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An exploration of the effect of doubt during disasters on equity premiums*

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Abstract

In this note, we consider the effect on equity premiums of a representative household's subjective expectations during disasters. In particular, we focus on the effect of doubt during disasters. Our contribution is to demonstrate that doubt during disasters—even mild ones—generates high equity premiums.

JEL classification: G02, G12.
Key words: *subjective expectations, disasters, equity premium.*

1 Introduction

Several researchers, including Rietz (1988) and Barro (2006), argue that a disaster risk generates large equity premiums even in an exchange economy with a representative agent. Recently, many researchers have explored the effects of various empirical characterizations of disasters on equity premiums.[1] In most of these studies, the rational expectations model is used. However, the problem is that the stochastic processes of disasters might be unknown because of their infrequency. Given that disasters tend to unfold over a number of periods and are followed by recoveries, households may be unable to predict accurately the associated increases in the volatility of consumption growth rates.

In this note, we examine how doubt, which is an example of the type of subjective expectation proposed by Abel (2002), affects equity premiums. Doubt is modeled by using the mean-preserving spread of the objective distribution. We demonstrate that whether doubt during disasters generates high equity premiums depends on the value of the intertemporal elasticity of substitution (IES). In particular, we demonstrate analytically that if the model incorporates a power utility function, doubt during disasters lowers equity premiums. However, if the model incorporates the recursive utility function proposed by Epstein and Zin (1991) and Weil (1989), with a high

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[1] Gourio (2008) considers the effects of the recoveries that follow disasters. Saito and Suzuki (forthcoming) explore the effects of persistent disasters. Barro and Jin (2011) consider the distribution of the scale of disasters. Nakamura et al. (2010) estimate disaster dynamics by using sophisticated econometric methods.

IES, doubt during even mild disasters generates high equity premiums. Ignoring doubt during disasters biases computed equity premiums downward, although the exact magnitude of the doubt during is difficult to determine.

2 The Model and its Equilibrium

2.1 Modeling doubt during disasters

Following Mehra and Prescott (1985) and others, we model an economy in which a representative agent consumes fruit from Lucas trees. We assume that the number of Lucas trees is constant. We let C_t and A_t denote consumption and output in period t, respectively. Because we model a closed economy, output equals consumption: $C_t = A_t$.

The two states, $s_t \in \{n, d\}$, are the normal and disaster states, denoted by n and d, respectively. Output depends on what state the economy is in: $A_t = A(s_t)$. The stochastic process for the logarithm of output is:

$$\ln A(s_{t+1}) = \ln A(s_t) + g + u_{t+1} + \ln(1-b)\xi(s_{t+1}) + v_{t+1}\zeta(s_t),$$

where g is the trend growth rate and b denotes the scale of the disaster. If there is a disaster in period $t+1$ (i.e., $s_{t+1} = d$), then $\xi(s_{t+1}) = 1$, but otherwise (i.e., $s_{t+1} = n$), $\xi(s_{t+1}) = 0$. In the normal state, disasters occur with a probability of ϕ. In disaster states, disasters are not repeated. Therefore, the stationary probability of the economy being in a disaster state is $\psi = \frac{\phi}{1+\phi}$. The term u_{t+1} is an independent and identically distributed normal shock with a distribution of $N(0, \sigma_u^2)$. Although disasters are one-off events, uncertainty about output growth rates increases following disasters. The term v_{t+1} represents doubt about output growth rates following a disaster. If a disaster occurs in the current period ($s_t = d$), then $\zeta(s_t) = 1$, but otherwise ($s_t = n$), $\zeta(s_t) = 0$. We make the assumption below about doubt during disasters.

Assumption 1 *Following Abel (2002), subjective doubt during disasters is modeled by using the mean-preserving spread. That is, the distribution of v_{t+1} is assumed to be $N(-\frac{\sigma_v^2}{2}, \sigma_v^2)$.*

The output growth rate from state s to state s' is $\frac{A(s')}{A(s)}$. The conditional expectation of the growth rate, $\bar{A}_{ss'} \equiv E_s\left[\frac{A(s')}{A(s)}\right]$, is $\bar{A}_{nn} \equiv \exp\{g + \frac{\sigma_u^2}{2}\}$ when there are no disasters, and $\bar{A}_{nd} \equiv (1-b)\bar{A}_{nn}$ when there is a disaster. Because doubt is modeled by using the mean-preserving spread, the conditional expected growth rate prevailing after a disaster is $\bar{A}_{dn} = \bar{A}_{nn}$.

2.2 Equilibrium equity premiums with doubt during disasters

$E^*[\cdot]$ denotes the subjective expectations operator. As Abel (2002) explains, asset prices are determined by the Euler equation under subjective probabilities. Suppose that m_{t+1} denotes the stochastic discount factor (SDF). Then, the return on asset i, denoted by R_{t+1}^i, must satisfy the following pricing equation:

$$1 = E_t^*[m_{t+1}R_{t+1}^i]. \tag{1}$$

We assume that disasters follow a Markov process and that the representative agent has a power utility function or a recursive utility function. In this case, asset prices are a function of the states. Hereafter, the subjective expectations operator conditional on the current state s is denoted by $E^*_s[\cdot]$.

The return on a safe asset is determined by the following equation:

$$R^f_s = \frac{1}{E^*_s[m_{ss'}]}, \tag{2}$$

where $m_{ss'}$ denotes the SDF as one moves from state s to s'. Although the return on a safe asset depends on the state of the economy, it is known in period t. The unconditional expectation of the return on a safe asset is $R^f = (1-\psi)R^f_n + \psi R^f_d$.

The price of a Lucas tree in state s is P^e_s. By using the price–dividend ratio in each state s, defined as $\omega_s \equiv \frac{P_s}{A_s}$, we can represent the ex post return on equity as one moves from state s to s' as follows:

$$R^e_{ss'} = \frac{A(s')}{A(s)} \frac{\omega_{s'} + 1}{\omega_s}. \tag{3}$$

From equation (1) and the above definition, we can derive the following equation:

$$\omega_s = E^*_s\Big[m_{ss'} \frac{A(s')}{A(s)}\Big(\omega_{s'} + 1\Big)\Big]. \tag{4}$$

We can use this equation to compute the price–dividend ratio in each state.

As explained by Abel (2002), because the sample mean equity return is computed from the objective distribution, this sample mean can be written as follows:

$$\begin{aligned} R^e_n &= (1-\phi)\bar{R}^e_{nn} + \phi\bar{R}^e_{nd} && (5)\\ &= \bar{A}_{nn}\Big[(1-\phi)\frac{\omega_n + 1}{\omega_n} + \phi(1-b)\frac{\omega_d + 1}{\omega_n}\Big] && (6)\\ R^e_d &= \bar{R}^e_{dn} && (7)\\ &= \bar{A}_{nn}\frac{w_n + 1}{w_d}, && (8) \end{aligned}$$

where $\bar{R}^e_{nn} \equiv E_n[R^e_{nn}]$, $\bar{R}^e_{nd} \equiv E_n[R^e_{nd}]$, and $\bar{R}^e_{dn} \equiv E_d[R^e_{dn}]$. Note that doubt does not affect the sample mean, because doubt is represented by the mean-preserving spread. The unconditional expected equity return is $R^e = (1-\psi)R^e_n + \psi R^e_d$.

Thus, the unconditional expected equity premium is:

$$\pi = R^e - R^f.$$

Simple manipulation of this expression yields the following unconditional expected equity premium:

$$\pi = -(1-\psi)\frac{\mathrm{cov}_n[m_{ns'}, R^e_{ns'}]}{E_n[m_{ns'}]}. \tag{9}$$

2.3 The power utility function

Based on a power utility function, the SDF is $m_{t+1} = e^{-\rho}\Big[\frac{A(s_{t+1})}{A(s_t)}\Big]^{-\gamma}$, where $-\rho$ denotes the subjective discount rate and γ denotes the coefficient of relative risk aversion (CRRA), which is equivalent to the reciprocal of the IES. Given equation (4), the price–dividend ratios in the normal and disaster states, respectively, solve the following equations:

$$\begin{aligned}\omega_n &= \beta[(1-\phi)(\omega_n+1)+\phi\delta(\omega_d+1)] \\ \omega_d &= \beta\alpha(\omega_n+1),\end{aligned}$$

where $\beta \equiv \exp\{-\rho+(1-\gamma)g+(1-\gamma)^2\frac{\sigma_u^2}{2}\}$ $\alpha \equiv \exp\{-\gamma(1-\gamma)\frac{\sigma_v^2}{2}\}$, and $\delta \equiv (1-b)^{1-\gamma}$. The price–dividend ratios in both states can be written as follows:

$$\begin{aligned}\omega_n &= \frac{\beta(1-\phi+\phi\delta)+\beta^2\phi\delta\alpha}{1-\beta(1-\phi)-\beta^2\phi\delta\alpha} \\ \omega_d &= \frac{(1+\phi\delta\beta)\beta\alpha}{1-\beta(1-\phi)-\beta^2\phi\delta\alpha}.\end{aligned}$$

The associated unconditional equity premiums are:

$$\begin{aligned}\pi &= -(1-\psi)\frac{\left(\bar{R}^e_{nd}-\bar{R}^e_{nn}\right)\left(\bar{m}_{nd}-\bar{m}_{nn}\right)}{E_n[m_{ns}]} \\ &= -\eta\frac{-[b+\beta(1-\phi)(1-b)+\phi\delta\beta]+(1-b)\beta\alpha}{\beta(1-\phi+\phi\delta)+\beta^2\phi\delta\alpha},\end{aligned}$$

where $\bar{m}_{nd} \equiv E_n[m_{nd}]$, $\bar{m}_{nn} \equiv E_n[m_{nn}]$, and $\eta \equiv \phi\frac{1-\phi}{1+\phi}\frac{(1-b)^{-\gamma}-1}{(1-\phi)+\phi(1-b)^{-\gamma}}\exp\left\{g+\frac{\sigma_u^2}{2}\right\}$.

Now we can derive the following proposition.

Proposition 1 *When $\gamma > 1$, an increase in the level of doubt during disasters lowers equity premiums.*

Proof. Because $\frac{\partial\pi}{\partial\sigma_v^2} = \frac{\partial\pi}{\partial\alpha}\frac{\partial\alpha}{\partial\sigma_v^2}$, we must check the signs of $\frac{\partial\pi}{\partial\alpha}$ and $\frac{\partial\alpha}{\partial\sigma_v^2}$. For risk-averse households ($\gamma > 0$), $\frac{\partial\pi}{\partial\alpha}$ is negative. When $\gamma > 1$, α is an increasing function of σ_v^2. π is a decreasing function of σ_v^2 if and only if $\gamma > 1$. Thus, when $\gamma > 1$, an increase in the level of doubt during a disaster lowers equity premiums. When $\gamma < 1$ π is an increasing function of σ_v^2. (Q.E.D.)

Proposition 1 is intuitive. Doubt during a disaster raises the price–dividend ratio in state d because of the precautionary savings motive. This increase raises the price–dividend ratio in state n. If a disaster is sufficiently unlikely, doubt increases the price–dividend ratio more in state d than in state n. To be precise, if $1 > \beta(1-\phi+\phi\delta)$, then $\frac{\partial\omega_n}{\partial\alpha} < \frac{\partial\omega_d}{\partial\alpha}$. The increase in the price–dividend ratio in the disaster state may mitigate the fall in equities during a disaster. Therefore, equity premiums decline because the degree to which equity returns and consumption growth rates are positively correlated lessens.

2.4 The recursive utility function

In this subsection, we consider the recursive utility function. Letting θ denote the reciprocal of the IES means that the SDF can be written as $m_{t+1} = e^{-\rho\frac{1-\gamma}{1-\theta}}\left[\frac{A(s_{t+1})}{A(s_t)}\right]^{-\theta\frac{1-\gamma}{1-\theta}} R^{e\,\frac{\theta-\gamma}{1-\theta}}_{t+1}$. In this case, the price–dividend ratios are:

$$\omega_t = e^{-\rho}E_t\Big\{\Big[\frac{A(s_{t+1})}{A(s_t)}\Big]^{1-\gamma}(\omega_{t+1}+1)^{\frac{1-\gamma}{1-\theta}}\Big\}^{\frac{1-\theta}{1-\gamma}}.$$

The price–dividend ratios in the normal and disaster states satisfy the following system of equations:

$$\omega_n = \tilde{\beta}\Big[(1-\phi)(\omega_n+1)^{\frac{1-\gamma}{1-\theta}} + \phi\delta(\omega_d+1)^{\frac{1-\gamma}{1-\theta}}\Big]^{\frac{1-\theta}{1-\gamma}} \quad (10)$$

$$\omega_d = \tilde{\beta}\tilde{\alpha}(\omega_n+1), \quad (11)$$

where $\tilde{\beta} \equiv \exp\{-\rho + (1-\theta)g + (1-\gamma)(1-\theta)\frac{\sigma_u^2}{2}\}$ and $\tilde{\alpha} \equiv \exp\big\{-\gamma(1-\theta)\frac{\sigma_v^2}{2}\big\}$. When a recursive utility function is specified, the effect on $\tilde{\alpha}$ of doubt during disasters depends on the value of the IES. We can derive the following analytical properties of the price–dividend ratios.

Proposition 2 *The price–dividend ratios, ω_n and ω_d, are nonincreasing functions of doubt during disasters, σ_v^2, if and only if $\theta < 1$.*

Proof. See Appendix.

Proposition 2 demonstrates that the effect of doubt during disasters on the equity price–dividend ratios depends not on the CRRA but on the IES. If $IES > 1$, doubt during disasters lowers both price–dividend ratios. If $\frac{\partial \omega_d}{\partial \sigma_v^2} < \frac{\partial \omega_n}{\partial \sigma_v^2} < 0$, the capital losses induced by the occurrence of disasters may yield high equity premiums. However, we cannot solve for equity premiums analytically. Therefore, we conduct numerical exercises to explore the effect of doubt during disasters on asset prices.

3 Numerical Exercises

3.1 Calibration parameters

Using Barro-Ursúa Macroeconomic Data[2], we begin by describing the empirical characteristics of disasters. Barro and Ursúa (2009) define disasters as events that induce declines in cumulative consumption of at least 10%. To characterize the greatly increased volatility of consumption growth during disasters, we limit our attention to cases in which per capita consumption declines by more than 10%. The horizontal axis of Figure 1 represents the consumption growth rate prevailing in the first three-year period following a disaster. The vertical axis of Figure 1 represents the consumption growth rate prevailing in the subsequent three-year period. Table 1 reports the summary statistics. The consumption growth rates during the first three years vary from −0.10 to −0.72. The average growth rate is −0.22 and the standard deviation is 0.13. The consumption growth rates in the subsequent three years range from −0.43 to 0.34. The average is 0.04 and the standard deviation is 0.17. For consumption growth rates in the subsequent three years, the Jarque–Bera statistic is 6.08, which implies that the null hypothesis of normality cannot be rejected at the 1% level.

[Figure 1]

[Table 1]

Based on these facts, we set b to 0.25, so that a disaster changes consumption by about −0.22 (i.e., causes it to fall). We also set σ_v to 0.17—the empirically observed standard deviation—and 0.27, which means that doubt raises volatility to 0.1 above the empirical standard deviation. When a severe disaster induces no doubt, $b = 0.325$ and $\sigma_v = 0.0$. This means that the power utility model generates the historical average level of equity premiums, 0.04. In addition, following Barro

[2] Barro and Ursúa (2008) explain the dataset in detail.

(2006), we assume that $\rho = 0.03$, $g = 0.025$, $\sigma_u = 0.03$, and $\phi = 0.017$. For the CRRA, we use $\gamma = 5$, which is widely used in the asset pricing literature.

3.2 Numerical results

Columns (1), (2), (3), and (4) of Table 2 report results based on an IES of 0.2, i.e., results based on the power utility function. Columns (5), (6), (7), and (8) of Table 2 report results based on an IES of 2.0, which is a value commonly used by researchers, including Nakamura et al. (2010). Columns (1) and (5) report results for the case in which there are no disasters. Columns (2) and (6) report results for the case in which there is a severe disaster ($b = 0.325$) that induces no doubt ($\sigma_v = 0.0$). Columns (3) and (7) relate to a mild disaster ($b = 0.25$) that induces a level of doubt consistent with the empirically observed $\sigma_v = 0.17$. Columns (4) and (8) relate to a mild disaster ($b = 0.25$) that induces severe doubt ($\sigma_v = 0.27$).

[Table 2]

If there are no disasters, equity premiums average 0.005 regardless of the value of the IES. Based on the power utility function, severe disasters generate equity premiums as high as 0.041. However, doubt during mild disasters lowers equity premiums to either 0.008 or −0.017. This result suggests that the disaster model incorporating a power utility function does not satisfactorily resolve the equity premium puzzle.

Assuming recursive utility changes the results dramatically. With an IES of 2, severe disasters generate equity premiums of 0.033. Mild disasters and the empirically observed volatility of consumption growth rates following disasters combine to lower equity premiums to 0.024. Subjective expectations that convey severe doubt generate equity premiums of 0.040. Column (8) shows that a model incorporating mild disasters that induce severe doubt is reassuringly consistent with risk-free rates of about 1%. Therefore, if the IES is high, doubt during disasters generates high equity premiums and low risk-free rates even if disasters are mild.

4 Discussion and Conclusions

In this note, we explored the effect of doubt on equity premiums during disasters. We analytically demonstrated that the disaster model incorporating the power utility function is not robust to potential rises in the volatility of consumption growth during disasters. However, the disaster model incorporating the recursive utility function and a high intertemporal elasticity of substitution performs well. Therefore, our contribution is to demonstrate that the disaster model incorporating recursive utility represents a potential resolution of the equity premium puzzle even if households have subjective expectations. Of course, it is difficult to measure doubt accurately. However, our result is important because it demonstrates that ignoring doubt during disasters biases computed equity premiums downward.

Appendix: Proof of Proposition 2

From equations (10) and (11), we define the following implicit function: $f(\omega_n, \tilde{\alpha}) \equiv \omega_n^{\frac{1-\gamma}{1-\theta}} - \bar{\beta}\left[(1-\phi)(\omega_n+1)^{\frac{1-\gamma}{1-\theta}} + \phi\delta\{\tilde{\alpha}\tilde{\beta}(\omega_n+1)+1\}^{\frac{1-\gamma}{1-\theta}}\right]$, where $\bar{\beta} = \exp\left\{-\rho\frac{1-\gamma}{1-\theta} + (1-\gamma)g + \frac{(1-\gamma)^2\sigma_u^2}{2}\right\}$. From the above equation, we can obtain the following derivative:

$$\frac{\partial w_n}{\partial \tilde{\alpha}} = -\frac{\frac{\partial f(\omega_n,\tilde{\alpha})}{\partial \tilde{\alpha}}}{\frac{\partial f(\omega_n,\tilde{\alpha})}{\partial \omega_n}}. \tag{12}$$

The denominator of (12) can be written as follows:

$$-\frac{\partial f(\omega_n,\tilde{\alpha})}{\partial\tilde{\alpha}} = \frac{1-\gamma}{1-\theta}\bar{\beta}\phi\delta(\tilde{\beta}\tilde{\alpha}\omega_n+\tilde{\beta}\tilde{\alpha}+1)^{\frac{1-\gamma}{1-\theta}-1}\tilde{\beta}(\omega_n+1).$$

Therefore, the sign of $-\frac{\partial f(\omega_n,\tilde{\alpha})}{\partial\tilde{\alpha}}$ depends on the sign of $\frac{1-\gamma}{1-\theta}$. $\frac{1-\gamma}{1-\theta} > (<)0$ implies that $-\frac{\partial f(\omega_n,\tilde{\alpha})}{\partial\tilde{\alpha}} > (<)0$. Determining the sign of the numerator, $\frac{\partial f(\omega_n,\tilde{\alpha})}{\partial\omega_n}$, is more complicated. Let $\omega_n^* > 0$ denote the equilibrium price–dividend ratio, where $f(\omega_n^*,\tilde{\alpha}) = 0$ holds. If $\frac{1-\gamma}{1-\theta} > (<)0$, we can easily show that $f(0,\tilde{\alpha}) < (>)0$. That is, $\frac{\partial f(\omega,\tilde{\alpha})}{\partial\omega_n} \leq (\geq)0$ around the equilibrium price–dividend ratio. Therefore, $\frac{\partial w_n}{\partial\tilde{\alpha}} \geq 0$. $\frac{\partial\omega_n}{\partial\alpha} \geq 0$ implies that the sign of $\frac{\partial\omega_n}{\partial\sigma_v^2} = \frac{\partial w_n}{\partial\tilde{\alpha}}\frac{\partial\tilde{\alpha}}{\partial\sigma_v^2}$ depends on the sign of $\frac{\partial\tilde{\alpha}}{\partial\sigma_v^2}$. $\theta < (>)1$ implies $\frac{\partial\tilde{\alpha}}{\partial\sigma_v^2} < (>)0$ and $\frac{\partial\omega_n}{\partial\sigma_v^2} \leq (\geq)0$. Note that $\omega_d = \tilde{\beta}\tilde{\alpha}(\omega_n+1)$, $\frac{\partial\omega_d}{\partial\sigma_v^2} = \tilde{\beta}\tilde{\alpha}\frac{\partial\omega_n}{\partial\sigma_v^2} + \tilde{\beta}(\omega_n+1)\frac{\partial\tilde{\alpha}}{\partial\sigma_v^2}$. $\theta < (>)1$ implies $\frac{\partial\omega_d}{\partial\sigma_v^2} \leq (\geq)0$.

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Table 1: Summary Statistics

	Sample Size	Mean	Max	Min	Std. Dev.	Skewness	Kurtosis	JB Stat.
First 3 years	81	-0.22	-0.1	-0.72	0.13	-1.85	6.33	83.44
Subsequent 3 years	81	0.04	0.34	-0.43	0.17	-0.66	3.24	6.08*

JB Stat. denotes Jarque-Bera Statistics. * implies that null hypothesis of normality cannot be rejected at 1% level.

Table 2: Calibration Parameters and Asset Prices; $\gamma = 5$, $\rho = 0.03$, $g = 0.025$, and $\sigma_u = 0.03$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
θ^{-1}	0.200	0.200	0.200	0.200	2.000	2.000	2.000	2.000
b	0.000	0.325	0.250	0.250	0.000	0.325	0.250	0.250
σ_v	0.000	0.000	0.170	0.270	0.000	0.000	0.170	0.270
w_n	7.654	15.118	13.064	23.097	53.849	38.376	40.151	34.635
w_d	7.654	14.255	16.607	44.182	53.849	38.658	38.967	31.938
R^e	1.160	1.088	1.099	1.069	1.045	1.047	1.047	1.052
R^f	1.155	1.047	1.091	1.086	1.040	1.013	1.023	1.011
π	0.005	0.041	0.008	-0.017	0.005	0.033	0.024	0.040

We denote γ as the coefficient of RRA, θ^{-1} as the coefficients of IES, ρ as the rate of time preference, g as the trend growth rate, b as the size of disasters, σ_u as the standard deviation of normal shocks, σ_v as the standard deviation of doubt during disasters, w_n as the price-dividend ratios in the state n, w_d as the price-dividend ratios in the state d, R^e as the unconditional expected equity returns, R^f as the unconditional risk-free rates, and π as the equity risk premiums.

Figure 1: Consumption growth rates during disasters