The equity risk premium puzzle

A cross-country study of asset returns, growth and disaster risk

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Abstract

The equity risk premium puzzle - even its very existence - is arguably one of the most fascinating as well as persistent phenomenons in the field of macro finance that has been attempted to rationalise since the famous seminal paper by Mehra and Prescott (1985).
Following the disaster risk approach initially proposed by Rietz (1988) and further developed by Barro (2006) I conduct a comprehensive study of asset returns, macroeconomic aggregates and moments related to disastrous events covering almost 150 years of financial markets and economic history across 16 developed countries.
Whereas previous studies of disaster risk focused on the reconciliation of economic theory and empirical data using a) aggregate output and b) rationalising the puzzle at a global level my contribution is twofold:

Firstly, I extend the analysis to private consumption expenditure data, a more accurate measure for consumption-based asset pricing for a now-available greater time horizon and secondly I allow for cross-country heterogeneity in characteristics with respect to disaster propensity/experience.

The major finding of my dissertation is that accounting for the effect of disasters on consumption risk (and output risk) does indeed rationalise the puzzle and country-specific preference parameter estimates are presented along with plausible model predictions for the rates of return on equity and risk-free, short-term government bills which appears to attenuate the equity premium puzzle if it also addresses the risk-free rate puzzle (Weil, 1989) jointly.

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1 Introduction

The equity risk premium (ERP) puzzle has been arguably one of the most fascinating and persistent topics in modern macroeconomics and finance since its 'discovery' by Mehra and Prescott (1985), indicating its high relevance to investors, firms, policy makers and the profession of economics alike.

In a binary world (disaster vs. normal), disaster risk (Rietz, 1988) comprises the decisive 'factor' that determines the compensation for being exposed to consumption risk (over being insured against it as governments rarely default on their debt obligations from providing public liquidity) originating from disastrous events only (Nakamura et al., 2013). I identify heterogeneity across 16 developed economies spanning almost 150 years of annual observations with respect to disaster risk, returns and macroeconomic growth rates and fully calibrate a consumption-based asset pricing model incorporating Epstein-Zin-Weil preferences based on the random walk with drift model by Barro (2006) at the country level.

The underlying idea is that countries with relatively higher probability of entering a disastrous state as well as higher contraction size should compensate investors more than less disaster-risky countries. I identify disaster periods according to an NBER-style peak-to-trough procedure which allows disasters to unfold over multiple years rather than occurring instantaneously which has been addressed by Julliard and Ghosh (2012).

Uncovering heterogeneity in preferences implied by within-country risk-sharing capacity may shed light on structural differences with respect to risk-carrying and tests the model's ability to rationalize the 'puzzle' at smaller units. I show that accounting for time-invariant disaster risk does indeed attenuate the 'puzzle' in the sense of a) reducing the implied coefficients of relative risk aversion significantly compared to the benchmark specification proposed in Mehra and Prescott (1985) and further developed in Mehra (2003) and b) yielding robust and plausible model predictions.

Moreover, the relative order of implied coefficients of relative risk aversion is being preserved compared to the benchmark specification. As Barro (2006) and Cochrane (2017) correctly point out, incorporating stochastic variations in the disaster probability p_t would help to explain business-cycle related return predictability and stock price volatility. In my quantitative analysis I treat disaster risk moments as constants (implying that normal and jump shocks are i.i.d. across time and countries and permanent) to provide a baseline estimation at the country level.

However, Nakamura et al. (2013) incorporate a) consumption data, b) multi-period disasters, c) disaster probability estimation using Bayesian Markov-Chain Monte-Carlo methods and d), most importantly, allow for partial recoveries after crises and therefore address a shortcoming of the (Barro, 2006) random-walk model which tends to overstate the riskiness of consumption that translates into substantially larger welfare costs of economic fluctuations (Barro, 2009) as well as higher ERP, at the global level. Accounting for c) and d) is beyond the scope of this paper but Nakamura et al. (2013) argue that it allows for predictability of consumption growth during disasters (which stresses the role of the IES) and reduces the implied coefficient of relative risk aversion to 6.4 and an intertemporal elasticity of substitution of 2.

In consumption-based asset pricing theory where (risk-averse) agents hold assets for the sole purpose of providing future consumption (Abel, 1991), optimally when the marginal utility of accessing it is the highest and thus allows for consumption smoothing, combined with general insights from portfolio theory (Markowitz, 1952) there must be a relationship between characteristics of asset returns and consumption, precisely captured by the so-called stochastic discount factor (volatility) and approximately captured by aggregate consumption (volatility). This is precisely where the puzzle arises: basic consumption-based asset pricing theory cannot be reconciled with the empirical observations, assuming 'plausible' values for preferences with respect to risk aversion. The historically observed ERP, originally and most frequently assessed for the US economy (Mehra and Prescott, 1985; Cecchetti et al., 1993) is too high compared to the model's predicted level for 'plausible' values for the coefficient of relative risk aversion (CRRA) and the historically low variability in aggregate consumption expenditures (for a modified version of the original model see Mehra (2003)).

Apart from theoretical and rather technical aspects "the real risk-adjusted returns on different asset classes reflect equilibrium resource allocations given societys investment and consumption choices over time" (Jordà et al., 2017) and involves debates about inequality (Piketty, 2015), secular stagnation (Summers, 2014) and the real rate of interest (Holston et al., 2017). Subtly, the ERP is cause and consequence in its own right. Specifically, it represents the excess return of holding a risky asset over the risk-free rate, or, in other words, the opportunity cost of not participating in a risky lottery, investors demand or expect to receive *in turn* affecting asset prices *in turn* affecting returns and the ERP. In the long run, therefore, the level of the ERP should approach its equilibrium value solely determined by preferences and consumption-related volatility.

The paper will proceed as follows: the remainder of this section will lay the theoretical foundation for an accurate treatment of the objects of interest where section 1.1 abstracts from asset markets and describes the behaviour and existence of a risk premium from a microeconomic perspective. Section 1.2 presents the benchmark asset pricing equations under expected power utility that initially gave rise to the aforementioned puzzle. Subsection 1.3 introduces the asset pricing model accounting for economic disasters. Section 2 presents the key global and cross-sectional moments and dynamics of international financial markets data as well as macroeconomic aggregates along with disaster model specific moments in the cross-section. Section 3 presents the results from a baseline calibration with special attention paid to the coefficient of relative risk aversion and rates of return. Sensitvity analyses are performed without altering the main results. Section 4 concludes with a brief discussion of the paper's implications for international risk-sharing, fiscal capacity as well as liquidity constraints.

1.1 Risk premium theory

Many modern applications and past advances in economics rest on the expected utility paradigm, that is assuming an additive, time-separable utility representation. In the light of a static lottery with an uncertain outcome over final wealth/-consumption and a risk-averse individual there exists a (positive) risk premium as defined as the difference between the expected value and the preference-specific certainty equivalent. Assuming risk-aversion translates into diminishing marginal utility, a reasonable and general description of human behaviour and satisfies strict concavity of the utility function. The very fact of facing an unknown outcome reduces the received utility already as decreasing departures from the mathematical expected value are marginally weighted higher in terms of (dis-)utility than increasing departures from the expected value. Of course, the individual always has the opportunity to opt out of the lottery **and** maintain the same level of utility *as-if* she would participate. Faced with this choice problem (participating in the risky lottery vs. not participating) one can determine the amount of an e.g. monetary transfer in order to eliminate all uncertainty that would need to occur such that the individual is exactly indifferent between either action as characterized by the level where expected utility of the lottery and utility of initial wealth less the risk premium are equalized.

Clearly, the higher the degree of risk aversion (or the degree of curvature of the utility function) the higher the price an individual is willing to pay to eliminate uncertainty, i.e. the risk premium would be higher. A common utility specification is of the class of isoelastic functions, that is

$$u(c) = \begin{cases} \frac{c^{1-\gamma}}{1-\gamma}, & \text{if } \gamma > 0 \\ ln(c), & \text{if } \gamma = 1 \\ 0, & \text{otherwise} \end{cases}$$

which is the standard CRRA utility with desirable properties from a mathematical point of view. Due to strict concavity ($\gamma > 0$) Jensen's inequality establishes the existence of a positive risk premium and allows for closed form solutions to the representative agent's first order conditions (see section 1.2), directly relating risk aversion to asset and consumption characteristics. Also note that the Arrow-Pratt index of relative risk aversion

$$-\frac{u''(c)c}{u'(c)} = \gamma$$

which shows that the function is unique up to an affine transformation and basically says that the representative agent's FOC remains unchanged since marginal utilities move in perfect tandem and is therefore independent of the level of initial wealth.

From a social science perspective, however, some assumptions or restrictions implicitly introduced with this functional form are problematic. For example, it introduces a restriction on the intertemporal elasticity of substitution (IES, denoted by $\psi > 0$) which needs to equal the inverse of the coefficient of relative risk aversion, γ, as shown below:

$$\psi = \frac{\partial ln(c_{t+1}/c_t)}{\partial r} = -\frac{\partial ln(c_{t+1}/c_t)}{\partial ln(u'(c_{t+1}/u'(c_t)))} = \frac{1}{\gamma}$$

where I have used that

$$R = \frac{u'(c_t)}{\beta u'(c_{t+1})} \quad \text{and} \quad ln(R) = r = -ln\left(\frac{u'(c_{t+1})}{u'(c_t)}\right) - ln(\beta)$$

In other words this "behaviorally groundless restriction" (Weil, 1989) means that a highly risk-averse individual has an implicit preference to strongly smooth consumption over time/states of the world by becoming more irresponsive to intertemporal incentives such as the interest rate as risk aversion increases and constant consumption growth becomes the main motive, i.e.

$$\frac{\partial^2 \frac{c_{t+1}}{c_t}}{\partial R \partial \gamma} < 0$$

This shortcoming has been recognized early on by Kreps and Porteus (1978), Epstein and Zin (1989) and Weil (1989) and a generalised form of expected utility has been proposed on which the model calibrated in this paper builds.

That the coefficient of relative risk aversion is assumed to be constant is not natural. For example risk aversion could be specified in absolute terms, i.e. portfolio allocations are made with respect to levels as initial wealth increases rather than weights, or (relative) risk aversion could be assumed to decrease as initial wealth increases. Empirical justification for the working assumption of CRRA has been provided by Brunnermeier and Nagel (2008) and Chiappori and Paiella (2011), though. The coefficient of relative risk aversion can (and does) fluctuate over the business cycle as wealth fluctuates (Brunnermeier and Nagel, 2008; Gourio, 2012).

1.2 Asset pricing theory

As has been already asserted, risk-averse agents dislike extreme levels of consumption contemporaneously and would like to, if they cannot fully eliminate it, minimize this variation at least by reducing risk. They can diversify their future-postponed contingent consumption, also referred to as invested wealth into assets that are independently affected by unfavorable downside events. When faced with the decision between an undiversified portfolio and a diversified one with the same expected return the risk averse agent would prefer the diversified one, since it has a lower variance, conditional that a) the events truly affect the individual components of the portfolio independently (or are mutually-exclusive) and b) the correlation of the individual returns is less than 1. In a well-functioning asset market any investor can achieve diversification individually and full diversification is possible in the sense that only aggregate risk to consumption remains where events aren't independent anymore but affect everyone alike, which matches the meaning of market completeness (Constantinides et al., 2003). Implicitly through diversifying the individual allocated some part of the entire risk associated with one asset to the market ('risk-spreading'), simply by not holding it entirely, where another individual holds part of the asset and is exposed to its risk proportionally to the value held. The preference for diversification is intrinsically equivalent to risk aversion as it aims to strike the optimal balance between risk and return, meaning keeping expected return constant but reducing variance, also referred to as mean-preserving spread, or in economic speech to maximize the net effect of additional expected utility from reallocating one probability unit of loss towards the mean (here: expected, mathematical value) and decreased expected utility from reallocating one probability unit of gains towards the mean (Eeckhoudt et al., 2011).

Power utility

It is sensible to start with the fundamental asset pricing equation (FAPE) which describes an investor's first-order condition under standard, expected power utility:

$$p_t = \mathbb{E}_t(m_{t+1}x_{t+1}) \quad \text{where} \quad m_{t+1} = \beta\frac{u'(c_{t+1})}{u'(c_t)} \quad \text{and} \quad x_{t+1} = p_{t+1} + d_{t+1}$$

The stochastic discount factor m_{t+1} is generally unobservable but its moments can be approximated by making use of the presumption that consumption is log-normally distributed (i.e. consumption growth is i.i.d.) and the CRRA form, yielding the Hansen and Jagannathan (1991) bounds and a closed form solution for the risk-free rate (in continuous time):

$$r_t^f = \rho + \gamma \mathbb{E}_t(\Delta ln(c_{t+1})) - \frac{1}{2}\gamma(\gamma+1)\sigma_t^2(\Delta ln(c_{t+1}))$$

which shows that the risk-free rate is determined by preferences ($\beta = \frac{1}{1+\rho}$ and γ) as well as precautionary savings due to uncertain consumption growth. To match the historically low level of real interest rates and low variability of consumption growth risk aversion would have to be sufficiently small, $\gamma \in [1,5]$ (Cochrane, 2005). Moreover, ignoring the third (precautionary savings) term, the second, linear term which is the product of the coefficient of relative risk aversion and the expected growth rate of consumption is positive, requiring ρ to be small or even negative which is the *risk-free rate puzzle* (Weil, 1989).

In their original paper Mehra and Prescott (1985) deploy a variation of Lucas (1978) endowment economy and assume that *the growth rate* of endowment follows a Markov process, not the *level*. The Euler equations for equity and a riskless one-period bond read

$$\begin{aligned} 1 &= \mathbb{E}_t(m_{t+1}R_{t+1}^e) \quad \text{where} \quad R_{t+1}^e = \frac{p_{t+1}+d_{t+1}}{p_t} \\ 1 &= \mathbb{E}_t(m_{t+1}R_{t+1}^f) \quad \text{where} \quad R_{t+1}^f = \frac{1}{q_t} \end{aligned}$$

After applying the covariance decomposition on the Euler equations and using that $R_{t+1}^f = \frac{1}{\mathbb{E}_t m_{t+1}}$ the equity premium equation is given by

$$\mathbb{E}_t(R_{t+1}^e) - R_{t+1}^f = -R_{t+1}^f \text{Cov}_t(m_{t+1}, R_{t+1}^e) = -\frac{\text{Cov}_t[u'(c_{t+1}), R_{t+1}^e]}{\mathbb{E}_t(u'(c_{t+1}))}$$

which shows that the expected excess return increases (and the asset's expected price falls) in the covariance between the asset's return and marginal utility of consumption. If this covariance is positive this asset provides *insurance*, making it a very valuable component of intertemporal utility meeting high demand which decreases its rate of return. Conversely, if the asset's returns covary negatively with marginal utility (i.e. it does pay off when consumption is high and marginal utility low) it exacerbates consumption variability and hence works against the consumption smoothing motive inherent from expected utility.

Originally, the authors solve this system of two equations by calibrating a discretized Markov process (Tauchen, 1986) for consumption growth and allow for values for $\gamma \in [0,10]$ and $\beta \in (0,1)$. They conclude that "The largest premium obtainable with the model is 0.35 percent, which is not close to the observed value" (Mehra and Prescott, 1985) which is about 6%.

In a modified version (Mehra and Prescott, 2008) with additional assumptions on the distributions of the growth rates consumption and dividends to be i.i.d. as well as both to be jointly log-normally distributed the (log) asset returns read

$$
\begin{aligned}
ln[\mathbb{E}_t(R^e_{t+1})] &= \rho + \gamma\mu_{\Delta ln(c_{t+1})} - \frac{1}{2}\gamma^2\sigma^2_{\Delta ln(c_{t+1})} + \gamma\sigma_{(\Delta ln(c_{t+1}),\Delta ln(d_{t+1}))} \\
ln(R^f_{t+1}) &= \rho + \gamma\mu_{\Delta ln(c_{t+1})} - \frac{1}{2}\gamma^2\sigma^2_{\Delta ln(c_{t+1})} \\
ln[\mathbb{E}_t(R^e_{t+1})] - ln(R^f_{t+1}) &= \gamma\sigma_{(\Delta ln(c_{t+1}),\Delta ln(d_{t+1}))}
\end{aligned}
$$

where the last equation is the (log) equity risk premium which is the product of the coefficient of relative risk aversion γ and the covariance between the growth rate of consumption and growth rate of dividends (or alternatively with the return on equity due to homogeneity of p_t of degree 1 in d_t). Using the last generalisation **and** imposing the equilibrium condition that

$$\Delta ln(c_{t+1}) = \Delta ln(d_{t+1})$$

i.e. the growth rate of consumption to be perfectly correlated with dividend growth (and hence return on equity) simplifies to

$$ln[\mathbb{E}_t(R^e_{t+1})] - ln(R^f_{t+1}) = \gamma\sigma^2_{\Delta ln(c_{t+1})}$$

which shows that the (log) ERP is equal to the product of the coefficient of relative risk aversion γ and the variance of consumption growth. It can be shown that under power utility with $\gamma > 1$ an increase in uncertainty ($\sigma^2_{\Delta ln(c_{t+1})}$ and/or disaster risk moments, see section 1.3) leads to the implausible prediction of a *higher* price-dividend ratio. This implication originates from the restriction on the IES $\psi = \frac{1}{\gamma}$. To produce plausible predictions the IES needs to be greater than 1.

Recursive utility

To overcome the aforementioned implicit restriction on the IES a generalised version of expected utility function was initially proposed by Kreps and Porteus (1978) and further developed by Epstein and Zin (1989) and Weil (1989).

$$U_t[c_t, \mathbb{E}_t U_{t+1}] = \left[(1-\beta)c_t^{1-\theta} + \beta(\mathbb{E}_t U_{t+1})^{\frac{1-\theta}{1-\gamma}}\right]^{\frac{1-\gamma}{1-\theta}}$$

where γ is the coefficient of relative risk aversion and θ captures the inverse of the intertemporal elasticity of substitution, ψ, and is independent of γ. This functional equation essentially allows marginal utilities across states to be dependent. If $\gamma = \theta$ the intertemporal program reduces to the "standard" expected utility framework where $\gamma = \frac{1}{\psi}$. The first-order condition for the representative agent's choices of consumption over time subject to the intertemporal budget constraint

$$w_{t+1} = (1 + R^w_{t+1})(w_t - c_t)$$

where w_{t+1} is the budget of wealth and $(1 + R^w_{t+1})$ is the gross rate of return on the portfolio of all invested wealth (= the market portfolio) can be shown to be

$$\beta^{\frac{(1-\gamma)}{(1-\theta)}} \cdot \mathbb{E}_t \left\{ \left(\frac{c_{t+1}}{c_t} \right)^{-\theta \left(\frac{1-\gamma}{1-\theta} \right)} \cdot R_{w,t+1}^{(\theta-\gamma)/(1-\theta)} \cdot R_{t+1} \right\} = 1$$

where $R_{w,t+1}$ is the gross return on overall wealth (in the sense of ownership rights on trees in the Lucas tree model) and R_{t+1} is the gross return on any asset (see Constantinides et al. (2003)).

Proceeding similarly to the expected utility case and assuming that the growth rate of consumption and asset returns are i.i.d. and jointly lognormal gives the following closed form solutions

$$ln[\mathbb{E}_t(R^e_{t+1})] = \zeta \frac{\sigma_{(\Delta ln(d_{t+1}), \Delta ln(c_{t+1}))}}{\psi} + (1-\zeta)\sigma_{(\Delta ln(d_{t+1}), \Delta ln(w_{t+1}))} + ln(R^f_{t+1}) - \frac{\sigma^2_{\Delta ln(d_{t+1})}}{2}$$

$$ln(R^f_{t+1}) = \rho + \frac{1}{\psi}\mathbb{E}_t(\Delta c_{t+1}) + \frac{\zeta - 1}{2}\sigma^2_{\Delta ln(w_{t+1})} - \frac{\zeta}{2\psi^2}\sigma^2_{\Delta ln(c_{t+1})}$$

where $\zeta = \frac{1-\gamma}{1-\frac{1}{\psi}}$ and is equal to 1 iff $\gamma = \frac{1}{\psi}$ and $\Delta ln(w_{t+1})$ is the net return on the portfolio of all invested wealth. Interestingly, this shows that a high degree of risk aversion doesn't require a low average risk-free rate (as compared to the case where $\zeta = 1$). On this note, Weil (1989) asserts that "with i.i.d. dividend growth, the equity premium, when defined in relative terms, is independent of the IES, and reflects only the properties of the dividend growth process and, of course, the magnitude of the CRRA."

1.3 Disaster risk theory

The disaster risk approach rests on the idea that the very possibility of rare but disastrous events such as the Great Depression and wars but also natural catastrophes affects investors' variance of marginal utility and hence prices and returns.

Real output per capita (or real consumption per capita in the closed economy with no investment and government) evolves exogenously as random walk with drift with constant population according to

$$ln(A_{t+1}) = ln(A_t) + g + u_{t+1} + v_{t+1}$$

where g is exogenous productivity growth (average growth rate of the economy during non-disastrous periods), u_{t+1} is i.i.d. normal with mean 0 and variance σ^2, reflecting non-disastrous economic fluctuations due to e.g. productivity shocks. v_{t+1} reflects jump shocks associated with economic disasters and is i.i.d. (also with u_{t+1}) which allows for closed-form solutions. As such, "they represent permanent effects on the level of output, rather than transitory disturbances to the level." (Barro and Ursúa, 2008)

The probability of a disastrous event occurring and hence for $v_{t+1} \neq 0$ is p. The disaster size, i.e. the fraction of output's contraction is b. The distribution of v_{t+1} is

$$v_{t+1} = \begin{cases} 0, & \text{with } 1-p \\ ln(1-b), & \text{with } p \end{cases}$$

where p is constant, a strong limitation for time-varying risk assessments. Recent research (Tsai and Wachter, 2015) addresses this limitation with respect to the *excess volatility puzzle* (Shiller, 1981).

The effective expected growth rate of output (or consumption) g^* is given by

$$g^* = g + \frac{1}{2}\sigma^2 - p \cdot \mathbb{E}(b)$$

where $\mathbb{E}(b)$ is the expected value of disastrous contractions. The representative agent is assumed to maximize utility with Epstein-Zin-Weil preferences and with i.i.d. shocks the first-order conditions reads

$$c_t^{-\gamma} = \beta^* \mathbb{E}_t(R_t c_{t+1}^{-\gamma})$$

where β^* is the effective subjective discount factor, $\beta^* = \frac{1}{1+\rho^*}$, $\beta = \frac{1}{1+\rho}$ and the effective time preference rate ρ^* is given by

$$\rho^* = \rho - (\gamma - \theta) \cdot \left\{ g^* - \frac{1}{2}\gamma\sigma^2 - \left(\frac{p}{\gamma - 1}\right) \cdot [\mathbb{E}(1-b)^{1-\gamma} - 1 - (\gamma - 1) \cdot \mathbb{E}(b)] \right\}$$

where $\theta = \frac{1}{\psi}$ and ψ is the IES. Intuitively, the (effective) time preference rate can be interpreted as the hypothetical riskless real interest rate that existed if consumption would be constant forever at the level g^* and that was known, without growth and variability and the same would hold for disaster risk parameters p and $\mathbb{E}(b)$.

The expected rate of return on equity (unlevered) reads

$$r^e = \rho^* + \gamma g^* - \frac{1}{2}\gamma(\gamma - 1)\sigma^2 - p \cdot [\mathbb{E}(1-b)^{1-\gamma} - 1 - (\gamma - 1)\,\mathbb{E}(b)]$$

which increases in the effective time preference rate ρ^*, the product of the coefficient of relative risk aversion and the effective growth rate of exogenous productivity and decreases in the variability of consumption growth (precautionary savings). The new term accounts for disaster risk which decreases the rate of return on equity as p and $\mathbb{E}(b)$ increase.

The risk-free rate is given by

$$r^f = \rho^* + \gamma g^* - \frac{1}{2}\gamma(\gamma+1)\sigma^2 - p \cdot [\mathbb{E}(1-b)^{-\gamma} - 1 - \gamma\mathbb{E}(b)]$$

The equity premium therefore is

$$r^e - r^f = \gamma\sigma^2 + p \cdot [\mathbb{E}(1-b)^{-\gamma} - \mathbb{E}(1-b)^{1-\gamma} - \mathbb{E}(b)] = \gamma\sigma^2 + p \cdot \mathbb{E}\{b \cdot [(1-b)^{-\gamma} - 1]\}$$

If $\gamma = \theta = \frac{1}{\psi}$ the term inside the curly brackets can be interpreted as the product between the proportionate decline in output and excess marginal utility of consumption in a disaster state over that in a normal state (the term inside the square brackets).

2 Data

The data presented in the following and was used to calibrate the disaster risk model has been taken from Jordà et al. (2017), who "painstakingly compiled annual asset return data for 16 advanced countries, over nearly 150 years." A current version of the public data set may be found on Jordà-Schularick-Taylor Macrohistory Database (http://www.macrohistory.net/data/). Moreover, the authors acknowledge the "largest but often ignored component of household wealth, housing" and provide total returns data, including housing. Although this component does certainly constitute a capital asset with its own, very specific characteristics affecting the households' consumption-savings decision I will omit it and focus on stock market returns (i.e. out of risky assets) for comparability across countries and the existing literature.

For convenience and familiarisation with the data set I found it useful to develop an own web application (http://disaster-app-master.herokuapp.com/) in Python using Dash[1] for visualisation and exploration. The GitHub repository may be found here https://github.com/gerwolf/macro-disaster.

Some corrections had to be applied, in particular for stock market data in Germany during the period of hyperinflation (1914-1924) where outliers were

[1] https://plotly.com/dash/, a HTML wrapper framework for building analytical web apps, mainly used in Machine Learning and Data Science drawing from interactive Plotly graphics

removed and imputed using the real performance index by Gielen (1994) which had a Pearson correlation coefficient of about 0.8 with the Jordà-Schularick-Taylor (JST) measure of real total return on equity between the years 1872 and 1992 excluding the years 1922-1924. Other missing values were imputed using moving averages.

Table 8 in the appendix describes the availability for each key series, earliest starting in 1870 and in unbalanced cases starting dates were chosen such that they were no different within countries, except for Belgium, Japan and Portugal due to missing consumption data but otherwise complete series.

Altogether, the sample accounts for about 35% of the world GDP in 2015 (PPP) according to the World Bank database[2]. The relative composition inside the sample [3], however, did change considerably between 1900 and 2015. The US increased their contribution from 30% to 47% whereas the UK's share decreased by 11% to 7% followed by Germany with a reduction of 8% to 8%. Japan increased it's proportionate contribution from 5% to 13%. At the global level returns and growth data are considered from 1900 to 2015 due to incompleteness of observations and weightings before that date.

2.1 International financial markets

Total nominal (gross) returns for asset i in country j at time t were calculated according to

$$R_{i,j,t} = \frac{P_{i,j,t} - P_{i,j,t-1}}{P_{i,j,t-1}} + Y_{i,j,t}$$

where P is the asset's price and Y is the yield component, e.g. dividends. Total real (net) returns were calculated according to

$$r_{i,j,t} = \frac{1 + R_{i,j,t}}{1 + \pi_{j,t}} - 1$$

where π is the inflation rate.

At the global level (see table 1), i.e. equally weighted as well as real GDP-value weighted average rates of return, real rates of return on equity outperformed Treasury bills with 6.57% (7.03%) equally weighted (real-GDP weighted) compared to -0.39% (-0.17%) resulting in an equity risk premium of 6.96% (7.20%). Variability was higher for equity than for relatively safe assets by a factor of 3.

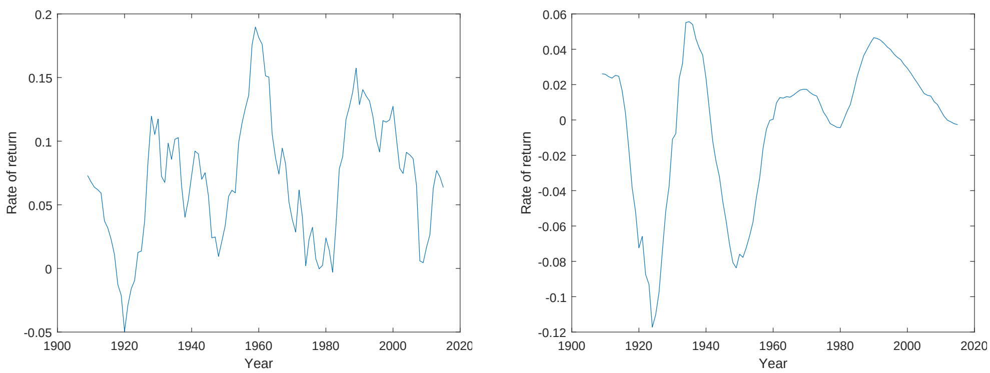
[2] Accessed 13/09/2020

[3] measured in real GDP (PPP) using the Maddison Project dataset

	All equally weighted			real GDP-weighted		
	Equity	Bills	ERP	Equity	Bills	ERP
Full sample						
Mean return p.a.	6.57	-0.39	6.96	7.03	-0.17	7.20
Std. dev.	15.43	6.28	14.66	15.26	5.95	15.02
Geometric mean	5.37	-0.61	5.88	5.86	-0.36	6.07
Median	6.68	1.07	6.97	7.46	1.39	8.27
Max	39.45	10.84	36.57	48.34	11.94	47.28
Min	-46.09	-28.83	-46.42	-41.38	-21.44	-41.20
Kurtosis	3.87	7.95	-4.08	3.61	6.64	3.82
Post-1984						
Mean return p.a.	10.89	2.22	8.67	9.31	1.93	7.37
Std. dev.	20.39	2.34	20.27	16.86	2.16	16.58
Geometric mean	8.77	2.20	6.54	7.84	1.91	5.94
Median	12.02	2.15	12.14	13.26	2.37	13.00
Max	39.45	5.83	35.28	33.81	5.11	32.52
Min	-46.09	-1.23	-46.42	-41.38	-1.83	-41.20
Kurtosis	3.65	1.74	3.38	4.44	1.76	4.17

Table 1 Global real returns (1900-2015)

For the post-1984 period subset returns across both asset classes were higher compared to the full sample Volatility was higher in this period for equity but smaller for T-bills.



(a) Equity (b) Treasury bills

Figure 1 Decadal, real-GDP weighted moving averages of asset returns

Figure 1 indicates that returns on equity and T-bills show some cyclical behaviour with equity being more volatile than risk-free rates.

At the country-level (see table 9 in the appendix) there is some degree of variation in asset returns; returns on equity range from values as low as 3.02% (France) to 8.90% (Finland). Treasury bills returned, on average, -2.57% (Germany) to 2.99% (Denmark). Interestingly, German investors lost on average 2.57% of their initial wealth when holding safe assets [4]. German *Bunds* are recognized as one of the assets with the lowest probability of default, hence making it a valuable asset as it provides (almost) perfect insurance, driving up its price and lowering its return. In total, for seven countries the measured average real risk-free rate was negative.

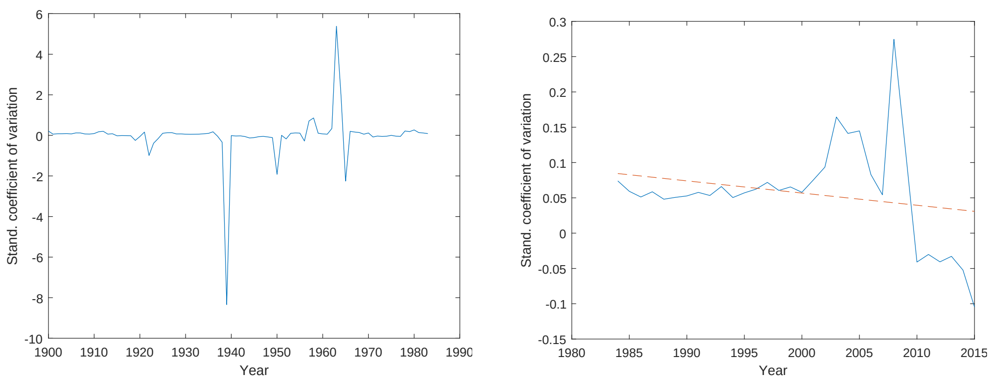
[4] Probst (2019) estimates the average short-term real interest rate for Germany (1871-2013) even lower at -3.5%.

The resulting premiums are documented in table 2 below:

Country	Full sample (1870-2015)		post-1984	
	Mean	Std	Mean	Std
Australia	6.59	15.86	5.13	18.76
Belgium	5.91	22.89	9.68	24.85
Denmark	4.90	18.01	8.15	22.72
Finland	10.34	30.90	12.90	42.40
France	4.34	21.37	8.02	24.45
Germany	10.47	36.62	8.50	24.96
Italy	6.50	30.81	7.09	29.80
Japan	9.24	27.00	4.20	22.56
Netherlands	6.51	23.08	8.66	22.80
Norway	5.00	20.36	10.36	29.24
Portugal	4.14	27.45	9.44	39.37
Spain	6.37	21.30	11.84	28.31
Sweden	6.45	20.00	11.75	28.10
Switzerland	5.76	18.73	9.39	22.51
United Kingdom	5.94	19.24	5.75	15.45
United States	6.28	18.36	7.92	16.44

Table 2 Equity risk premium (country-level), %

Measuring the intra-sample consistency (by the standardized coefficient of variation across countries) in risk-free rates shows an interesting picture how stable they really were in the past:



(a) 1900-1983 (b) Post-1984

Figure 2 Standardized coefficient of variation (risk-free rate)

The right panel of figure 2 shows a period of global calmness interrupted by the Dot-com bubble and the 2008 financial crisis. Since then risk-free rates entered negative terrain, although monetary authorities' responses were quite consistent in this regard. Using cross-sectional aggregates it is noteworthy to highlight the two different asset classes' characteristics with respect to "risk" and expected return.

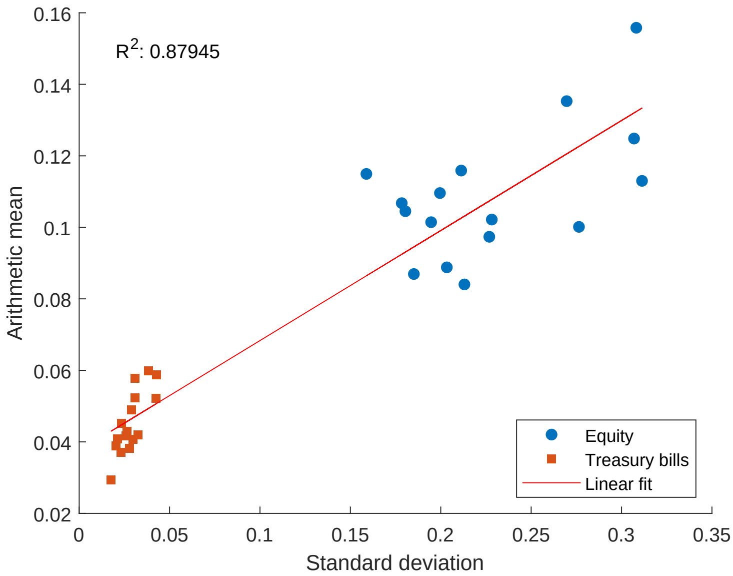


Figure 3 Capital market line

The capital market line (figure 3) plots the arithmetic mean of nominal returns against the volatility, measured as the standard deviation of these returns for the two asset classes. Clearly, there is a positive relationship between expected return and volatility within the asset classes but also across them, as confirmed by a formal Chow-test for structural differences between these two classes. Adding an intercept for each class does not improve the goodness of fit (F-distributed Chow-test statistic: 5.42 $<$ critical value with $k = 2$ degrees of freedom in the numerator and $n = 28$ degrees of freedom in the denominator at $\alpha = 0.05$: 8.93), hence there are no structural differences in the risk-return relationship across programmes.

Finally, turning to the cross-country equity risk premiums reveals dynamic variation within and across countries (figure 4 below).

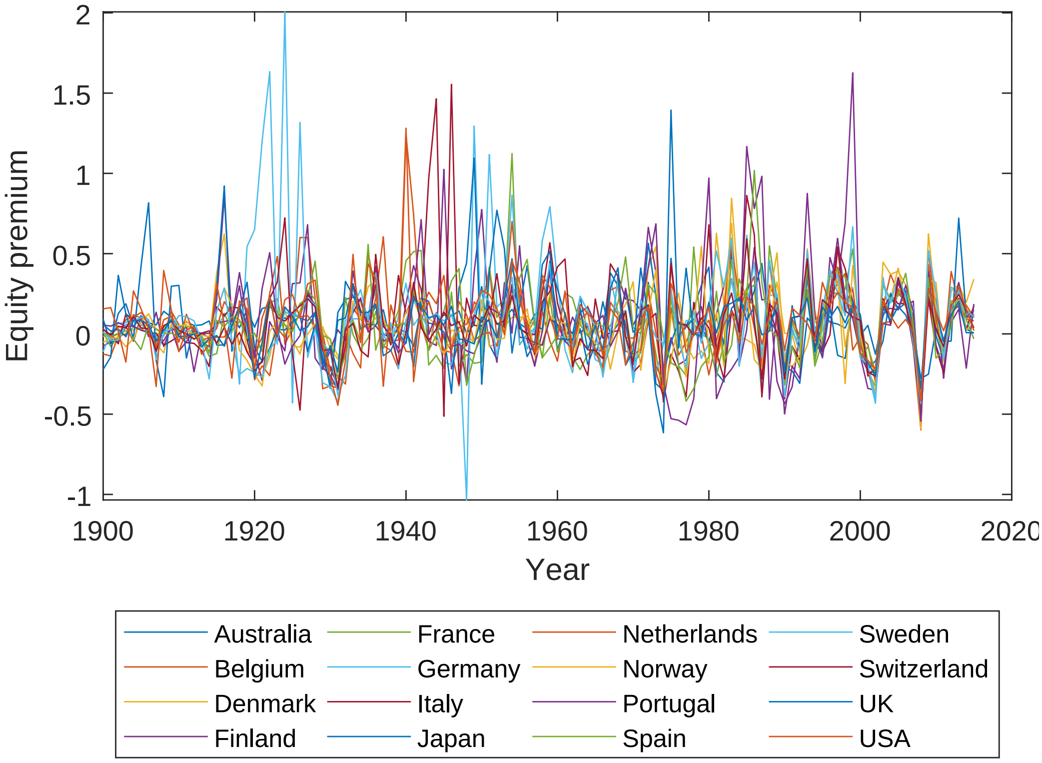


Figure 4 Equity risk premiums across countries over time

It appears there is some volatility clustering during wartime across countries but also during prolonged episodes of peace and economic prosperity. The global measure for the equity risk premiums provides more clarity on the dynamic behaviour, that is it's high when there is turmoil and falls as economic conditions improve (see figure 5). Figure 6 confirms an overall and more recent harmonization **and** synchronization of equity risk premiums across countries.

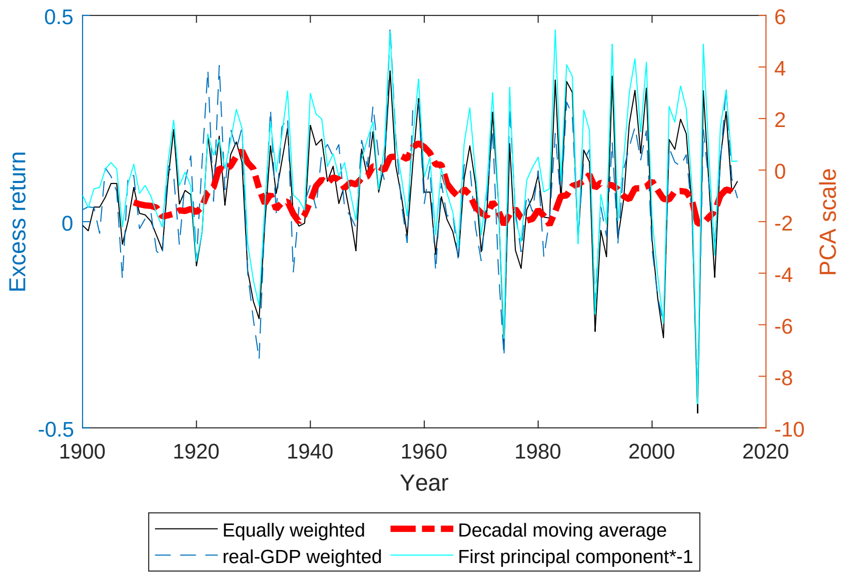
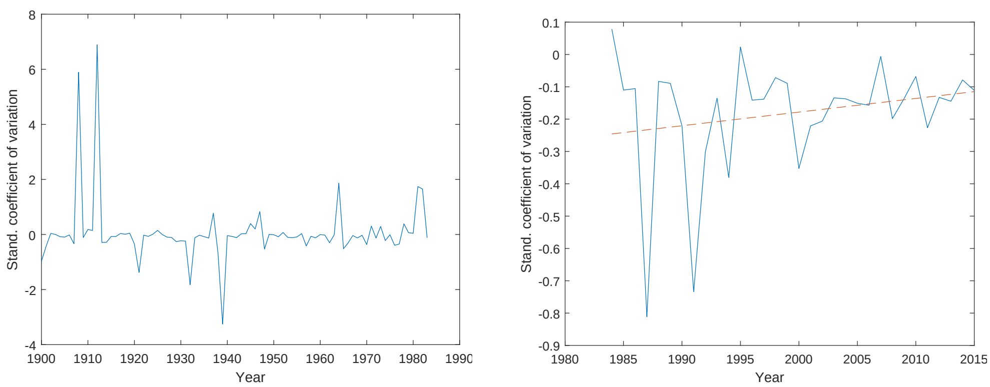


Figure 5 Global equity risk premium over time



(a) 1900-1983

(b) Post-1984

Figure 6 Standardized coefficient of variation (equity risk premium)

2.2 International macroeconomic aggregates

Descriptive statistics for global growth rates are given in table 3 below:

	Equally weighted		real GDP-weighted	
	GDP	consumption	GDP	consumption
Full sample				
Mean growth rate p.a.	2.10	1.87	2.14	1.81
Std.dev.	2.68	2.98	3.12	2.53
Geometric mean	2.06	1.83	2.09	1.78
Median	2.41	1.91	2.24	2.03
Max	11.10	15.17	9.60	13.84
Min	-6.40	-6.98	-9.41	-5.28
Kurtosis	5.00	8.02	5.15	7.45
Post-1984				
Mean growth rate p.a.	1.60	1.53	1.67	1.71
Std.dev.	1.60	1.23	1.54	1.18
Geometric mean	1.59	1.52	1.66	1.71
Median	2.02	1.66	1.94	1.75
Max	3.66	3.60	4.19	3.55
Min	-4.38	-1.54	-4.20	-1.45
Kurtosis	7.92	2.96	8.99	3.52

Table 3 Global growth rates (1900-2015), %

As one can see, GDP growth was higher than consumption growth and slightly more volatile. The post-1984 period is characterised by overall lower growth rates but also volatility where consumption growth is nearly normal distributed. Table 10 in the appendix presents the same statistics for growth rates of the HP-filtered trend component where growth rates are overall lower and also less volatile than the unfiltered data.

Growth rates across countries are presented in table 4 below.

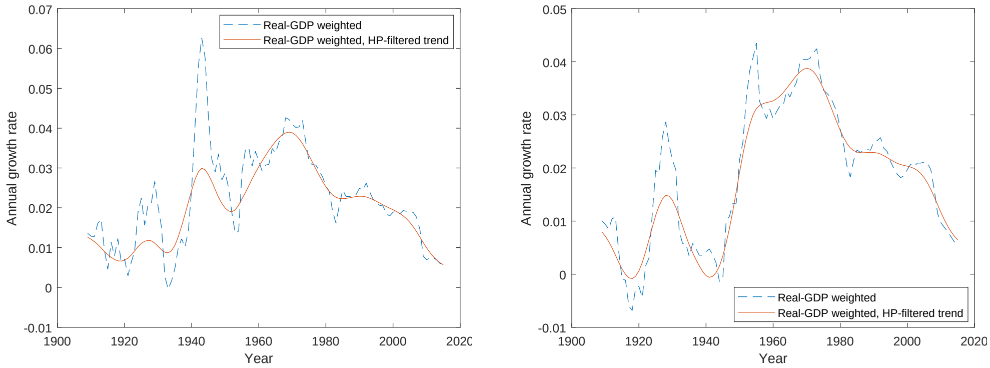
Country	Full sample (1870-2015)				post-1984			
	GDP		consumption		GDP		Consumption	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Australia	1.54	4.10	1.28	5.73	1.91	1.47	1.77	1.39
Belgium*	1.93	8.16	1.73	8.64	1.49	1.50	1.22	1.26
Denmark	1.76	3.66	1.53	5.27	1.17	1.95	0.93	2.40
Finland	2.18	4.50	2.24	5.51	1.52	3.40	1.84	2.82
France	1.85	6.25	1.60	6.53	1.26	1.46	1.25	1.18
Germany	2.09	7.92	1.84	5.54	1.70	1.97	1.40	1.22
Italy	1.92	4.68	1.55	3.70	1.37	2.60	0.96	2.29
Japan*	2.62	5.97	2.36	6.70	1.55	2.23	1.61	1.52
Netherlands	1.79	7.38	1.76	8.32	1.73	1.76	1.15	1.66
Norway	2.18	3.56	1.92	3.71	1.83	1.95	2.27	2.32
Portugal*	1.95	4.25	2.49	4.42	1.77	2.85	2.31	3.21
Spain	2.00	4.90	1.88	7.53	2.04	2.67	1.55	2.71
Sweden	2.10	3.39	1.91	4.33	1.66	2.42	1.35	2.03
Switzerland	1.50	3.90	1.40	6.03	1.03	1.69	0.84	0.86
United Kingdom	1.45	2.87	1.37	2.80	1.80	1.88	2.10	2.25
United States	2.05	4.90	1.83	3.48	1.73	1.75	1.95	1.45
Average	1.93	-	1.79	-	1.60	-	1.53	-

* Belgium: 1914-2015, Japan: 1875-2015, Portugal: 1911-2015

Table 4 Real growth rates (country-level), %

Table 11 in the appendix repeats the same exercise with HP-trend filtered data[5] with overall lower growth rates and lower volatility.

[5] Individual country's indices for real GDP per capita and real consumption expenditures per capita were HP-filtered first and the growth rates of the trend component were then real GDP-weighted.



(a) Real GDP/capita growth (b) Real consumption/capita growth

Figure 7 Decadal moving averages of real-GDP weighted growth rates

Figure 7 shows the 10-year moving averages for the annual growth rates together with the HP-filtered trend components' growth rates per country, all real-GDP weighted. Since the 1970s both macroeconomic aggregates have been growing at positive but decreasing rates where GDP appears to fluctuate more frequently and variably than consumption. Finally, figure 8 displays the real-GDP weighted, HP-filtered countries' trend components growth capturing the world's business cycle dynamics of the last century. Since the 1960s both aggregates move in almost perfect tandem following a downward trend from 4% annual growth to less than 1% per year.

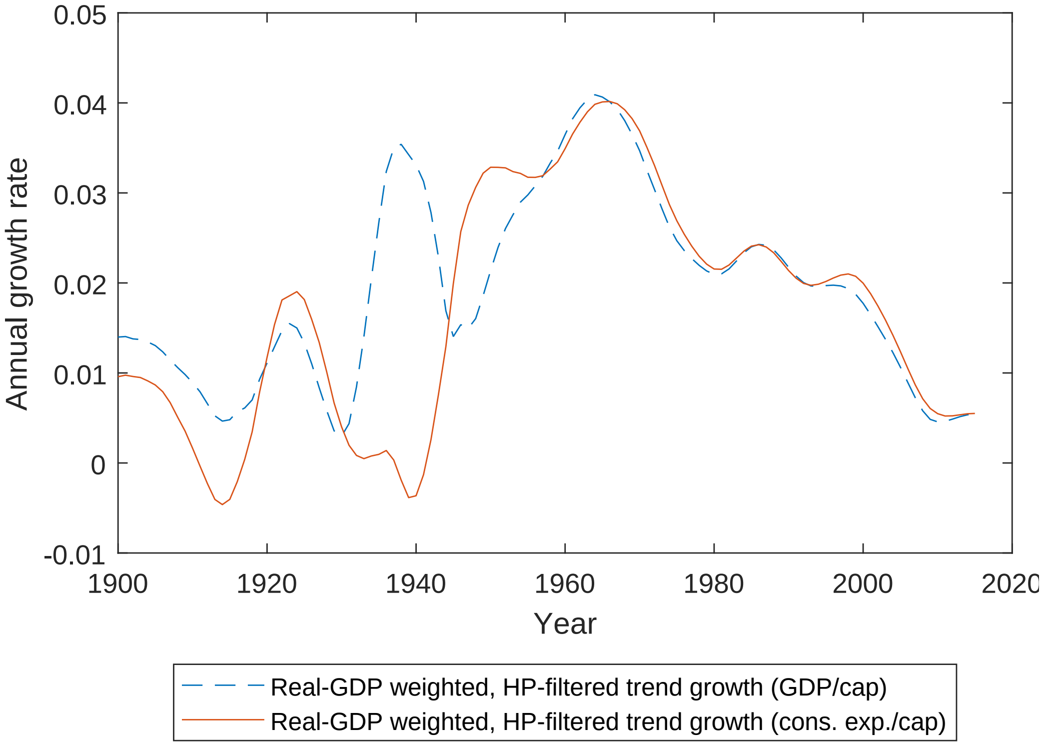


Figure 8 Global business cycle

2.3 Macro-finance

According to Cochrane (2017), "Macro-finance studies the relationship between asset prices and economic fluctuations." Stock market returns driven by capital gains tend to be high during economic expansions, reflecting higher expected corporate earnings are low during recessions. "The" interest rate (solid red line in figure 9), however, reflects the opportunity cost of consuming rather than investing and provides a, perhaps the most decisive, incentive to postpone consumption (solid blue line in figure 9) when it's high, resulting in lower consumption growth. Figure 9 below illustrates these relationships of real-GDP weighted returns and growth rates. Whereas the first fact, i.e. there is a positive correlation between GDP growth (or consumption growth) and stock market returns ($\rho_{(r^e,\Delta GDP)} = 0.23$, $\rho_{(r^e,\Delta cons)} = 0.35$) roughly holds over a long horizon the second relationship, i.e. a negative correlation between GDP growth (or consumption growth) and the interest rate appears to have broken down since the 1960s (pre-1965: $\rho_{(r^f,\Delta GDP)} = -0.16$, $\rho_{(r^f,\Delta cons)} = -0.17$, post-1965: $\rho_{(r^f,\Delta GDP)} = 0.09$, $\rho_{(r^f,\Delta cons)} = 0.03$). These covariances are exactly the quantities of undiversifyable risk that investors, in theory, are compensated for. The *adequate* magnitude in expectation is the equity risk premium which has been measured in a vast body of

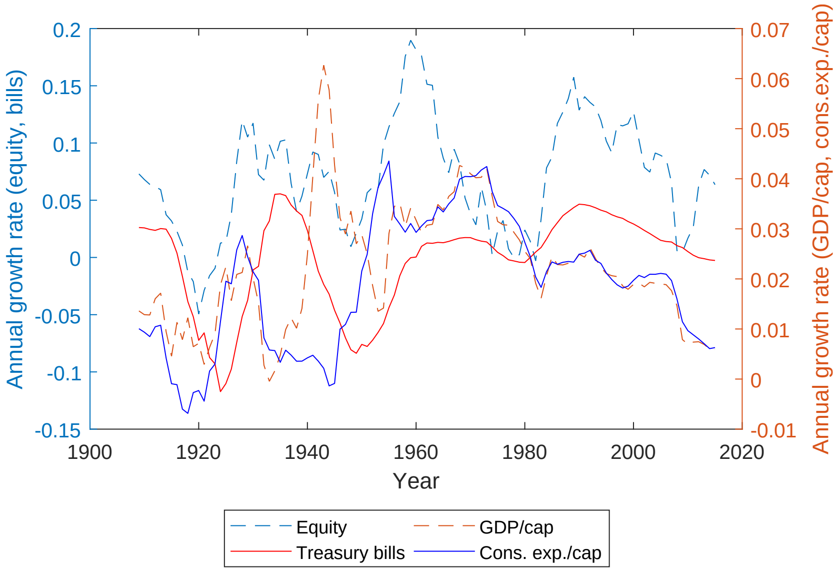
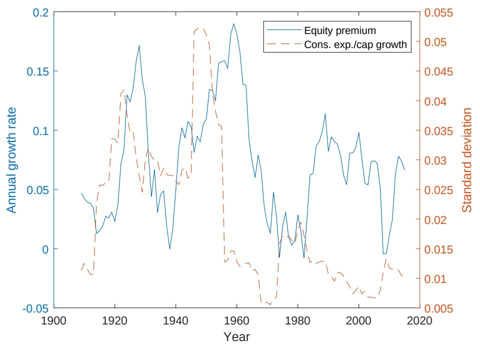


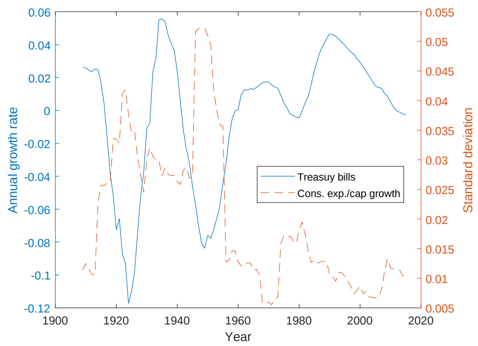
Figure 9 Financial markets and real economy

literature and applications between 4% and 8%.

For any given level of risk aversion, higher variability in consumption growth (i.e. risk) increases the expected excess return by decreasing the risk-free rate due to the precautionary savings effect. Figure 10 below illustrates the theoretical conjectures in the data with the aforementioned divergence starting in the 1980s when global interest rates started to descend.



(a) Equity risk premium and consumption volatility



(b) Risk-free rate and consumption volatility

Figure 10 Global decadal moving average of ERP and standard deviation of consumption growth, real-GDP weighted

The ERP is positively correlated with the variability in consumption growth

(Pearson correlation coefficient of 0.22) whereas the risk-free rate is strongly negatively correlated with variability in consumption growth (Pearson correlation coefficient of -0.73).

With all the ingredients from a (log-normal) consumption-based asset pricing model under time-separable expected utility at hand it is straightforward to derive implied coefficients of relative risk aversion $\underline{\gamma}$ (see tables 6 and 14 for consumption data and GDP data, respectively for comparison). These are orders of magnitude above the standard evidence for low values of γ, around 1, coming from the relationship between the risk-free rate and consumption growth which rises quickly in γ.

2.4 Disaster empirics

A somewhat arbitrary lower bound (Barro, 2006) needs to be chosen that would at least approximately match the proportionate decline required to materialize the extremely high level of marginal utility. In the baseline calibration I follow Barro and Ursúa (2012) and set the threshold to 0.095, i.e. a contraction of at least 9.5%. This threshold corresponds to the 92^{nd} percentile of the left-sided distribution of all annual growth rates of GDP and consumption for the entire sample. Anything above this proportionate decline is considered a 'disaster' which is the case for about 8% of the time in annual growth rates in the full sample. A disastrous event may occur as period of successive economic decline. I apply a NBER-like peak-to-trough procedure (see Python code 1 in the appendix) to identify those periods and occurrences. Figure 11 below illustrates the identified disaster periods (grey) with respect to consumption growth.

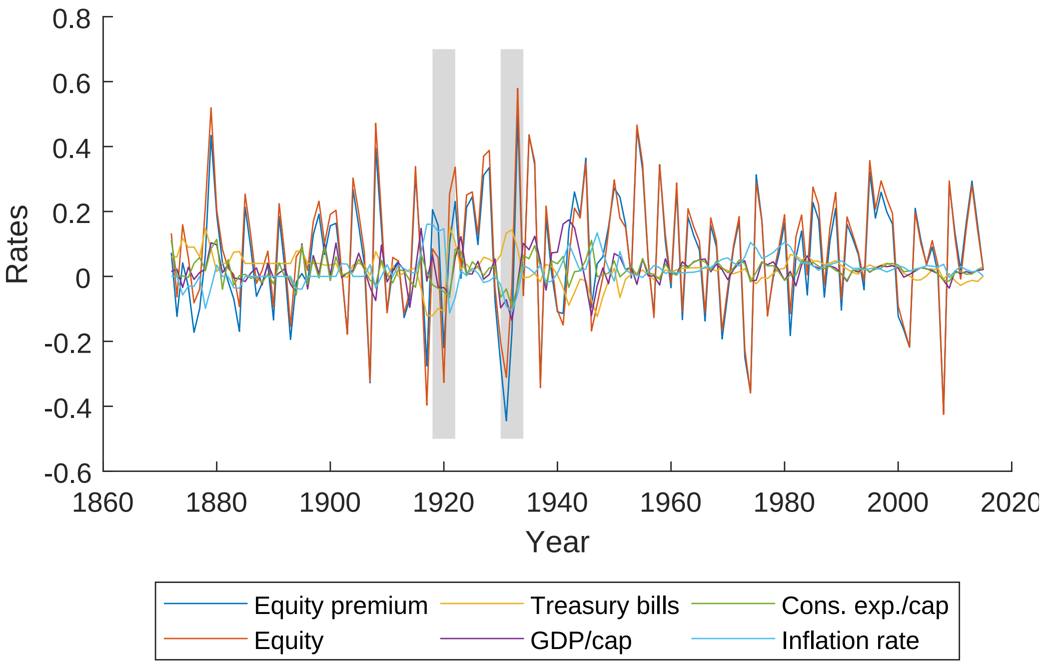


Figure 11 US, consumption disasters

For the US there were two disaster periods of equal lengths but different contraction sizes identified: the first one started 1918 with the onset of a global pandemic caused by an H1N1 virus, better known as the Spanish flu, which would later account for 500 million deaths worldwide and about 675,000 deaths occurring in the United States and triggered a depression in subsequent years lasting for four years (until 1922) with an average proportionate contraction of 18%. The second consumption disaster period started in 1930 and captures the most severe part of the Great Depression where real consumption per capita fell about 23% per year over this period (ended in 1934) (see Nakamura et al. (2013) for similar estimates).

The disaster probability p is calculated as the total number of disasters (irrespective of duration) divided by the number of non-disaster years to provide a measure at an annual frequency. The expected disaster size $\mathbb{E}(b)$ is the unweighted average of annual proportionate declines > threshold.

Country	No. disasters	No. disaster years	No. non-disaster years	Disaster probability (%)	Average disaster size (%)
Australia	6	17	128	4.69	22.60
Belgium*	4	11	91	4.40	34.50
Denmark	3	6	139	2.16	22.31
Finland	5	16	129	3.90	21.75
France	2	8	137	1.50	49.83
Germany	4	17	128	3.13	31.75
Italy	1	5	140	0.71	32.13
Japan*	1	8	133	0.75	90.35
Netherlands	3	10	135	2.22	42.14
Norway	3	9	136	2.21	14.69
Portugal*	3	9	96	3.13	15.25
Spain	13	31	114	11.40	16.21
Sweden	2	4	141	1.41	14.82
Switzerland	6	14	131	4.60	17.73
United Kingdom	2	8	137	1.50	17.72
United States	2	8	137	1.50	20.02
Σ	60	181	2,052	2.92	$\mu = 28.99$

* Belgium: 1914-2015, Japan: 1875-2015, Portugal: 1911-2015

Table 5 Disaster risk moments (consumption)

As table 5 amd figure 12 show there is quite some variation across countries in propensity with respect to consumption disasters.

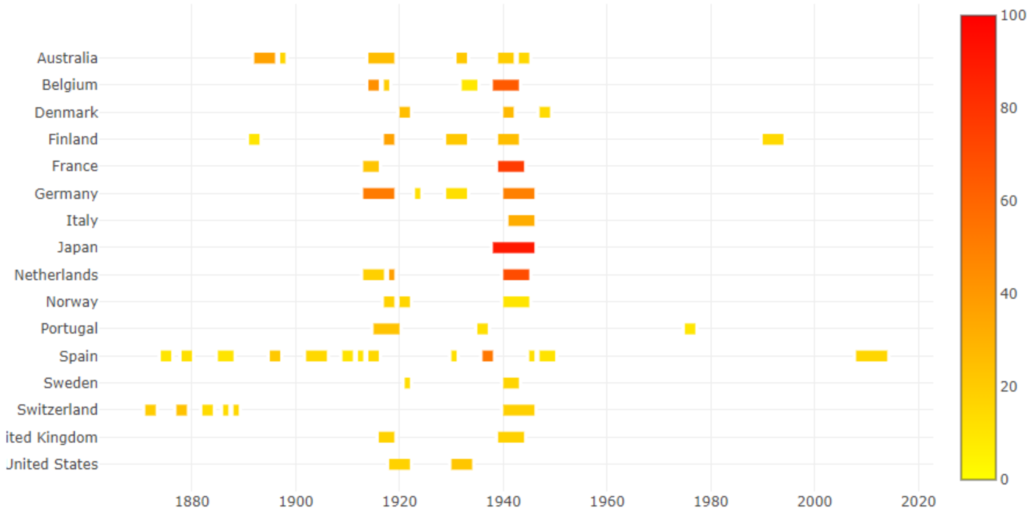


Figure 12 Consumption disasters across countries over time

Clearly, wartime events affected most countries, though with different strength. Spain experienced multiple rather mild disasters whereas France, the Netherlands and Japan were hit by only few but abysmal events. The interactive version with additional information on individual disasters can be accessed from this link:
(https://plotly.com/ gerwolf/54/consumption-disasters-percentage/)
Table 12 and figure 16 in the appendix provide the same overview for GDP data.
[Interactive version:
(https://plotly.com/ gerwolf/68/gdp-disasters-percentage/)]

Consumption disasters occur slightly more frequently than GDP disasters but with a larger average contraction size. Notably, Japan suffered from the worst consumption disasters in the data set in the wake of WWII whereas the GDP contractions were not as severe. In general, average GDP contractions were less pronounced than consumption contractions which is probably due to the stabilizing measures taken by authorities by the onset of a disaster. Moreover, consumption tends to continue falling in response to a disaster shock before recovering, resulting in longer disaster durations pointing towards the crucial role of the IES and a high consumers' willingness to substitute consumption across time.

3 Results

3.1 Baseline calibration

The disaster risk model was fully calibrated except for values of β (or ρ) where $\beta = \frac{1}{1+\rho}$ which was set to 0.95, corresponding to an annualized, hypothetical risk-free interest rate "if consumption were known to be constant forever at its current level, with no growth and no volatility" (Constantinides et al., 2003) of 5%[6] and the IES which was set to the value of microeconometric evidence from cross-individual differences in after-tax real interest rates of (around) 2 (Gruber, 2013). Table 13 in the appendix provides additional moments used for calibration of exogeneous productivity growth and variability during non-disaster periods.

Solving the non-linear equation for the ERP incorporating disaster risk with `MINPACK`'s `hybrd` subroutine implemented in Python yielded the implied coefficients of relative risk aversion γ. For comparison the implied coefficients of relative risk aversion from the original specification leading to the puzzle indicated with an upper bar are also presented in table 6 below.

The results for GDP data are documented in table 14 in the appendix. A few observations can be made from these results:

1. When accounting for disaster risk **all** implied coefficients of relative risk aversion decrease. For consumption (GDP) data the implied coefficients drop by 72% (69%) on average compared to the benchmark values.

2. The relative order is approximately preserved, meaning that the disaster risk model is consistent when accounting for heterogeneity in disaster characteristics (see figure 13).

3. Risk-free rates are consistently overestimated. They are, nevertheless roughly in line with the levels of their empirical counterparts and this relationship is statistically significant at the 0.05 confidence level (see figures 14 and 17 [appendix] for consumption and GDP data, respectively). However, predicted risk-free rates are upwards biased (also statistically significant mean of residuals, $\mu^{cons} = -2.54$, $\mu^{GDP} = -2.62$) and are never negative whereas long-run real T-bill rates were negative for six countries in the sample.

4. For consumption (GDP) data two (six) countries have negative implied effective time preference rates ρ^*, meaning that $\beta^* > 1$ when assuming that

[6] 5% is approximately the annual, unweighted average of nominal T-bills and bonds in Jordà et al. (2017) across countries in the sample and was also used by Weil (1989) for calibration that resulted in the *risk-free rate puzzle*

Country	g^* (%)	ρ^*	β^*	r^e (%)	r^f (%)	$\underline{\gamma}$	γ
Australia	1.55	0.0628	0.9409	6.91	2.52	20.10	5.54
Belgium	2.14	0.0419	0.9598	7.14	3.20	7.91	2.54
Denmark	1.69	0.0308	0.9701	6.77	3.50	17.66	6.53
Finland	2.61	0.0444	0.9575	7.82	0.92	34.01	8.15
France	1.82	0.0405	0.9610	6.70	3.81	10.17	2.07
Germany	2.17	0.0622	0.9415	7.54	0.56	34.08	5.13
Italy	1.66	0.0310	0.9700	6.76	2.43	47.37	7.21
Japan	2.65	0.0456	0.9564	7.20	1.01	20.62	0.97
Netherlands	2.12	0.0429	0.9588	7.16	2.82	9.41	2.66
Norway	2.09	-0.0426	1.0445	6.96	3.63	36.28	12.67
Portugal	2.79	-0.0777	1.0843	7.25	4.49	21.17	8.61
Spain	2.54	0.0226	0.9780	7.47	3.23	11.23	5.09
Sweden	2.04	0.0159	0.9843	7.18	2.88	34.45	14.48
Switzerland	1.69	0.0519	0.9507	6.94	3.10	15.88	6.49
United Kingdom	1.48	0.0290	0.9718	6.65	2.69	76.32	13.36
United States	1.98	-0.0028	1.0028	6.98	2.80	51.76	11.01
Global							

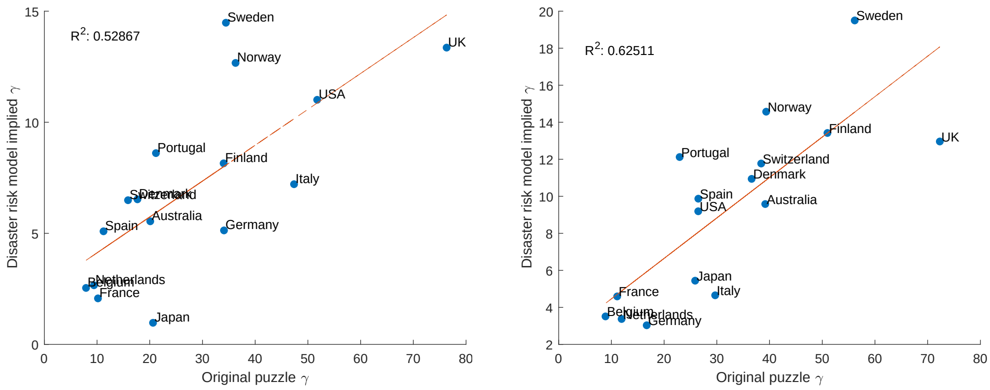
Table 6 Calibration & results (consumption)

markets are complete, i.e. $(1+r^*)\beta^* = 1$ and $r^* = \rho^*$ in the steady state. From a mathematical point of view this may be problematic: the infinite, discounted sum of expected utility explodes as $t \longrightarrow \infty$. Intuitively, agents prefer present utility over utility in the future due to *impatience*. This presumption translates into a positive interest rate. If this wasn't the case agents would have an incentive to borrow an infinite amount and the transversality condition would be violated which cannot coincide with a competitive equilibrium. However, Kocherlakota (1990) argues that a parameterized version of the subject discount factor (such as β^*) greater than 1 can indeed coincide with a competitive equilibrium in a growth environment, given that a) the IES is less than 1 and the stream of consumption is constant. Under these conditions the agent prefers future consumption over present consumption which conflicts with the empirical observation that real interest rates are typically positive. In the sample presented in chapter 2, however, seven countries appeared to have negative real T-bills rates whereas the model predicted strictly positive risk-free rates. Of those seven countries three implied negative effective time preference rates ρ^* when using GDP data. Also, Hansen and Singleton (1982) derived point estimates of β

significantly greater than 1, adding support that in artificial economies "unreasonable" (Kocherlakota, 1990) values for $\beta > 1$ shouldn't be precluded.

5. In general, when moving from GDP data to consumption data four out of six countries' effective subjective discount factors β^* become less than 1, indicating that consumption is a more robust measure with respect to intertemporal considerations than overall output. Effective time preference rates, however, behave inconsistently when using consumption and GDP data, meaning that for one country (Norway) β^* gets closer to 1 (from GDP to consumption) whereas for the other country (Portugal) β^* moves further away from 1.

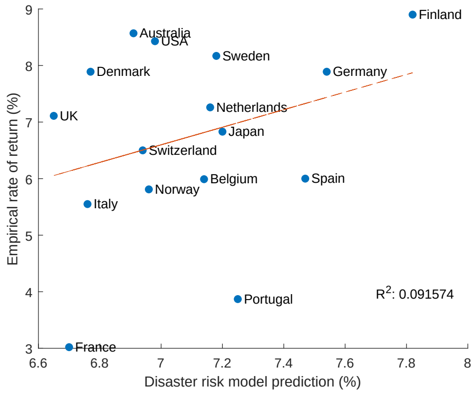
6. The implied coefficients of relative risk aversion are somewhat higher when using GDP data compared to consumption data. Levels of the predicted rates are also higher, shifted by a constant that is due to the effect of the product of lower disaster probability and average disaster size which more than outweighs the higher average growth rates and higher variability in growth rates in non-disaster years.



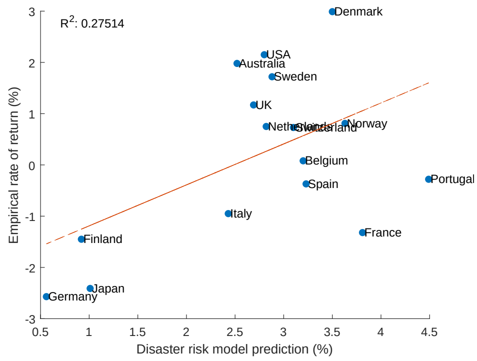
(a) Consumption data implied γ

(b) GDP-data implied γ

Figure 13 Disaster model γ vs. benchmark model γ



(a) Expected rates of return on equity



(b) Risk-free rates

Figure 14 Actual vs. predicted rates of return (consumption data)

3.2 Robustness

As already mentioned the disaster threshold was chosen arbitrarily, thus verifying robustness of the results when varying that parameter seems appropriate. When increasing the threshold from a proportionate decline of 9.5% to 15% (see table 15 in the appendix) the total number of disaster events in the sample decreases from 60 to 40 and from 56 to 32 for consumption data and GDP data, respectively.

Hence, overall disaster probability decreases from 2.92% to 1.90% and from 2.60% to 1.44% for consumption data and GDP data, respectively. The average disaster size, on the other hand, increases from 28.99% to 32.69% and from 22.23% to 29.17% for consumption data and GDP data, respectively.

The implied coefficients of relative risk aversion (table 7 below) do not change substantially or do not change at all.

Applying the Hodrick-Prescott filter[7] with $\lambda = 100$ to the annual, raw consumption expenditures and GDP indices may eliminate periods of temporary measurement error in consumption and GDP. As a result (see table 16), seven (nine) countries did not experience disastrous declines in consumption (GDP) growth rates. Average duration, however, was higher compared to the raw data. The resulting volatility of consumption and GDP growth was too small after filtering, deteriorating the standard model's and the disaster risk model's ability to link asset returns and real-economy based aggregates. The implied risk aversion coefficients appear to still decrease relative to the benchmark model but some of them are 0, implying risk neutrality when derived from HP-filtered data (see table 17 in the

[7] I used the Python implementation `tsa` from the `statsmodels` API which performs the method equivalent to Matlab's built-in `hpfilter` function

Country	g^* (%)	ρ^*	β^*	r^e (%)	r^f (%)	$\underline{\gamma}$	γ
Consumption							
Australia	1.55	0.0628	0.9409	6.91	2.52	20.10	5.54
Belgium	2.08	0.0438	0.9580	7.07	3.13	7.91	2.11
Denmark	1.67	0.0311	0.9698	6.75	3.48	17.66	6.11
Finland	2.51	0.0425	0.9593	7.69	0.80	34.01	7.00
France	1.82	0.0405	0.9610	6.70	3.81	10.17	2.07
Germany	2.11	0.0515	0.9510	7.35	0.37	34.08	3.14
Italy	1.66	0.0310	0.9700	6.80	2.43	47.37	7.21
Japan	2.65	0.0456	0.9564	7.17	1.01	20.62	0.97
Netherlands	2.12	0.0429	0.9588	7.16	2.82	9.41	2.66
Norway	2.02	-0.0358	1.0371	6.91	3.58	36.28	12.30
Portugal	2.70	-0.0564	1.0598	7.17	4.41	21.17	7.41
Spain	2.31	0.0326	0.9684	7.33	3.08	11.23	4.61
Sweden	2.04	0.0186	0.9818	7.18	2.89	34.45	15.05
Switzerland	1.67	0.0532	0.9495	6.94	3.10	15.88	6.55
United Kingdom	1.48	0.0290	0.9718	6.65	2.69	76.32	13.36
United States	1.98	-0.0028	1.0028	6.98	2.80	51.76	11.01
Global							
GDP							
Australia	1.71	0.0429	0.9589	6.92	2.53	39.18	9.20
Belgium	2.30	0.0346	0.9665	7.25	3.31	8.88	3.32
Denmark	1.84	-0.0082	1.0083	6.74	3.48	36.61	9.00
Finland	2.29	0.0317	0.9692	7.43	0.54	50.99	9.23
France	2.14	0.0162	0.9840	6.96	4.07	11.10	4.60
Germany	2.40	0.0482	0.9540	7.54	0.56	16.70	2.36
Italy	2.10	0.0248	0.9758	7.03	2.70	29.69	4.65
Japan	2.85	0.0250	0.9756	7.50	1.34	25.89	2.78
Netherlands	2.14	0.0403	0.9612	7.12	2.78	11.94	2.70
Norway	2.27	-0.0919	1.1012	7.07	3.74	39.36	16.23
Portugal	2.06	-0.0400	1.0417	6.92	4.16	22.95	12.11
Spain	2.14	0.0100	0.9901	7.05	2.81	26.49	6.62
Sweden	2.18	-0.0594	1.0631	7.14	2.84	56.16	18.90
Switzerland	1.62	0.0348	0.9664	6.81	2.97	38.42	12.06
United Kingdom	1.55	0.0231	0.9774	6.69	2.73	72.30	12.96
United States	2.25	0.0056	0.9944	7.18	2.99	26.47	7.54
Global							

Table 7 Calibration & results (disaster threshold = 0.15)

appendix). This robustness specification is also the only one which predicted a negative interest rate (Australia).

Varying the IES predicted a common behaviour across countries, that is the predicted rates of expected return on equity and risk-free rate decreased quickly on the interval $\psi \in (0, 0.5]$ and then converge, leaving the risk premium (and coefficient of relative risk aversion) unaffected.

4 Conclusion

This paper has assessed the consumption-based asset pricing model's ability to rationalise observed financial returns when accounting for disaster risk. Comprehensively analyzing a newly available dataset by Jordà et al. (2017) which covers almost 150 years of financial and macroeconomic history of 16 developed countries and deploying a richer preference specification of the EZW-class that disentangles the preference parameters with respect to marginal utility in the intratemporal (risk aversion) and intertemporal (IES) space showed to yield implied preference parameters which accord with theoretical insights and attenuate the equity risk premium puzzle by a considerable proportion. Having itentified heterogeneity with respect to risk-sharing capacity and risk preference across countries lays path to a departure towards policy-related studies addressing the roles of fiscal capacity, market regulation and globalisation, to name just a few.

Conventional measures of aggregate consumption show still too high idiosyncratic consumption volatility (conditional on output) and too low international consumption correlations which "have remained approximately constant after 1980 and and thoughout the 1990s" (Artis and Hoffmann, 2008) which is known as the *risk-sharing puzzle*. Cochrane (1991) compares the basic idea of consumption insurance as the cross-sectional counterpart of the permanent income hypothesis, i.e. aggregate consumption of any individual country does not vary in response to idiosyncratic income shocks. A competitive equilibrium requires markets to be complete and/or institutional arrangements implementing optimal allocations (Canova and Ravn, 1996). In the context of disaster risk those arrangements (e.g. charities, disaster relief programs, international lending agreements or direct foreign aid) do exist in reality but were put in place successively in response to the most severe disasters in modern history. Systemic crises pose significant distortions to optimal consumption allocations across countries with strong persistence. Canova and Ravn (1996) empirically argue that consumption correlations are not perfect (meaning that marginal utility of consumption is not equalized across countries) and that countries with closer economic ties (E.E.C. back then) “may also have more efficient risk sharing mechanisms.”[8], contrasting the theoretical implications of international business cycle (IBC) models such as in Backus et al. (1992). Epstein et al. (2016) empirically test consumption, asset and labor income tax differentials within this class of models and argue that accounting for taxation does explain time-varying degree of risk sharing (and hence time-varying degree of risk-aversion).

After controlling for disaster risk the implied coefficients of relative risk aversion as in the baseline calibration may be subject to country-specific factors (or histories of policies) shaping the economic environment. Cui (2016) models market liquidity explicitly as an endogeneous process of competetive search and match that gives rise to optimal monetary-fiscal interaction. Public liquidity in form of government bonds may be also subject to liquidity risk, that is the degree of easiness of trading an asset and the price’s sensitivity to the trades. Weak fiscal capacity therefore does not only increase the probability of default but also government bonds are less desirable, agents cannot fully self-insure through muted precautionary savings effects which induces them to require a higher premium. Fiscal capacity can be captured by the tax revenue to GDP ratio[9] which accurately describes economic policy since both move one-by-one with the business cycle.

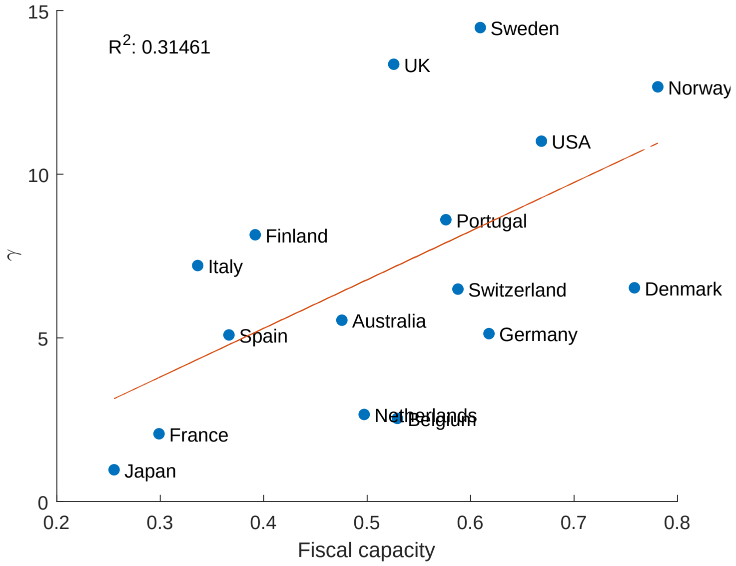


Figure 15 Standardized coefficients of variation, within-country tax revenue/GDP

[8] They also provide estimates of CRRA coefficients for the representative agent in each country (relative to the U.S.) for eight developed countries which deviate substantially from the ones reported in this paper.

[9] Also taken from JST dataset

Figure 15 above indicates that after controlling for disaster risk there is some variation stemming from fiscal capacity measured as the standardized coefficients of variation of within-country tax revenue/GDP. The higher the coefficient, the more the economic environment fluctuates and imposes distortions to financial markets, leading to liquidity premiums which leads to higher risk aversion. Further research could study different taxation types in the cross-section.

As Barro (2006) suggests the analysis of real rates of return might include housing as component of the wealth portfolio as well. Given that such data is available (Jordà et al., 2017) the implementation should be straight-forward.

Barro (2006) and Nakamura et al. (2013) point at incorporating time-varying disaster moments which has been followed by Tsai and Wachter (2015). The finding of Nakamura et al. (2013) on the role of the IES (especially at the onset of disasters) points at time-varying properties of the IES itself. Apart from dynamic aspects of disasters they also point out the distinction between actual and perceived disaster risks due to learning in order to alleviate the uncertainty regarding disaster parameters.

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Appendix

Country	Equity	Bills	GDP (per capita)	Consumption (per capita)	Inflation
Australia	1870-2015	1870-2015	1870-2015	1870-2015	1870-2015
Belgium	1870-2015	1870-2015	1870-2015	1913-2015	1870-2015
Denmark	1873-2015	1875-2015	1870-2015	1870-2015	1870-2015
Finland	1896-2015	1870-2015	1870-2015	1870-2015	1870-2015
France	1870-2015	1870-2015	1870-2015	1870-2015	1870-2015
Germany	1870-2015	1870-2015	1870-2015	1870-2015	1870-2015
Italy	1870-2015	1885-2015	1870-2015	1870-2015	1870-2015
Japan	1886-2015	1876-2015	1870-2015	1870-2015	1870-2015
Netherlands	1900-2015	1870-2015	1870-2015	1870-2015	1870-2015
Norway	1881-2015	1870-2015	1870-2015	1870-2015	1870-2015
Portugal	1871-2015	1880-2015	1870-2015	1910-2015	1870-2015
Spain	1900-2015	1870-2015	1870-2015	1870-2015	1870-2015
Sweden	1871-2015	1870-2015	1870-2015	1870-2015	1870-2015
Switzerland	1900-2015	1900-2015	1870-2015	1870-2015	1870-2015
United Kingdom	1871-2015	1870-2015	1870-2015	1870-2015	1870-2015
United States	1872-2015	1870-2015	1870-2015	1870-2015	1870-2015

Table 8 Data coverage

Country	Full sample (1870-2015)				post-1984			
	Equity		Bills		Equity		Bills	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Australia	8.57	16.49	1.98	4.47	8.75	18.94	3.62	2.48
Belgium	5.99	22.92	0.08	12.61	11.92	24.90	2.24	2.87
Denmark	7.89	17.41	2.99	5.61	10.84	21.53	2.70	3.17
Finland	8.90	33.26	-1.45	14.90	15.74	42.53	2.84	3.65
France	3.02	23.67	-1.32	9.58	10.47	24.49	2.45	2.71
Germany	7.89	30.56	-2.57	27.64	10.31	24.72	1.86	1.92
Italy	5.55	29.71	-0.95	16.26	9.99	29.99	2.86	2.94
Japan	6.83	35.76	-2.41	23.90	5.46	22.63	1.26	1.90
Netherlands	7.26	22.65	0.75	4.92	10.69	22.81	2.03	2.56
Norway	5.81	20.72	0.81	6.04	12.55	28.90	2.19	1.86
Portugal	3.87	28.93	-0.28	10.50	11.41	39.75	1.97	2.94
Spain	6.00	22.28	-0.37	7.15	14.23	28.66	2.39	3.54
Sweden	8.17	20.45	1.72	5.65	13.55	28.24	1.80	1.73
Switzerland	6.50	19.41	0.73	5.00	10.12	22.53	0.73	1.72
United Kingdom	7.11	19.37	1.17	4.89	8.67	15.64	2.92	3.14
United States	8.43	19.00	2.15	4.62	9.59	16.85	1.67	2.36
Average	6.74	-	0.20	-	10.89	-	2.22	-

Table 9 Real rates of return (country-level), %

	Equally weighted		real GDP-weighted	
	GDP	consumption	GDP	consumption
Full sample				
Mean growth rate p.a.	1.95	1.73	1.93	1.70
Std.dev.	1.17	1.39	1.06	1.29
Geometric mean	1.95	1.72	1.93	1.70
Median	1.97	1.84	1.95	1.87
Max	4.39	4.10	4.09	4.02
Min	0.21	-1.26	0.30	-0.46
Kurtosis	2.47	2.26	2.13	1.89
Post-1984				
Mean growth rate p.a.	1.49	1.43	1.51	1.59
Std.dev.	0.78	0.69	0.72	0.70
Geometric mean	1.48	1.42	1.51	1.59
Median	1.96	1.79	1.82	1.98
Max	2.24	2.10	2.43	2.42
Min	0.21	0.24	0.46	0.52
Kurtosis	1.74	1.91	1.50	1.61

Table 10 Global growth rates (1900-2015), %, HP-filtered ($\lambda = 100$)

Country	Full sample (1870-2015)				post-1984			
	GDP		consumption		GDP		Consumption	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Australia	1.45	1.30	1.16	1.60	1.83	0.51	1.76	0.61
Belgium*	1.66	2.10	1.68	2.10	1.41	0.68	1.17	0.71
Denmark	1.69	1.06	1.37	0.78	1.06	0.64	0.78	0.48
Finland	2.09	1.39	2.12	1.39	1.50	1.17	1.80	0.77
France	1.64	2.01	1.42	2.10	1.24	0.65	1.23	0.52
Germany	1.67	2.38	1.67	2.31	1.61	0.32	1.30	0.64
Italy	1.84	1.78	1.49	1.97	1.24	1.65	0.82	1.49
Japan*	2.46	2.64	2.18	3.23	1.42	1.05	1.58	0.91
Netherlands	1.57	1.72	1.43	1.80	1.60	0.84	1.02	1.05
Norway	2.10	1.15	1.84	0.81	1.73	1.12	2.16	0.64
Portugal*	1.88	1.79	2.36	1.94	1.63	1.53	2.17	1.91
Spain	1.81	1.98	1.51	2.18	1.84	1.58	1.32	1.57
Sweden	2.02	0.91	1.80	0.72	1.51	0.58	1.14	0.42
Switzerland	1.38	1.07	1.27	0.90	0.94	0.27	0.80	0.17
United Kingdom	1.39	0.81	1.32	0.97	1.66	0.82	1.95	1.12
United States	1.94	1.33	1.77	1.04	1.53	0.65	1.81	0.64
Average	1.79	-		-	1.49	-		-

* Belgium: 1914-2015, Japan: 1875-2015, Portugal: 1911-2015

Table 11 Real growth rates (country-level), %, HP-filtered ($\lambda = 100$)

```
data = pd.read_excel(<ENTER DATASET HERE>, sheet_name = 'C
                                JST')
data['year'] = data['C pc']
del data['C pc']
data = data.iloc[1:]
data.set_index('year', inplace=True, drop=True)
start_year = 1870
end_year = 2015
data = data.loc[start_year:end_year];
threshold = 0.095
countries = list(data.columns)
years = list(data.index)
data_pct = data.pct_change()
cons_df = data_pct
country_list = []
disaster_df_list = []
for country in countries:
    country_dict = {}
```

```
sub_frame = data_pct[country]
total_years = len(sub_frame.dropna())
sub_frame_less = sub_frame.iloc[1:]
na_index = sub_frame_less.loc[pd.isna(sub_frame_less)].
                                index
succession_counter = 0
succession_container = []
succession_year_container = []

for x in years:
    if x+1 <= end_year and sub_frame.loc[x] < 0 and
                                    sub_frame.loc[x+1] < 0
                                    :

      succession_counter += 1
        if succession_counter == 1:

            empty_list = [sub_frame.loc[x], sub_frame.loc
                                        [x+1]]
            empty_year_list = [x, x+1]

        elif succession_counter > 1:

            empty_list.append(sub_frame.loc[x+1])
            empty_year_list.append(x+1)

        succession_container.append(empty_list)
        succession_year_container.append(empty_year_list)

    else:

        succession_counter = 0

unique_periods = list(succession_year_container for
                                succession_year_container,
                                _ in itertools.groupby(
                                succession_year_container)
                                )

cumulative_contractions = []

for i in list(succession_container for
                                succession_container,_ in
                                itertools.groupby(
                                succession_container)):

    cumulative_contractions.append(sum(i))

empty_check_list = []
```

```python
for idx, i in enumerate(cumulative_contractions):

    empty_dict = {}

    if i <= - threshold:

        empty_dict['contraction'] = i
        empty_dict['index'] = idx
  empty_check_list.append(empty_dict)

disaster_df = pd.DataFrame(empty_check_list)

disaster_periods = []

for i in list(disaster_df['index'].values):

    disaster_periods.append(unique_periods[i])

disaster_df['period'] = disaster_periods
disaster_df['country'] = country

flat_list = []
for sublist in disaster_periods:
    for item in sublist:
        flat_list.append(item)

single_years = sub_frame[sub_frame <= - threshold]
single_year_list = []

for idx, i in enumerate(single_years.index):

    if i not in flat_list:

        single_year_list.append(i)

left_over_df = pd.DataFrame(single_years[single_year_list
                                ])
left_over_df.reset_index(drop = False, inplace = True)
left_over_df.columns = ['period', 'contraction']
left_over_df['country'] = country
del disaster_df['index']
final_df = disaster_df.append(left_over_df)
final_df.reset_index(inplace=True, drop = True)
disaster_df_list.append(final_df)
total_number_disasters = len(final_df)
flattened_years = []

for i in range(len(final_df)):
```

```
        sub_years = final_df['period'][i]

        if type(sub_years) != int:

            sub_years = [str(item) for item in sub_years]

            for x in sub_years:

                flattened_years.append(x)

        elif type(sub_years) == int:

            flattened_years.append(str(sub_years))

    total_number_disaster_years = len(flattened_years)
    average_disaster_size = abs(final_df['contraction'].mean
                                ())
    non_disaster_years = total_years-
                                total_number_disaster_years

    disaster_probability = total_number_disasters /
                                non_disaster_years

    country_dict['Country'] = country
    country_dict['no disasters'] = total_number_disasters
    country_dict['no disaster years'] =
                                total_number_disaster_years

    country_dict['average disaster size'] =
                                average_disaster_size
    country_dict['no non-disaster years'] =
                                non_disaster_years
    country_dict['disaster probability'] =
                                disaster_probability
    country_dict['annual average growth rate'] = sub_frame.
                                mean()
    country_dict['standard deviation annual growth rate'] =
                                sub_frame.std()
    country_dict['kurtosis'] = sub_frame.kurtosis()
    country_dict['total years'] = total_years
    country_dict['missing years'] = np.NaN
    country_dict['number missing years'] = np.NaN

    if len(na_index) != 0:

        missing_years = sub_frame_less.loc[na_index]
        country_dict['missing years'] = list(sub_frame_less.
                                    loc[na_index].index)
```

```
        country_dict['number missing years'] = len(
                                                    missing_years)

    country_list.append(country_dict)

consumption_disaster_df = pd.DataFrame(country_list)
consumption_disaster_events = pd.concat(disaster_df_list)
```

Code Listing 1 Peak-to-trough algorithm

Country	No. disasters	No. disaster years	No. non-disaster years	Disaster probability (%)	Average disaster size (%)
Australia	4	15	130	3.08	18.18
Belgium*	5	13	132	3.79	27.59
Denmark	2	4	141	1.42	18.50
Finland	5	15	130	3.85	15.48
France	7	21	124	5.65	19.11
Germany	4	14	131	3.05	44.03
Italy	2	8	137	1.46	36.17
Japan*	2	8	137	1.46	35.19
Netherlands	3	15	130	2.31	35.92
Norway	3	6	139	2.16	13.23
Portugal*	2	3	142	1.41	13.14
Spain	4	13	132	3.03	16.73
Sweden	3	5	140	2.14	11.90
Switzerland	3	9	136	2.21	16.09
United Kingdom	2	7	138	1.45	18.05
United States	5	13	132	3.79	16.45
Σ	56	169	2,151	2.60	$\mu = 22.23$

* Belgium: 1914-2015, Japan: 1875-2015, Portugal: 1911-2015

Table 12 Disaster risk moments (GDP)

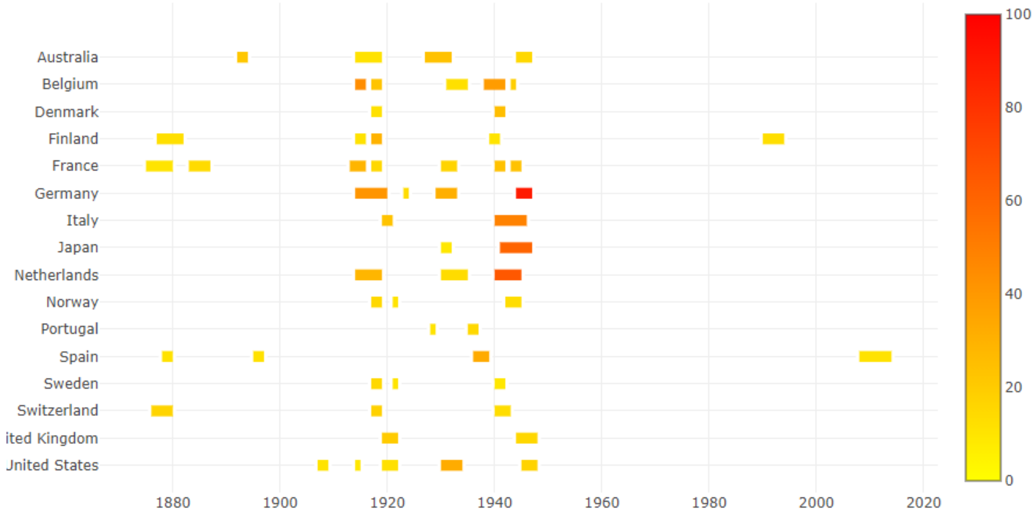

Figure 16 GDP disasters across countries over time

Country	Consumption		GDP	
	g	σ	g	σ
Australia	2.51	4.41	2.28	3.44
Belgium	3.46	6.34	3.17	7.03
Denmark	2.08	4.36	2.07	3.13
Finland	3.36	4.31	3.02	3.69
France	2.41	5.30	3.24	4.94
Germany	3.08	4.22	3.66	4.20
Italy	1.83	3.35	2.56	3.58
Japan	3.18	5.41	3.28	4.77
Netherlands	2.82	6.89	2.83	6.57
Norway	2.37	3.11	2.56	3.06
Portugal	3.20	3.82	2.17	3.98
Spain	4.24	5.52	2.70	4.11
Sweden	2.17	4.04	2.43	2.81
Switzerland	2.36	5.22	1.95	3.45
United Kingdom	1.71	2.32	1.78	2.43
United States	2.23	3.11	2.87	4.12

Table 13 Growth rates (non-disaster years), %

Country	g^* (%)	ρ^*	β^*	r^e (%)	r^f (%)	$\underline{\gamma}$	γ
Australia	1.78	0.0414	0.9603	6.98	2.58	39.18	9.58
Belgium	2.37	0.0328	0.9683	7.30	3.36	8.88	3.51
Denmark	1.86	-0.0142	1.0144	6.80	3.54	36.61	10.94
Finland	2.50	0.0529	0.9498	7.76	0.86	50.99	13.42
France	2.28	0.0115	0.9887	7.04	4.15	11.10	4.59
Germany	2.40	0.0501	0.9523	7.61	0.64	16.70	3.03
Italy	2.10	0.0248	0.9758	7.03	2.70	29.69	4.65
Japan	2.88	0.0106	0.9895	7.72	1.56	25.89	5.44
Netherlands	2.21	0.0385	0.9629	7.23	2.89	11.94	3.37
Norway	2.32	-0.0872	1.0956	7.09	3.75	39.36	14.57
Portugal	2.07	-0.0413	1.0431	6.93	4.16	22.95	12.12
Spain	2.28	-0.0003	1.0003	7.26	3.02	26.49	9.87
Sweden	2.21	-0.0628	1.0670	7.17	2.87	56.16	19.50
Switzerland	1.66	0.0345	0.9667	6.84	3.00	38.42	11.77
United Kingdom	1.55	0.0231	0.9774	6.69	2.73	72.30	12.96
United States	2.33	-0.0015	1.0015	7.28	3.10	26.47	9.19
Global							

Table 14 Calibration & results (GDP)

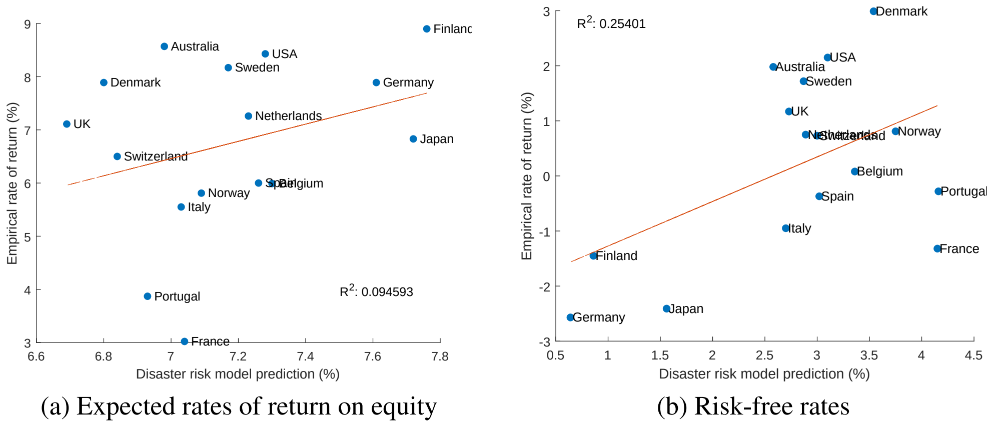

Figure 17 Actual vs. predicted rates of return (GDP data)

Country	No. disasters	No. disaster years	No. non-disaster years	Disaster probability (%)	Average disaster size (%)
			Consumption		
Australia	6	17	128	4.69	22.60
Belgium*	3	8	94	3.19	42.82
Denmark	2	4	141	1.42	26.20
Finland	3	10	135	2.22	27.85
France	2	8	137	1.46	49.83
Germany	2	12	133	1.50	50.82
Italy	1	5	140	0.71	32.13
Japan*	1	8	133	0.75	90.35
Netherlands	3	10	135	2.22	42.14
Norway	2	4	141	1.42	16.88
Portugal*	1	5	100	1.00	23.47
Spain	5	16	129	3.88	24.18
Sweden	1	3	142	0.70	16.43
Switzerland	4	11	134	2.99	19.52
United Kingdom	2	8	137	1.46	17.72
United States	2	8	137	1.46	20.02
Σ	40	137	2,096	1.90	$\mu = 32.69$

			GDP		
Australia	3	10	135	2.22	20.45
Belgium*	4	9	136	2.94	31.44
Denmark	1	2	143	0.70	25.43
Finland	1	2	143	0.70	29.94
France	5	12	133	3.76	21.86
Germany	3	13	132	2.27	54.14
Italy	2	8	137	1.46	36.17
Japan*	1	6	139	0.72	60.88
Netherlands	2	10	135	1.48	47.09
Norway	1	2	143	0.70	15.31
Portugal*	1	2	143	0.70	15.40
Spain	1	3	142	0.70	32.86
Sweden	1	2	143	0.70	15.39
Switzerland	2	6	139	1.44	17.55
United Kingdom	2	7	138	1.45	18.05
United States	2	7	138	1.45	24.80
Σ	32	101	2,219	1.44	$\mu = 29.17$

* Belgium: 1914-2015, Japan: 1875-2015, Portugal: 1911-2015

Table 15 Disaster risk moments (disaster threshold = 0.15)

Country	No. disasters	No. disaster years	No. non-disaster years	Disaster probability (%)	Average disaster size (%)
		Consumption			
Australia	2	26	119	1.68	19.01
Belgium*	1	12	90	1.11	32.44
Denmark	-	-	-	-	-
Finland	-	-	-	-	-
France	1	13	132	0.76	34.17
Germany	2	20	125	1.60	21.67
Italy	2	25	120	1.67	11.20
Japan*	1	18	123	0.81	53.38
Netherlands	1	10	135	0.74	20.88
Norway	-	-	-	-	-
Portugal*	1	8	97	1.03	9.57
Spain	1	12	133	0.75	26.90
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	-	-	-	-	-
Σ	12	144	1,074	1.12	$\mu = 25.47$
		GDP			
Australia	1	12	133	0.75	15.97
Belgium*	2	21	124	1.61	19.51
Denmark	-	-	-	-	-
Finland	-	-	-	-	-
France	1	12	133	0.75	23.79
Germany	2	20	125	1.60	25.85
Italy	-	-	-	-	-
Japan*	1	8	137	0.73	21.08
Netherlands	1	13	132	0.76	20.92
Norway	-	-	-	-	-
Portugal*	-	-	-	-	-
Spain	1	10	135	0.74	18.12
Sweden	-	-	-	-	-
Switzerland	-	-	-	-	-
United Kingdom	-	-	-	-	-
United States	-	-	-	-	-
Σ	9	96	919	0.98	$\mu = 20.75$

* Belgium: 1914-2015, Japan: 1875-2015, Portugal: 1911-2015

Table 16 Disaster risk moments (HP-filtered trend, $\lambda = 100$)

Country	g^* (%)	ρ^*	β^*	r^e (%)	r^f (%)	$\underline{\gamma}$	γ
			Consumption				
Australia	1.73	0.0033	0.9967	3.33	-1.07	20.10	12.63
Belgium	1.91	0.0087	0.9914	6.79	2.85	7.91	6.25
Denmark	-	-	-	-	-	-	-
Finland	-	-	-	-	-	-	-
France	1.57	0.0143	0.9859	6.48	3.58	10.17	5.85
Germany	1.96	0.0621	0.9416	6.24	6.24	34.08	0.02
Italy	1.82	-0.0593	1.0630	6.85	2.52	47.37	25.18
Japan	2.54	0.0234	0.9771	7.32	1.16	20.62	3.52
Netherlands	1.54	0.0603	0.9431	6.04	6.03	9.41	0.00
Norway	-	-	-	-	-	-	-
Portugal	2.57	-0.4229	1.7327	7.02	4.26	21.17	29.87
Spain	1.67	0.0083	0.9917	6.69	2.44	11.23	9.60
Sweden	-	-	-	-	-	-	-
Switzerland	-	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-	-
United States	-	-	-	-	-	-	-
Global							
			GDP				
Australia	1.59	0.0606	0.9429	6.06	6.06	39.18	0.00
Belgium	1.95	-0.0296	1.0305	6.85	2.90	8.88	11.66
Denmark	-	-	-	-	-	-	-
Finland	-	-	-	-	-	-	-
France	1.80	-0.0367	1.0381	6.60	3.70	11.10	10.07
Germany	1.95	0.0619	0.9417	6.24	6.23	16.70	0.02
Italy	-	-	-	-	-	-	-
Japan	2.63	0.0655	0.9386	6.58	6.58	25.89	0.01
Netherlands	1.74	0.0613	0.9423	6.13	6.13	11.94	0.00
Norway	-	-	-	-	-	-	-
Portugal	-	-	-	-	-	-	-
Spain	1.96	0.0618	0.9418	6.25	6.24	26.49	0.03
Sweden	-	-	-	-	-	-	-
Switzerland	-	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-	-
United States	-	-	-	-	-	-	-
Global							

Table 17 Calibration & results (HP-filtered trend, $\lambda = 100$)

Statutory Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this thesis are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This thesis is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 10,000 words excluding bibliography and appendices.

Gerome Wolf
September 23, 2020