THE EFFECT OF CLIMATE CHANGE ON GREEN STOCKS

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Abstract

This is a theoretical paper that analyses the effect of climate change on the price of green stocks. I explore how climate damage on global consumption impacts the price. I review the literature on climate damage then connect them to green stocks through an asset pricing model, to capture its effect on the risk premium. The conclusion is that a rise in expected climate damage on future consumption increases the price of green stocks.

Introduction

The aim of this paper is to analyse the effect of climate change on the price of green stocks. I borrow the Fundamental Asset Pricing Equation from Cochrane (2009) to capture the effect of climate damage on future consumption in the price space of green stocks. I base my analysis on the empirical analysis in the literature on economic impact of climate change and its volatility.

This paper has its significance in two ways: it attempts to bridge the gap in the literature and explores the question significant to the long-term green stock investors. Most of the literature on green stocks is focused on their correlation with energy prices, stock market indices, or governmental policies; they tend not to build a connection to climate change. For instance, Sadorsky (2012) suggests that sales growth of a renewable energy company has a negative effect on its risk whilst oil price increases have a positive effect. This indicates that oil price returns are the main factor which determines the risk in renewable energy company stocks. Another example is Inchauspe *et al* (2015) where the key result shows that the MSCI World Index and technology stocks are the main factors of the green stocks' risk.

Section 1 I introduce the asset pricing theory from Cochrane (2009) and how its components can link to climate damage on expected future consumption. Then in Section 2 I outline the process through which climate change decreases global consumption; I focus on the climate damage function and its attributes, as well as the feedback through which the damage becomes more severe and volatile (Stern, 2008; Dietz *et al*, 2016; Anderson *et al*, 2007).

1. Modelling of Green Stock Price

Turning to modelling the price of green stocks, I assume a two-period world with today (t) and the future (t+1). To capture the effect of climate change there is an unspecified but sufficient gap between the two periods. I also assume that the dividends of green stocks (d_{t+1})—which are paid in the future for if the investor buys green stocks

today—are negatively correlated with climate change. In other words, the worse the effect of climate change on the future consumption is the higher the d_{t+1}. This comes from the view that if climate change decreases future consumption the households and policymakers would increase the demand for the renewables to offset the effect of climate change, increasing the profit of the renewable energy companies and hence dividends. The underlying assumption is that the consumers are optimistic; they would substitute fossil fuels with the renewables in belief that it would slow down or stop climate change.

Using a form of the FAPE from Cochrane (2009, pp. 16-23), I can express the price of green stocks as following:

$$P_t = E_t[m_{t,t+1}]E_t\,[d_{t+1}] + Cov_t[m_{t,t+1}, d_{t+1}]$$

Here, $m_{t,t+1}$ is the stochastic discount factor (SDF), also known as intertemporal marginal rate of substitution, and expressed as $\beta\frac{u'(c_{t+1})}{u'(c_t)}$ where β is the investor's subjective discount rate, $u'(c_t)$ the marginal utility of the investor as a function of consumption today c_t and $u'(c_{t+1})$ that of future. $Cov_t[m_{t,t+1}, d_{t+1}]$ represents the risk premium; the positive covariance increases the price and vice versa (Cochrane, 2009, p. 23).

Assuming the investor has the diminishing marginal utility, the utility function in this model is concave; $u'(c_t)$ and c_t has an inverse correlation. Hence, the risk premium can be unfolded as following:

$$Cov_t[m_{t,t+1}, d_{t+1}] = Cov_t\left[\beta\frac{u'(c_{t+1})}{u'(c_t)}, d_{t+1}\right]$$

$$\propto -Cov_t\left[\frac{(c_{t+1})}{(c_t)}, d_{t+1}\right]$$

Here, $\frac{(c_{t+1})}{(c_t)}$ is the future consumption relative to today's consumption. Following the assumption that the dividends are negatively correlated with the effect of climate change on future consumption, the risk premium is positive. In other words, green stocks are assumed as an insurance that pays out when the future consumption decreases due

to climate change; hence the worse the expected risk of climate change—the probability and scale of climate change—the higher the price of green stocks. This concept is useful in understanding the literature on climate risk, often referred to as "climate sensitivity" (Weitzman, 2009).

2. Climate Damage on Future Consumption

A good starting point with analysing the economic damage of climate change is Stern (2008). The paper uses consumption as a factor of GDP to estimate the climate damage on the global economy. The paper suggests that with no substantial reduction in the GHG emissions and thus the global temperature no lower than its current trajectory, the expected damage is 10% decrease in consumption (2008, p. 18). This damage on consumption is measured in terms of the Balanced Growth Equivalent (BGE) and calculated from the expected social utility integral $N_i \frac{C_i}{N_i} e^{-\delta t}$ where C_i and N_i are consumption and population in region i. In the applied model entitled Policy Analysis of the Greenhouse Effect (PAGE model), the expected social utility model is used in conjunction with climate damage function AT^{γ} (A is a constant, T temperature, and γ is a damage function exponent) to estimate the loss of consumption (measured in BGE) for each level of climate change (Stern, 2008, p. 18). Anderson *et al* (2007) uses the same method and calculate the total economic loss due to climate change for different scenarios. All losses are relative to that in the case with no climate change.

Table 1: Economic Damage of Climate Change in % BGE

Damage function exponent (γ)	Consumption elasticity of social marginal utility (η)		
	1	1.5	2
2	10.4 (2.2–22.8)	6.0 (1.7–14.1)	3.3 (0.9–7.8)
2.5	16.5 (3.2–37.8)	10.0 (2.3–24.5)	5.2 (1.1–13.2)
3	33.3 (4.5–73.0)	29.3 (3.0–57.2)	29.1 (1.7–35.1)

Source: Anderson *et el* (2007, p. 246).

Table 1 provides the loss in consumption due to climate damage measured in % BGE (a measurement unit used in the literature) for each damage function exponent and consumption elasticity of social marginal utility, with a 5-95 percent confidence interval in brackets. The damage function exponent γ contains the structural risks whilst consumption elasticity of social marginal utility captures aversion to inequality and risk. The increase in structural risks naturally increases the climate damage on consumption whilst increase in aversion to inequality and risk decreases the climate damage (Stern, 2008, p. 19). The damage function exponent carries both the effect of temperature on damages, and the shape of the distribution of temperatures. The former is the effect of a unit increase in γ on the damage function and hence on consumption; the higher the γ the bigger the damage on consumption measured by change in BGE in the table. The latter requires to investigate the probability distribution function (PDF) of temperature change due to climate change, in other words how sensitive the temperature is to the GHG emission. This is often referred to as climate sensitivity. More weight in the upper tail of its PDF—towards the higher increase in temperature—indicates the higher probability of substantial damages on consumption and hence GDP (Stern, 2008, p. 19).

The narrow definition is denoted as S_1 in the formula $\Delta T \approx \frac{S1}{\ln 2} \times \Delta \ln \mathrm{CO}_2$ where $\Delta \ln \mathrm{CO}_2$ is the sustained relative change in atmospheric carbon dioxide and ΔT temperature response towards equilibrium (p. 7). In other words, the effect of the change in CO_2 on the temperature is weighted by climate sensitivity. Hence the higher the climate sensitivity the higher the damage on consumption by climate change represented by the change in CO_2.

The general definition, S_2, has a positive feedback element, in other words simultaneity, of greenhouse warming due to heat-induced releases of sequestered CO_2. For instance, there is a possibility of the offshore deposits of CH_4 released into the atmosphere if water temperatures increase. This can act as an amplifier in the long-run positive feedback process of global warming; the release of CH_4 adds to GHG emission, further increases the temperature and triggering additional release of methane previously hidden under the ocean. The source of sequestered CO_2 lies not only under water but in soil, forests and others (Weitzman, 2009, p. 8). Given this additional self-amplifying

mechanism arising from hidden CO_2, S_2 is defined as "generalized climate-sensitivity-like multiplier-parameter" and takes the form $S_2 = \frac{S_0}{1-g}$ where g < 1 is a feedback coefficient where S_0 is the climate sensitivity in the absence of any feedback gain. (Weitzman, 2009, p. 12)

The key finding of Weitzman (2009) is that the PDF of S_2 has a longer and fatter tail than the PDF of S_1 due to its positive feedback attribute. Weitzman (2009) brings in the calculation from Torn and Harte (2006) to support this claim (p. 8). Given that the universal consensus is S_0 = 1.2°C, adding g_1 (the feedback coefficient associated with S_1) can express $S_1 = \frac{1.2}{1-g1}$ (Torn and Harte, 2006, p. 2). Further estimation is as following: the positive feedback through the releases of sequestered CO_2 adds approximately 0.067 to g_1. This makes $S_2 = \frac{1.2}{1-g2}$ where $g_2 = g_1 + 0.067$. Naturally S_2 is bigger than S_1—significantly enough to make the substantial difference in its PDF. If the PDF of g stretches to near one, the PDF of S_2 has a long and fat-tailed shape (Weitzman, 2009, p. 8). The logic is that as g_2 is bigger than g_1, S_2 has higher probability than S_1 to be of a very high value. In other words, S_2 carries more uncertainty and hence higher climate sensitivity (Weitzman, 2009, p. 12). This links back to the damage function exponent; the fatter the tail of the PDF of climate sensitivity is, the larger the climate damage on future consumption (Stern, 2008, p. 19).

The fatter and longer the tail of the PDF of climate sensitive means two things: higher expected climate damage on consumption and higher volatility of that. This can be perceived as higher climate risk. Connecting back the risk premium with the assumption of green stocks as an insurance, the higher the climate risk the lower the future consumption c_{t+1} and hence the higher the price of green stocks. The increase in the price can also be explained through the stochastic discount factor (SDF) itself ($m_{t,t+1} = \beta \frac{u'(c_{t+1})}{u'(c_t)}$ in the equation below).

$$P_t = E_t[m_{t,t+1}]E_t\,[d_{t+1}] + Cov_t[m_{t,t+1}, d_{t+1}]$$

As the investor in this model has concave utility function, the lower the c_{t+1} the higher $u'(c_{t+1})$ and hence, for the given c_t, the higher the price P_t. Whilst the risk premium

channel reflects the insurance attribute of green stocks, the SDF channel indicates the risk averseness of the investor which is applicable to every other asset.

Conclusion

This paper offers a theoretical analysis of the effect of climate change on green stocks. The outcome is that the longer and fatter PDF of climate sensitivity (i.e. higher climate risk) leads to higher risk premium and hence higher price of green stocks.

This exploration suggests that the financial institutions need to understand the feedback behind climate damage on consumption in order to assess the risk in their assets. Taking into account this self-reinforcing mechanism will adjust their expectation of the climate risk (higher risk) and may accelerate their response.

With the trend of increasing global temperature not reversing, the governments and institutions may want to increase their position in green stocks as an insurance—the governments have duty to protect the people and the planet whilst the financial institutions must seek for the stability and growth of their portfolio. This paper suggests that the sustainability and the financial incentives are aligned in face of the threat of climate change, giving room for the political and financial institutions to work together to implement the solutions through not only public policies but private investments.

This paper carries limitations and room for further study. The main shortcoming is that I do not contest the assumption of positive risk premium—that if global consumption falls due to climate change the price of green stocks will increase as demand for renewables rises. Some may argue that the consumers would no longer care about the future if the climate damage is too devastating—the case of an exogenous event in Stern (2008). Another limitation is that this study is purely theoretical; there is much room for further study with empirical data to contest the key assumption as well as explore the causal relationship between climate change and green stocks price with more exogenous variables. The fundamentals explored in this paper around the stochastic discount factor may serve as a guide for more advanced research around this topic.

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