switching vector error correction model (MS-VECM) approach over a sample period of 1970 to 2011. Chiang et al. (2020) use a Markov switching vector autoregressive model (MS-VAR) to observe the dynamic relationships between housing market returns and stocks in the US over a sample period of 1987 to 2017. They identify a significant regime-dependent autocorrelation between stock and housing returns in both low-volatility and high-volatility regimes.

Our paper is also related to the listed real estate literature on optimal portfolio composition. An abundant amount of literature investigated portfolio optimizations in a mean-variance framework advocating that real estate holdings improve the mean-variance efficiency of a diversified portfolio (Fogler, 1984; Firstenberg et al., 1988; and Ennis and Burik, 1991). By using US REIT data, several studies demonstrate that the risk-return trade-off for U.S. investors can be mitigated (Burns and Epley, 1982; Miles and McCue, 1982; Ennis and Burik, 1991). Several studies demonstrate the benefits of diversifying into international real estate using a variety of data (Giliberto, 1990; Eichholtz, 1996; Conover et al., 2002).[2] Others focus on the performance of different asset types (Lee and Stevenson, 2005; Chiang et al., 2008; Newell and Marzuki, 2016).

Fewer studies follow the approach of expected shortfall by finding the optimal portfolio (Leibowitz and Henriksson, 1989; Leibowitz and Kogelman, 1991; Lucas and Klaassen, 1998; Smith and Gould, 2007; Brière and Signori, 2012). Only Brière and Signori (2012) determine the allocation of their portfolio by minimizing the shortfall probability, with the constraint that returns are above a target return in an inflation-hedging context. They conclude that the portfolio allocation depends on the time horizon as well as the real return target. According to Leibowitz and Kogelman (1991), downside risk is determined by the shortfall probability relative to a minimum return threshold. Providing both a threshold and a shortfall probability allows them to determine the maximum allocation to risky assets based on a shortfall constraint. Additionally, they examine how the risky asset allocation is affected by changes in volatility, equity risk premium, return thresholds, and shortfall probabilities.

3. Data and Method

3.1 Data Description

Data were compiled for the US, the UK, Japan, and Australia. We use time-series variables that are available monthly from 1990 to the end of 2021. LRE total return indexes come from the European Public Real Estate Association (EPRA). Stock total return indexes are obtained from Refinitiv Datastream. Specifically, these are the S&P 500 index for the US, the FTSE 250 index

[2] A comprehensive summary of the existing literature can be found in Worzala and Sirmans (2003).

for the UK, the Nikkei 500 index for Japan, and the S&P/ASX 200 index for Australia. Additionally, we also include the price of gold, silver, and oil in US Dollars, along with the total return index of the S&P GSCI Agriculture and the real three-month Treasury Bill rates, which is a proxy for the risk-free rate, as well as the nominal GDP.[3]

Table 1 displays the corresponding summary statistics of our data. The index values make it possible to infer that the highest average total return is recorded in the US with 11.27% annually, while Australia, the UK, and Japan follow with annual rates of 7.99%, 5.28%, and 1.36%, respectively. The US faces the highest average expected inflation rate of 2.85%, while Japan comes across with the lowest rate of 1.63%. In the US, the average unexpected inflation rate is almost equal to zero, while Japan underwent a negative rate of unexpected inflation (-1.28%).

<< Table 1 about here>>

3.2 Inflation Decomposition

We decompose the observed inflation (I_t) into expected inflation (EI_t) and unexpected inflation (UI_t). Expected inflation is the inflation element that economic agents expect to arise. It is what they have already embedded in their economic choice. Unexpected inflation is the surprise component of inflation that people haven't incorporated in their pricing and costing. We follow Fama and Schwert's (1977) framework to make the decomposition. We can define inflation based on the prior anticipated inflation rate, adjusted for differences between actual inflation and the prior expectation for each period. This leads to a univariate time series approach using Box-Jenkins / ARIMA (1,0,1) procedures to inflation:

[3] Because GDP is only available on a quarterly basis, we use temporal disaggregation. Temporal disaggregation methods are used to disaggregate and interpolate a low frequency time series to a higher frequency series. Using real GDP provides similar results.

$EI_t = \alpha + \rho I_{t-1} + \varepsilon_t,$

$\varepsilon_t = \Theta \varepsilon_{t-1} + e_t.$ (1)

where α, ρ, and Θ are parameters. The fitted value for EI_t is taken as the expected inflation and the residual, e_t, is interpreted as unexpected inflation.

3.3 Stationarity and Cointegration

Using the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test for stationarity, we show that all US series are I(1), indicating stationarity in first differences. Similarly, the series for the UK, Japan, and Australia are I(1) and therefore, in first-difference stationary. The results are shown in Appendix 1. Considering that the variables are I(1) series, we further perform the cointegration test using the trace test.

The trace test investigates the null hypothesis of *r* cointegrating vectors against the alternative hypothesis of *n* cointegrating vectors. To determine ranks and estimate coefficients, maximum likelihood estimation is used. Accordingly, likelihood ratio tests are as follows:

$$\lambda_{Trace} = -T \sum_{i=1}^{k} \ln(1 - \lambda_i) \quad (2)$$

where *T* is the sample size and λ represents the estimated eigenvalues of the reduced rank of the matrix π.[4] In the process, the sequential test strategy begins with *r*=0 and is continued until the null hypothesis for the 5% significance level cannot be rejected for the first time. The related value of *r* ultimately corresponds to the cointegration rank. In this way, there are (*n*-*r*) stochastic trends in the system.

[4] The coefficients of the co-integrating relationships (co-integration vectors) and of the error correction term are contained in the matrix π, with $\pi = \alpha\beta'$, where β represents a (n$\times$r) matrix of the r co-integrating vectors. The (n$\times$r) matrix α contains the so-called loading parameter, i.e., those coefficients that describe the contribution of the *r* long-term relationships in the individual equations.

3.4 Markov-Switching Vector Error Correction Model (MS-VECM)

By following Beckman and Czudaj (2013) a MS-VECM is used to examine the relationship between the price of assets and expected and unexpected inflation. The parameters of this model are designed to take a constant value in each regime and to shift discretely from one regime to the other with different switching probabilities. Switches between states are assumed to follow an exogenous stochastic process. Consider an M-regime *p*th order MS-VECM, which in general allows for regime shifts in the vector of intercept terms, the autoregressive part, the long-run matrix, and the variance-covariance matrix of the errors:

$$\Delta Y_t = v(s_t) + \Gamma(L)(s_t)\Delta Y_{t-1} + \Pi(s_t)Y_{t-1} + \varepsilon_t, \tag{3}$$

where Δ denotes the difference operator, Y_t represents a K-dimensional vector of time series, $Y_t = [R_t, EI_t, UI_t, X_t]$ and R_t is a vector of asset returns, including stocks, LRE, commodities, silver, and gold. X_t are economic control variables such as GDP, real interest rates, and oil prices. $v(s_t)$ denominates a K-dimensional vector of regime-dependent intercept terms. ε_t is a vector of error terms with a regime-dependent variance-covariance matrix $\sum(s_t)$, $\varepsilon_t \sim NIID(0, \sum(s_t))$. $\Gamma(L)(s_t)$ is the K×K matrix for the state-dependent short-run dynamics. (Beckman and Czudaj, 2013). The stochastic regime-generating process is assumed to be an ergodic, homogenous, and irreducible first-order Markov chain with a finite number of regimes, $s_t \in \{1, \dots, M\}$, and constant transition probabilities:

$$p_{ij} = \Pr(s_{t+1} = j | s_t = i), p_{ij} > 0, \sum_{j=1}^{M} p_{ij} = 1 \ \forall i, j \in \{1, \dots, M\}. \tag{4}$$

The first expression of Eq. (4) gives the probability of switching from regime i to regime j at time t + 1 which is independent of the history of the process. p_{ij} is the element in the ith row and the jth column of the M × M matrix of the transition probabilities P. In this paper, we consider two regimes.

4. Empirical Results

4.1 Long-Term Hedging Properties

Based on the Johansen cointegration test, we identify two cointegration relationships in the US, the UK, and Japan. For Australia, no rank could be determined, hence Australia does not have a co-integrating relationship. Table 2 reports long-term relationships (β-vectors). In each model with a cointegration matrix, the first vector is normalized to the LRE returns, while the second vector is normalized to the general stock market performance.

<< Table 2 about here>>

The MS-VECM representation given in Eq. (3) has been estimated for each country while enabling each parameter to switch between two regimes, including the intercept, the autoregressive elements, the residual variance-covariance matrix, and, most notably, the adjustment parameters to deviations from long-run relationships. Results regarding the long-term relationships of the MS-VECM are presented in Table 2, while Table 3 illustrates the short-term results.

In all models, we find significant long-term relationships between the performance of listed real estate markets and both expected and unexpected inflation. In the long term, LRE can positively hedge against expected inflation in the US, the UK, and Japan. This can be explained by the fact that many commercial leases may be inflation-adjusted. As a result, the cash flows of commercial properties are expected to increase with inflation. A percent increase in expected inflation is related to a 0.124 percent, a 0.019 percent, and a 0.061 percent increase in returns in the US, the UK, and Japan, respectively.

For the long-term hedging ability against unexpected inflation, the results are slightly mixed. In Japan, LRE positively hedges against unexpected inflation. A percent increase in unexpected inflation is related to a 0.065 percent increase in the return, in Japan. However, in US and UK, LRE is not significantly related to unexpected inflation in the long-term relationship. This is consistent with most prior literature, which also finds mixed results in terms of the hedging ability of real estate against unexpected inflation. For instance, Limmack and Ward (1988) found that office and retail properties offered no significant hedge against unexpected inflation.

Moreover, we always find a significantly negative long-term coefficient between stock returns and expected and/or unexpected inflation, indicating that general stocks do not provide an effective long-term hedge against inflation. This finding is in line with previous literature. For instance, using Swiss data, Hoesli (1994) shows that real estate hedges better in the long run than stocks. When the inflation rate is divided into expected and unexpected inflation, stocks exhibit negative coefficients for both expected and unexpected inflation. Meanwhile, the coefficient for unexpected inflation is positive for real estate.

Concerning the long-term equilibrium relationships, we find a positive long-term relationship between LRE returns and oil prices in the US and the UK. Furthermore, we observe a positive long-term relationship between the gold price and LRE returns in the US. We discover a significant negative long-term elasticity of the price of silver on LRE returns in the US and Japan. In the US and the UK, agricultural commodities have a negative long-term relationship with LRE returns, whereas Japan shows a positive long-term relationship between LRE returns and agricultural commodities. Moreover, we find a negative long-term elasticity of interest rates on LRE returns in the UK, which can be explained by the fact that increasing capital costs lead to lower demand for real estate and, therefore, to lower returns. Besides, we find a negative relationship between LRE returns and GDP in all four economies.[5]

4.2 Short-Term Hedging Properties

The short-term relationships and the matrices of transition are reported for both regimes in Table 3. The MS-VECM model identifies the transmission matrix from one regime to another for each country. In the US, the probability of staying in Regime 1 is 95.1%, while the probability of switching to Regime 2 is 4.9%. It suggests the dominance of the first regime. Switching from Regime 2 to Regime 1 shows a probability of 18.3%, while staying in Regime 2 shows a probability of 81.7%. The associated probabilities for the UK, Japan, and Australia are comparable.

To better understand the two regimes, Figure 1 illustrates the switching process for the US, UK, Japan, and Australia. The blue line shows the probability of switching to Regime 1, and the grey area indicates that the probability of Regime 1 is larger than 50%. For comparison purposes, we also illustrate the LRE return in each graph (dashed line). As shown in Figure 1, it is quite obvious that Regime 1 captures the non-crisis periods and Regime 2 the times of turbulence, particularly for the US, the UK, and Australia. For instance, crises like the global financial crisis (GFC), the dot-com bubble, or the COVID-19 pandemic appear to lead to a switching process to Regime 1. Meanwhile, we also see a remarkable decrease in LRE returns in Regime 2. However, for Japan, we see that this is not obvious. In the case of Japan, specific economic development can provide an explanation. The collapse of the asset price bubble in Japan in 1991 resulted in a period of economic stagnation. Between 1995 and 2007, the nominal

[5] The negative long-term relationship between GDP and LRE is contradictory to our expectation, which may be due to the merged crises during the sample period. To test our argument, we add a crisis dummy into the long-term relationship equations, and the coefficients for GDP become positive. However, the coefficients for expected and unexpected inflation in the long-term relationships remain very robust. So, we keep our baseline model as the one without a crisis dummy. Detailed results are available upon request.

GDP fell from 5.33 trillion to 4.36 trillion US Dollars. From the early 2000s, the Bank of Japan set out to encourage economic growth through quantitative easing, which indicates the special role of Japan as an economy.

<<Figure 1 about here>>

We report the estimation coefficients in Table 3. For the US, we see a significant short-term impact of expected and unexpected inflation on LRE performance in Regime 1 (non-crisis periods). In contrast, unexpected inflation has a significant negative impact on LRE returns in Regime 2 (crisis periods). In other words, in the short term, LRE can hedge against expected and unexpected inflation, but the hedging ability becomes negative during crisis periods. In the UK, expected inflation has a significant positive impact on LRE returns in the short term in Regime 1 (non-crisis periods), but a non-significant impact in Regime 2 (crisis periods). The hedging ability is accordingly lost in times of crisis. For Australia, we see a positive significant short-term impact of expected inflation on LRE in Regime 1, but perverse hedging attributes in Regime 2.

<< Table 3 about here>>

To provide a better intuitive overview, we illustrate the restricted[6] time-varying short-term impact of expected and unexpected inflation on LRE returns based on the smoothed transmission probability and the coefficient in each regime:

$$EI_t = p_1 * coefEI_1 + (1 - p_1) * coefEI_2 \quad (5)$$

$$UI_t = p_1 * coefUI_1 + (1 - p_1) * coefUI_2 \quad (6)$$

[6] If the estimated coefficient is statistically insignificant, we restrict this coefficient to be zero.

We depict the time-varying coefficients if at least one coefficient in Equation is significant in Regimes 1 and 2. Hence, we show the time-varying coefficients of expected and unexpected inflation in the US (Figures 2a and 2b), that of expected inflation in the UK (Figure 2c), those of expected and unexpected inflation in Japan (Figures 2d and 2e), and that of expected inflation in Australia (Figure 2f).

First, in the US, UK, and Australia, we find that during non-crisis periods, LRE provides good protection against expected and/or unexpected inflation in the short term. However, the relationship becomes negative or zero during crisis periods. As shown in Figures 2a and 2b, the coefficient in the US varies between 0.023 and 0.000 for expected inflation (between 0.025 and -0.150 for unexpected inflation). In Regime 1 (non-crisis periods), the coefficient remains positive. But in Regime 2 (e.g., 2007 and 2009-2010), the coefficient becomes negative or zero. In the UK, as shown in Figure 2c, the coefficient of expected inflation varies from 0.018 to 0.000 and behaves similarly to that for the US. While in Regime 1 (non-crisis periods) the coefficient remains positive, Regime 2 leads to negative coefficients (e.g., 1992, 1993, and 2007-2009). As illustrated in Figure 2f, in Australia, the coefficient of expected inflation varies from 0.014 to -0.129. While in Regime 1 (non-crisis periods) the coefficient remains positive, Regime 2 leads to negative coefficients (e.g., 2008-2009 and 2020). This finding is consistent with previous literature. For instance, focusing on the short-term relationship, Bond and Seiler (1998) find that residential real estate is a significant hedge against both expected and unexpected inflation using data for the US covering the 1969-1994 period. However, our analysis shows that the short-term inflation-hedging ability of LRE can be perverse during crisis periods. Second, in Japan, the short-term relationship between inflation and LRE is negative or zero, even during non-crisis periods. As shown in Figures 2d and 2e, the coefficient of expected inflation in Japan ranges from -0.030 to 0.000, and the coefficient of unexpected inflation varies between -0.056 and 0.000. One explanation could be the long-lasting mild deflation in Japan since the latter half of the 1990s. The negative relationship between LRE and inflation has also been documented in the literature. For instance, by examining REIT data from the US covering the period 1972-1992, Yobaccio et al. (1995) find that REITs are perverse hedges against unexpected inflation.

<< Figure 2 about here>>

If we compare the short-term hedging ability of LRE with that of stocks, we can see that LRE provides better inflation hedging effectiveness than stocks also in the short term. Figure 3 compares the time-varying coefficients of EI and UI for stocks and LRE returns for the US, UK, Japanese, and Australian markets. The red dotted line shows the coefficient for LRE, and the blue line indicates the coefficient for stocks. In the US, compared to stocks, LRE reacts more positively to expected and unexpected inflation, especially during non-crisis periods (Figures 3a and 3b). We can see a significant positive coefficient for expected inflation for stocks and LRE as well, albeit that for stocks his of lesser magnitude (Figure 3a). In the UK (Figure 3b), LRE also shows better hedging properties concerning expected inflation, as compared to stocks. Regarding unexpected inflation, LRE has an insignificant relationship, while stocks exhibit a negative relationship. Overall, LRE provides better inflation-hedging abilities than stocks in the US and UK. However, LRE in Japan and Australia does not show better short-term inflation hedging properties compared to stocks.

<< Figure 3 about here>>

4.3 Alternative Inflation Disaggregation

We also examine the hedging qualities of LRE against four specific manifestations of inflation. Following Fang et al. (2022), we decompose the overhead inflation to Energy, Food, and Core by using their corresponding CPI. Furthermore, we extend those three measurements by using the Housing CPI. By conducting the same methodology as in section 3.4, we get results for the long and short run. Table 4 displays the long-run results, while Figure 4 illustrates the short-run effects.

<< Table 4 about here>>

In the long run, LRE is a good hedge against energy inflation in the US and the UK. For Japan, the hedging capability against energy inflation is perverse. By investigating the effects of food inflation on LRE, we identify hedging characteristics for the US and Japan in the long run. For the UK, the hedging characteristics against food inflation are negative. In the case of core inflation, LRE might be a good protection in the US. For the UK and Japan, we do not find any significant hedging capability. This is consistent with the work by Fang et al. (2022). They find that currencies, commodities, and real estate also mostly hedge against energy but not core inflation.

Turning to the short-term hedging properties, LRE provides good protection against energy inflation during non-crisis periods in the short term in the US and Australia. However, for the US, the relationship becomes zero during the crisis period. As shown in Figure 3, the coefficient in the US varies between 0.001 and 0.000 for energy inflation. In Regime 1 (non-crisis periods), the coefficient remains positive, but in Regime 2, the coefficient becomes zero. Connolly and Stivers (2022) find that the co-movement of REIT returns and energy-inflation shocks is always stronger during weaker economic periods.

<< Figure 4 about here>>

As illustrated in Figure 4, in Japan and the UK, LRE acts as a significant perverse hedge for energy inflation in the short term. In Japan, the short-term relationship between core, food, and housing inflation and LRE is positive. However, the relationship between food inflation and LRE returns becomes negative during crisis periods. Connecting to Connolly and Stivers (2022), they find that the relation between REIT returns and core-inflation shocks is never significantly different during weaker economic periods.

5. Inflation Hedging Portfolios

In this section, we construct an inflation-hedging portfolio. We examine the case of an investor wishing to hedge inflation over her investment horizon with a target real return. The optimal allocations are determinted by minimizing the shortfall probability under the constraint that real returns exceed the investor's desired target (Brière and Signori, 2012).

$$Min_w\ P\left(\sum_{i=1}^{n} w_i R_{iT} < \pi_T + \overline{R}\right) \quad (7)$$

$$E\left[\sum_{i=1}^{n} w_i R_{iT} - \left(\pi_T + \overline{R}\right)\right] > 0 \quad (8)$$

$$\sum_{i=1}^{n} w_i = 1 \quad (9)$$

$$w_i \geq 0 \quad (10)$$

where $R_T = (R_{1T}, R_{2T}, \ldots, R_{nT})$ is the annualized return of the *n* assets in the portfolio over the investment horizon T; $w = (w_1, w_2, \ldots, w_n)$ is the part of the capital invested in the asset I; π_T is the annual inflation rate during that horizon T; and $\overline{R}$ is the target real return in excess of inflation. E is the expectation operator concerning the probability distribution P of the asset returns.

We present optimal portfolios using the shortfall probability approach for the US, UK, Japan, and Australia for a target real return of 3% and an investment horizon of T (T = 2 years, rebalancing every two years).[7] Figure 5 illustrates the calculated weights over time for each country. As expected, the weights for LRE vary over time. In three regions, the UK, Japan, and Australia, we find a relatively higher weight for LRE from 2003 to 2007 and from 2011 to 2015, compared to other periods. This might be explained by the rapid growth of LRE in these regions during the abovementioned periods. In contrast, during the GFC, the precious metal silver had the highest weight in each country's portfolio, whereas gold had significant portfolio shares during the dot-com bubble. This is also in line with our expectations, as precious metals are always considered good investments during crisis periods. This is also consistent with our MS-VECM results. During crisis periods, listed real estate shows poor hedging properties.

The inflation-hedging portfolios suggest different weights compared to the classic mean-variance approach. To undertake this comparison, we also present the results of optimal portfolios based on the mean-variance criterion for each country. In the US and Australia, the inflation-hedging portfolio indicates significantly higher weights for LRE compared to the standard mean-variance portfolio. This is in line with the desired inflation-hedging properties of LRE. For instance, for the US, over the 2017 to 2018 period, the mean-variance portfolio suggests 2% for US LRE, but the inflation-hedging portfolio suggests 15%. On average, over the entire sample period, the inflation hedging portfolios suggest 6.4% and 48.8% weights for the US and Australia, respectively. Meanwhile, the mean-variance portfolios suggest only 3.2% and 19.5%, respectively, for the two countries. In the UK and Japan, the weights for LRE in the inflation-hedging portfolio are slightly lower than those in the mean-variance portfolios. On average, the weights for LRE are around 20% and 16% for the UK and Japan, respectively.

[7] The results pertaining to the average weight of LRE in an optimal portfolio composition over a 2-year, 5-year, 10-year, and 30-year investment horizon for the US are shown in Appendix 2. In addition, the results for a variety of target real returns are presented for the US. As shown in Appendix 2, the weight for listed real estate varies between 3.40% and 35.33% as the investment horizon changes.

<< Figure 5 about here>>

Moreover, the inflation-hedging portfolios provide higher expected returns than the mean-variance portfolios. Table 5 reports summary statistics for the portfolios, averaged across all years. As shown in Table 5, inflation-hedging portfolios achieve an average annual expected return between 3.97% (Australia) and 5.73% (US), while the average annual expected return in the mean-variance portfolio is less than 1%. In Japan, the mean-variance portfolio even has a negative average expected return. If we consider the risk, as measured by the variance, the inflation-hedging portfolios also achieve a higher Sharpe ratio than mean-variance portfolios in the US and Japan. If we measure the risk by the probability of shortfall, as shown in Table 5, in all regions, the inflation-hedging portfolio achieves a lower probability of shortfall, meanwhile a higher average expected return than the mean-variance portfolio.

<< Table 5 about here>>

6. Conclusion

Since 2022, inflation has again become a global concern. Hence, investors need to understand the inflation-hedging ability of the different asset classes. Using listed real estate company stock return data from 1990 to 2021 in four regions, we examine four major economies, the US, the UK, Australia, and Japan, to determine whether listed real estate can be used to hedge against inflation. Overall, our study confirms the desired inflation-hedging properties of LRE. Our main findings can be summarized as follows.

First, listed real estate is a good hedge against inflation, but mainly for expected inflation and in the long term. This can be explained by the fact that many commercial leases are inflation-adjusted, which leads to a positive adjustment in the capital value. As a result, LRE performance can also respond positively to expected inflation. Moreover, because most commercial leases are long-term, the hedging capability of listed real estate assets is particularly striking over a long-time horizon. Moreover, in the long term, LRE provides better hedging against inflation than stocks.

Second, the short-term hedging ability moves toward being negative during crisis periods. In non-crisis periods, LRE provides good protection against inflation, but the ability becomes negative or zero in times of turbulence. On the other hand, this will also indicate that if deflation happens during the crisis, LRE performance will not be adversely affected by deflation. From an investor's perspective, the efficiency of LRE as an inflation hedge is highly dependent on the time horizon.

Third, the inflation hedging ability of LRE also varies across countries. Long-term positive inflation hedging against both expected and unexpected inflation is detected only for Japan. In the US and the UK, although LRE provides long-term hedging against expected inflation, we see no hedging or perverse hedging characteristics against unexpected inflation. Expected inflation shows the highest long-term elasticity to real estate equity returns in the US, amounting to 0.12%. Furthermore, Japan has the highest long-term elasticity of unexpected inflation to LRE returns, amounting to 0.07%. In the short term, LRE in the US, the UK, and Australia provide short-term positive inflation hedging against expected inflation, by a 0.023, 0.018, and 0.014 percent increase, respectively, with a one percent increase in expected inflation. Only in the US does LRE provide inflation protection against unexpected inflation in non-crisis periods, by a 0.025 percent increase with a one percent increase in unexpected inflation.

Fourth, the disaggregation of inflation into energy, food, core, and housing CPIs indicates that LRE is adequately hedged against all forms of inflation in the US. In the UK, we observe positive hedging characteristics concerning the energy and housing inflation, while we observe a perverse hedging effect in relation to food inflation. In Japan, LRE offers a high degree of protection against housing and food inflation, however, hedging against energy inflation is perverse.

Fifth, our inflation-hedging portfolios provide more realistic and less extreme allocations to listed real estate than when the classic mean-variance approach is used. The mean-variance approach uses variance as the risk measurement, which may not correspond best to investors' objectives. Instead, the inflation-hedging portfolio uses the expected shortfall as the risk measure, which focuses on the risk of being far below the expected real return (i.e., the downside risk). Based on an inflation-hedging portfolio, listed real estate plays a significant role in an investor's portfolio. The average percentages of the portfolios for the US, UK, Japan, and Australia over the entire period are 6.35%, 19.21%, 16.02%, and 48.81%, respectively, clearly highlighting the benefits of holding listed real estate for investors. The inflation-hedging portfolio also shows a desirable performance. It provides a higher Sharpe ratio than the mean-variance approach for the US and Japan. It also achieves a lower shortfall probability and a higher average expected return than the mean-variance portfolio in all four regions.

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Table 1: Summary Statistics

	Mean	Std.	Max.	Min.	SP	Obs.
Panel A: US						
LRE	0.940%	6.328%	31.182%	-40.520%	1990/01	384
Stocks	0.855%	4.601%	17.970%	-32.969%	1990/01	384
Oil	0.333%	10.687%	39.566%	-58.590%	1990/01	384
Gold	0.382%	4.577%	21.609%	-20.478%	1990/01	384
Silver	0.374%	7.968%	36.863%	-35.844%	1990/01	384
Agricultural Commodities	0.169%	5.812%	26.534%	-22.335%	1990/01	384
GDP (mio. USD)	13,289,102	4,949,983	24,163,226	5,856,250	1990/01	384
Interest rate	2.229%	2.066%	8.329%	0.000%	1990/01	384
EI index	0.238%	0.160%	0.902%	-0.936%	1990/01	384
UI index	-0.033%	0.248%	0.880%	-1.458%	1990/01	384
Panel B: UK						
LRE	0.440%	6.286%	24.851%	-35.632%	1990/01	384
Stocks	0.819%	5.046%	15.311%	-32.469%	1990/01	384
Oil	0.333%	10.687%	39.566%	-58.590%	1990/01	384
Gold	0.382%	4.577%	21.609%	-20.478%	1990/01	384
Silver	0.374%	7.968%	36.863%	-35.844%	1990/01	384
Agricultural Commodities	0.169%	5.812%	26.534%	-22.335%	1990/01	384
GDP (mio. GBP)	1,640,917	285,568	2,130,386	1,167,190	1990/01	384
Interest rate	3.245%	3.273%	15.198%	0.015%	1990/01	384
EI index	0.204%	0.109%	0.657%	0.017%	1990/01	384
UI index	-0.007%	0.205%	1.570%	-0.856%	1990/01	384
Panel C: JPN						
LRE	0.113%	8.494%	34.276%	-26.445%	1990/01	384
Stocks	-0.083%	5.506%	16.681%	-22.837%	1990/01	384
Oil	0.333%	10.687%	39.566%	-58.590%	1990/01	384
Gold	0.382%	4.577%	21.609%	-20.478%	1990/01	384
Silver	0.374%	7.968%	36.863%	-35.844%	1990/01	384
Agricultural Commodities	0.169%	5.812%	26.534%	-22.335%	1990/01	384
GDP (mio. JPY)	499,635,182	36,882,773	560,806,963	408,421,413	1990/01	384

Interest rate	0.948%	1.906%	8.288%	-0.629%	1990/01	384
EI index	0.136%	0.273%	1.140%	-0.653%	1990/01	384
UI index	-0.107%	0.336%	1.848%	-1.025%	1990/01	384
			Panel D: AUS			
LRE	0.666%	5.876%	26.489%	-47.944%	1992/06	355
Stocks	0.757%	4.187%	13.685%	-27.893%	1992/06	355
Oil	0.333%	10.687%	39.566%	-58.590%	1992/06	355
Gold	0.382%	4.577%	21.609%	-20.478%	1992/06	355
Silver	0.374%	7.968%	36.863%	-35.844%	1990/01	355
Agricultural Commodities	0.169%	5.812%	26.534%	-22.335%	1990/01	355
GDP (mio. AUD)	1,103,652	545,518	2,259,806	406,777	1992/06	355
Interest rate	3.060%	1.785%	7.343%	0.005%	1992/06	355
EI index	0.225%	0.162%	1.095%	-0.401%	1992/06	355
UI index	-0.021%	0.124%	0.853%	-0.895%	1992/06	355

Notes: US stands for United States of America, UK for United Kingdom, JPN for Japan, and AU for Australia. LRE denotes the FTSE/EPRA/NAREIT real estate stock monthly total return. Stocks denotes for each country the corresponding monthly total return of the stock market. Oil denotes the change of oil price in US Dollars. Gold denotes the change of gold price in US Dollars. Silver denotes the change of silver price in US Dollars. Agricultural Commodities denotes the S&P GSCI Agriculture monthly total return. GDP stands for GDP of each country. Interest rate are the 3-month treasury bill rates. EI index and UI index stand for the rate of expected and unexpected inflation, respectively. SP denotes the starting point of the time series and Obs. displays the number of observations.

Table 2: Long-Term Equilibrium Relationships (β -vectors)

Country	Rank	$r_{LRE,t-1}$	$r_{stock,t-1}$	$r_{oil,t-1}$	$r_{gold,t-1}$	$r_{silver,t-1}$	$r_{agri,t-1}$	GDP_{t-1}	ir_{t-1}	EI_{t-1}	UI_{t-1}
US	2	1.000	0.000	0.356**	1.811***	-1.445***	-1.315***	-0.077***	0.113	0.124***	-0.074
		(0.000)	(0.000)	(0.179)	(0.296)	(0.291)	(0.406)	(0.010)	(0.083)	(0.027)	(0.152)
		0.000	1.000	0.333**	1.099***	-0.123	0.185	0.025***	-0.119***	-0.148***	-0.470***
		(0.000)	(0.000)	(0.152)	(0.251)	(0.248)	(0.346)	(0.008)	(0.037)	(0.023)	(0.130)
UK	2	1.000	0.000	0.022***	-0.032	-0.546	-1.176**	-0.058***	-0.173***	0.019**	-0.175
		(0.000)	(0.000)	(0.008)	(0.431)	(0.342)	(0.552)	(0.012)	(0.035)	(0.010)	(0.137)
		0.000	1.000	0.007*	0.035	-0.602***	0.378	-0.045***	-0.053***	-0.008	-0.327***
		(0.000)	(0.000)	(0.004)	(0.238)	(0.189)	(0.305)	(0.007)	(0.019)	(0.006)	(0.076)
JPN	2	1.000	0.000	0.012	-0.775	-1.049***	1.495***	-0.088***	0.005	0.061***	0.065***
		(0.000)	(0.000)	(0.008)	(0.535)	(0.406)	(0.499)	(0.021)	(0.054)	(0.027)	(0.042)
		0.000	1.000	-0.016***	-0.592**	0.128	0.501**	-0.063***	-0.123***	-0.042***	-0.100***
		(0.000)	(0.000)	(0.004)	(0.254)	(0.193)	(0.237)	(0.010)	(0.026)	(0.013)	(0.020)

Notes: US stands for United States of America, UK for United Kingdom, JPN for Japan. The analysis of the US, UK, and Japan is conducted by using an unrestricted constant. $R_{LRE,t-1}$ denotes the FTSE/EPRA/NAREIT real estate stock total return index. $r_{stock,t-1}$ denotes for each country the corresponding total return of the stock market index. $r_{oil,t-1}$ denotes the oil price in US Dollars. $r_{gold,t-1}$ denotes the gold price in US Dollars. $r_{silver,t-1}$ denotes the silver price in US Dollars. Australia is not reported because the rand of listed real estate, stocks, oil, gold, silver, agricultural, GDP, interest rate, expected and unexpected inflation in Australia is zero, indicating that these variables are not co-integrated. $r_{agri,t-1}$ denotes the total return index of S&P GSCI Agriculture. GDP_{t-1} stands for GDP of each country. ir_{t-1} are the 3-month treasury bill rates. EI_{t-1} and UI_{t-1} stand for expected and unexpected inflation, respectively. Rank denotes the rank of π matrix. Standard errors are included in the parentheses. ***. **, * denotes significance level at 1%, 5% or 10%, respectively.

Table 3: Short-term Coefficients and Transition Probability Matrix

		Short-term coefficients for Regime 1 and 2													Transition probability matrix P	
Country		$\Delta r_{LRE,t-1}$	$\Delta r_{stock,t-1}$	$\Delta r_{oil,t-1}$	$\Delta r_{gold,t-1}$	$\Delta r_{silver,t-1}$	$\Delta r_{agri,t-1}$	ΔGDP_{t-1}	Δir_{t-1}	ΔEI	ΔUI	ECT1	ECT2		Regime 1	Regime 2
U.S.	Regime 1	-0.015 (0.070)	0.064 (0.073)	-0.074** (0.028)	-0.069 (0.078)	-0.012 (0.051)	-0.001 (0.005)	0.001 (0.001)	0.022 (0.018)	0.0231* (0.012)	0.025* (0.013)	0.006 (0.008)	0.009 (0.011)	Regime 1	0.951	0.183
	Regime 2	-0.666*** (0.170)	1.041*** (0.296)	0.205** (0.097)	0.456 (0.411)	-0.436** (0.222)	0.291 (0.200)	0.011*** (0.004)	-0.186*** (0.069)	-0.010 (0.035)	-0.168** (0.067)	0.033 (0.026)	-0.018 (0.032)	Regime 2	0.049	0.817
UK	Regime 1	-0.032 (0.063)	0.006 (0.080)	-0.001 (0.001)	-0.165*** (0.060)	-0.001 (0.012)	0.146** (0.061)	0.001 (0.001)	-0.024 (0.019)	0.018*** (0.006)	-0.007 (0.012)	0.016*** (0.004)	0.001 (0.024)	Regime 1	0.959	0.270
	Regime 2	0.001 (0.026)	0.587** (0.296)	0.002 (0.006)	0.435 (0.349)	-0.271 (0.221)	-1.125* (0.591)	0.086** (0.036)	0.004 (0.087)	-0.017 (0.224)	-0.122 (0.083)	-0.141** (0.070)	0.236* (0.126)	Regime 2	0.041	0.730
JPN	Regime 1	-0.315*** (0.077)	0.288*** (0.087)	-0.001 (0.001)	-0.707*** (0.100)	0.211*** (0.055)	0.099* (0.055)	-0.004 (0.0038)	0.015 (0.034)	-0.030** (0.015)	-0.056*** (0.015)	0.013* (0.008)	-0.043** (0.017)	Regime 1	0.900	0.040
	Regime 2	-0.203*** (0.054)	0.947*** (0.095)	0.002 (0.002)	0.311** (0.158)	-0.145 (0.090)	0.086 (0.088)	0.004 (0.005)	-0.014 (0.049)	-0.011 (0.021)	0.021 (0.024)	- 0.044*** (0.013)	-0.003 (0.025)	Regime 2	0.100	0.960
AUS	Regime 1	-0.125** (0.063)	0.041 (0.066)	-0.002** (0.001)	-0.0710 (0.060)	-0.008 (0.034)	-0.008 (0.049)	-0.002*** (0.001)	-0.027* (0.015)	0.014** (0.008)	0.015 (0.018)			Regime 1	0.990	0.106
	Regime 2	-0.689** (0.271)	0.971* (0.553)	0.003 (0.006)	0.663 (0.768)	-0.236 (0.512)	-1.726*** (0.472)	-0.000 (0.011)	0.613*** (0.170)	-0.129** (0.063)	0.388 (0.465)			Regime 2	0.010	0.894

Notes: US stands for United States of America, UK for United Kingdom, JPN for Japan, and AU for Australia. We only report the equation for LRE returns. r_{LRE},t-1 denotes the FTSE/EPRA/NAREIT real estate stock total return index. $r_{stock,t-1}$ denotes for each country the corresponding total return of the stock market index. roil,t-1 denotes the oil price in US Dollars. Rgold,t-1 denotes the gold price in US Dollars. rsilver,t-1 denotes the silver price in US Dollars. ragri,t-1 denotes the total return index of S&P GSCI Agriculture. GDPt-1 stands for GDP of each country. ir_{t-1} are the 3-month treasury bill rates. EI_{t-1} and UI_{t-1} stand for expected and unexpected inflation, respectively. ECT1, ECT2, and ECT3 are the coefficients of error correction terms. Regime 1 and 2 are reported. The transition matrix P reports the transition probabilities of the stochastic process.

Table 4: Long-Term Equilibrium Relationships (β -vectors) between LRE and Energy, Food, Core, and Housing CPI

Country	Rank	$EnergyI_{t-1}$	Rank	$FoodI_{t-1}$	Rank	$CoreI_{t-1}$	Rank	$HousingI_{t-1}$
US	2	0.058***		0.205***	1	0.076***	2	0.222***
		(0.010)		(0.031)		(0.017)		(0.037)
UK	1	0.049***	2	-0.159***	1	0.024	1	0.048*
		(0.005)		(0.041)		(0.021)		(0.026)
JPN	3	-0.345**	3	0.062***	3	-0.106	1	0.319***
		(0.172)		(0.022)		(0.116)		(0.096)

Notes: US stands for United States of America, UK for United Kingdom, JPN for Japan. The analysis of the US, UK, and Japan is conducted by using an unrestricted constant. $EnergyI_{t-1}$,$FoodI_{t-1}$,$CoreI_{t-1}$, and $HousingI_{t-1}$ stand for energy, food, core, and housing inflation, respectively. Rank denotes the rank of the π matrix. Standard errors are included in the parentheses. ***. **, * denotes significance level at 1%, 5% or 10%, respectively.

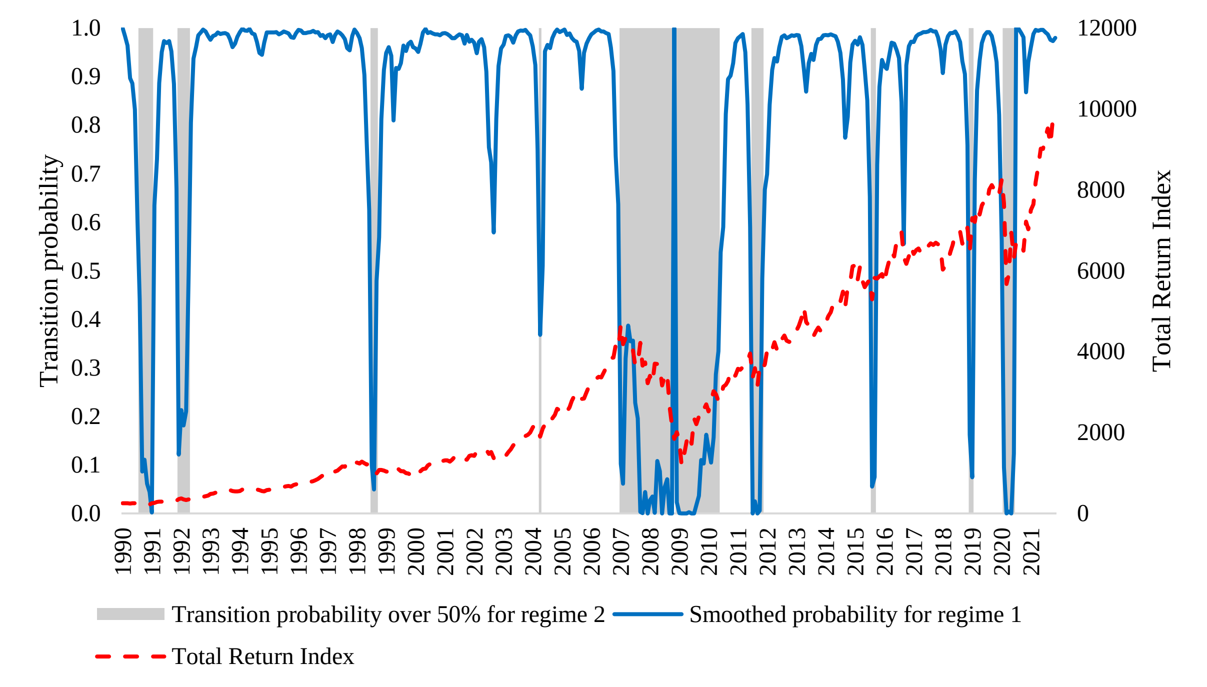
Table 5: Average Summary Statistics of Portfolios with 2-year-Investment Horizon over the Entire Sample Period

	LRE Weight	Shortfall Probability	Mean	SD	Sharpe Ratio
US					
Inflation Hedging (r=3%)	6.35%	2.93%	5.73%	24.60%	23.29%
Mean-Variance	3.20%	19.20%	0.23%	14.21%	1.92%
UK					
Inflation Hedging (r=3%)	19.21%	4.54%	4.02%	22.05%	18.23%
Mean-Variance	26.74%	10.86%	0.84%	5.92%	19.84%
Japan					
Inflation Hedging (r=3%)	16.02%	4.69%	4.08%	27.53%	14.82%
Mean-Variance	21.90%	11.28%	-0.12%	6.43%	1.22%
Australia					
Inflation Hedging (r=3%)	48.81%	3.63%	3.97%	21.59%	18.39%
Mean-Variance	19.54%	7.43%	0.86%	4.05%	27.30%

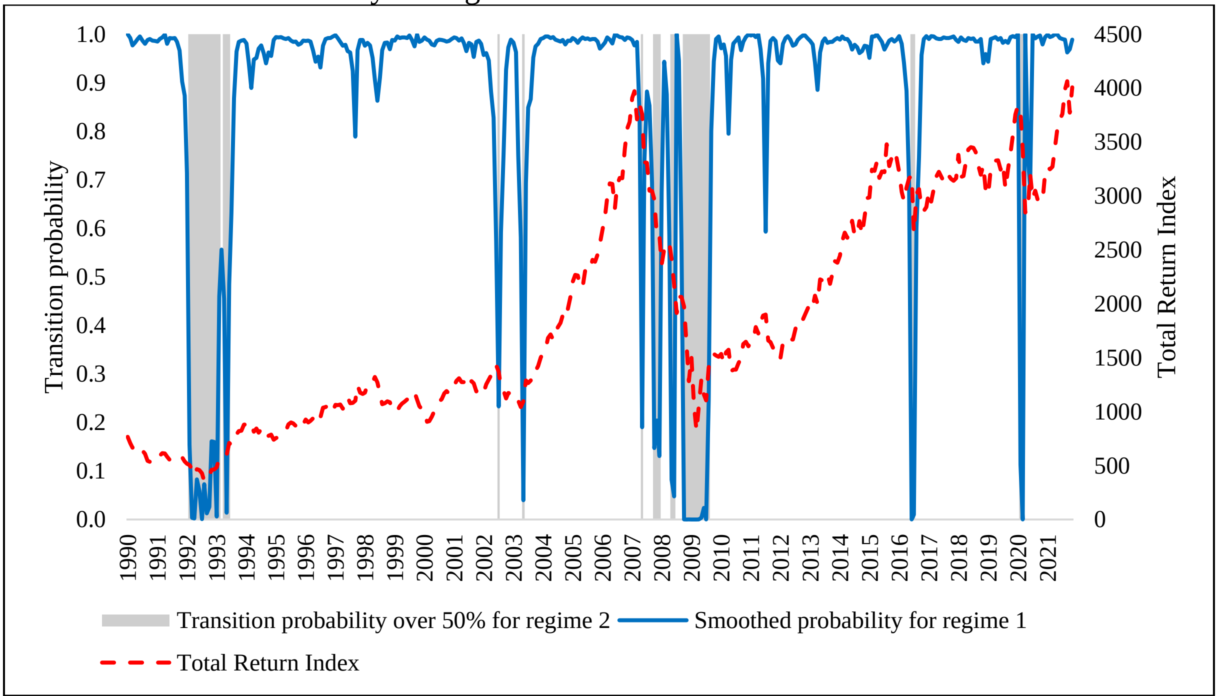
Note: The weights of LRE, the shortfall probability, the mean of portfolio returns, the standard deviation of portfolio returns (SD), and the Sharpe ratios of portfolios are the average values over the entire sample period.

Figure 1: Transition Probability and Total Returns

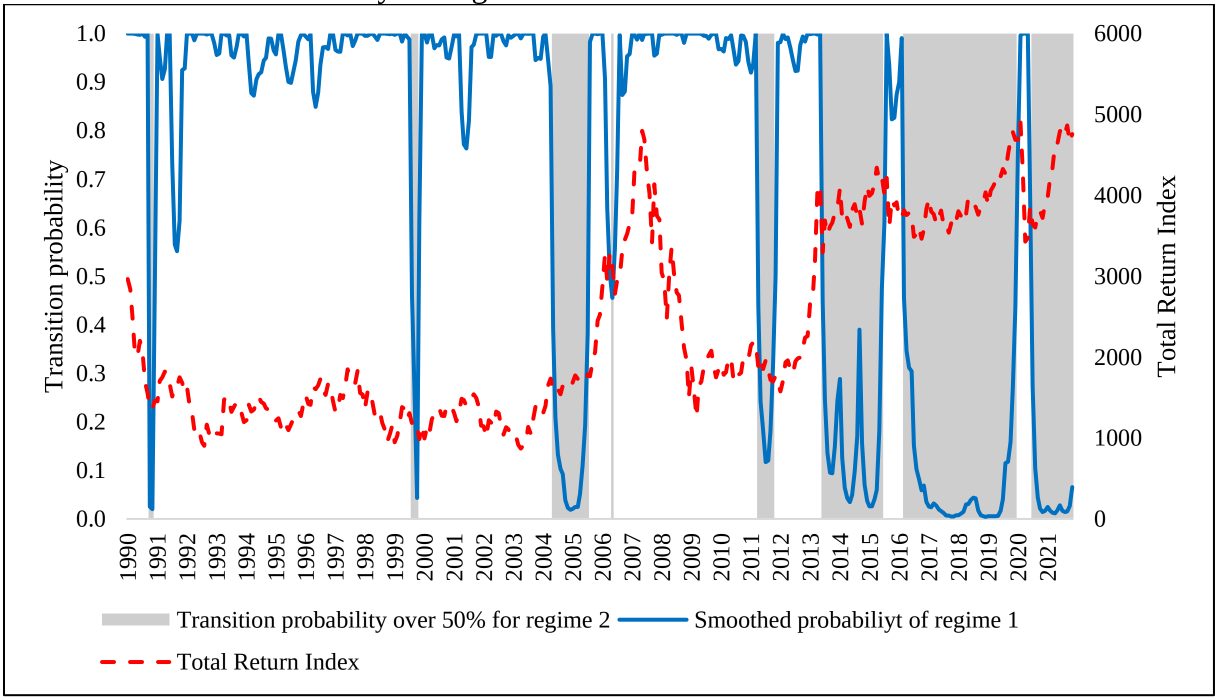
a. US Smoothed Probability of Regime 1



b. UK Smoothed Probability of Regime 1



c. JPN Smoothed Probability of Regime 1



d. AUS Smoothed Probability of Regime 1

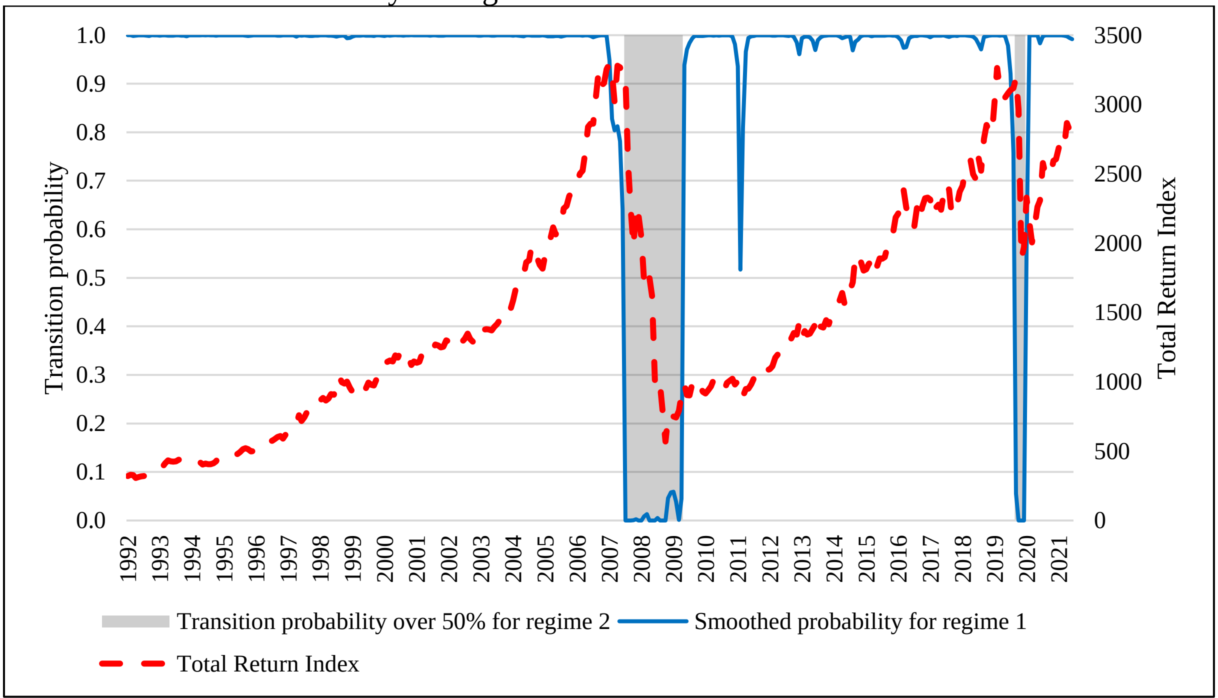
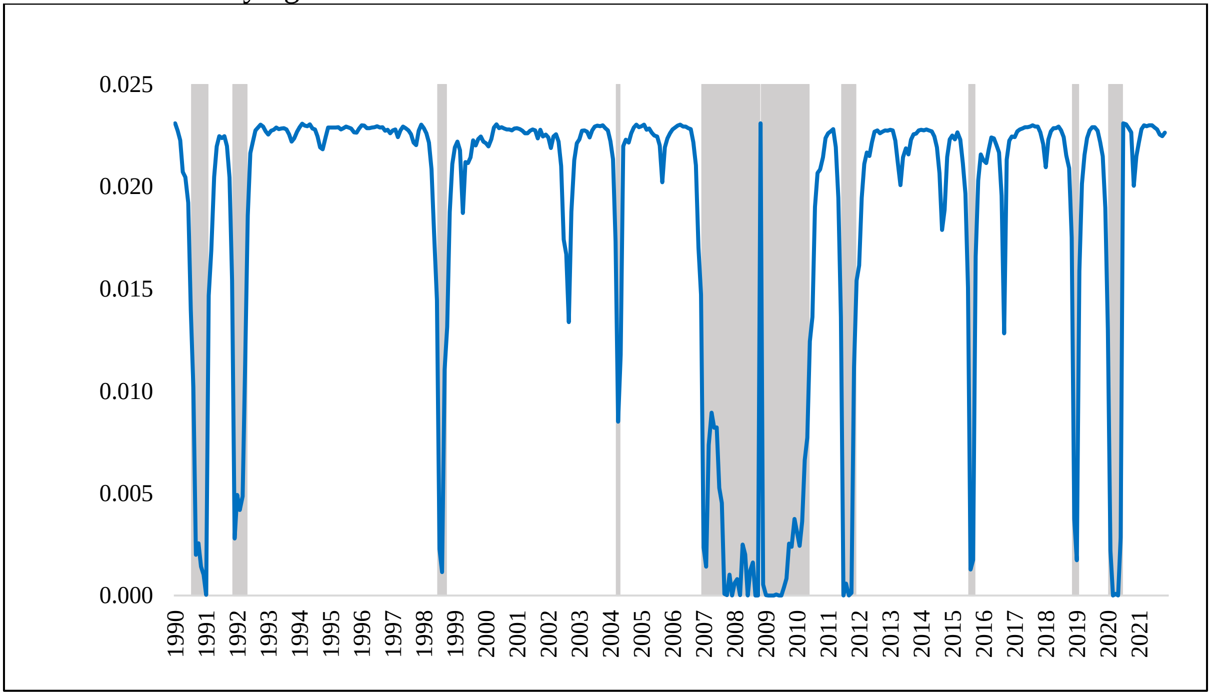


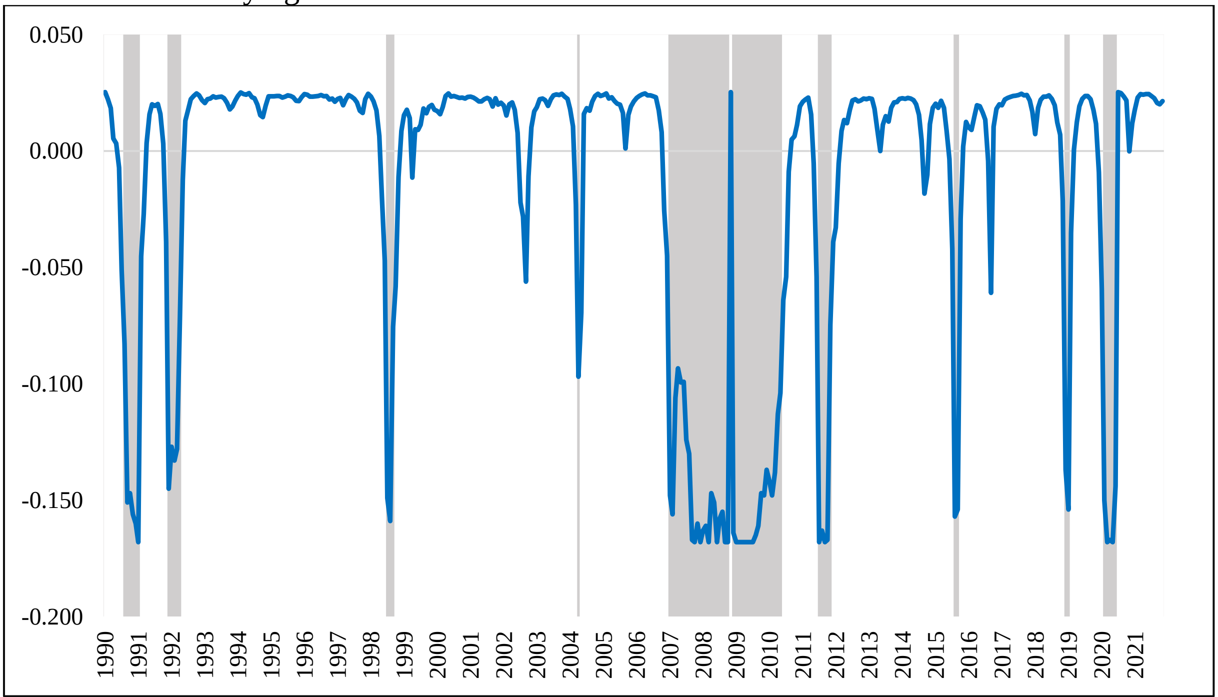
Figure 2: Time-Varying Short-Term Impact of Inflation on Real Estate Equity Returns

a. U.S. Time-Varying Coefficient of EI



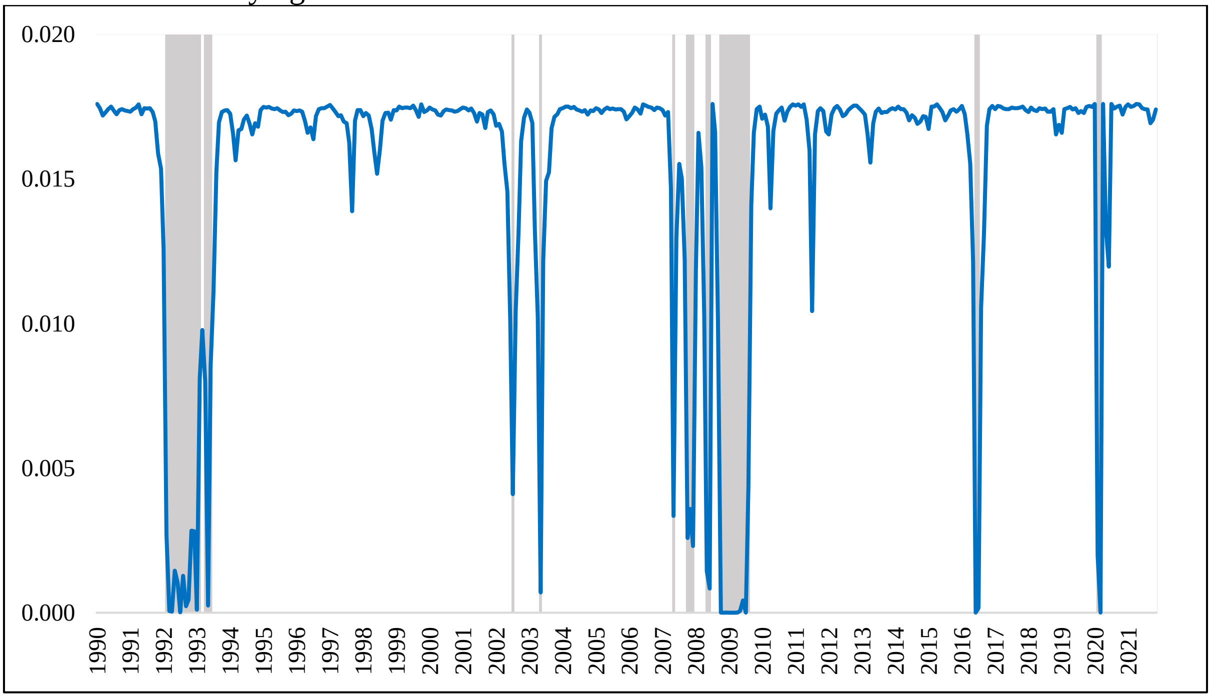
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. If the estimated coefficient in Equation (3) is statistically insignificant, it is restricted to zero in the estimation of time-varying coefficient (Equations 5 and 6).

b. U.S. Time-Varying Coefficient of UI



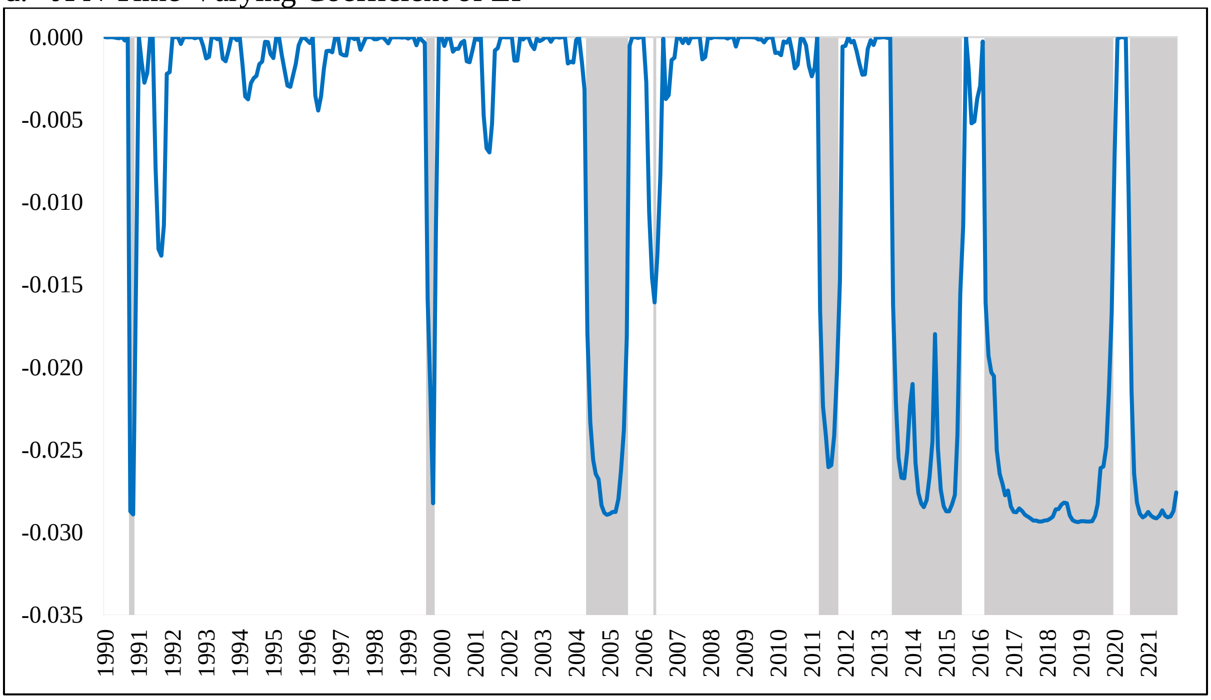
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. If the estimated coefficient in Equation (3) is statistically insignificant, it is restricted to zero in the estimation of time-varying coefficient (Equations 5 and 6).

c. U.K. Time-Varying Coefficient of EI



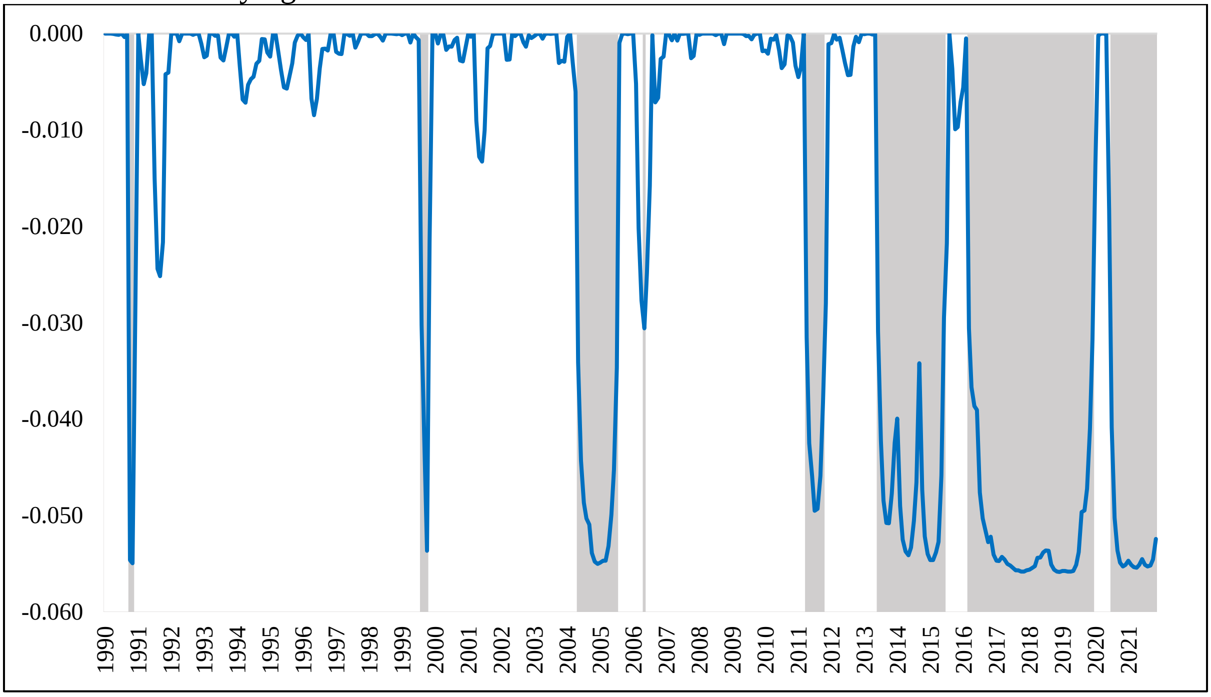
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. If the estimated coefficient in Equation (3) is statistically insignificant, it is restricted to zero in the estimation of time-varying coefficient (Equations 5 and 6).

d. JPN Time-Varying Coefficient of EI



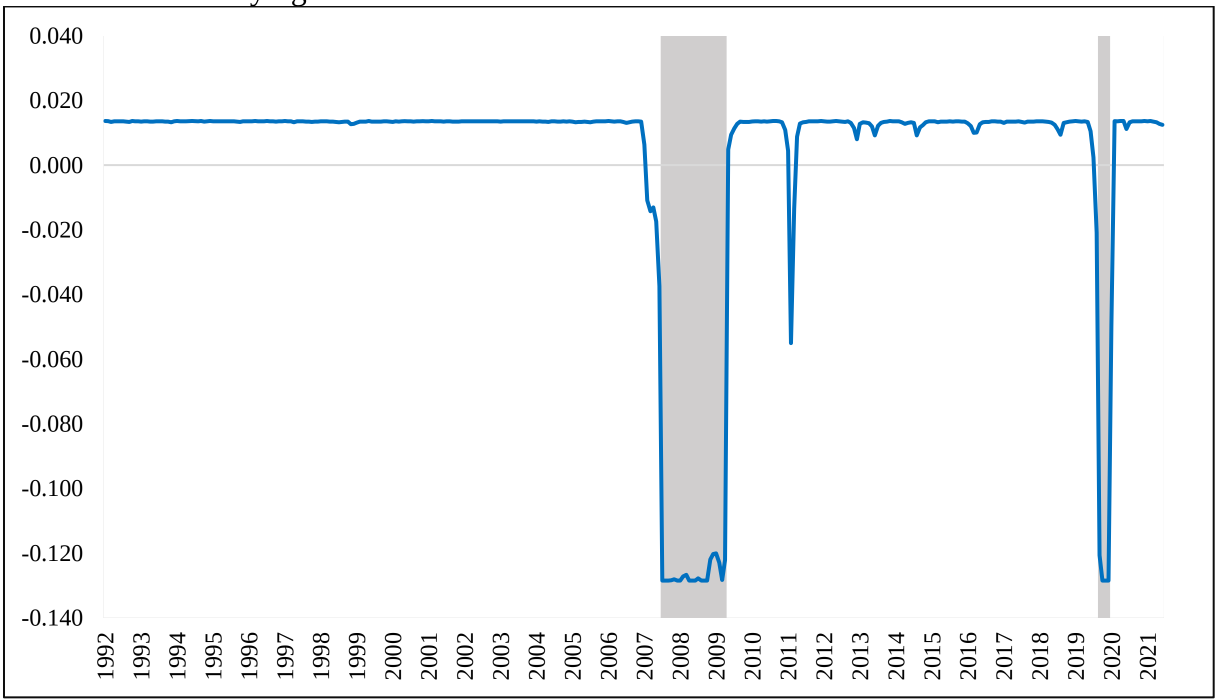
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. If the estimated coefficient in Equation (3) is statistically insignificant, it is restricted to zero in the estimation of time-varying coefficient (Equations 5 and 6).

e. JPN Time-Varying Coefficient of UI



Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. If the estimated coefficient in Equation (3) is statistically insignificant, it is restricted to zero in the estimation of time-varying coefficient (Equations 5 and 6).

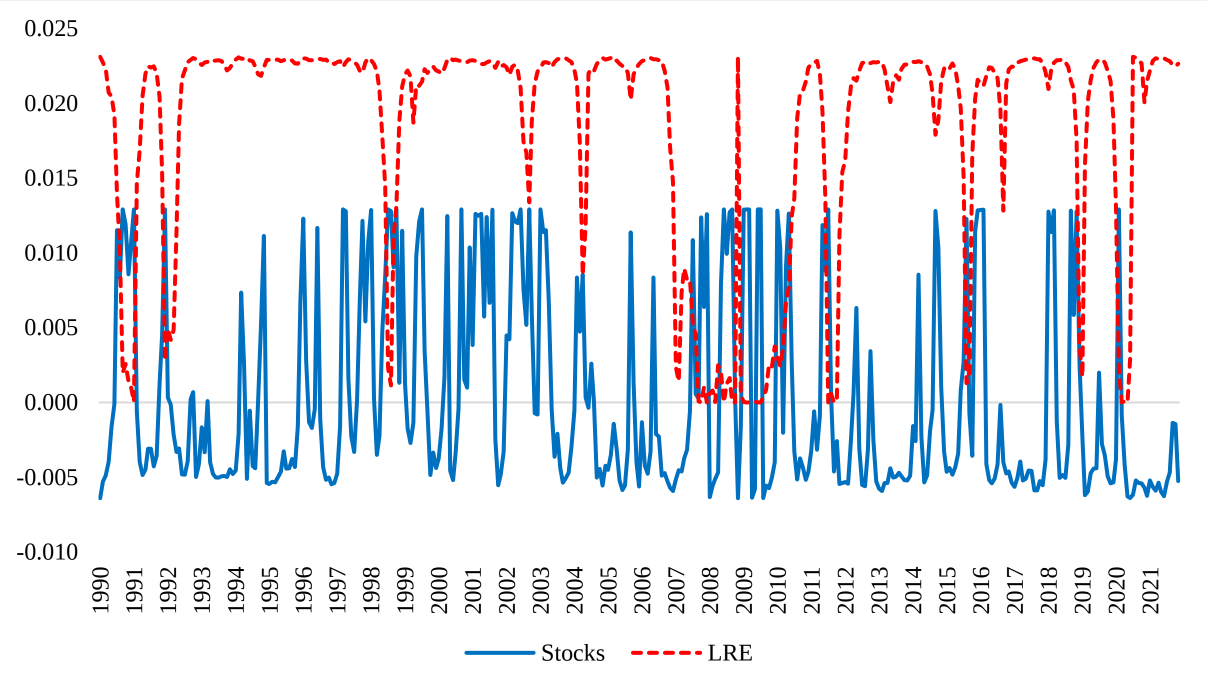
f. AUS Time-Varying Coefficient of EI



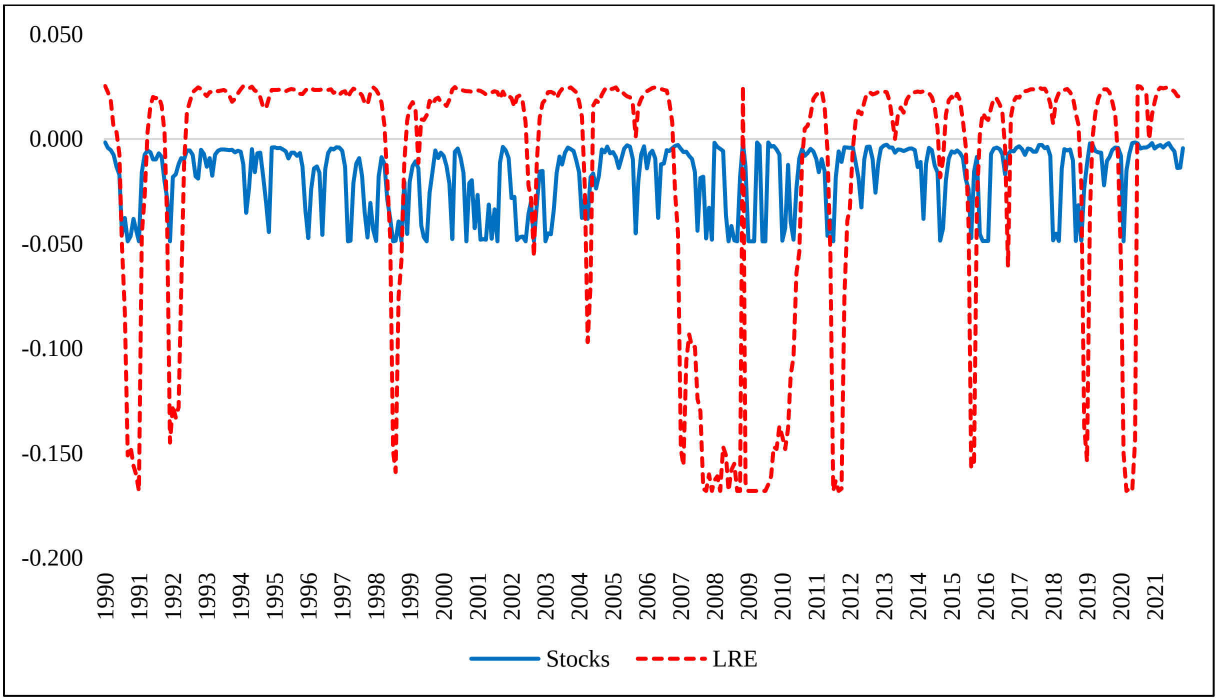
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. If the estimated coefficient in Equation (3) is statistically insignificant, it is restricted to zero in the estimation of time-varying coefficient (Equations 5 and 6).

Figure 3: Time-Varying Coefficients of LRE and Stocks

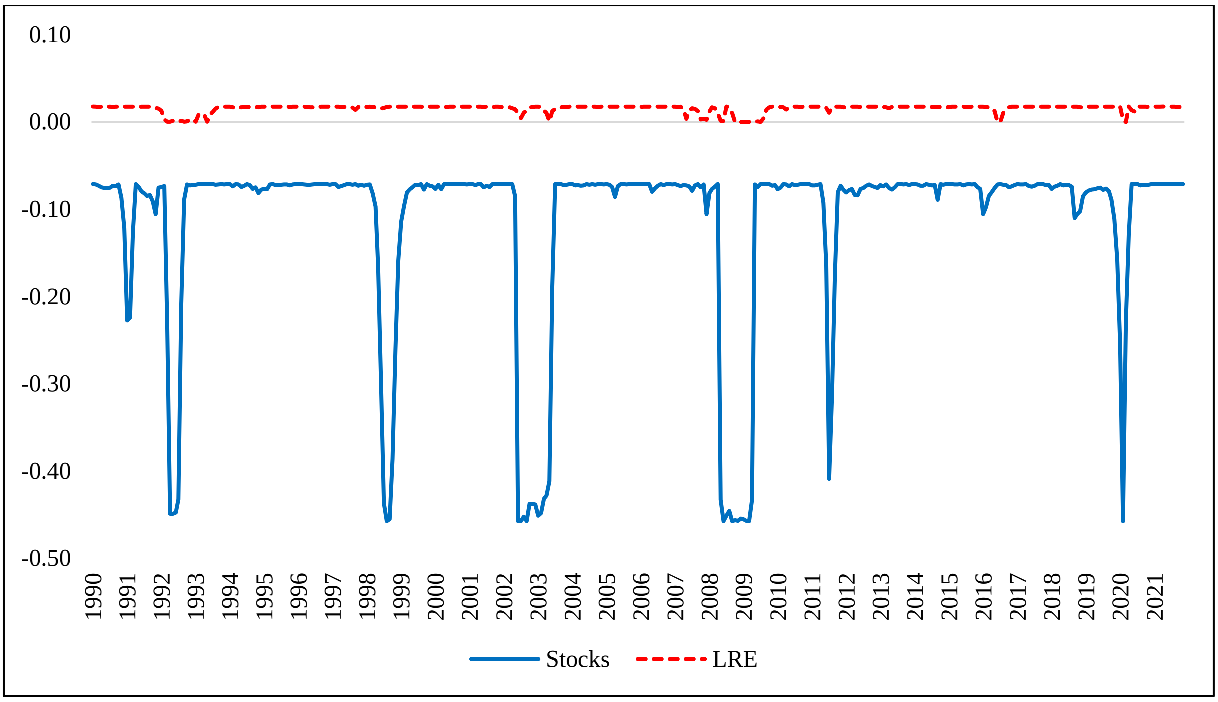
a. U.S. Time-Varying Coefficient of EI



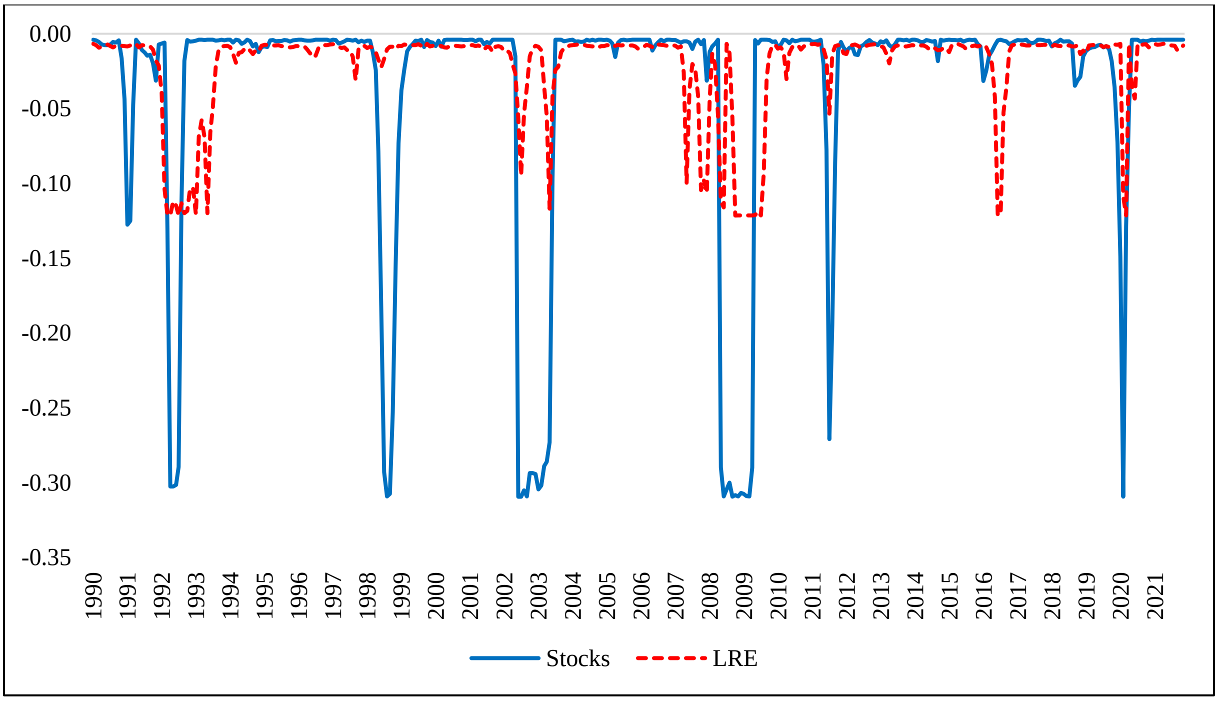
b. U.S. Time-Varying Coefficient of UI



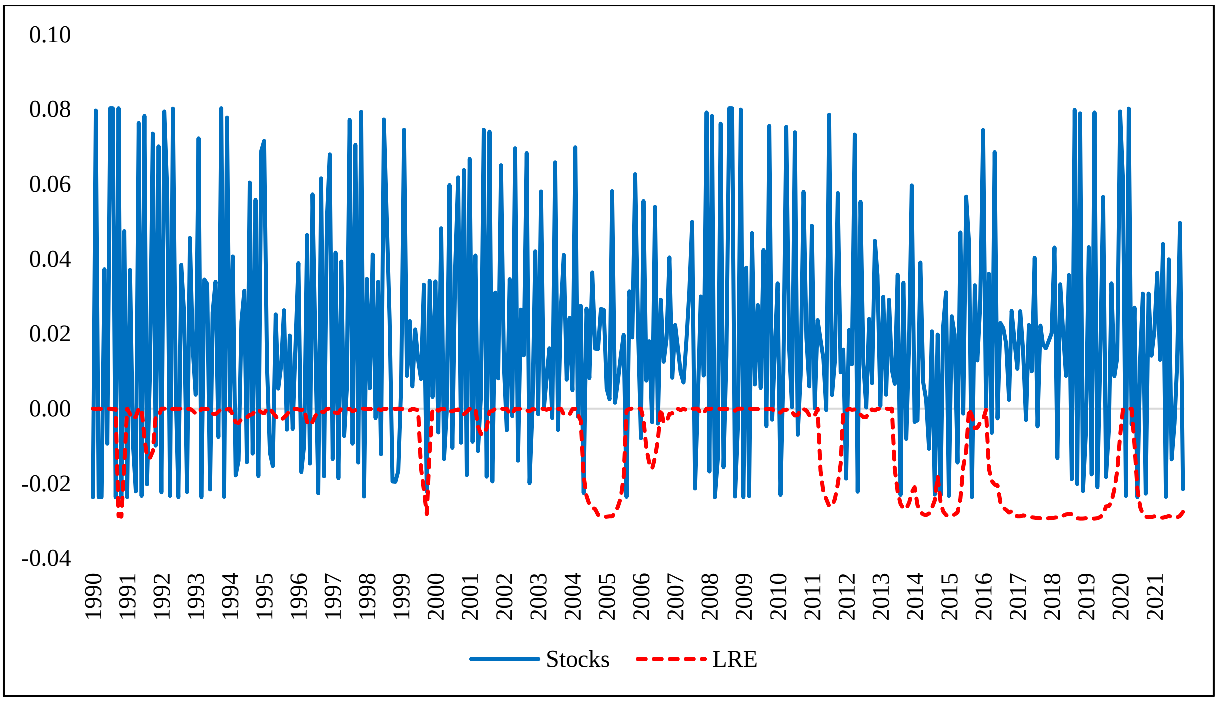
c. U.K. Time-Varying Coefficient of EI



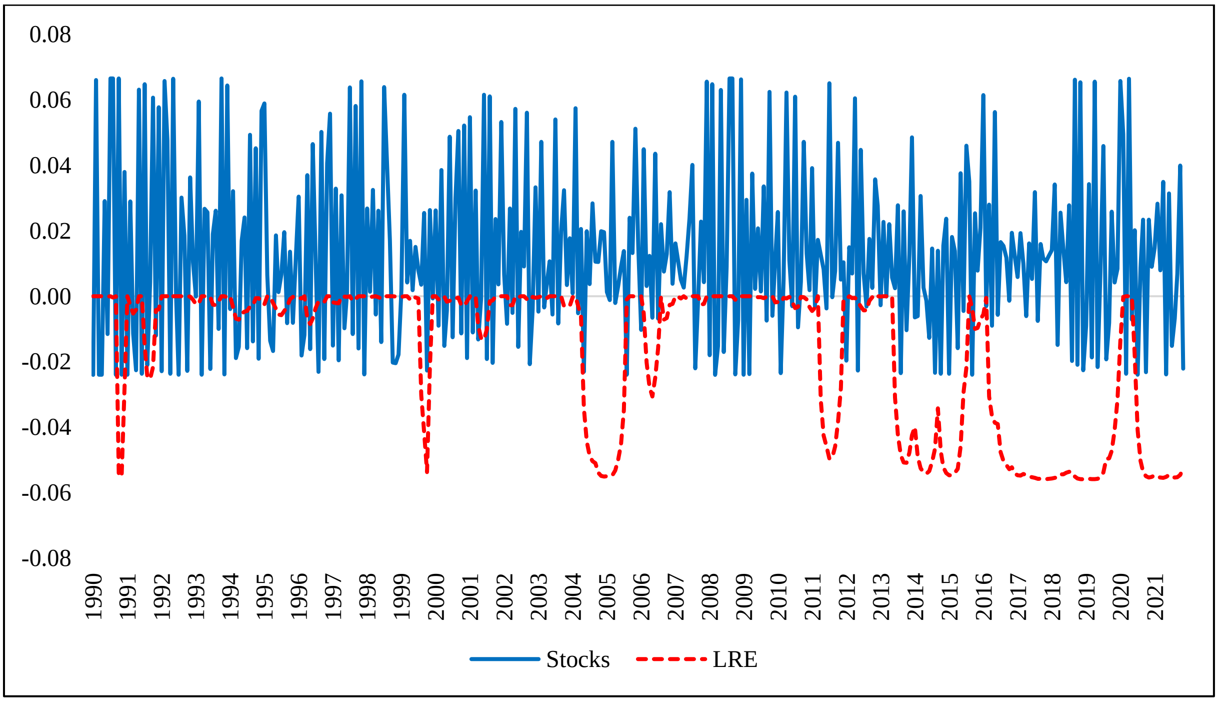
d. U.K. Time-Varying Coefficient of UI



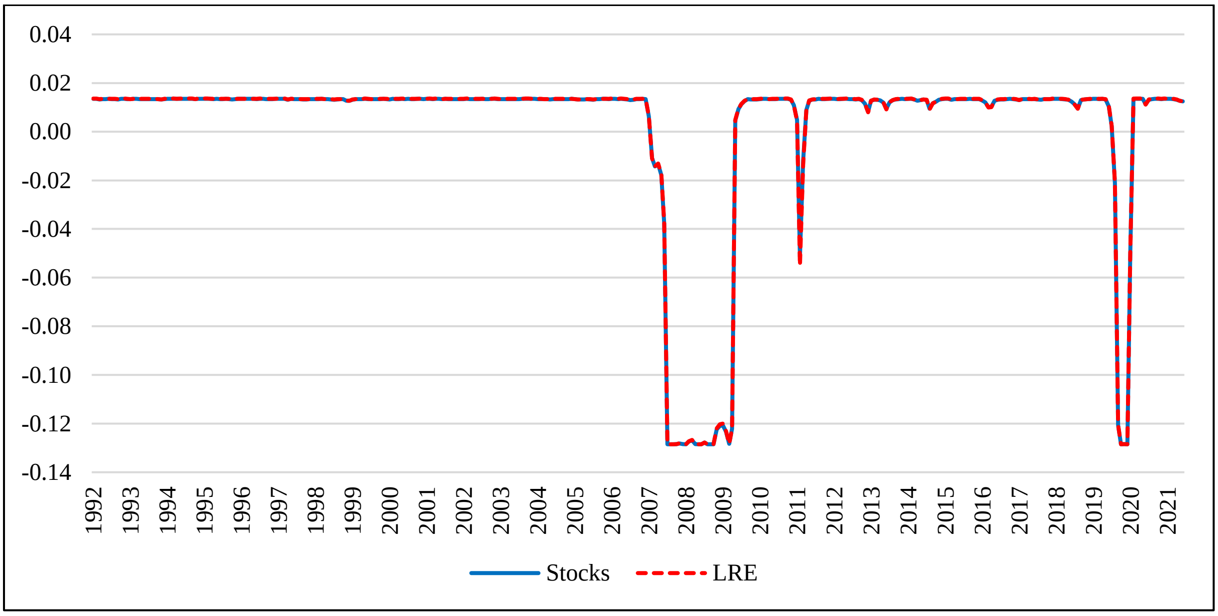
e. Japan Time-Varying Coefficient of EI



f. Japan Time-Varying Coefficient of UI



g. Australia Time-Varying Coefficient of EI



h. Australia Time-Varying Coefficient of UI

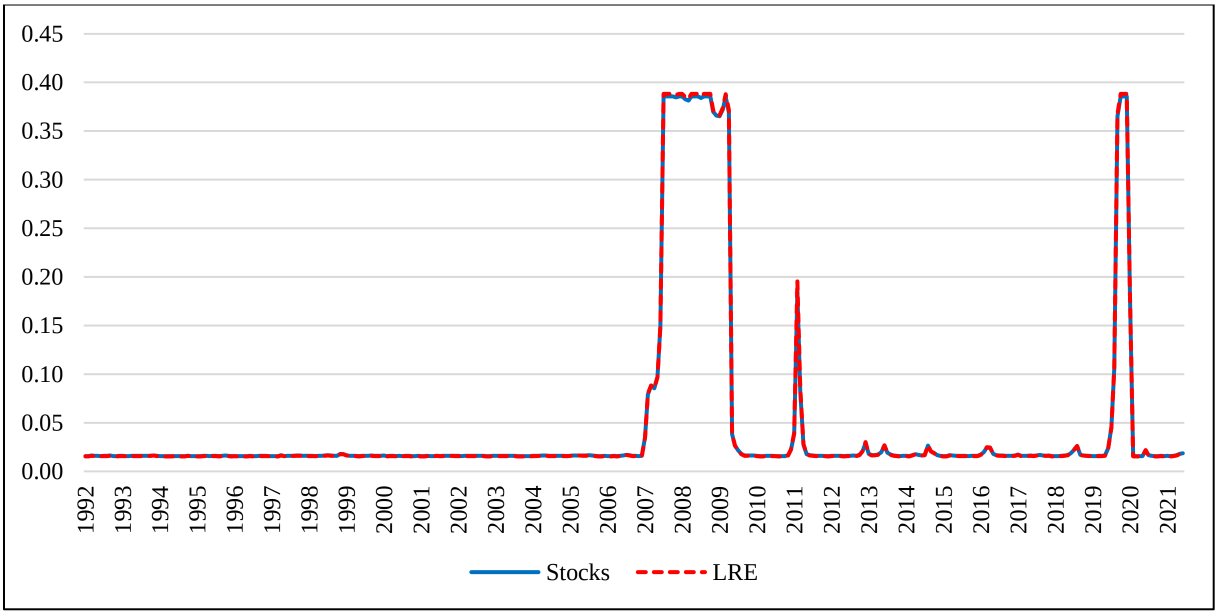
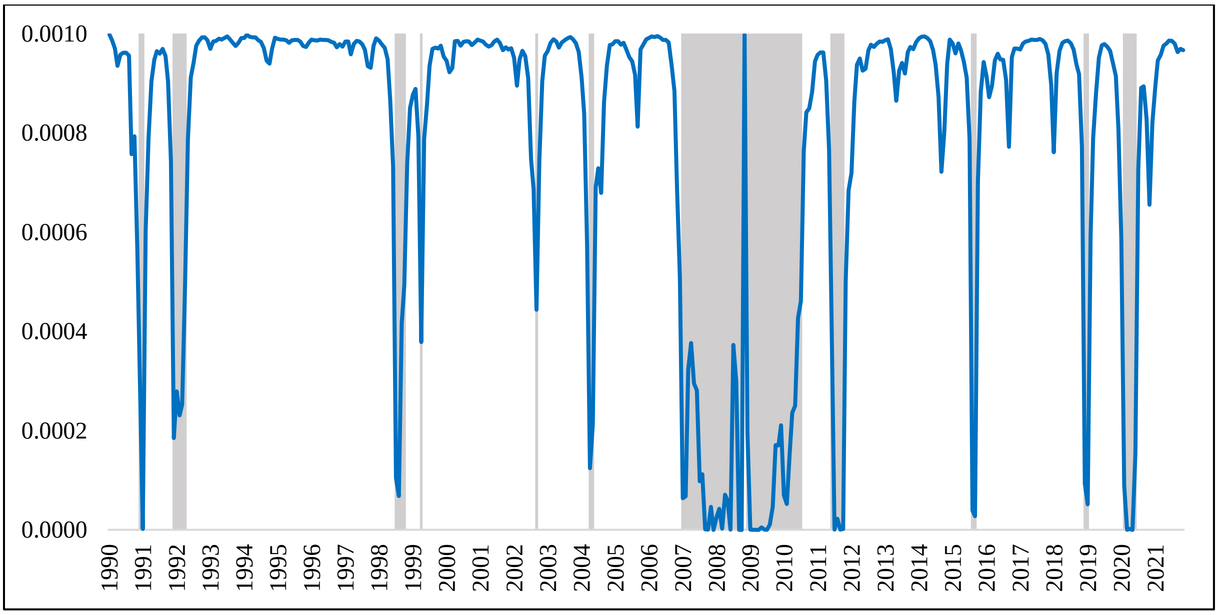


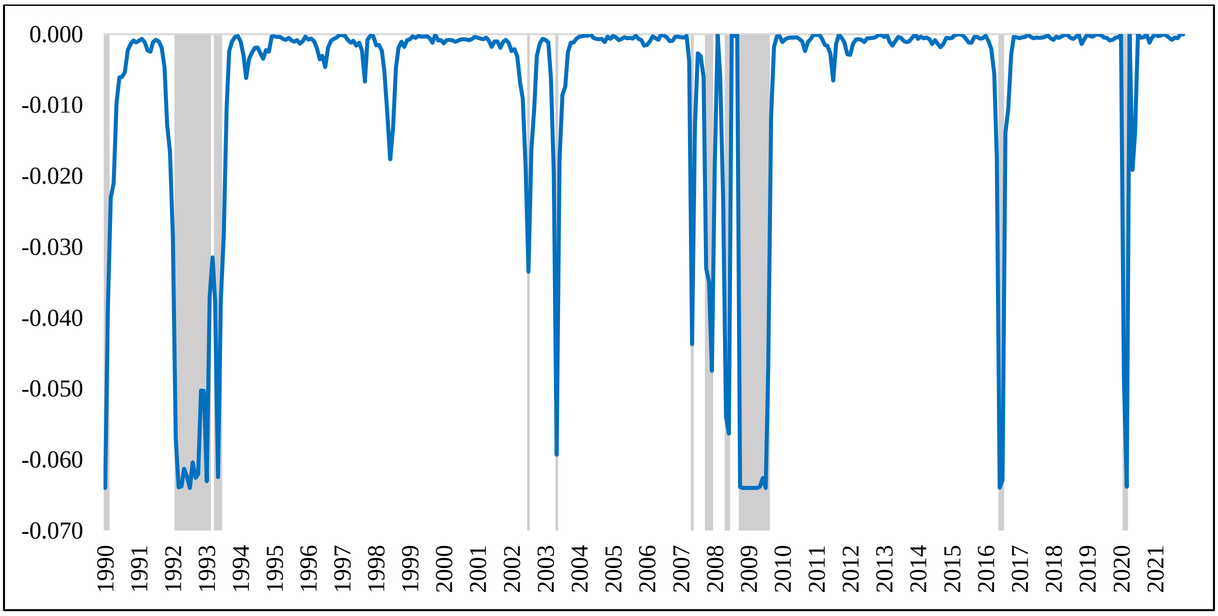
Figure 4: Time-Varying Short-Term Impact of Inflation on Real Estate Equity Returns

a. U.S. Time-Varying Coefficient of Energy Inflation



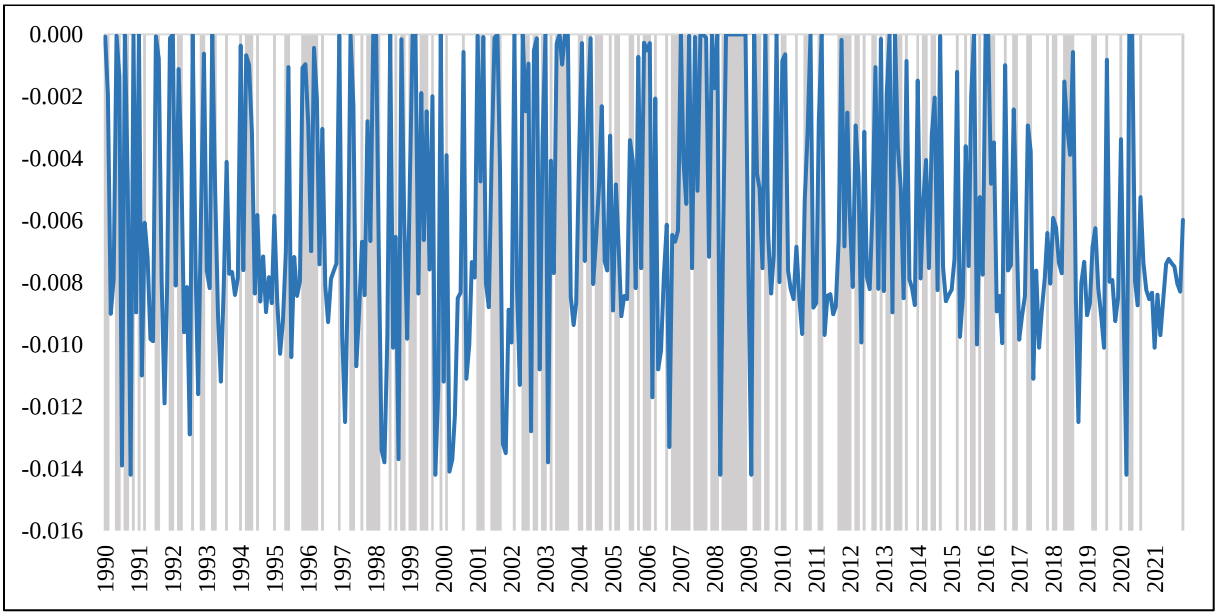
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. A coefficient that is not significant is assigned the value 0 and is multiplied by its associated transmission probability.

b. U.K. Time-Varying Coefficient of Energy Inflation



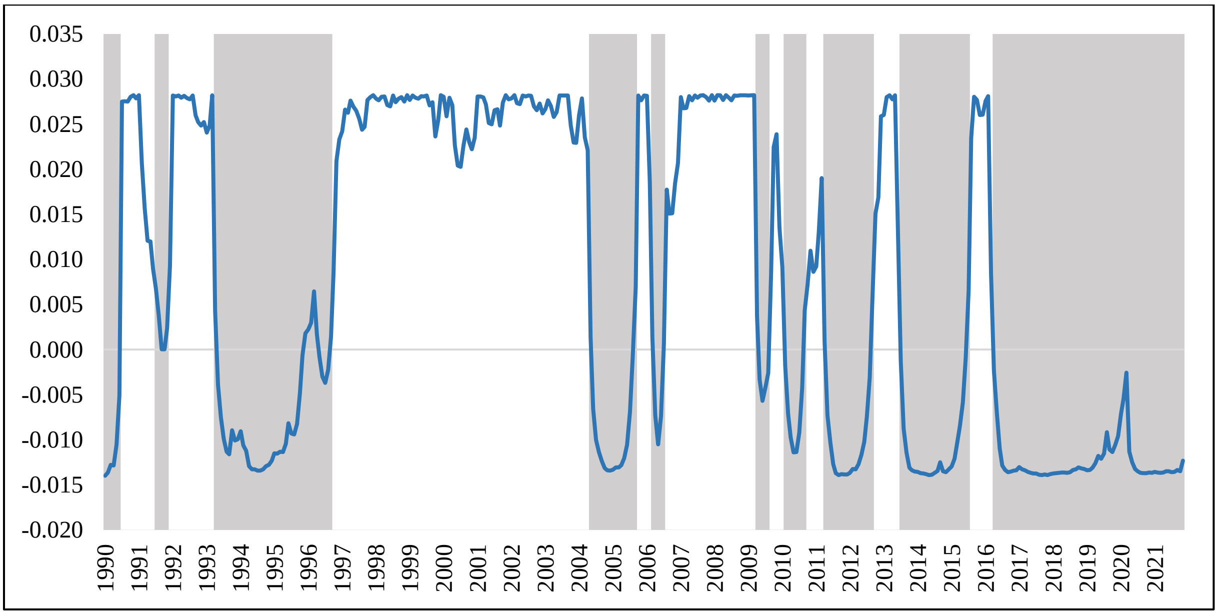
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. A coefficient that is not significant is assigned the value 0 and is multiplied by its associated transmission probability.

c. Japan Time-Varying Coefficient of Energy Inflation



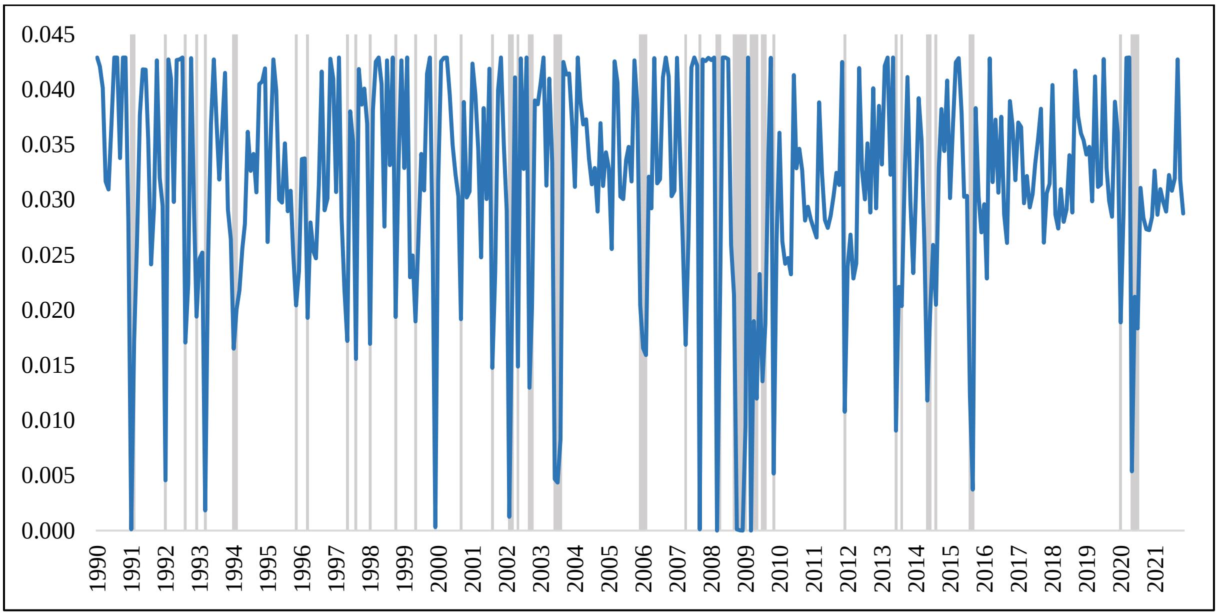
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. A coefficient that is not significant is assigned the value 0 and is multiplied by its associated transmission probability.

d. Japan Time-Varying Coefficient of Food Inflation



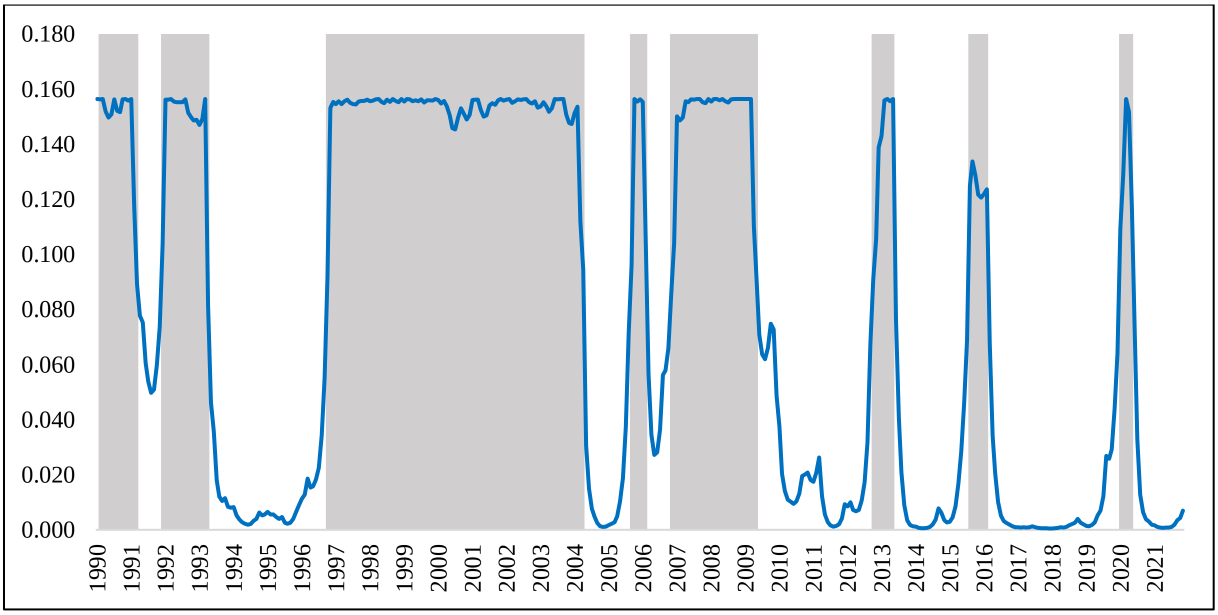
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. A coefficient that is not significant is assigned the value 0 and is multiplied by its associated transmission probability.

e. Japan Time-Varying Coefficient of Core Inflation



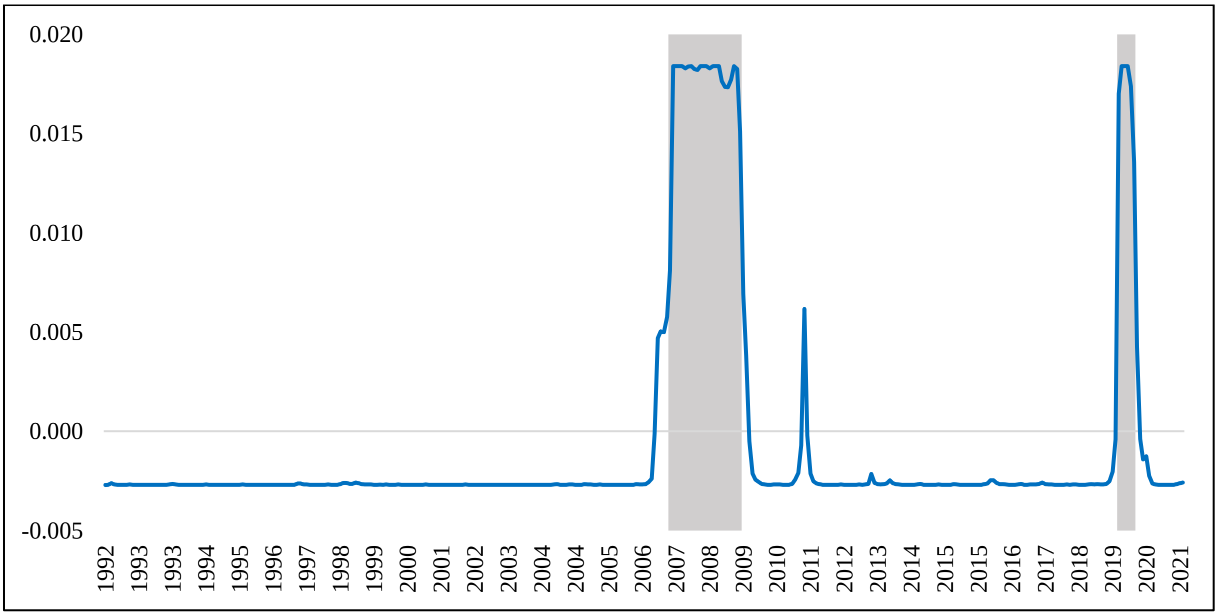
Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. A coefficient that is not significant is assigned the value 0 and is multiplied by its associated transmission probability.

f. Japan Time-Varying Coefficient of Housing Inflation



Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. A coefficient that is not significant is assigned the value 0 and is multiplied by its associated transmission probability.

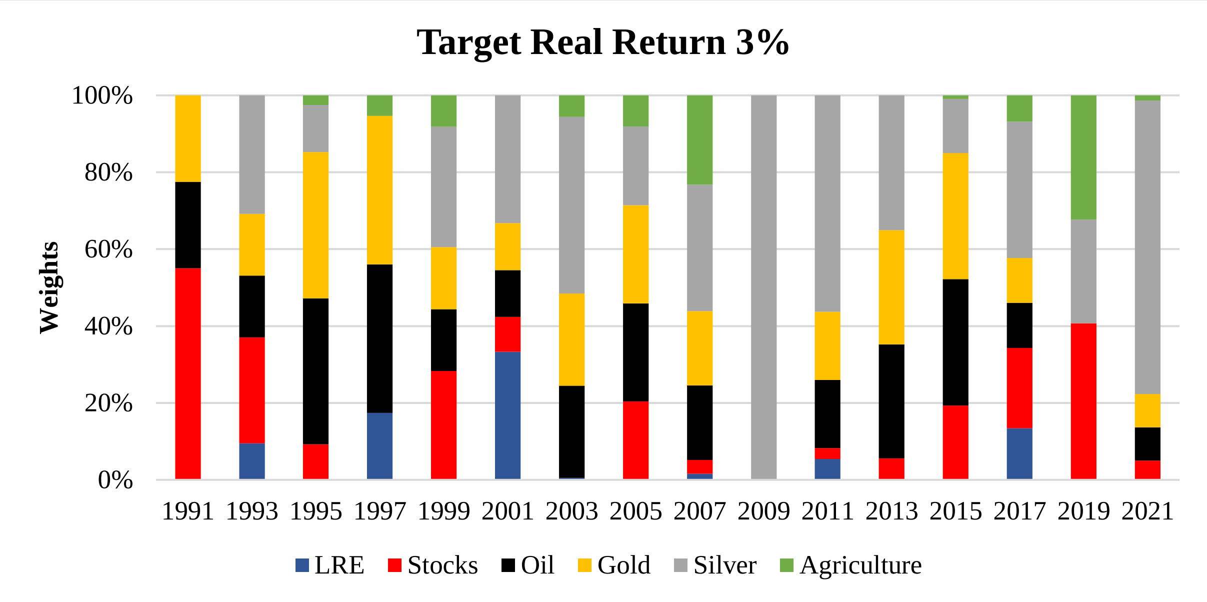
g. Australia Time-Varying Coefficient of Energy Inflation

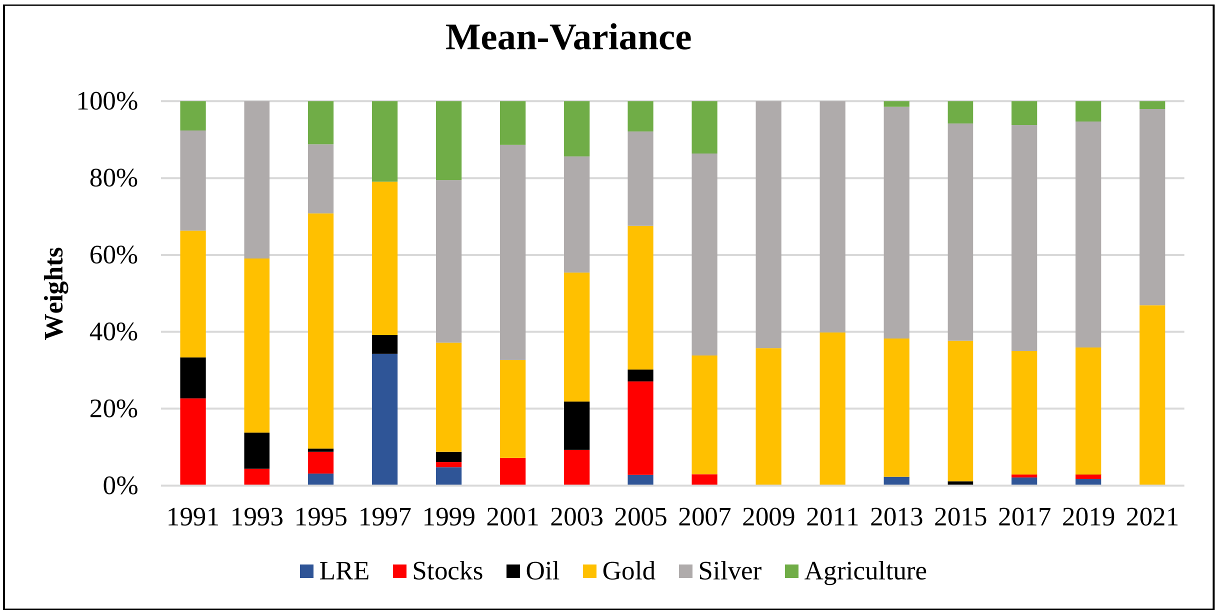


Note: The time-varying coefficient is calculated by multiplying the smoothed probability of Regime 1 with the coefficient of expected or unexpected inflation in Regime 1 plus the smoothed probability of Regime 2 multiplied by the coefficient of expected or unexpected inflation in Regime 2. A coefficient that is not significant is assigned the value 0 and is multiplied by its associated transmission probability.

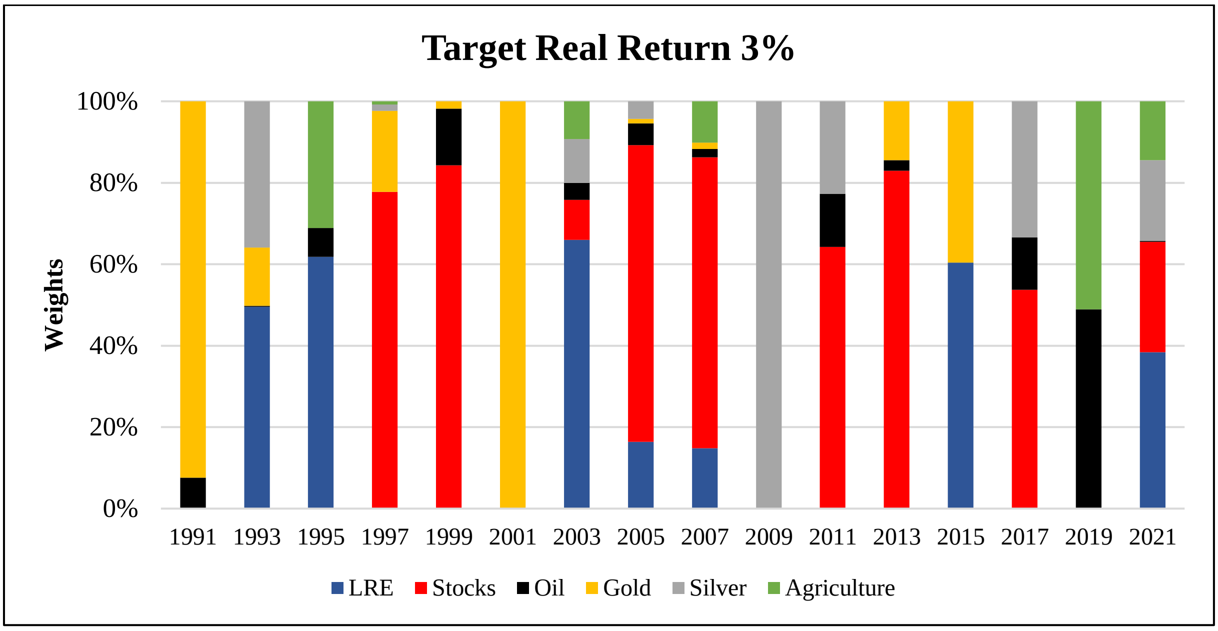
Figure 5: Portfolio Optimizations [Rebalancing Every 2 Years]

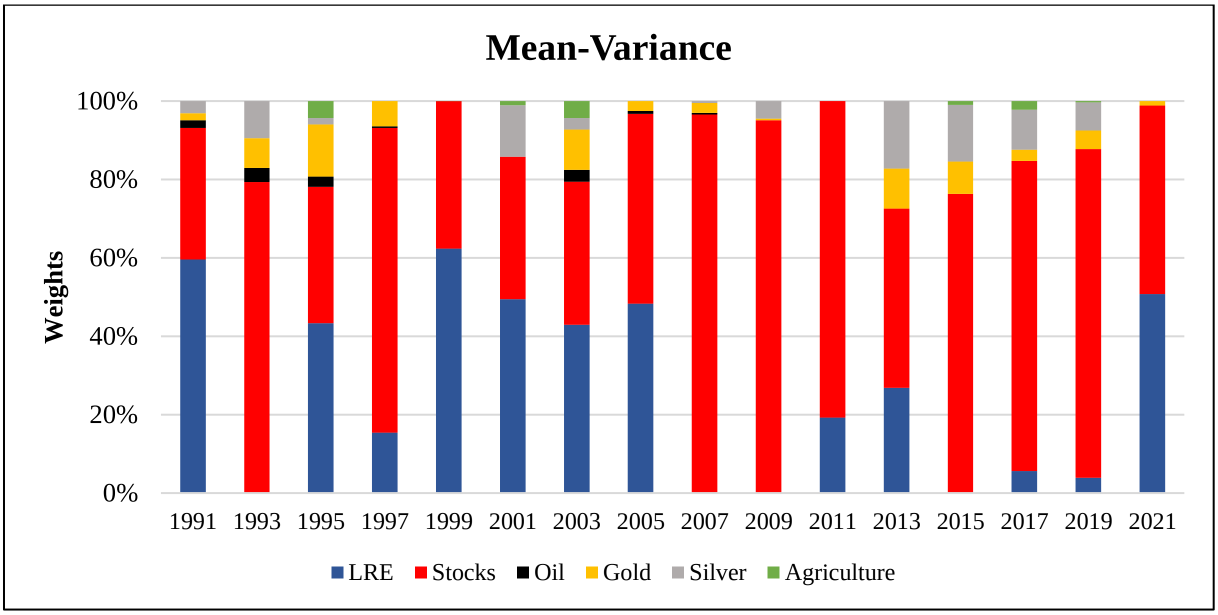
a. Weights of Shortfall Probability and Mean-Variance for the US



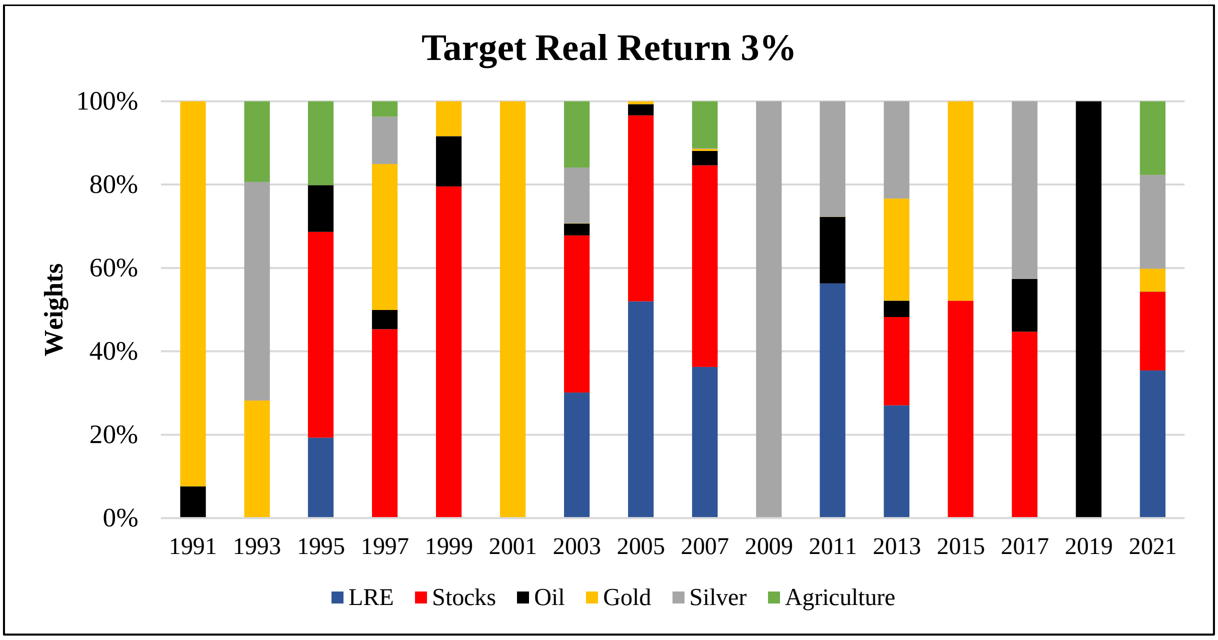


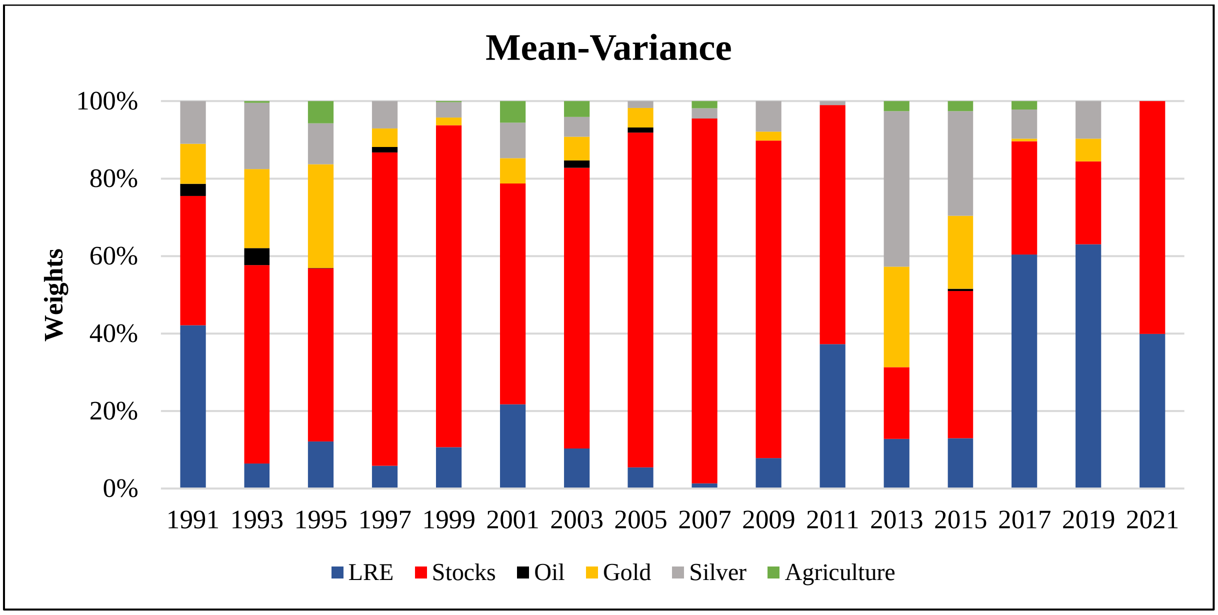
b. Weights of Shortfall Probability and Mean-Variance for the UK



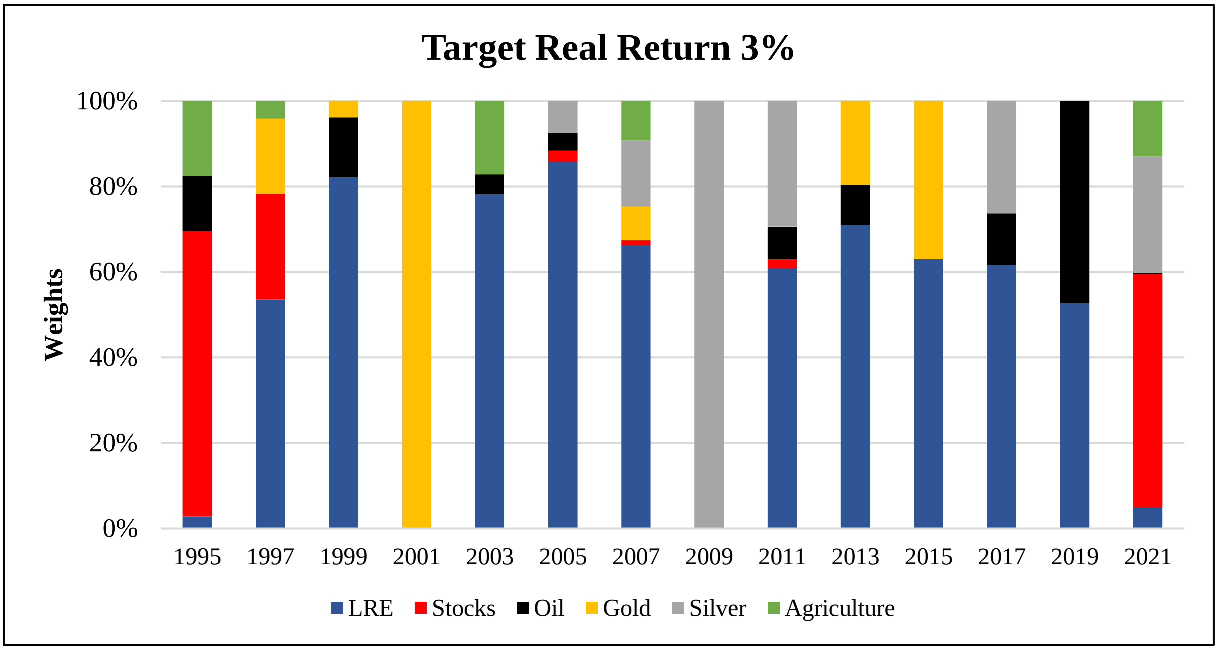


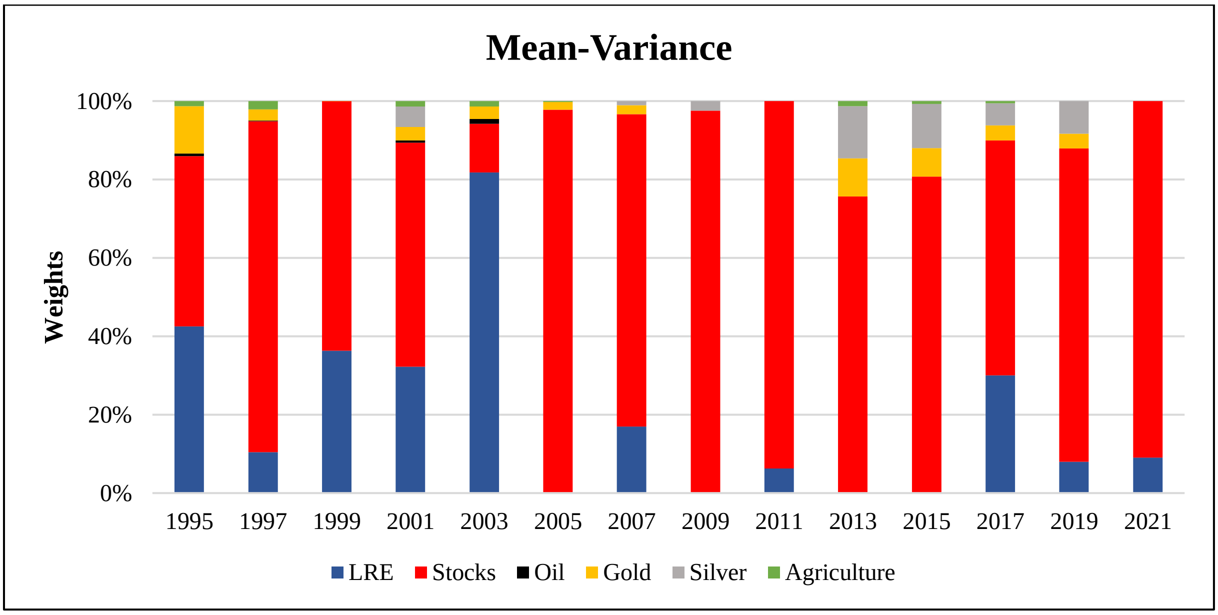
c. Weights of Shortfall Probability and Mean-Variance for Japan





d. Weights of Shortfall Probability and Mean-Variance for Australia





Appendix

Appendix 1: Results of Kwiatowski-Phillips-Schmidt-Shin (KPSS) Test

		Level	Difference	I(d)		Level	Difference	I(d)
lnLRE	US	6.105***	0.079	1	AUS	4.563***	0.130	1
lnStocks		5.808***	0.099	1		5.295***	0.053	1
lnOil		4.500***	0.054	1		4.500***	0.054	1
lnGold		5.633***	0.286	1		5.633***	0.286	1
lnSilver		5.408***	0.089	1		5.408***	0.089	1
lnAgriculture		3.040***	0.066	1		3.040***	0.066	1
lnGDP		6.409***	0.167	1		6.525***	0.163	1
Interest Rate		4.712***	0.141	1		4.587***	0.473	1
EI index		6.498***	0.616	1		6.516***	0.492	1
UI index		6.375***	0.083	1		6.354***	0.060	1
lnLRE	UK	5.284***	0.044	1	JPN	4.544***	0.178	1
lnStocks		6.293***	0.031	1		0.849***	0.264	1
lnOil		4.500***	0.054	1		4.500***	0.054	1
lnGold		5.633***	0.286	1		5.633***	0.286	1
lnSilver		5.408***	0.089	1		5.408***	0.089	1
lnAgriculture		3.040***	0.066	1		3.040***	0.066	1
lnGDP		6.426***	0.243	1		1.496***	0.329	1
Interest Rate		4.904***	0.484	1		2.836***	0.364	1
EI index		6.418***	0.263	1		6.418***	0.501	1
UI index		5.388***	0.102	1		6.508***	0.662	1

Notes: US stands for United States of America, UK for United Kingdom, JPN for Japan, and AU for Australia. LRE denotes the FTSE/EPRA/NAREIT real estate stock total return index. Stocks denotes for each country the corresponding total return of the stock market index. Oil denotes the oil price in US Dollars. Gold denotes the gold price in US Dollars. GDP stands for GDP of each country. Interest rate are the 3-month treasury bill rates. EI index and UI index stand for an index of expected and unexpected inflation, respectively. SP denotes the starting point of the time series and Obs. displays the number of observations. I(1) is given for all variables in all countrie

Appendix 2: Average Summary Statistics of Portfolios with Various Real Target Returns and Investment Horizons for the US over the Entire Sample Period

Target Real Return	Weights of LRE	Shortfall Probability	Mean	SD	Sharpe Ratio
Rebalanced every 2 years					
r = 0%	5.86%	2.54%	3.52%	21.09%	16.69%
r = 1%	5.55%	2.57%	4.34%	21.64%	20.06%
r = 2%	6.85%	2.69%	5.47%	23.59%	23.19%
r = 3%	6.35%	2.93%	5.73%	24.60%	23.29%
Rebalanced every 5 years					
r = 3%	11.79%	4.09%	4.58%	22.11%	20.71%
Rebalanced every 10 years					
r = 3%	3.40%	4.36%	4.00%	28.94%	13.82%
Rebalanced every 30 years					
r = 3%	35.33%	4.80%	4.50%	35.46%	12.69%

Note: The weights of LRE, the shortfall probability, the mean of portfolio returns, the standard deviation of portfolio returns (SD), and the Sharpe ratios of portfolios are the average values over the entire sample period.