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From bias to balance: a hierarchical Bayesian approach for correcting survivorship bias in the equity risk premium puzzle

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Zusammenfassung

Diese Dissertation untersucht, ob der Survivorship Bias die Messung der US-Aktienrisikoprämiere verzerrt. Aufbauend auf Goetzmann und Jorion (1999), die feststellen, dass die US-Prämie im Zeitraum 1921–1996 nach oben verzerrt ist, erweitert diese Studie die Stichprobe auf 1921–2020 und 1870–2020, um die Persistenz dieser Verzerrung in jährlichen Finanzmarktdaten aus sechzehn fortgeschrittenen Volkswirtschaften zu untersuchen. Die Studie kombiniert ein konsumorientiertes Asset-Pricing-Modell mit einem hierarchischen Bayesianischen Crash-Risiko-Lernmodell. Die Ergebnisse zeigen, dass die USA zwar durchgehend eine hohe Aktienrisikoprämie aufwiesen, der Survivorship-Bias jedoch nur einen kleinen Teil dieser Größe erklärt.

Abstract

This thesis investigates whether survivorship bias distorts the measurement of the U.S. equity risk premium. Building on Goetzmann and Jorion (1999), who find the U.S. premium to be upward biased in 1921-1996, this study extends the sample to 1921-2020 and 1870-2020 to assess the persistence of the bias over a more extended history. Using annual financial market data across sixteen advanced economies, the study combines a consumption-based asset pricing model with a hierarchical Bayesian crash-risk learning framework. The results show that although the U.S. consistently exhibits a high equity risk premium, survivorship bias accounts for only a small portion of its magnitude.

List of Figures

List of Tables

Contents

1 Introduction

The contradiction between economic theory and empirical evidence has often been a source of progress in economic science. One of the most persistent discrepancies between theory and evidence, known as the equity risk premium puzzle, challenges the foundations of financial macroeconomics. The fundamental asset pricing theory states that a risky asset must offer a risk premium relative to a risk-free asset to attract investors, and the magnitude of this premium depends on the covariance between the risky asset's return and the investor's stochastic discount factor. However, empirical evidence has shown that this relationship does not fully align with observed market outcomes. As Shiller (1982) demonstrated using volatility bounds, when the stochastic discount factor is derived from a standard power utility function, the combination of high equity returns and plausible levels of risk aversion would imply a discount factor that is far more volatile than that implied by actual consumption data. Mehra and Prescott (1985) employed a two-state general equilibrium model and showed that, under reasonable assumptions about risk aversion and consumption growth, the predicted excess return on equities was much lower than in historical data. The vast literature has proposed many potential solutions since the puzzle was identified, including alternative preference specifications, more complex consumption dynamics, rare disasters, market imperfections, behavioural explanations, and survivorship bias. This thesis contributes to the existing literature by building on the conclusion of Goetzmann and Jorion (1999) that the performance of the United States equity market is the exception rather than the rule. In their study of 39 global markets from 1921 to 1996, the authors were among the first to find that markets with longer and uninterrupted histories of operation tend to have higher realised rates of return, suggesting that relying only on data from surviving markets may lead to a biased estimate for the expected return on equity. Similarly, Brown, Goetzmann, and Ross (1995) modelled survival by showing that when markets face a persistent risk of collapse, the conditional survival of successful markets can generate a higher positive ex post equity premium, even if the ex ante premium were zero. More recently, van Binsbergen et al. (2020) quantified the magnitude of survivorship bias in U.S. market performance by comparing the ex post realised rates of return in each market with the ex ante expected rates of return. They modelled an investor's subjective crash belief and inferred the crash risk in the United States by cross-learning from other countries, using a hierarchical Bayesian approach.

This thesis builds on this literature by revisiting the role of survivorship bias in the U.S. equity market using the long-run Jordà-Schularick-Taylor macrohistory database.[1] The dataset covers sixteen advanced economies: Australia, Belgium, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States over the period 1870-2020. Unlike Goetzmann and Jorion (1999), who studied a broader cross-section of markets, this thesis focuses on a smaller but consistently available group of advanced economies and extends the historical period on both sides. The longer sample provides a richer perspective for evaluating whether the U.S. equity premium remains an outlier and whether survivorship bias diminishes when more historical crash episodes, such as wars, crises, and recoveries, are incorporated. Specifically, the thesis considers the idea that the U.S. equity market may have been exposed to large potential crashes that did not occur in the historical sample, yet investors were still compensated for the possibility of such events.

The research questions of this thesis are:

1. How does the equity risk premium in the United States and fifteen other advanced economies vary across the alternative sample periods (1921-1996, 1921-2020, 1870-2020), and what are its main components?

2. Does the equity risk premium in the United States tend to be biased due to the survivorship effect when compared with the other fifteen advanced economies in the sample, and how does the magnitude of this bias change when estimated over alternative sample periods (1921-1996, 1921-2020, 1870-2020)?

To address these questions, the thesis proceeds in two steps. First, the study computes the equity risk premium and its main components using Mehra and Prescott's (1985) consumption-based asset pricing model and its extension in Mehra (2003) across the three sample periods. This model is used to evaluate whether observed equity premia can be reconciled with standard preferences by examining the volatility of consumption growth, its covariance with equity returns, and the coefficient of relative risk aversion. Comparing results across three alternative periods further reveals how sensitive the U.S. premium's exceptional performance is to both the length of the sample size and the set of historical events covered.

[1] Òscar Jordà, Katharina Knoll, Dmitry Kuvshinov, Moritz Schularick, and Alan M. Taylor. 2019. "The Rate of Return on Everything, 1870–2015." Quarterly Journal of Economics, 134(3), 1225-1298.

Second, the study implements the hierarchical Bayesian learning model of van Binsbergen et al. (2020) to quantify the extent to which survivorship bias inflates the U.S. equity premium relative to fifteen other advanced economies in the sample. In this thesis, the survivorship effect refers to the country that was minimally affected by market crashes and weathered the vicissitudes of financial fluctuations. Also in this thesis, a market crash is defined as a real annual equity return below -30%. The model assumes that each country's crash probability is drawn from a common global distribution, whereas a naive investor starts with an uninformative prior over global crash risk. As annual data accumulate, the investor updates beliefs about market crash risk by combining the country's own crash history with information from the whole cross-section of advanced economies. Posterior crash probabilities are estimated using a state-of-the-art Markov chain Monte Carlo (MCMC) algorithm, more specifically Hamiltonian Monte Carlo (HMC).[2] By estimating the model separately for the three sample periods, the thesis shows that the magnitude of survivorship bias varies with the extent of the time and information.

The remainder of this thesis is organised as follows. Chapter 2 reviews the related literature. Next, Chapter 3 presents the theoretical framework, while Chapter 4 describes the empirical framework. Chapter 5 reports the empirical results. Finally, Chapter 6 summarises the findings and presents concluding remarks.

[2]Neal (2011), Hoffman and Gelman (2011), Betancourt et al. (2017)

2 Related Literature

The equity risk premium was first introduced by Mehra and Prescott in their article "The Equity Premium: A Puzzle" in 1985. They identified that the historical equity premium in the United States was much higher than could be explained by a standard general equilibrium model of the Arrow-Debreu economy. They characterised this gap between empirical evidence and theoretical predictions as a puzzle. Using a neoclassical model, they combined U.S. annual consumption growth data with empirically plausible parameters of risk aversion and the subjective discount factor to predict the equity premium. Their parametrisation implied that the equity risk premium should be around one per cent; however, the historical equity risk premium in U.S. financial market data was 6.18 per cent. Kocherlakota (1996) proposed several approaches to resolve the puzzle, including relaxing market completeness by introducing transaction costs, adopting a generalised expected utility function, and specifying individual utility as a function of the aggregate level of social consumption. Weil (1989) argued that the unusually high premium might not be due to an excessively high average return on equities, but rather to an abnormally low risk-free rate. He extended Mehra and Prescott's (1985) model by separating risk aversion from the intertemporal elasticity of substitutions in the utility function. However, his results indicated that this modification was insufficient to resolve either puzzle. Since then, some researchers have modified the standard assumptions about investor preferences introducing features such as habit formation, time-varying risk aversion or recursive utility,[1] while others have emphasised the role of incomplete market,[2] taxation, liquidity and various market imperfections.[3] Other approaches have focused on limited participation in equity markets[4] or problems of temporal aggregation.[5] Finally, more recent contributions have adopted behavioural perspectives, such as prospect theory, integrating psychological factors into asset pricing to explain investors' attitudes toward risk and return.[6]

The thesis draws on two lines of literature on survivorship bias and crash risk. Goetzmann and Jorion (1999) were among the first to find that markets with a long history tend to show higher average realised

[1] Bansal and Yaron (2004), Campbell and Cochrane (1999), Epstein and Zin (1989)
[2] Bewley (1987), Heaton and Lucas (2000)
[3] Amihud and Mendelson(1986), Brennan, Chordia, and Subrahmanyam (1998), Alvarez and Jermann (2000)
[4] Mankiw and Zeldes (1991) and Vissing-Jorgensen (2002)
[5] Gabaix and Laibson (2001)
[6] Kahneman and Tversky (1979)

returns, suggesting that the survivorship bias may partly explain the higher premium in the markets that have persisted over time. They collected capital appreciation and inflation data for a large sample of the world's equity markets from 1921 to 1996, covering both continuously operating markets and those that experienced temporary or permanent interruptions. Their work revealed that the U.S. has the highest real equity returns at 4.32 per cent, while the median return across all other countries is 0.75 per cent and 2.35 per cent for 11 countries with continuous history, excluding the U.S. market. Later, Mehra (2003) conducted a retrospective research and also observed that the equity risk premium phenomenon is not unique to the U.S. market. In his study, Mehra (2003) compared the premiums across France, Germany, Japan, the United Kingdom and the United States, which together account for more than 85 per cent of global stock market capitalisation. The equity premium was 4.6 per cent in the United Kingdom (1947-1999), 6.3 per cent in France (1973-1998), 3.3 per cent in Japan (1970-1999), 6.6 per cent in Germany (1978-1997), and 6.92 per cent in the United States (1889-2000). Although the equity premium in the U.S. is higher, it remains high in other major global markets.

Investing in equities exposes investors to multiple sources of risk, including the possibility of rare but catastrophic market crashes. Rietz (1988) tried to explain the high equity risk premium by the probability of disaster events that can have dramatic and lasting effects on investors' wealth. During such episodes, equity prices may collapse to the point where markets temporarily cease functioning, or investors may be unable to recover their losses within their lifetimes. Historical examples of such events include several disruptions during World War I (1914-1918) and World War II (1939-1945), the Spanish Civil War (1936-1939), the Great Depression (1929-1939), hyperinflation in Germany (1923), the collapse of Japanese equities (late 1980s), as well as more recent episodes as the Global Financial Crisis in 2008. Later, Barro (2006) identified rare disasters as periods when real GDP per capita dropped by roughly 30 per cent, with a fixed probability of 1.5-2 per cent per year. He combined empirical data for 35 countries up to 2000 with a consumption-based model that incorporated both disaster and partial default on government bonds. As a result, Barrow (2006) concluded that rare disasters are key to understanding the observed equity risk premium of 5-7 per cent without requiring implausibly high risk aversion. Later, Barro and Ursua (2008), and Barro and Jin (2011) built on this approach by using long-run international data to assess the frequency and impact of rare disasters empirically. Barro and Ursua (2008) identified 87 crises between 1870 and 2007, with an average stock price decline of

22 per cent, implying an equity premium of about 7 per cent. Barro and Jin (2011) combined rare disasters and long-run risks using long consumption data for 42 countries, arguing that fluctuations in the perceived likelihood of disasters drive equity risk premiums. More recently, van Binsbergen et al. (2020) employed a hierarchical Bayesian model to quantify the magnitude of survivorship bias in U.S. equity market performance using data from 55 equity markets spanning 1921 to 2020. Their framework models the subjective crash beliefs of investors who infer U.S. crash risk through cross-country learning, rather than relying only on domestic history. The empirical findings reveal a persistent and widening divergence between the estimated U.S. crash probability and the global average, suggesting that the U.S. has been less exposed to extreme negative shocks than other markets, accounting for one-third of the observed equity risk premium. Damodaran (2023) argued that a series of macroeconomic shocks has affected global markets in recent years, suggesting that financial integration and globalisation may have increased both the frequency and the probability of rare disasters, therefore increasing the equity risk premium globally.

3 Theoretical Framework

3.1 The equity risk premium puzzle within the consumption-based asset pricing model

The equity premium puzzle can be illustrated within a neoclassical growth model of a frictionless economy, where a representative agent maximises expected lifetime utility over stochastic consumption paths using a time-separable utility function defined as:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U(c_t) \right\}, \quad 0 < \beta < 1, \tag{3.1}$$

where $E_0\{\cdot\}$ represents expectations conditional on information available today, while $U : \mathbb{R}^+ \to \mathbb{R}$ is assumed to be an increasing, continuously differentiable, and concave utility function. The consumption per capita is denoted as c_t, and β^t is the subjective time discount factor at time t. The representative agent is assumed to have a constant relative risk aversion (CRRA) utility function:

$$U(c, \gamma) = \frac{c^{1-\gamma}}{1-\gamma}, \quad 0 < \gamma < \infty. \tag{3.2}$$

where the parameter γ measures the curvature of the utility function and the degree of risk aversion. The economy consists of a single productive unit that generates dividends d_t, while the representative agent, endowed with e_t each period, can trade an asset priced as p_t that delivers a stochastic next period payoff $x_{t+1} = p_{t+1} + d_{t+1}$. The intertemporal optimisation problem is stated as follows:

$$\max_{\xi} \; u(c_t) + \beta E_t \left[u(c_{t+1}) \right], \tag{3.3}$$

where ξ denotes the agent's asset holdings, subject to the budget constraints:

$$c_t = e_t - p_t \xi, \tag{3.4}$$

$$c_{t+1} = e_{t+1} + x_{t+1} \xi. \tag{3.5}$$

Combining the first-order condition with the budget constraints yields the Euler equation:

$$p_t u'(c_t) = E_t\left[\beta u'(c_{t+1}) x_{t+1}\right]. \tag{3.6}$$

This states that the marginal utility loss from reducing current consumption today equals the expected discounted marginal utility gain from the asset's future payoff. Defining the stochastic discount factor as:

$$m_{t+1} \equiv \frac{u'(c_{t+1})}{u'(c_t)}, \tag{3.7}$$

where m_{t+1} is strictly positive. The pricing conditions for equity and the risk-free asset are:

$$1 = \beta E_t\left\{ m_{t+1} R_{e,t+1}\right\}, 1 = \beta E_t\{ m_{t+1}\} R_{f,t+1}. \tag{3.8}$$

These two equations yield the standard decomposition of expected equity returns:

$$E_t(R_{e,t+1}) = R_{f,t+1} + \mathrm{cov}_t\left(\frac{-u'(c_{t+1}),\ R_{e,t+1}}{E_t\left[u'(c_{t+1})\right]}\right). \tag{3.9}$$

Risk compensation is determined by the covariance between returns on risky assets and the marginal utility of consumption. Specifically, risky assets that covary positively with consumption must offer a higher premium to compensate investors for bearing consumption risk. In the framework of Mehra (2003), under the assumptions that consumption and dividends grow i.i.d. and are jointly log normally distributed, the logarithmic equity premium is expressed as the product of the coefficient of relative risk aversion, γ, and the covariance between consumption growth and equity returns, $\sigma_{w,R_{e,t+1}}$:

$$\ln E\{R_{e,t+1}\} - \ln R_f = \gamma\sigma_{w,R_{e,t+1}} \tag{3.10}$$

In equilibrium, the model requires that equity returns are perfectly correlated with consumption growth, and therefore, the equity risk premium can be written as:

$$\ln E\{R_{e,t+1}\} - \ln R_f = \gamma\sigma_w^2 \tag{3.11}$$

In this formulation, the equity premium is given by the product of the coefficient of relative risk aversion, γ, and the variance of the growth rate of consumption, σ_w^2. The equity premium puzzle becomes evident when these values are compared with historical data. According to Mehra and Prescott (1985), the variance of consumption growth was only 0.00125, while the observed average equity premium was approximately 6 per cent between 1889 and 1978. Reconciling these figures within the consumption-based asset pricing model would require a coefficient of relative risk aversion at the level of 45-50, which is implausibly high. Therefore, the limited variability in consumption growth rates, combined with the historically high equity premium, constitutes the essence of the puzzle.

3.1.1 Rare disasters

The literature following Rietz (1988) and Barro (2006) shows that the equity premium puzzle can be addressed by introducing rare but catastrophic events in consumption growth. In this asset pricing model, the logarithmic consumption growth, Δc_{t+1}, follows a random walk with drift and rare jumps:

$$\Delta c_{t+1} = \mu + \varepsilon_{t+1} + v_{t+1}, \tag{3.12}$$

where μ is the mean growth rate and is positive, ε_{t+1} is an i.i.d. random term with variance σ^2 and mean 0, while the random term v_{t+1} represents the jump component associated with a disaster. Following Barro (2006), a rare disaster occurs with probability p_t, and the size of the downward jump is b. The jump component v_{t+1} is defined as:

$$v_{t+1} = \begin{cases} \log(1-b), & \text{with probability } p_t, \\ 0, & \text{with probability } 1-p_t. \end{cases} \tag{3.13}$$

The state $v_{t+1} = log(1-b)$ corresponds to a rare disaster in which consumption falls by $b * 100\%$ with probability p_t. Under CRRA preferences, a higher disaster probability increases the equity premium:

$$\ln E\{R_{e,t+1}\} - \ln R_f = \gamma\sigma_w^2 \ + \ b\big[(1-b)^{-\gamma} - 1\big]p_t, \tag{3.14}$$

where the $\gamma\sigma_w^2$ captures standard risk compensation, while the $b\left[(1-b)^{-\gamma}-1\right]p_t$ gives the disaster-risk premium, which rises in the size of the consumption drop b and in the probability of a disaster p_t. In the model of van Binsbergen et al.(2020), the agent is endowed with imperfect information and forms subjective beliefs about disaster risk, updating them as new information arrives. Since the price-dividend ratio reflects the expectation about future payoffs and disaster risk, it depends directly on the subjective probability p_t. Thus, p_t becomes a time-varying endogenous state variable affecting asset prices through expected cash flows and discount rates. If subjective disaster risk declines and the price-dividend ratio increases, the realised return exceeds the ex ante expected return. However, as shown by Tsai and Wachter (2015), for the price-dividend ratio to increase when subjective crash probability falls, it is necessary that risk aversion $\gamma < 1$. Otherwise, the increase in the risk-free rate outweighs the decline in the risk premium, causing the price-dividend ratio to fall. To avoid this, van Binsbergen et al. (2020) employ Epstein-Zin preferences, where the agent's utility function is:

$$V_t = \left[(1-\delta)C_t^{1-1/\psi} + \delta\left(\mathbb{E}(V_{t+1}^{1-\gamma})\right)^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}}. \tag{3.15}$$

In this recursive function equation, the coefficient δ denotes the subjective discount factor, and the parameter ψ is the elasticity of intertemporal substitution. The dividend process is modelled as a levered claim on consumption $d_t = \lambda c_t$. The stochastic discount factor is given by logarithmic consumption growth Δc_{t+1} and the return on the market portfolio $r_{m,t+1}$:

$$m_{t+1} = \theta \log \delta - \frac{\theta}{\psi}\Delta c_{t+1} + (\theta - 1)\, r_{m,t+1}, \tag{3.16}$$

where $\theta = \frac{1-\gamma}{1-1/\psi}$ is a parameter that determines how the stochastic discount factor loads on consumption growth and asset returns. By the Euler equation, the price of the dividend claim satisfies:

$$P_t^D = E_t\left[e^{m_{t+1}}(P_{t+1}^D + D_{t+1})\right]. \tag{3.17}$$

The equilibrium price-dividend ratio $Z_t^D = P_t^D/D_t$ depends on p_t. A convenient monotonic transformation is:

$$K_t^D \equiv \frac{Z_t^D}{1+Z_t^D}. \tag{3.18}$$

In the model, K_t^D has a closed-form expression:

$$\begin{aligned} K_t^D &= \delta e^{\left(\lambda-\frac{1}{\psi}\right)\mu+\frac{1}{2}\left((1-\gamma)\left(\gamma-\frac{1}{\psi}\right)+(\lambda-\gamma)^2\right)\sigma^2} \\ &\quad \times \left[(1-b)^{1-\gamma}p_t+1-p_t\right]^{\frac{\gamma-1/\psi}{1-\gamma}}\left[(1-b)^{\lambda-\gamma}p_t+1-p_t\right]. \end{aligned} \tag{3.19}$$

In this thesis, the calibration parameters were applied the same as in the works of Barro (2006) and van Binsbergen et al. (2020) such as $\sigma = 3, \beta = 0.98, \mu = 0.0252, \lambda = 2.6, \psi = 1$, $b = 0.3$ and show that K_t^D remains decreasing in the empirically relevant range of disaster probabilities satisfying the economic intuition.

3.2 A hierarchical Bayesian crash-risk learning model

This section presents a hierarchical Bayesian empirical model in which the investor updates her beliefs about a country-specific crash probability using the cross-sectional distribution of observed returns. This model is used in the thesis to present an unbiased picture of the equity risk premium puzzle.

Prior and Hyperprior. The investor's prior beliefs about each country i's an equity market crash probability p_t are modelled as:

$$p_i \mid \alpha, \beta \sim \text{Beta}(\alpha, \beta), \qquad i = 1, \ldots, n. \tag{3.20}$$

where the $Beta()$ distribution is defined on the interval $(0, 1)$. In this thesis, the investor is assumed to be naive and to start from an uninformative prior over crash probabilities, implying a Uniform $(0, 1)$ distribution before any cross-country data are observed. Although this assumption may seem extreme, because this implies a prior mean global crash risk to be equal to 50 per cent, it is widely used and theoretically appealing (Gelman et al., 2013). The parameters α and β are treated as random variables and determine the investor's prior beliefs about the likelihood of a crash. However, to specify a prior over these parameters, the model requires a hyperprior distribution over (α, β) that assumes a global crash-risk distribution. Therefore, the hyperprior is introduced through a convenient reparameterisation of the Beta distribution in terms of

$$\phi = \frac{\alpha}{\alpha + \beta}, \qquad \lambda = \alpha + \beta, \tag{3.21}$$

where ϕ represents the global average crash risk and λ is the sample size. A larger value of λ implies a more concentrated global prior, while a small λ allows more dispersed crash risk. The uninformative hyperprior is assumed to have the form of

$$\phi \sim \text{Uniform}(0, 1), \qquad \lambda \sim \text{Pareto}(1, 0.5), \tag{3.22}$$

where λ has a heavy-tailed prior and therefore allows the global crash-risk distribution to remain flexible. The join prior for (ϕ, λ) is

$$f(\phi, \lambda) \propto \lambda^{-3/2} \mathbf{1}_{\{\phi \in [0,1]\}}. \tag{3.23}$$

Under the change of variables the implied hyperprior for (α, β) is

$$f(\alpha, \beta) = (\alpha + \beta)^{-5/2}. \tag{3.24}$$

Likelihood. In each period, the investor observes a realised crash for a country i at time t in the cross-section of n countries. The crash indicator $D_{i,t}$ takes the value one if a crash occurs in the specific country t and zero otherwise, conditional on the country-specific crash probability p_i. It is assumed to be i.i.d. over time and across countries for convenience (van Binsbergen et al., 2020). From the uninformative investor's perspective, who does not observe p_i directly, the realisation of crashes appears as a random Bernoulli distribution:

$$D_{i,t} \mid p_i \overset{\text{i.i.d.}}{\sim} \text{Bernoulli}(p_i). \tag{3.25}$$

$Y_{i,\tau}$ is the vector of i.i.d. crash realisations for country i up to time τ:

$$Y_{i,\tau} = [D_{i,1}, D_{i,2}, \ldots, D_{i,\tau}]. \tag{3.26}$$

Posterior. Given the complete set of crash observations across all countries $i = 1, ..., n$ and years $t = 1, ..., \tau$, denoted as $\{D_{i,t}\}_{i=1,t=1}^{n,\tau}$, the investor first updates her prior beliefs about the global hyperparameters α and β, as well as about the country-specific crash probabilities.

The joint posterior distribution of the $f(\{p_i\}_{i=1}^{n}, \alpha, \beta \mid \{D_{j,t}\}_{j=1,t=1}^{n,\tau})$ follows from Bayes' rule:

$$f(\{p_i\}_{i=1}^{n}, \alpha, \beta \mid \{D_{j,t}\}_{j=1,t=1}^{n,\tau}) \propto f(\{D_{j,t}\}_{j=1,t=1}^{n,\tau} \mid \{p_i\}_{i=1}^{n}, \alpha, \beta)\, f(\{p_i\}_{i=1}^{n} \mid \alpha, \beta)\, f(\alpha, \beta), \quad (3.27)$$

where the posterior is proportional to the likelihood $f(\{D_{j,t}\}_{j=1,t=1}^{n,\tau} \mid \{p_i\}_{i=1}^{n}, \alpha, \beta)$, times the prior $f(\{p_i\}_{i=1}^{n} \mid \alpha, \beta)$, times the hyperprior $f(\alpha, \beta)$. The prior global crash distribution (α, β) is updated dynamically over time as new crash observations become available in the country by the laws of conditional probability:

$$f(\{p_i\}_{i=1}^{n}, \alpha, \beta \mid \{D_{i,t}\}) = f(\{p_i\}_{i=1}^{n} \mid \alpha, \beta, \{D_{i,t}\})\, f(\alpha, \beta \mid \{D_{i,t}\}) \quad (3.28)$$

and

$$f(\alpha, \beta \mid \{D_{i,t}\}) = \frac{f(\{p_i\}_{i=1}^{n}, \alpha, \beta \mid \{D_{i,t}\})}{f(\{p_i\}_{i=1}^{n} \mid \alpha, \beta, \{D_{i,t}\})} \quad (3.29)$$

Although the investor uses the cross-country crashes to update the global hyperparameters α and β, the crash probability for a given country i is inferred only from country-specific information, that is, $f(p_i \mid \alpha, \beta, \{D_{j,t}\}) = f(p_i \mid \alpha, \beta, Y_{i,\tau})$. Using the Bayesian equation, the conditional posterior distribution is therefore:

$$p_i \mid \{\alpha, \beta, \{D_{i,t}\}_{j=1,t=1}^{n,\tau}\} \sim \text{Beta}\big(Y_{i,\tau} + \alpha,\ \tau - Y_{i,\tau} + \beta\big), \qquad \forall i. \quad (3.30)$$

At any time τ, the investor updates the crash probability for country i by observing the number of crashes in country i's crash history with her prior information given by the global crash distribution (α, β). The marginal posterior for the country-specific crash probability must account for the uncertainty in the global crash-risk parameters. This is achieved by integrating over all possible values of (α, β):

$$f(p_i \mid \{D_{j,t}\}_{j=1,t=1}^{n,\tau}) = \int_{\alpha,\beta} f(p_i \mid \{D_{j,t}\}_{j=1,t=1}^{n,\tau}, \alpha, \beta)\, f(\alpha, \beta \mid \{D_{j,t}\}_{j=1,t=1}^{n,\tau}\, d(\alpha, \beta), \qquad \forall i. \quad (3.31)$$

After integrating out the uncertainty, the posterior mean crash probability for each country is taken as a weighted average of its own crash range $Y_{i,\tau}$ and the global mean crash risk $\alpha/((\alpha+\beta)$:

$$\mathbb{E}\Big[p_i \mid \alpha, \beta, \{D_{j,t}\}_{j=1,t=1}^{n,\tau}\Big] = \frac{Y_{i,\tau}\mathbf{1}^\top}{\tau}\left(\frac{\tau}{\tau+\alpha+\beta}\right) + \frac{\alpha}{\alpha+\beta}\left(1 - \frac{\tau}{\tau+\alpha+\beta}\right). \tag{3.32}$$

The weight of the global component increases with the effective sample size $\alpha+\beta$. As a result, the hierarchical Bayesian model generates a shrinkage effect, meaning that the posterior means for riskier countries are reduced, while posterior means for less risky countries are increased. The strength of the shrinkage effect depends on the length of the country-specific sample. As the sample size increases toward infinity, the conditional posterior mean of crash risk probability converges to the country's true crash frequency by the law of large numbers:

$$\lim_{\tau_i\to\infty} \mathbb{E}\Big[p_i \mid \alpha, \beta, \{D_{j,t}\}_{j=1,t=1}^{n,\tau}\Big] = \lim_{\tau_i\to\infty} \frac{\dfrac{Y_{i,\tau_i}\mathbf{1}^\top}{\tau_i} + \dfrac{\alpha}{\tau_i}}{1 + \dfrac{\alpha+\beta}{\tau_i}} = \lim_{\tau_i\to\infty} \frac{Y_{i,\tau_i}\mathbf{1}^\top}{\tau_i}. \tag{3.33}$$

The posterior mean of the country-specific crash risk is a weighted average of the conditional means, given the observed global crash risk. Formally,

$$\mathbb{E}[p_i \mid \{D_{j,t}\}_{j=1,t=1}^{n,\tau}] = \mathbb{E}\Big[\mathbb{E}\big[p_i \mid \alpha, \beta, \{D_{j,t}\}_{j=1,t=1}^{n,\tau}\big] \,\Big|\, \{D_{j,t}\}_{j=1,t=1}^{n,\tau}\Big]. \tag{3.34}$$

Overall, the hierarchical Bayesian model provides a parsimonious framework for estimating country-specific crash probabilities. By integrating local and global information, the model allows for the formation of unbiased beliefs about crash risk in the United States.

4 Empirical framework

4.1 Data Description

The empirical part of this thesis is based on the Jordà-Schularick-Taylor (JST) Macrohistory Database,[1] which provides annual macroeconomic and financial series for up to sixteen advanced economies over 1870-2020. The sample covers the following countries: Australia, Belgium, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. All returns are constructed at the national aggregate-holdings level, allowing interpretation as the returns received by a representative investor in the country's aggregate portfolio.

Equity returns. Total returns were constructed using broad national equity indices, including both price changes and dividends. The historical series relied on the most comprehensive market indices available for each period. When full "all-share" indices were unavailable, the JTS database used broader composite indices, and when necessary, "blue-chip" indices that covered only the most actively traded. Weighting schemes varied with data availability: market-capitalisation weights are preferred, but book-value, turnover, equal-weight, or hybrid methods were also applied when market-capitalisation data were missing. In more recent decades, the series were extended using Fama-French factors (Chen at. 2022) for all countries except Portugal and the United States. For Portugal, the PSI All-Share index and Euronext Lisbon indices were used. For the United States, the series were taken from Robert Shiller's database, where the capital gains were computed from the S&P Index, and dividend yields were computed from the growth of nominal dividends. The total nominal return on equities was calculated as:

$$r_t^{e,nominal} = \frac{p_t + d_t}{p_{t-1}} - 1. \tag{4.1}$$

Bills. In the JST dataset, bill returns were defined as yields on short-term government securities, typically Treasury bills with a maturity of around three months. In the absence of Treasury bill data, money market rates or deposit rates were used as proxies. Since the issuance of short-term government

[1] Òscar Jordà, Katharina Knoll, Dmitry Kuvshinov, Moritz Schularick, and Alan M. Taylor. 2019. "The Rate of Return on Everything, 1870–2015." Quarterly Journal of Economics, 134(3), 1225-1298.

debt was relatively uncommon in earlier historical periods, particularly prior to the 1960s, a substantial portion of the early bill series relied on deposit rates. The series was extended through 2020 using three-month interbank rates from the OECD Main Economic Indicators, money market rates from the IMF IFS, and deposit rates from National Central Banks. The nominal bill rate was computed as:

$$r_t^{f,nominal} = \frac{coupon_t}{p_{t-1}} \tag{4.2}$$

Real consumption per capita (index, 2006=100). The early periods series were taken from the Barro-Ursua Macroeconomic Data, which provides long-run estimates of real per capita consumption. For all countries, the data were extended using World Bank indicators, specifically household final consumption per capita. When the Barro-Ursua dataset did not cover the earliest years, the JST dataset used the available national historical sources. The annual growth rate of real per capita consumption was calculated as:

$$g_{t+1} = \frac{c_{t+1}}{c_t} - 1. \tag{4.3}$$

Consumer prices (index, 1990=100). Long-run CPI series were conducted using a chain-linked method, drawing on the most reliable national and research-based sources. For many countries, data before 1997 were taken from Taylor's (2002) century-long PPP/CPI compilations, while from the late 1990s onward, the series were extended using the IMF World Economic Outlook (WEO), specifically the "Inflation, average consumer prices" indicator. Where necessary, country-specific adjustments were made using national statistical offices or specialised historical reconstructions.

Inflation. Annual consumer price inflation was calculated at the country-year level as the gross growth rate of the CPI index:

$$\pi_t = \frac{\mathrm{CPI}_t}{\mathrm{CPI}_{t-1}} - 1. \tag{4.4}$$

4.1.1 Definition of crashes and sample periods

In this thesis, a market crash is defined as an annual return decline of -30% or worse. The investor in the model updates her beliefs according to the observed frequency of such crashes. Given the data's annual frequency, temporary market crashes lasting less than one year are not included in the dataset and are irrelevant to the study. The archival reconstruction of equity returns in the dataset provides continuous annual coverage, allowing capture of all market downturns an investor would have experienced during the period 1870-2020.

Table 4.1 reports the number of crash episodes n, the number of observations N, and the frequency of market crashes $p(\%)$ for each country in the sample from 1870 to 2020:

Table 4.1: Frequency of crashes (-30%)

Country	Period	n	N	p(%)	Country	Period	n	N	p(%)	Country	Period	n	N	p(%)
Australia	1871–2020	3	150	2.00	Germany	1871–2020	8	150	5.33	Sweden	1871–2020	5	150	3.33
Belgium	1871–2020	6	150	4.00	Italy	1871–2020	10	150	6.67	Switzerland	1900–2020	2	121	1.65
Denmark	1873–2020	2	148	1.35	Japan	1886–2020	4	133	3.01	UK	1871–2020	4	150	2.67
Finland	1896–2020	9	125	7.20	Netherlands	1900–2020	4	121	3.31	USA	1872–2020	6	149	4.03
France	1871–2020	8	150	5.33	Norway	1881–2020	5	140	3.57					
Portugal	1871–2020	12	150	8.00	Spain	1900–2020	3	121	2.48					

Crash frequencies vary across countries from 1-2% in Switzerland and Denmark to 7-8% in Finland and Portugal. The U.S. crash frequency of 4.03% lies around the average, providing a re-evaluation of the survivorship bias conclusion reached by Goetzmann and Jorion (1999) using a longer dataset.

4.2 Research questions and methodology

The thesis investigates how survivorship bias affects the measurement of the U.S. equity risk premium relative to fifteen other advanced economies. While Goetzmann and Jorion (1999) study a broader set of countries over the period of 1921-1996 and argue that the U.S. shows a survivorship-biased premium, this thesis focuses on a smaller but consistently available group of advanced economies. The contribution of this study lies in extending the time horizon to 1921-2020 and 1870-2020, which provides a longer historical perspective and allows for assessing how survivorship bias evolves over the sample periods.

The research questions of this thesis are:

1. How does the equity risk premium in the United States and fifteen other advanced economies vary across the alternative sample periods (1921-1996, 1921-2020, 1870-2020), and what are its main components?

2. Does the equity risk premium in the United States tend to be biased due to the survivorship effect when compared with the other fifteen advanced economies in the sample, and how does

the magnitude of this bias change when estimated over alternative sample periods (1921-1996, 1921-2020, 1870-2020)?

Motivated by these considerations, the empirical part of this thesis is proceeded in two steps. First, the equity risk premium and its main components are computed across all countries in the sample using Mehra and Prescott's (1985) model and its extension in Mehra (2003). This provides a benchmark for comparing long-run equity returns, evaluating whether the U.S. premium appears unusually high relative to other advanced economies, and assessing whether the U.S. premium's performance is stable across the three sub-samples. Second, the thesis employs a hierarchical Bayesian model following van Binsbergen et al. (2020) to estimate time-varying beliefs about rare-disaster risk, where a crash is defined as a real annual equity return below -30%. The hierarchical structure allows an investor to update crash-risk beliefs using both domestic crash histories and the cross-sectional distribution of crashes. It implies a shrinkage effect in which country-level crash frequencies toward the global average. Comparing the expected returns implied by these posterior crash probabilities with realised U.S. returns provides a quantitative measure of survivorship bias.

4.2.1 Measuring the equity risk premium

This section presents the implementation of the consumption-based asset pricing model introduced in the theoretical framework. The excess equity returns can be expressed as the strictly positive market price of consumption risk, λ, and the exposure of equity returns to fluctuation in consumption, β_c:

$$E(R_{e,t+1} - R_{f,t+1}) = \lambda\beta_c, \tag{4.5}$$

These terms are defined within the coefficient of relative risk aversion, γ, and the growth rate of real per capita consumption, w_{t+1}:

$$\lambda = \frac{\gamma \mathrm{Var}(w_{t+1})}{1 - \gamma E(w_{t+1} - 1)}, \qquad \beta_c = \frac{\mathrm{Cov}(w_{t+1}, R_{e,t+1} - R_{f,t+1})}{\mathrm{Var}(w_{t+1})}. \tag{4.6}$$

While the market price of risk depends on preference parameters that cannot be directly observed, the consumption beta is an empirical object that can be estimated from the covariance of observed returns and consumption growth. Under the assumption that returns are approximately lognormally distributed, the implied coefficient of relative risk aversion is calculated as:

$$RRA = \gamma = \frac{\ln E(R_{e,t+1}) - \ln E(R_{f,t+1})}{\mathrm{Cov}(\ln R_{e,t+1}, \ln w_{t+1})}. \tag{4.7}$$

4.2.2 Estimation of the hierarchical Bayesian model

The posterior distribution of the hierarchical Bayesian learning model is constructed following the estimation procedure in van Binsbergen et al. (2020). Posterior crash probabilities are obtained using Hamiltonian Monte Carlo (HMC), a gradient-based Markov Chain Monte Carlo algorithm (Neal, 2011). Four independent Markov chains are initialised at dispersed random starting values, and each chain generates 10 000 iterations, of which the first 2 000 iterations are discarded as burn-in. The remaining samples are pooled across chains to form the posterior distribution. The estimation is repeated under an expanding-window design, allowing the information set to grow over time, as a Bayesian investor would update beliefs as additional country-level crash observations become available. Standard convergence diagnostics are employed to assess the stability of the chains, including the Gelman-Rubin statistics (Gelman and Rubin, 1992) and effective sample size, which compares within- and between- chain variability.

5 Results and Discussion

This section presents the empirical results. The analysis follows three sub-sample periods. First, the historical period 1921-1996 used by Goetzmann and Jorion (1999) is replicated. Second, the sample is extended to 1921-2020 to examine how the inclusion of recent crises affects estimates of the equity premium and crash-risk. Finally, the whole historical period 1870-2020 is reviewed to evaluate long-run patterns in equity returns, survivorship bias, and subjective disaster risk. For each period, measures of the equity risk premium following Mehra and Prescott's (1985) model and the extended framework of Mehra (2003) are computed. After that, the hierarchical Bayesian crash-risk learning model is applied to quantify the survivorship effect by modelling subjective crash probabilities across countries. Gelman and Rubin's (1992) statistics are used to confirm the reliability of the model parameter estimates. Out of more than four thousand generating parameters, only 39 exceed the conventional threshold of $\hat{R} > 1.1$ or the effective size $N < 200$. Nearly all deviations correspond to the hyperparameter λ, while the country-specific crash probabilities p_i show stable convergence. For the period 1870-2020, the model's performance is assessed by comparing model-implied and realised 10-year rolling average U.S. equity returns. The resulting correlation of 0.355 indicates that the model captures long-run return movements, while short-run volatility is not well captured, as the analysis is based on annual returns data.

5.1 Replication of Goetzmann and Jorion, 1921-1996

Table 5.1 reports summary statistics for equity risk premium and consumption risk for each country, as well as for the world index and world excluding U.S. index for the period 1921 - 1996. The column w_{t+1} presents the average growth rate of real consumption, while the column R_f reports real bill returns. The next columns contain the equity risk premium ERP and the real equity returns R_e. The final set of columns shows the covariance between equity returns and consumption growth $\text{Cov}(R_e, w)$, the related consumption beta β_c and the coefficient of relative risk aversion $\hat{\gamma}$ obtained from the log C-CAPM. First, it is important to note that the equity premium is positive and high in all countries, while the implied risk-aversion parameters reach unrealistically high levels, giving the equity premium puzzle. The risk premium for countries such as Germany (12.47%), Finland (10.35%), the United States

(8.15%), Japan (8.13%), the United Kingdom (7.95%), Italy (7.82%), Sweden (7.55%), Spain (7.27%), and the Netherlands (7.18%) is above the world average (7.10%). Right after the world excluding

Table 5.1: Summary statistics for equity premia and consumption risk, 1921-1996

		% w_{t+1}		% real R_f		% ERP		% real R_e		Consumption and risk		
Country	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Cov(R_e, w)	β_c	$\hat{\gamma}$
Australia	73	1.34	4.70	1.52	4.85	6.77	18.22	8.28	19.04	0.00011	0.050	5739.43
Belgium	76	2.14	8.24	0.42	10.44	5.76	23.24	6.18	21.68	0.00008	-0.800	-370.05
Denmark	76	1.48	5.91	3.50	5.81	3.46	17.24	6.96	16.55	0.00193	0.474	10.81
Finland	76	2.87	5.19	-0.39	8.85	10.35	26.73	9.97	28.42	0.00204	1.033	45.41
France	75	2.39	7.72	-2.47	10.03	4.55	24.84	2.07	27.09	-0.00537	-0.648	-3.22
Germany	70	3.30	5.19	-0.06	15.95	12.47	38.39	12.41	34.61	-0.00216	0.427	-20.33
Italy	75	2.55	4.42	-0.82	13.28	7.82	29.83	7.00	31.51	0.00068	0.040	59.02
Japan	74	2.53	7.01	-0.23	13.48	8.13	21.75	7.91	23.71	0.00934	0.773	3.45
Netherlands	76	2.48	9.15	1.39	5.28	7.18	23.82	8.57	22.84	-0.00402	-0.462	-17.32
Norway	76	2.08	3.57	0.86	6.31	5.38	19.89	6.25	20.22	0.00105	0.738	35.51
Portugal	76	3.37	4.50	-0.89	9.42	4.58	29.28	3.69	30.44	0.00134	1.016	4.36
Spain	73	3.28	6.37	-0.43	7.52	7.27	21.90	6.84	23.26	0.00111	0.507	43.98
Sweden	76	1.81	4.53	1.73	5.46	7.55	20.31	9.28	19.95	0.00023	0.055	230.58
Switzerland	76	1.62	4.44	1.42	5.13	6.61	19.55	8.03	20.02	0.00011	-0.218	1341.98
UK	76	1.75	2.70	1.17	5.20	7.95	21.82	9.12	21.90	0.00104	0.737	48.93
US	76	2.16	3.37	1.92	4.48	8.15	19.28	10.07	19.39	0.00040	0.783	117.90
World	1200	2.32	5.72	0.55	8.92	7.10	23.95	7.64	24.22	0.00048	0.060	55.33
World ex US	1124	2.33	5.84	0.46	9.14	7.03	24.24	7.48	24.51	0.00049	0.045	52.77

the U.S. average (7.03%) comes Australia (6.77%). Australia and the United States have the lowest volatility of equity premia, while Germany and Finland show the highest. In contrast, negative real bill returns are observed only in Germany (-0.06%), Finland (-0.39%), Japan (-0.23%), Italy (-0.82%), and Spain (-0.43%), which makes the equity premium even higher in these countries. To summarise, the countries with high real returns, non-negative real bill returns, and low volatility are the United States, the United Kingdom, Sweden, and Australia. The observed results are consistent with the main findings of Goetzmann and Jorion (1999), and the United States emerges as the leading market in terms of the equity premium over this period.

Figure 5.1 plots the historical frequency of large market crashes (%) against the subjective crash risk for sixteen countries over 1921-1996. The grey bars show the historical frequency of crashes below -30%, while the red dots report the posterior mean crash probabilities from the hierarchical Bayesian model. The sample size N denotes the number of annual observations on real equity returns. The percentages following the points measure the deviation of the subjective crash risk from the historical frequency: positive values indicate an overestimation of crash risk, and negative values indicate an underestimation. For the United States, the posterior crash probability (4.15%) exceeds the historical frequency (3.95%) by 5.01%. A higher expected crash probability raises the ex ante required equity premium, but because no such large crashes have historically occurred, the investor is overcompensated by 5.01%. This implies that the U.S. equity risk premium is upward biased by at least 5%.

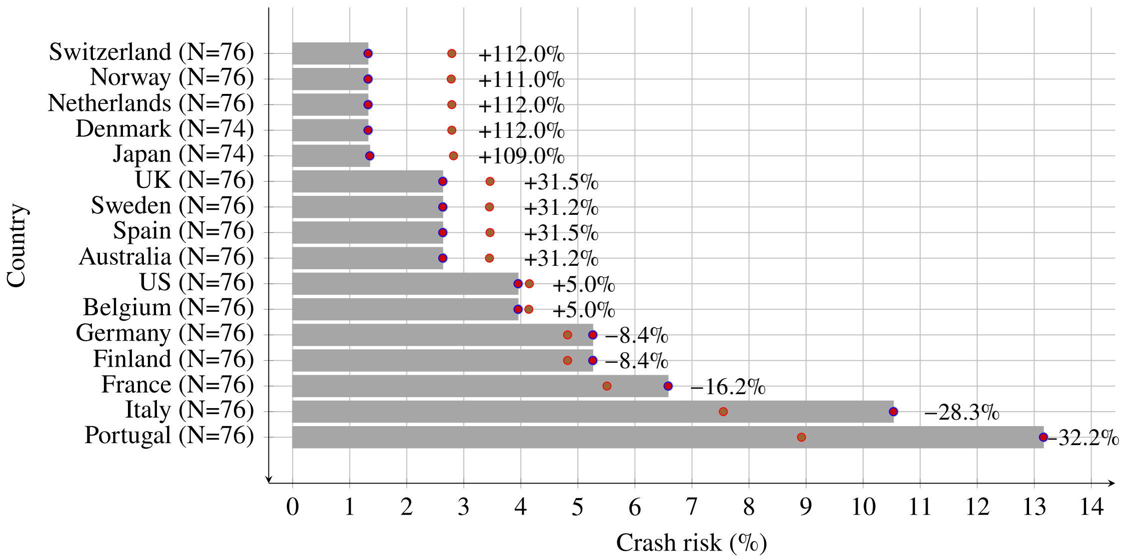

Figure 5.1: Subjective crash risk and in-sample frequency, 1921-1996

5.2 Extending sample, 1921-2020

Table 5.2 presents the summary statistics for the extended period spanning from 1921 to 2020. The cross-country patterns remain broadly consistent with those in the 1921-1996 sample. The U.S. equity premium decreases from 8.15% to 7.93%, moving closer to the world excluding the U.S. average

(7.32%). Both components fall: real equity returns decrease from 10.07% to 9.44%, and the real bill return declines from 1.92% to 1.51%. Countries with an equity premium above the world average include Finland (11,46%), Germany (11,32%), Sweden (8.65%), the United States (7.93%), and Italy (7.49%). While most have positive real bill returns, Finland, Italy and Spain remain negative. Several countries that were among the top performers in 1921-1996, such as the Netherlands (7.31%), Japan (7.15%), Switzerland (7.14%), and the United Kingdom (7.07%), with the extended period, fall below the world average (7.36%). The United States continues to stand out among countries with a high equity premium and low volatility.

Table 5.2: Summary statistics for equity premia and consumption risk, 1921-2020

		% w_{t+1}		% real R_f		% ERP		% real R_e		Consumption and risk		
Country	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	$\mathrm{Cov}(R_e, w)$	β_c	$\hat{\gamma}$
Australia	97	1.36	4.16	1.54	4.26	6.57	17.55	8.11	18.22	0.00014	0.058	647.46
Belgium	100	1.76	7.29	0.27	9.13	6.21	23.53	6.48	22.42	0.00031	-0.735	181.10
Denmark	100	1.32	5.24	2.74	5.28	5.73	19.24	8.47	18.44	0.00147	0.444	23.77
Finland	100	2.57	4.67	-0.27	7.76	11.46	30.34	11.19	31.76	0.00180	1.060	54.88
France	99	2.02	6.81	-1.81	8.82	5.47	24.05	3.66	25.92	-0.00402	-0.610	-6.55
Germany	94	2.63	4.70	0.01	13.77	11.32	35.01	11.33	31.91	-0.00143	0.471	-24.06
Italy	99	1.91	4.26	-0.53	11.57	7.49	28.20	6.96	29.61	0.00101	0.320	45.76
Japan	97	2.10	6.18	-0.19	11.70	7.15	21.71	6.96	23.18	0.00753	0.867	3.69
Netherlands	100	2.00	8.09	1.04	4.70	7.31	23.35	8.35	22.57	-0.00301	-0.456	-23.08
Norway	100	1.98	3.32	0.79	5.55	6.50	21.93	7.29	22.02	0.00094	0.748	44.52
Portugal	100	2.79	4.31	-0.66	8.24	4.47	27.82	3.81	28.84	0.00121	0.947	6.60
Spain	96	2.61	5.96	-0.36	6.58	7.52	21.63	7.15	22.77	0.00116	0.525	43.27
Sweden	100	1.66	4.07	1.42	4.84	8.65	21.68	10.07	21.40	0.00032	0.109	178.47
Switzerland	100	1.39	3.94	1.04	4.55	7.14	19.55	8.18	19.93	0.00015	-0.190	649.75
UK	100	1.60	2.83	1.07	4.72	7.07	20.48	8.14	20.52	0.00101	0.657	45.88
US	100	2.00	3.07	1.51	4.06	7.93	18.54	9.44	18.69	0.00043	0.787	112.45
World	1582	1.98	5.14	0.48	7.81	7.36	23.77	7.84	24.00	0.00055	0.110	59.50
World ex US	1482	1.98	5.26	0.41	8.00	7.32	24.09	7.73	24.32	0.00056	0.095	57.36

Figure 5.2 plots the historical frequency of large market crashes (%) against the subjective crash risk for sixteen countries over the extended period 1921-2020. Compared with 1921-1996 results, the extended sample shows a larger deviation between subjective and historical crash risks for the United States. The posterior probability (4.38%) now exceeds the historical frequency (4.00%) by 9.61%, nearly double the earlier 5.01%. This indicates that extending the sample reduces the realised U.S. equity premium but strengthens the survivorship effect, as the United States experienced only one large crash in 2008, while many other countries also faced major losses during the 2001-2002 dot-com collapse, increasing global crash risk.

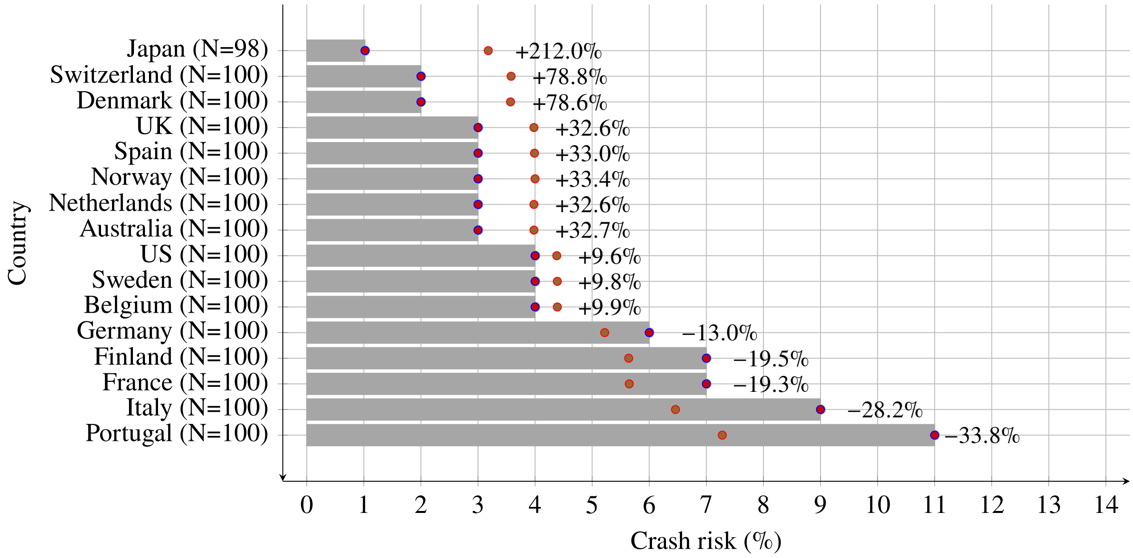

Figure 5.2: Subjective crash risk and in-sample frequency, 1921-2020

5.3 Full sample, 1870-2020

Table 5.3 reports summary statistics for equity risk premium and consumption risk for 1870 - 2020. The premiums range from 3.70% in Portugal to 9.66% in Finland. Real consumption growth is smooth, and its covariance with equity returns is near zero or negative in some countries (France, the Netherlands, and Sweden), resulting in low or negative consumption betas β_c and implausibly high implied risk aversion coefficients $\hat{\gamma}$. The U.S. equity premium equals 6.35%, above the world excluding the U.S. average (6.21%) and combined with one of the lowest volatilities (17.83%). Similar low volatility and high premiums are observed only in Australia (6.40%), Denmark (4.89%) and the United Kingdom (5.69%).

By contrast, Finland (9.66%, SD: 28.20%), Germany (8.94%, SD: 29.24%) and Japan (8.79%, SD: 25.32%) show the high premia and high volatility, indicating repeated large downturns and recoveries.

Table 5.3: Summary statistics for equity premia and consumption risk, 1870-2020

		% w_{t+1}		% real R_f		% ERP		% real R_e		Consumption and risk		
Country	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Cov(R_e, w)	β_c	$\hat{\gamma}$
Australia	147	1.03	5.43	1.95	4.38	6.40	15.06	8.34	15.75	0.00037	0.137	181.77
Belgium	103	1.79	7.69	1.55	9.79	5.05	20.51	6.60	21.19	0.00130	-0.569	51.48
Denmark	146	1.49	5.24	2.87	5.71	4.89	17.12	7.76	16.47	0.00113	0.426	27.72
Finland	125	2.31	5.65	-0.76	10.71	9.66	28.20	8.91	30.00	0.00392	0.639	14.29
France	143	1.54	6.30	-0.48	7.65	4.64	20.43	4.16	21.97	-0.00269	-0.442	-9.04
Germany	144	1.87	5.00	-0.28	12.94	8.94	29.24	8.66	27.13	0.00062	0.651	-72.14
Italy	130	1.62	3.89	0.53	10.30	6.01	25.84	6.54	26.85	0.00073	0.346	53.63
Japan	132	2.01	5.71	-0.02	10.99	8.79	25.32	8.77	27.29	0.00541	0.788	5.79
Netherlands	121	1.82	8.91	0.68	4.83	6.47	21.65	7.15	21.18	-0.00172	-0.263	-52.81
Norway	140	1.88	3.77	0.81	5.92	4.96	19.20	5.77	19.51	0.00085	0.474	35.84
Portugal	110	2.39	4.45	-0.05	9.27	3.70	23.91	3.65	25.23	0.00153	0.733	7.85
Spain	117	2.35	6.46	-0.25	6.89	6.23	19.88	5.97	20.97	0.00109	0.422	40.92
Sweden	150	1.84	4.30	1.65	5.55	6.48	19.17	8.12	19.35	-0.00001	-0.034	11881.10
Switzerland	121	1.26	4.07	0.72	4.98	5.87	18.19	6.59	18.92	0.00024	-0.138	279.86
UK	150	1.30	2.94	1.07	4.76	5.69	17.31	6.76	17.62	0.00096	0.596	41.33
US	149	1.80	3.47	2.09	4.50	6.35	17.83	8.44	18.23	0.00091	0.852	48.46
World	2128	1.75	5.33	0.80	7.94	6.22	21.44	7.02	21.98	0.00086	0.159	40.16
World ex US	1979	1.74	5.44	0.71	8.13	6.21	21.68	6.92	22.23	0.00086	0.138	39.68

Figure 5.3 visualises the main findings presented in the table. It shows the annualised arithmetic mean equity risk premia relative to bill returns for all sixteen countries over the period 1870-2020. The red bars represent the magnitude of the equity risk premium, while the blue line shows the corresponding real equity returns. Among countries with premia above the world average, real equity returns exceed the premium only in Sweden, the Netherlands, Australia, and the United States, while in Finland, Germany, Japan, and Spain, premia are primarily driven by negative real bill returns. Over the full 1870-2020

period, only Australia and the United States combine a high equity premium with low volatility and a non-negative bill return.

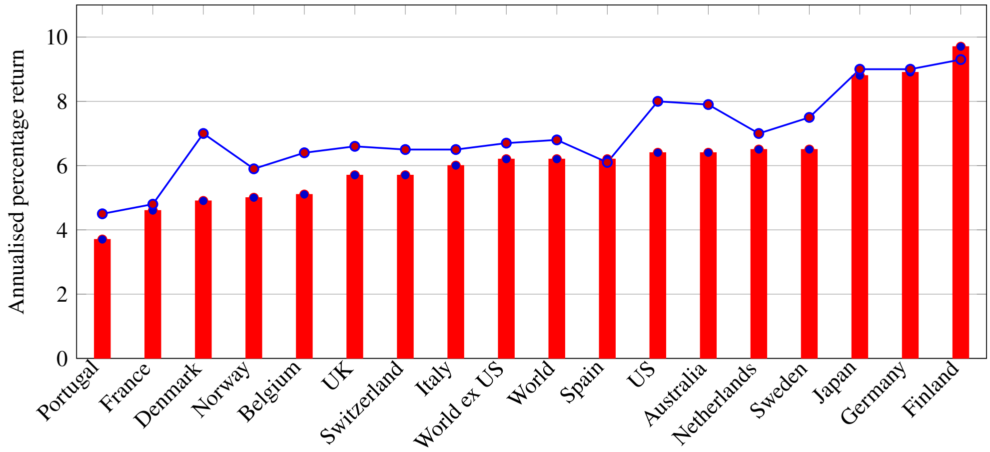

Figure 5.3: Worldwide annualised real equity returns and risk premia, 1870-2020

Figure 5.4 plots the historical frequency of large market crashes (%) against the subjective crash risk for sixteen countries over 1870-2020. First, it is important to note that the subjective crash probability is not a monotonic function of the historical frequency of market crashes. For example, in countries such

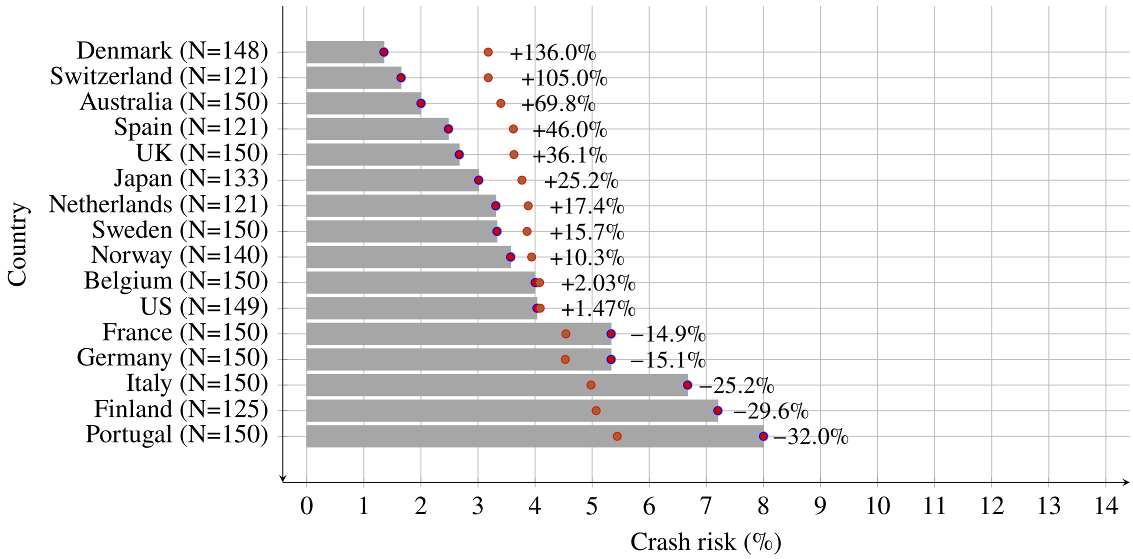

Figure 5.4: Subjective crash risk and in-sample frequency, 1870-2020

as France and Germany, despite having the same number of major crashes and a comparable number of observations (N=150), the posterior risk estimates are different. This occurs because not only the number of crashes but also the periods during which they appear matter for the subjective assessment of risk. For most countries, the subjective probability of a crash exceeds the historical frequency of market crashes. The strongest shrinkage effect is in Denmark and Switzerland, where the subjective crash risk is 136% and 105% higher than the historical frequency, respectively. This reflects the fact that global crash-risk hyperparameters are constructed from all country-level observations and shift upward during periods of global crashes. As a result, the subjective crash probability increases even in countries where no major crashes have occurred. A strong shrinkage effect is observed in Portugal, Finland, and Italy, where the posterior crash probability is lower than the historical frequency by -32%, -29.6%, and -25.2%. This indicates that investors would expect fewer crashes than have actually occurred. For the United States, the effect is moderate: the crash probability increases from 4.03% in the data to 4.09% in the posterior estimate, corresponding to a 1.47% adjustment toward correcting for survivorship bias.

Figure 5.5 depicts the evolution of the subjective crash probability for the United States and for the average country over the period 1870-2020. The red line represents the global mean crash risk, $\alpha/(\alpha+\beta)$, whereas the blue line corresponds to the country-specific estimate for the United States.

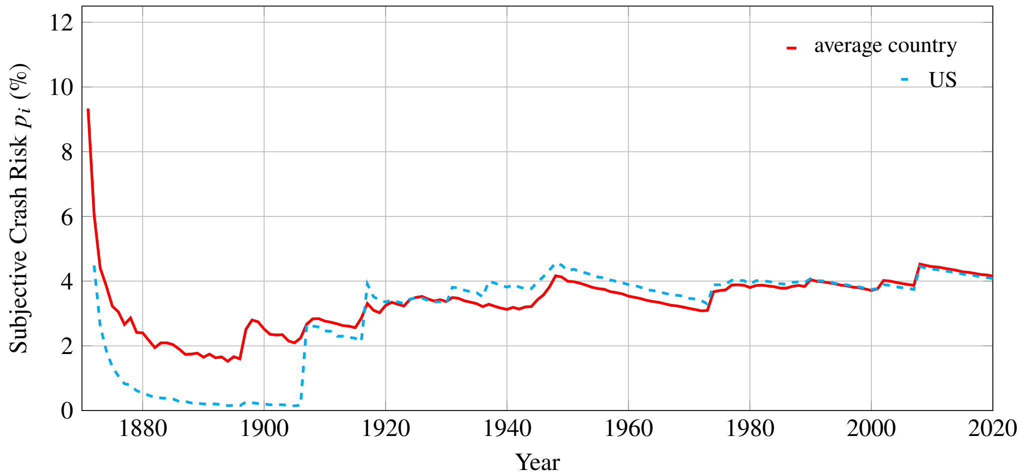

Figure 5.5: Subjective crash risk for the United States and the average country, 1870–2020

At the beginning of the sample, the estimated crash probabilities are high, reflecting the limited available data and the influence of the prior distribution. As observations are accumulated, the subjective estimates decline and stabilise at much lower levels. Prior to the early twentieth century, the subjective crash risk for the United States was below the global mean. This follows from the fact that before 1907, the U.S. experienced no decline in equity returns worse than -30%, whereas Japan underwent a banking crisis in 1897-98. After 1900, the gap between the U.S. and the global average began to narrow. In the 1930s, the subjective crash risk for the U.S. rose due to the impact of the Great Depression, specifically, the severe downturns of 1931 (-34.4%) and 1937 (-33%). During these years, the U.S. estimate exceeded the global mean. From the mid-twentieth century onward, the subjective crash probability becomes more stable. Following World War II, the United States experienced fewer large crashes, causing its posterior estimate to converge toward the global average. Nevertheless, spikes in subjective risk persist in response to major global shocks, such as the 1974 oil crisis and the 2008 global financial crisis. By the end of the sample, the U.S. crash probability stands at 4.08%, while the global estimate is 4.16%. The small difference between them indicates an almost complete convergence of the U.S. market and the average country. Figure 5.6 contains the 95% credible intervals obtained from the Bayesian hierarchical model. The shaded red region represents 95% credible intervals for the posterior mean of the average country crash risk, while the blue dashed region reports the 95% credible interval for the posterior mean for the U.S.

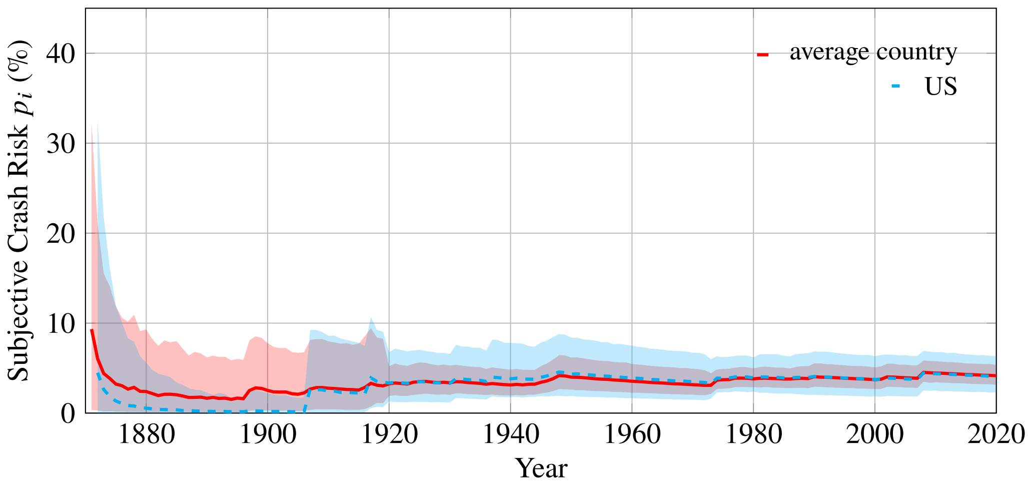

Figure 5.6: Subjective crash risk with 95% credible intervals, 1870–2020

The 95% simulation-based credible intervals at the beginning of the sample for the average country are wider than for the United States and have right-skewness. After the 1920s, the intervals begin to narrow rapidly and become more symmetric, although some degree of right-skewness remains. Notably, the credible interval for the global crash risk parameters shrinks the most because it aggregates information across all countries; the global estimate is inferred with considerably greater precision. By the end of the sample, the credible interval becomes very narrow.

Figure 5.7 compares the model-implied 10-year rolling average U.S. equity returns (solid red line) with empirically realised returns (dashed blue line). The model is calibrated using the parameters $\gamma = 3$, $\beta = 0.98$, $\mu = 0.0252$, $\sigma = 0.02$, $\lambda = 2.6$, $\psi = 1$, and $b = 0.3$. Using posterior crash beliefs as time-varying disaster risk, the model captures the long-run return level but not the volatility. Before 1920, realised returns exceeded the implied-model returns. Between 1920 and 1940, model-implied returns fell sharply in response to major global crashes, including the post-WWI recovery (early 1920s), German hyperinflation (1920-1925), the Italian currency crisis (1926), the Great Depression (1929-1931), and the 1937 recession. Between the 1940s and early 1960s, the United States did not experience major crashes, while many other countries experienced severe market disruptions during World War II and the postwar period.

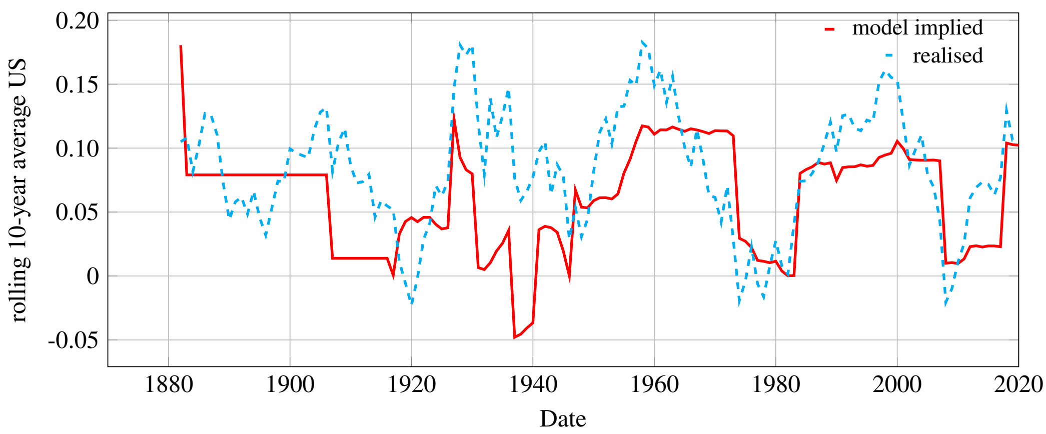

Figure 5.7: 10-year rolling average returns in the United States, 1870–2020

As a result, model-implied returns fall below the realised returns in this period. From the 1960s to the early 1980s, the dynamics of returns reflect the influence of a series of global crashes, including the oil crises of the 1970s, high inflation in Italy in 1977, and the 1981-82 debt crisis. The U.S. market reacts only during the oil crises, when realised returns temporarily drop more than the model predicts. From the mid-1980s until 2008, the U.S. avoided large crashes and posted sustained growth, whereas several other countries faced major crises (e.g. the Finnish banking crisis and recessions in Italy and Sweden in 1990). As a result, realised returns in the United States during this period exceeded the model-implied returns, which reflect higher global risk. In 2008, the United States experienced a sharp decline in realised returns, larger than what the model predicts, reflecting the impact of the global financial crisis.

6 Conclusion

Within the first research question, the thesis examines the dynamics of the equity risk premium in the United States and fifteen advanced economies across three periods. In the 1921-1996 period, the U.S. equity premium equals 8.15%, exceeded only by Germany (12.47%) and Finland (10.35%), which are indicated by high volatility and negative bill returns. Among low-volatility markets, only the United Kingdom (7.95%) and Australia (6.77%) show comparable values. Extending the period to 2020 lowers the U.S. equity premium to 7.93%, close to the world excluding the U.S. average (7.32%). Over 1870-2020, the U.S. equity premium equals 6.35%, slightly above the world excluding U.S. average (6.21%), and accompanied by positive bill returns and low volatility, a combination shared only by Australia (6.40%). Across all three periods, the Mehra and Prescott (1985) and Mehra (2003) models fail to account for the observed premium due to smooth consumption growth and near zero covariation with equity returns, confirming the persistence of the equity premium puzzle.

Within the second research question, the hierarchical Bayesian model evaluates survivorship bias by constructing subjective crash probabilities based on both within-country and cross-country crash histories. A market crash is defined as a decline in equity returns of -30% or more. For the 1921-1996 period, the subjective U.S. crash probability exceeds its historical frequency by 5.01%, rising to 9.61% in the 1921-2020 sample and falling to 1.47% over 1870-2020, indicating that the survivorship effect becomes negligible when the whole historical period is considered. The model suggests that the unbiased equity risk premium in the U.S. would be at least 1.47% lower, and that the magnitude of this adjustment changes across sample periods.

In conclusion, these results align with Goetzmann and Jorion's (1999) findings that the equity risk premium in the U.S. is upward biased. Although the United States shows a high premium across all three samples, the contribution of the survivorship effect is too small to account for the premium's magnitude highlighted by Mehra and Prescott (1985). This thesis is subject to several limitations, including a restricted country sample, partially reconstructed historical data, annual data frequency, and the fixed crash threshold. Future research may extend the country coverage, vary the disaster threshold, or incorporate periods of extremely low real bill returns.

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8 Appendix

Table 8.1: Appendix: Overview of bills and equity data, 1870–2020

Country	Bills		Equities	
	Period	Type (Source)	Period	Coverage / Weighting (Source)
Australia	1870–1928	Deposit rate (RORE*)	1870–1881	Listed abroad (RORE)
	1929–1944	Money market rate (RORE)	1882–2015	Broad, market cap (RORE)
	1948–2015	Government bill rate (RORE)	2016–2020	Fama–French (FF**)
	2016–2020	Interbank rate (OECD MEI)		
Belgium	1870–1899	Bank discount rate (RORE)	1870–2015	All share, market cap (RORE)
	1900–1964	Deposit rate (RORE)	2016–2020	Fama–French, market cap (FF)
	1965–2015	Government bill rate (RORE)		
	2016–2020	Interbank rate (OECD MEI)		
Denmark	1875–2015	Money market rate (RORE)	1873–1899	All share, market cap (RORE)
	2016–2020	Money market rate (IMF IFS)	1900–1999	Broad, market cap (RORE)
			2000–2001	Blue chip, market cap (RORE)
			2002–2015	All share, market cap (RORE)
			2016–2020	Fama–French, market cap (FF)
Finland	1870–1977	Money market rate (RORE)	1896–1911	Broad, book cap (RORE)
	1978–2015	Interbank rate (RORE)	1912–1969	All share, market cap (RORE)
	2016–2020	Interbank rate (OECD MEI)	1970–1990	Broad, market cap (RORE)
			1991–2015	All share, market cap (RORE)
			2016–2020	Fama–French, market cap (FF)
France	1870–1998	Money market rate (RORE)	1870–2015	Blue chip, market cap (RORE)
	1999–2015	Government bill rate (RORE)	2016–2020	Fama–French, market cap (FF)
	2016–2020	Money market rate (IMF IFS)		
Germany	1870–1922	Money market rate (RORE)	1870–1889	Blue chip, market cap (RORE)
	1924–1944	Interbank rate (RORE)	1890–1913	All share, market cap (RORE)
	1950–2015	Money market rate (RORE)	1914–1959	Blue chip, market cap (RORE)
	2016–2020	Interbank rate (OECD MEI)	1960–2015	Broad, market cap (RORE)
			2016–2020	Fama–French, market cap (FF)
Italy	1870–1977	Money market rate (RORE)	1870–1887	Selected stocks (RORE)
	1978–2015	Government bill rate (RORE)	1888–2015	Broad, market cap (RORE)
	2016–2020	Government bill rate (IMF IFS)	2016–2020	Fama–French, market cap (FF)
Japan	1876–1956	Deposit rate (RORE)	1882–1975	Transaction value (RORE)
	1957–2015	Money market rate (RORE)	1976–2015	All share (RORE)

Continued on next page

Country	**Bills**		**Equities**	
	Period	Type (Source)	Period	Coverage / Weighting (Source)
	2016–2020	Deposit rate (Bank of Japan)	2016–2020	Fama-French, market cap (FF)
Netherlands	1870–1957	Money market rate (RORE)	1900–2003	Broad (RORE)
	1958–1964	Bank discount rate (RORE)	2004–2015	All share, market cap (RORE)
	1965–2015	Monay market rate (RORE)	2016–2020	Fama–French, market cap (FF)
	2016–2020	Interbank rate (OECD MEI)		
Norway	1870–2015	Deposit rate (RORE)	1881–1920	All share, market cap (RORE)
	2016–2020	Deposit rate (IMF IFS)	1921–1955	All share (RORE)
			1956–2000	All share (RORE)
			2001–2015	Most traded shares (RORE)
			2016–2020	Fama–French, market cap (FF)
Portugal	1880–1914	Money market rate (RORE)	1871–2015	All share, market cap (RORE)
	1915–1946	Bank discount rate (RORE)	2016–2020	PSI all shares and EL (JST)
	1947–1977	Deposit rate (RORE)		
	1978–2015	Moeny market rate (RORE)		
	2016–2020	Interbank rate (OECD MEI)		
Spain	1870–1921	Money market rate (RORE)	1900–2015	All share, market cap (RORE)
	1922–1974	Deposit rate (RORE)	2016–2020	Fama-French, market cap (FF)
	1975–2015	Money market rate (RORE)		
	2016–2020	Market rate (IMF IFS)***		
Sweden	1870–1998	Deposit rate (RORE)	1871–2001	Broad, market cap (RORE)
	1999–2015	Government bill rate (RORE)	2002–2015	All share, market cap (RORE)
	2016–2020	(not specified)****	2016–2020	Fama-French, market cap (FF)
Switzerland	1870–1968	Deposit rate (RORE)	1900–1925	All share, market cap (RORE)
	1969–2015	Money market rate (RORE)	1926–1959	Broad, equally w. (RORE)
	2016–2020	Deposit rate (SNB)	1960–2015	Broad, market cap (RORE)
			2016–2020	Fama-French, market cap (FF)
UK	1870–2015	Money market rate (RORE)	1870–1928	All share, market cap (RORE)
	2016–2020	Deposit rate (Bank of England)	1929–1963	Blue chip, market cap (RORE)
			1964–2015	All share, market cap (RORE)
			2016–2020	Fama-French, market cap (FF)
US	1870–2013	Deposit rate (RORE)	1872–2015	Broad, market cap (RORE)
	2014–2015	Money market rate (RORE)	2016–2020	S&P CPI, market cap (Shiller)
	2016–2020	Money market rate (IMF IFS)		

Sources: Jorda et al. (2019), Chen et al.(2022).

Notes: *RORE = Rate of Return on Everything;**FF = Fama-French;***2018 missing;****Source not listed.

Table 8.2: Appendix: Declines of 30% or more in real equity returns

Country	Crisis (Year: Return (Description))	**Country**	Crisis (Year: Return (Description))
Australia	1973: -0.3222 (Oil crisis); 1974: -0.3589 (Oil crisis); 2008: -0.4287 (Global financial crisis);	**Spain**	1948: -0.3387 (Post-WWII); 1977: -0.4280 (Political transition); 2008: -0.3942 (Global financial crisis);
Belgium	1916: -0.3733 (WWI); 1917: -0.4404 (WWI); 1929: -0.3461 (Great Depression); 1947: -0.3219 (Post-WWII); 1974: -0.3321 (Oil crisis); 2008: -0.5794 (Global financial crisis);	**US**	1907: -0.3191 (Panic of 1907); 1917: -0.3492 (WWI); 1931: -0.3440 (Great Depression); 1937: -0.3312 (Recession); 1974: -0.3283 (Oil crisis); 2008: -0.4102 (Global financial crisis);
Denmark	1974: -0.3287 (Oil crisis); 2008: -0.4978 (Global financial crisis);	**Switzerland**	1974: -0.3909 (Oil crisis); 2008: -0.3561 (Global financial crisis);
Finland	1917: -0.4273 (Independence); 1918: -0.6076 (Civil War); 1921: -0.3778 (Post-WWI); 1946: -0.4900 (Post-WWII); 1948: -0.4452 (Post-WWII); 1990: -0.3455 (Banking crisis); 2001: -0.3243 (Dot-com crash); 2002: -0.3414 (Dot-com crash); 2008: -0.5314 (Global financial crisis);	**France**	1920: -0.3268 (Post-WWI); 1943: -0.3357 (WWII); 1945: -0.4607 (WWII); 1947: -0.4535 (Post-WWII); 1948: -0.4373 (Post-WWII); 1974: -0.3589 (Oil crisis); 2002: -0.3061 (Dot-com crash); 2008: -0.4251 (Global financial crisis);
Norway	1918: -0.3259 (WWI); 1920: -0.3106 (Post-WWI); 1974: -0.3835 (Oil crisis); 2002: -0.3196 (Dot-com crash); 2008: -0.5573 (Global financial crisis);	**Japan**	1897: -0.4112 (Banking crisis); 1898: -0.3187 (Post-crisis recession); 1908: -0.3174 (Global recession); 1945: -0.9035 (WWII);
Germany	1918: -0.4034 (WWI); 1920: -0.3135 (Pre-hyperinflation); 1924: -0.8744 (Hyperinflation); 1925: -0.4037 (Post-hyperinflation); 1948: -0.8996 (Currency reform); 1987: -0.3367 (Black Monday); 2002: -0.4071 (Dot-com crash); 2008: -0.4411 (Global financial crisis);	**Italy**	1920: -0.3771 (Post-WWI); 1926: -0.4349 (Lira "Quota 90"); 1944: -0.4340 (WWII); 1945: -0.7289 (WWII); 1947: -0.5450 (Post-WWII); 1974: -0.3954 (Oil crisis); 1977: -0.3628 (High inflation); 1987: -0.3173 (Black Monday); 1990: -0.3240 (Early 1990s recession); 2008: -0.4863 (Global financial crisis);
Sweden	1918: -0.4547 (Post-WWI); 1931: -0.3241 (Great Depression); 1990: -0.3604 (Banking crisis); 2002: -0.3725 (Dot-com crash); 2008: -0.4129 (Global financial crisis);	**Portugal**	1920: -0.4682 (Post-WWI); 1924: -0.3511 (Post-war instability); 1974: -0.4441 (Carnation Revolution); 1975: -0.5301 (Carnation Revolution);
Netherlands	1920: -0.3188 (Post-WWI); 1941: -0.3680 (WWI); 2002: -0.3532 (Dot-com crash); 2008: -0.5056 (Global financial crisis);		1976: -0.5383 (Post-revolution crisis); 1977: -0.5795 (Post-revolution crisis); 1978: -0.3855 (Inflation crisis); 1981: -0.4065 (Debt crisis);
UK	1920: -0.3184 (Post-WWI); 1973: -0.3415 (Oil crisis); 1974: -0.5697 (Oil crisis); 2008: -0.3219 (Global financial crisis)		1982: -0.3090 (European debt crisis); 1988: -0.3425 (Pre-ERM reforms); 1990: -0.4087 (European recession); 2008: -0.5102 (Global financial crisis)