Economic Impact of Natural Disasters Under the New Normal of Climate Change: The Role of Green Technologies

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Abstract

We examine the effect that higher natural disaster frequency has on economic outcomes. Even if there is clear evidence that natural disaster incidents are not only going to be more frequent but will also start affecting a wider pool of countries, research has not yet analyzed the economic impact of the interaction between climate change and more frequent extreme rare events. With this study, we try to unveil the mechanisms through which natural disasters and climate change are interconnected, as well as provide policy insights regarding the adoption of greener inputs, in the form of green capital. Our findings suggest that raising temperatures are expected to negatively affect consumption as well as increase debt. We also show that under "green" technology adaptation, countries are projected to achieve higher levels of consumption and welfare.

Keywords: Green Technologies, Natural Disasters, Climate Change, Sustainable Developement

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1. Introduction

Climate change has been a central topic in environmental economics during the most recent years. It is dramatically changing the way economic agents behave, as the rise on global temperatures is not only changing the parameters of the maximization problems agents have to solve, but is also increasing the uncertainty they have to face (Heal and Kriström, 2002). The most commonly discussed tool, in order to alleviate climate change impact, is the reduction of emissions by either taxing emission-intensive technologies or subsidizing green means of production.

One obvious downfall of rising temperatures, would be the impact on the agricultural sector (Hossain et al., 2019; Gul et al., 2019). In addition, the negative impact of climate change on economic behaviour, is not restricted on sector-specific disturbances. Even though the projected differences in temperatures have so far been affecting a limited fraction of countries, they are expected to affect every economy on the planet during the course of the 21st century (Tol, 2013).

Climate change impacts have been widely analyzed in Integrated Assessment Models and more frequently using Dynamic Integrated Climate Economy (DICE) models. Diaz and Keller (2016) utilize a DICE model and find that current policies are not efficient, because they tend to be myopical in terms of discounting costs for the far future. For example, severe losses that will occur due to climate change in 2300, play little to none role in determining current optimal decisions.

Furthermore, there is a growing body of literature that connects rising temperatures with natural disasters. That is, under worsening climate projections, natural disasters are expected to be not only more severe, but also more frequent. The higher frequency of devastating natural disaster occurrences, can be (at least partially) attributed to climate change (Van Aalst, 2006). Disaster-prone countries have experienced disaster occurrences with not only higher intensity but also higher frequency (Cantelmo et al., 2019). Most recent climate change reports (Hoegh-Guldberg et al., 2018), are projecting an increase in both the severity and the frequency of natural disaster incidents, due to rising temperatures. As a result, we can expect more countries to be prone to extreme weather related events in the near future.

Natural disaster incidents have several economic implications for the countries they affect. Firstly, in the short-term, a severe natural disaster occurrence will lead to a loss of capital. That would mostly consist of physical capital, but depending on the severity, it might also include human capital losses and might even lead to the deterioration of land quality. That being said, it is always possible that a developing economy facing one or multiple severe disasters, will be trapped in a low-income equilibrium (Noy, 2009; Loayza et al., 2012; Fomby et al., 2013; Panwar and Sen, 2019). The issue of not being able to mitigate those negative effects efficiently, seems to not affect more developed countries, with greater quality of institutions (Noy, 2009; Panwar and Sen, 2019). Overall research on the short-term effects of natural disasters on the economy tend to find a negative relationship between disasters and economic outcomes. However, a minority of studies find evidence of a positive effect on the short-run, but that would only occur in specific sectors of the economy, such as the agricultural sector (Loayza et al., 2012; Fomby et al., 2013; Panwar and Sen, 2019).

In the long-run, the effect of the occurrence of natural disasters on economic variables, is found to be ambiguous by some studies (Loayza et al., 2012; Noy and duPont IV, 2016; Fatouros and Sun, 2020). A negative effect would most certainly arise, in case that the short-term destruction of capital, leads the economy to a poverty trap (Panwar and Sen, 2019). A long-run negative impact can be also observed in countries with repeatedly severe incidents, if there is a permanent fall in investment due to uncertainty (Cavallo et al., 2013). Lastly, there has been evidence that, when taking into account alternative natural disaster cases, there might even be a positive economic effect (Fomby et al., 2013).

All in all, there is a stream of the literature investigating the economic impact of natural disasters, as well as a separate stream that is trying to assess the economic cost of climate change. Even if there is clear evidence that natural disasters are not only going to be more frequent and severe, but will also start affecting a wider pool of countries (Cantelmo et al., 2022), research has not yet analyzed the economic impact of the interaction between climate change and the occurrence of extreme rare events, in a macroeconomic framework. The challenges created by climate change should be studied in combination with the higher risk of natural disasters due to the rising temperatures (Van Aalst, 2006).

Lastly, the examination of the joint economic impact of Climate Change and natural disasters has been mainly restricted to catastrophe models. Catastrophe models typically use geographic information systems (GISs) to estimate the potential losses in the aftermath of natural disasters by simulating for a specific location, hypothetical physical characteristics. Then, the predicted damage of natural disaster incidence is estimated with probabilities, that can later be used to estimate the annual expected damage (Botzen et al., 2019). Catastrophe models not only focus on physical damage damage, but also on estimating casualties caused by natural disasters occurrences (Jonkman and Vrijling, 2008). The importance of reducing disaster risk is highlighted in this stream of literature as cost-benefit analysis suggests that, the benefit would outweigh the risk (Shreve and Kelman, 2014; Mechler, 2016).

Overall, the effort of estimating the joint effect of climate change and natural disasters on economic outcomes has been restricted to catastrophe models. However, it would be extremely beneficial to analyze this complex inter-dependencies, using macroeconomic models. This paper aims to fill that exact void in the literature. Our aim is to firstly assess the possible impact natural disasters[1] might have on economic outcomes. Secondly, we want to examine if this effect is changing in a non-linear manner, as the probabilities of an extreme weather related event are increasing (as climate change projections suggest). In other words, we want to investigate if the effect is varying with respect to the development level of an economy. Lastly, we aim to examine the economic outcome of

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[1] Our model implicitly focuses on extreme weather related events such as hurricanes, floods and draughts.

higher environmental friendly inputs in the future, as more recent studies suggest that the market portfolio should get fully de-carbonized by the end of the 21^{st} century (Karydas and Xepapadeas, 2019). The structure of the paper is as follows: In Section 2 we present our theoretical model, solution method, as well as our theoretical results, and Section 3 presents the concluding remarks of our study.

2. Model

2.1. Model and Solution Method

The representative agent of the world economy, seeks to maximize the following utility function:

$$\max_{c_t} E_o \int_0^{\infty} e^{-\rho t} U(c_t) dt \tag{1}$$

Subject to:

$$dk_t = (z_t + rk_t - c_t)dt \tag{2}$$

Where c_t is the consumption bundle, ρ is the discount factor, k_t is the capital used in production, $z_t \in \{z_1, z_2\}$ is a Markov Chain, with transition probabilities λ_1 and λ_2. More precisely, λ_1 is the probability that a natural disaster incident concludes, whereas λ_2 is the probability of a natural disaster incident occurrence. In addition, we assume that $U_c > 0$ and $U_{cc} < 0$, while z_2 denotes the investment premium due to the abscence of a natural disaster occurrence and z_1 represents the opposite (loss of additional capital accumulation due to a natural disaster occurrence). We also impose an exogenous borrowing limit $k_t \geq -\phi$, in order to allow for economies to accumulate debt. The Hamilton–Jacobi–Bellman equation (hereafter HJB equation) becomes:

$$\rho V_i(k) = \max_c \{u(c) + s_i(k) V_i^{'}(k)\} + \lambda_i (V_j(k) - V_i(k)) \tag{3}$$

And the drift equation[2]:

$$s_i(k) = z_i + rk - c(k), \qquad i = 1, 2 \tag{4}$$

The first order conditions (hereafter FOC):

$$u^{'}(c_i(k)) = V_i^{'}(k) \tag{5}$$

Since an analytical solution would not be feasible, we follow Achdou et al. (2017) by employing an upwind finite differences solution scheme. Our solution, using that exact the upwind finite differences scheme, will converge to the viscocity solution of our problem. We can approximate $V(k)$ on a finite grid, with step $\Delta k : k \in \{k_1, k_2, \ldots, k_m\}$, where $k_m = k_{m-1} + \Delta k = k_1 + (m-1)\Delta k$, for $2 \leq m \leq M$. In addition, the lower and upper bounds of our grid will be $k_1 = -\phi$ and $k_M = k^*$. For the rest of the analysis, let $V_m = V(k_m), \forall\, 2 \leq m \leq M$. The approximation of the derivative of our value function is going to be either the forward $(V_{iF}^{'})$ or the backward ($V_{iB}^{'}$) approximation:

$$V_{iF}^{'}(k_m) \approx \frac{V_{i,m+1} - V_{i,m}}{\Delta k}$$

$$V_{iB}^{'}(k_m) \approx \frac{V_{i,m} - V_{i,m-1}}{\Delta k}$$

The choice of approximation method is going to be determined by the sign of the drift as follows:

$$V_i^{'}(k_m) = \begin{cases} V_{iF}^{'}(k_m) \approx \frac{V_{i,m+1} - V_{i,m}}{\Delta k} & S_{iF}(k_m) > 0 \\ V_{iB}^{'}(k_m) \approx \frac{V_{i,m} - V_{i,m-1}}{\Delta k} & S_{iF}(k_m) < 0 \\ C_{im} = Z_i + rk_m & S_i(k_m) = 0 \end{cases} \tag{6}$$

In other words, using this upwind method[3], we are using the forward approximation

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[2] The drift equation represents savings if it is positive and, debt if it negative.

[3] The upwind scheme typically refers to a class of numerical discretization methods for solving hyper-

when an economy is accumulating capital, and the backward when the opposite happens. This enables us to estimate our HJB equation, for a given number of iterations (n), up until the point of convergence to the viscocity solution[4]. In the next section, we are discussing the choice of parameters used, as well as the results obtained using the upwind finite difference scheme, described above.

2.2. Results

In this section we provide the results produced using the method outlined in Subsection 2.1. In our benchmark calibration, following Nuño and Thomas (2016) the discount factor (ρ) is set to 0.03, the marginal product of capital (r) is set to 0.03, while the transition probabilities (λ_1) and (λ_2) are set to 0.05747 and 0.0005 respectively, in order to match an average fraction of time spent in a disastrous extreme occurrence to roughly 3 days, as we think this is a reasonable assumption for a global model. Later, we perform sensitivity analysis in order to see how our results would change, if the average fraction spent in a disaster state is 2.5, 1.9, 1.25 and 0.6 day. We normalize the additional capital accumulated due to the absence of natural disasters (z_2) to 1.5, and the capital loss (less value added) due the event realization (z_1) to 1. Our model's exogenous borrowing limit (ϕ) is set to 2, while the upper bound of asset accumulation (k^*) is set to 6 units. In addition we assume that our CRRA utility function is of the form:

$$U(C_t) = \frac{c_t^{1-\gamma} - 1}{1-\gamma}$$

The degree of relative risk aversion (γ) is assumed to take the value of 2. Lastly, the number of grid points (M) is set to 1000.

The results of our baseline calibration can be summarized in Figure 1. There is a significant difference in our policy function curves depending on the realization (or not)

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bolic partial differential equations. The derivatives are estimated using a set of points set to be more "upwind" of the query point, with respect to the direction of the drift.

[4] The viscosity solution concept is a generalization of the classical concept of the solution for a partial differential equation.

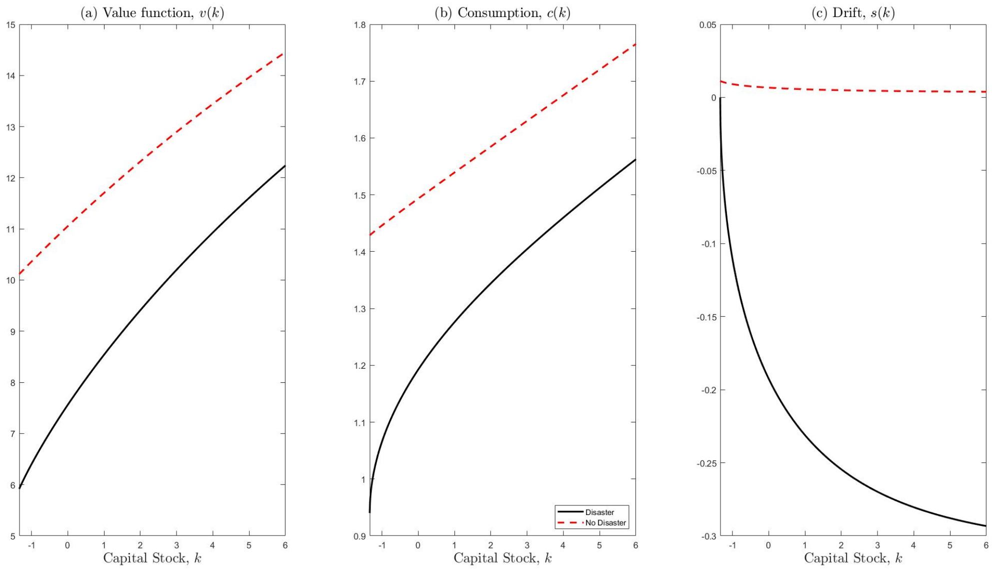


Figure 1: Baseline Calibration

of a natural disaster occurrence. This finding for our baseline calibration, indicates that as a result of climate change, not only disaster-prone countries are expected to experience a decline in their consumption, but also an increase in debt. That is because climate change is expected to increase the severity of natural disasters in the near future. In addition, this pessimistic prediction will most likely hold true for both current and future disaster-prone countries. That is because, current climate projections predict that as temperatures increase, more countries will have to face more severe weather related events, even more frequently (Cantelmo et al., 2019).

2.3. Scenario Analysis and the Role of Green Capital

We now proceed on performing sensitivity and scenario analysis on our model's results, which will serve a dual purpose. Firstly, we want to examine if our model's results rely on the parameter values specified in our baseline calibration. Secondly -and more importantly- we want to examine, how different countries in terms of their disaster risk, would be able to adapt a more "green" version of physical capital.

It is widely assumed that for carbon-intensive economies, green capital is more inefficient than brown capital, a hypothesis known as the "carbon lock-in" hypothesis (Unruh, 2000; Edenhofer et al., 2006; Kemp-Benedict, 2014). In our model, the only input is physical capital. A way to directly modify our model in order to account for "greener" means of production, is by introducing a more inefficient version of physical capital. That could be achieved in the context of our paper by reducing the rental rate of capital, or in our case the interest rate.

In addition, as we have argued widely in Section 1, there is a direct positive relationship between emissions and temperatures. Thus, it would be safe to assume that broader usage of abatement activities, would help at least containing the immense problem that is climate change. In the context of our model, this would directly translate to a reduction in the natural disaster's probability of occurrence. All in all, a lower probability of disaster occurrence (λ_2), as well as a lower rental rate (r), would suffice, in order for our model to account for a more "green" version of physical capital.

In order to further investigate the impact that green capital would have, we define the following scenarios with all the parameters taking the exact same values as in our baseline calibration, with the exception of the parameters specified in the parenthesis:

- $A_0\,(\lambda_2 = 0.005)$, $A_1\,(\lambda_2 = 0.004)$, $A_2\,(\lambda_2 = 0.003)$, $A_3\,(\lambda_2 = 0.020)$ and $A_4\,(\lambda_2 = 0.001)$
- $B_0\,(r = 0.03)$, $B_1\,(r = 0.024)$, $B_2\,(r = 0.018)$, $B_3\,(r = 0.012)$ and $B_4\,(r = 0.006)$
- $C_0\,(\lambda_2 = 0.005, r = 0.03)$, $C_1\,(\lambda_2 = 0.004, r = 0.024)$, $C_2\,(\lambda_2 = 0.003, r = 0.018)$, $C_3\,(\lambda_2 = 0.002, r = 0.012)$ and $C_4\,(\lambda_2 = 0.001, r = 0.006)$

Alternative values of λ_2 will yield different average fractions of time spent in a disastrous event. So for each alternative specifications in the scenarios A and C above, $\lambda_2 = \{0.001, 0.002, 0.003, 0.004, 0.005\}$ will yield an average fraction of time spent in a disastrous event that is equal to 0.6, 1.25, 1.9, 2.5 and 3 days respectively. In other words, we assume that broader usage of green capital is going to reduce the intensity and severity of natural disaster occurrences, as their average duration would decrease. Our results for each one of these 15 scenarios are presented in Figures A.2 - C.16 of the Appendix.

Our results regarding scenario A, essentially represent the sensitivity analysis with respect to the initiation probability of a natural disaster incident (λ_2), and are summarized in Figures A.2 - A.6. As the initiation probability decreases, consumption is increasing. However, this increment is sharper given that there has been no disaster realization. The results are in line with the fundamentals, as the savings/de-savings decisions are expected to be more "loose", due to a lower probability of a bankruptcy threatening event.

In addition, scenario B represents our sensitivity analysis with respect to the rental rate of capital (r), and is summarized in Figures B.7 - B.11. Similarly with scenario A, our results are in line with the stylized facts, as a decline in the rental rate of capital would increase consumption and decrease savings / increase debt (the substitution effect is stronger). Overall, both scenarios A and B (which are essentially our comparative statics with respect to λ_2 and r), seem to be in line with the observed empirical regularities.

As we have mentioned above, in our model green technologies can be replicated by a simultaneous decrease in both λ_2 and r. In other words, given that technological progress stands in the early 21^{st} century figures, "green" capital is less efficient than "brown", but it also helps control the immense problem that is climate change, which in turn decreases the chance of a rare weather related event. Figures C.12 - C.16 illustrate our results for scenario C, where both r and λ_2 decrease simultaneously (with a reduction step of 20%).

Our findings suggest that, under "green" technology adaptation, our model would predict that countries achieve higher levels of consumption and utility. This result however tends to be stronger for more developed countries, as we can see that the differences for lower levels of capital accumulation, are much smaller. However, we argue that for both cases we can most likely hope to observe a similar response, under the assumption that technological progress will make more environmentally friendly inputs more efficient.

Under this assumption, economies could achieve a more balanced increase in consumption. That is because, under the assumption that “green” technologies will be as efficient as the “brown” ones, economies could achieve a more fair in terms of welfare gains distribution of outcomes, as shown in scenario A.

3. Concluding Remarks

The economic impact of natural disasters, as well as the economic cost of climate change have been two widely debated topics in the literature of environmental economics. Even if there is clear evidence that, due to climate change, natural disasters are not only going to be more frequent but will also be directly affecting a substantially greater number of countries, the topics of disaster economic outcomes and climate change are usually studied independently, with the exception of Catastrophe models. With this paper, we aim to assess the economic outcomes of a natural disaster occurrence, under a new reality of rising temperatures and more frequent disaster occurrences.

In our model of the world economy, raising temperatures are expected to negatively affect consumption as well as increase debt. The most frequently proposed possible solution to climate change, is the de-carbonization of production, by using more “green” technologies. Under “green” technology adaptation, countries would be projected to achieve higher levels of consumption and welfare. This positive effect of more environmentally friendly means of production, tends to be stronger for more developed countries. However, under the assumption of greater technological progress of the “green” sector, our results show that even developing countries would be projected to follow the same path of higher and more sustainable levels of consumption and welfare.

Even though our model’s results, appear to be robust due to the sensitivity and scenario analysis, there are some potential pitfalls that we have to take into account. Firstly, our model is a model of the world economy, and as one it might fail to capture both the heterogeneity in terms of infrastructure and disaster risk, as well as strategic dependence between countries. Future research on the subject could potentially aim to expand this framework in order to take heterogeneity and strategic interaction between countries into account. Lastly, our model's results could benefit greatly by an expansion towards an endogenous probability of natural disaster occurrence, which could be linked explicitly to temperature levels.

References

[1] G. Heal, B. Kriström, Uncertainty and climate change, Environmental and Resource Economics 22 (2002) 3–39.

[2] M. S. Hossain, M. Arshad, L. Qian, M. Zhao, Y. Mehmood, H. Kächele, Economic impact of climate change on crop farming in bangladesh: An application of ricardian method, Ecological Economics 164 (2019) 106354.

[3] F. Gul, D. Jan, M. Ashfaq, Assessing the socio-economic impact of climate change on wheat production in khyber pakhtunkhwa, pakistan, Environmental Science and Pollution Research 26 (2019) 6576–6585.

[4] R. S. Tol, The economic impact of climate change in the 20th and 21st centuries, Climatic change 117 (2013) 795–808.

[5] D. Diaz, K. Keller, A potential disintegration of the west antarctic ice sheet: implications for economic analyses of climate policy, American Economic Review 106 (2016) 607–11.

[6] M. K. Van Aalst, The impacts of climate change on the risk of natural disasters, Disasters 30 (2006) 5–18.

[7] M. A. Cantelmo, M. G. Melina, M. C. Papageorgiou, Macroeconomic outcomes in disaster-prone countries, International Monetary Fund, 2019.

[8] O. Hoegh-Guldberg, D. Jacob, M. Bindi, S. Brown, I. Camilloni, A. Diedhiou, R. Djalante, K. Ebi, F. Engelbrecht, J. Guiot, et al., Impacts of 1.5 c global warming on natural and human systems, Global warming of 1.5 C. An IPCC Special Report (2018).

[9] I. Noy, The macroeconomic consequences of disasters, Journal of Development economics 88 (2009) 221–231.

[10] N. V. Loayza, E. Olaberria, J. Rigolini, L. Christiaensen, Natural disasters and growth: Going beyond the averages, World Development 40 (2012) 1317–1336.

[11] T. Fomby, Y. Ikeda, N. V. Loayza, The growth aftermath of natural disasters, Journal of applied econometrics 28 (2013) 412–434.

[12] V. Panwar, S. Sen, Economic impact of natural disasters: An empirical re-examination, Margin: The Journal of Applied Economic Research 13 (2019) 109–139.

[13] I. Noy, W. duPont IV, The long-term consequences of natural disasters—a summary of the literature (2016).

[14] N. Fatouros, Y. Sun, Natural disasters and economic growth: A semiparametric smooth coefficient model approach, Journal of Risk and Financial Management 13 (2020) 320.

[15] E. Cavallo, S. Galiani, I. Noy, J. Pantano, Catastrophic natural disasters and economic growth, Review of Economics and Statistics 95 (2013) 1549–1561.

[16] M. A. Cantelmo, N. Fatouros, M. G. Melina, M. C. Papageorgiou, Monetary policy in disaster-prone developing countries, International Monetary Fund, 2022.

[17] W. W. Botzen, O. Deschenes, M. Sanders, The economic impacts of natural disasters: A review of models and empirical studies, Review of Environmental Economics and Policy 13 (2019) 167–188.

[18] S. Jonkman, J. Vrijling, Loss of life due to floods, Journal of Flood Risk Management 1 (2008) 43–56.

[19] C. M. Shreve, I. Kelman, Does mitigation save? reviewing cost-benefit analyses of disaster risk reduction, International journal of disaster risk reduction 10 (2014) 213–235.

[20] R. Mechler, Reviewing estimates of the economic efficiency of disaster risk management: opportunities and limitations of using risk-based cost–benefit analysis, Natural Hazards 81 (2016) 2121–2147.

[21] C. Karydas, A. Xepapadeas, Pricing climate change risks: Capm with rare disasters and stochastic probabilities, CER-ETH Working Paper Series Working Paper 19 (2019) 311.

[22] Y. Achdou, J. Han, J.-M. Lasry, P.-L. Lions, B. Moll, Income and wealth distribution in macroeconomics: A continuous-time approach, Technical Report, National Bureau of Economic Research, 2017.

[23] G. Nuño, C. Thomas, Optimal monetary policy in a heterogeneous monetary union (2016).

[24] G. C. Unruh, Understanding carbon lock-in, Energy policy 28 (2000) 817–830.

[25] O. Edenhofer, K. Lessmann, C. Kemfert, M. Grubb, J. Kohler, Induced technological change: Exploring its implications for the economics of atmospheric stabilization: Synthesis report from the innovation modeling comparison project, The Energy Journal (2006).

[26] E. Kemp-Benedict, Shifting to a green economy: Lock-in, path dependence, and policy options (2014).

Appendix A. Sensitivity Analysis with respect to λ_2

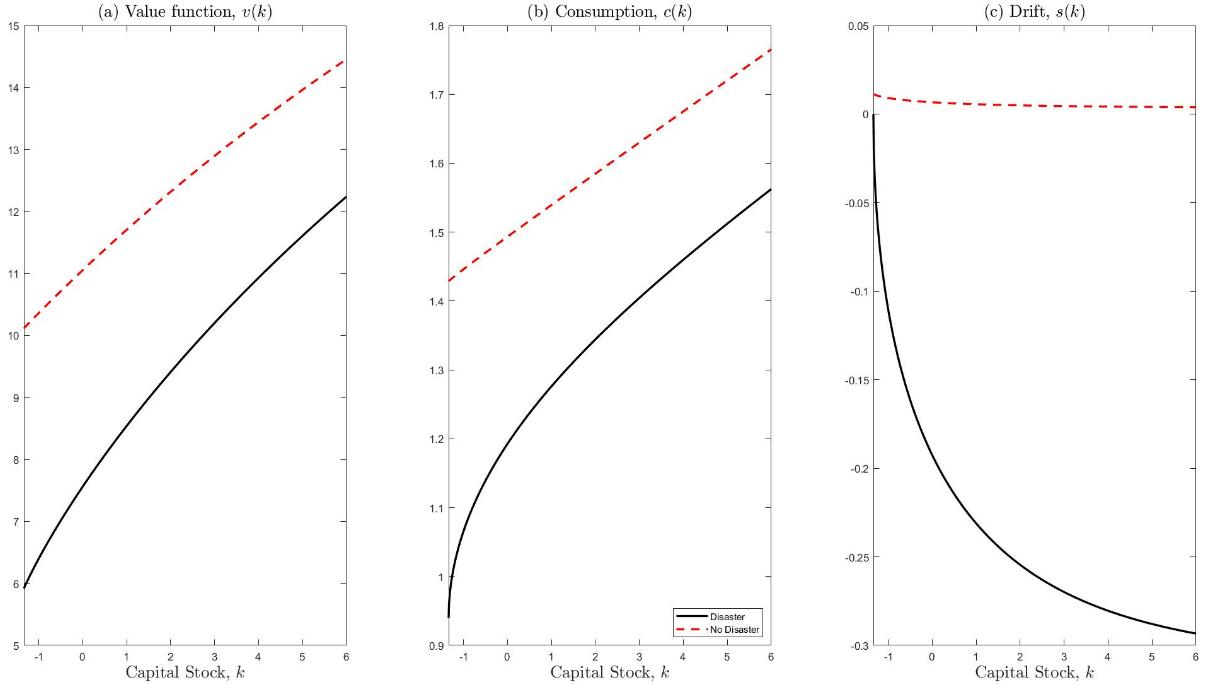


Figure A.2: Scenario A_0 ($r = 0.03, \lambda_2 = 0.0005$)

Appendix B. Sensitivity Analysis with respect to r

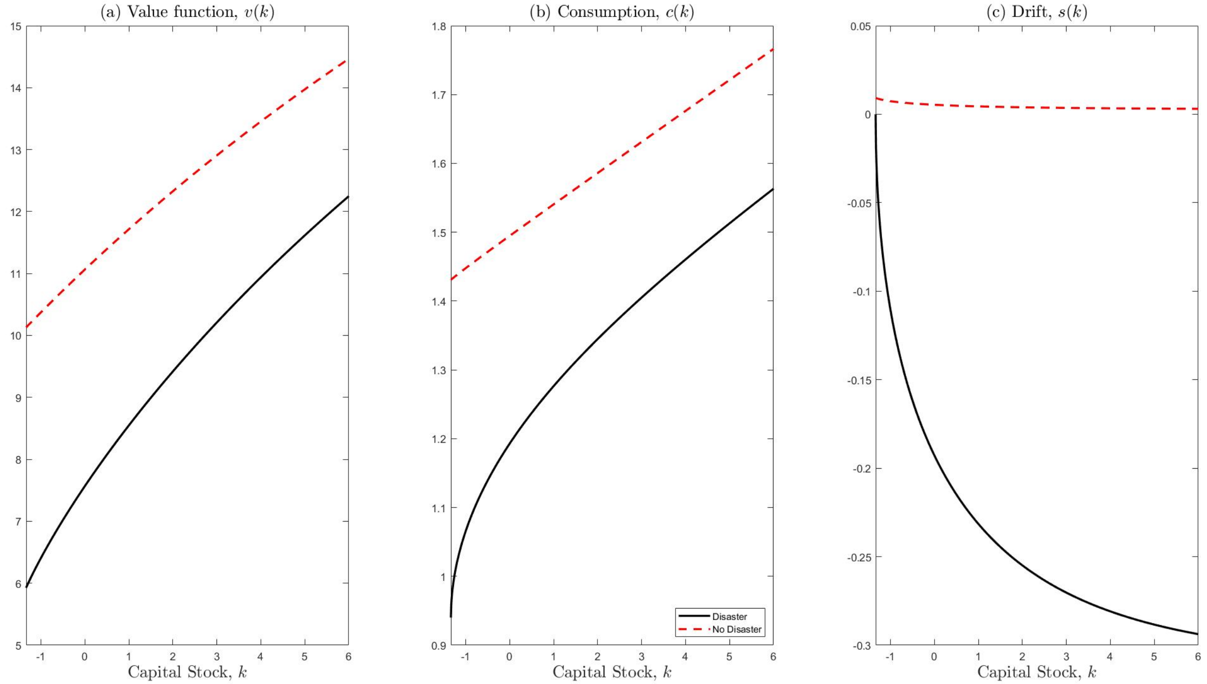
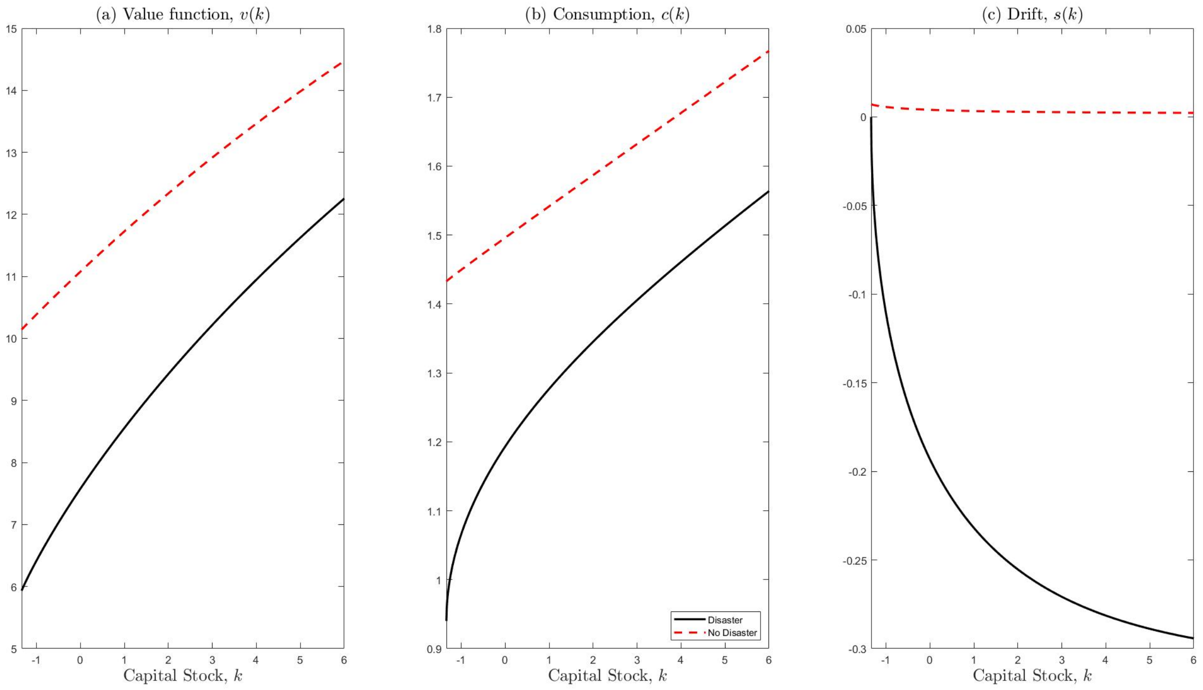


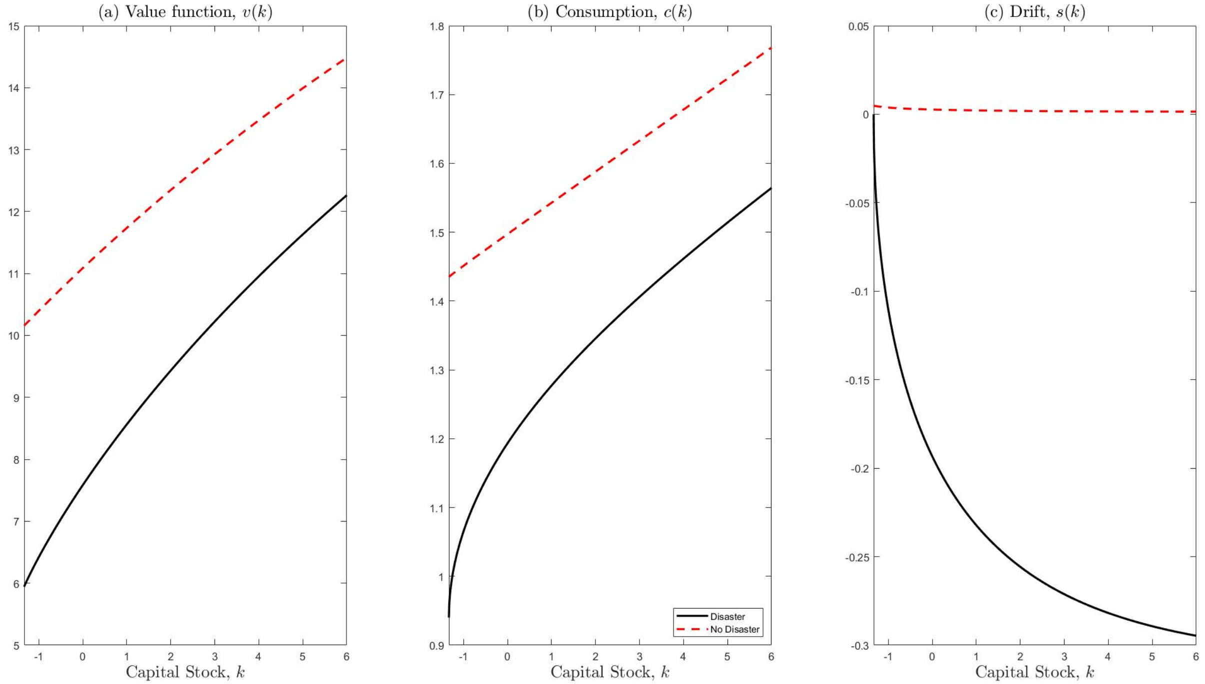
Figure A.3: Scenario A_1 ($r = 0.03, \lambda_2 = 0.0004$)


(a) Value function, $v(k)$

(b) Consumption, $c(k)$

(c) Drift, $s(k)$

Figure A.4: Scenario A_2 $(r = 0.03, \lambda_2 = 0.0003)$



(a) Value function, $v(k)$

(b) Consumption, $c(k)$

(c) Drift, $s(k)$

Figure A.5: Scenario A_3 ($r = 0.03, \lambda_2 = 0.0002$)

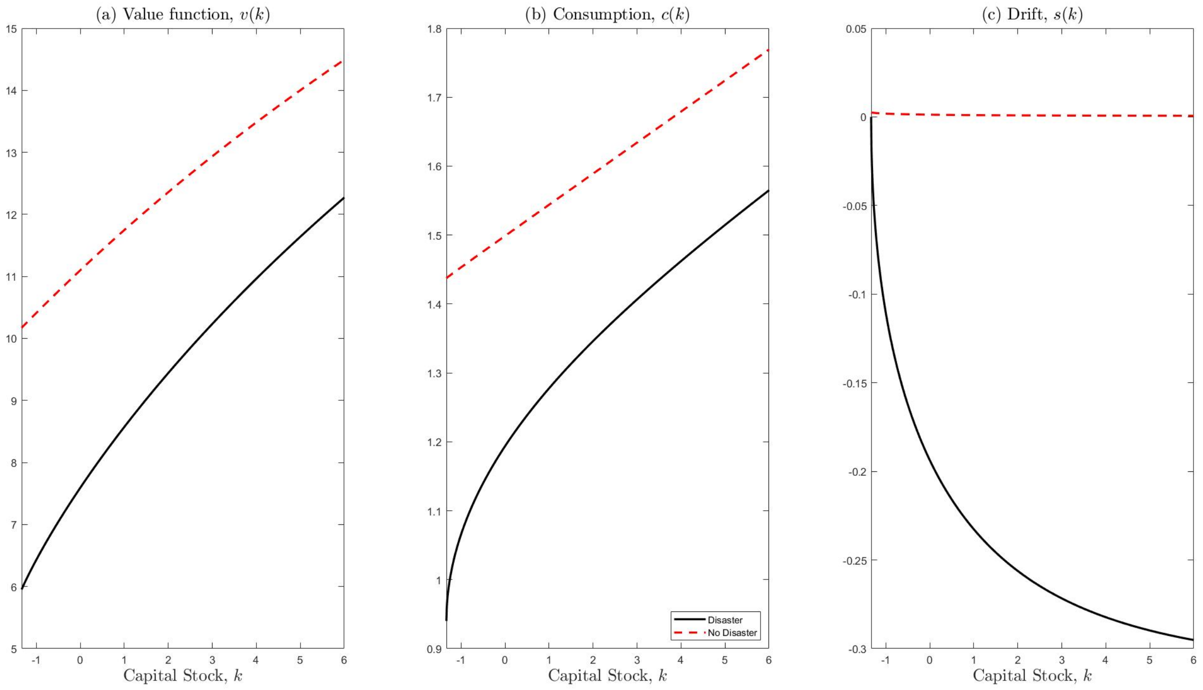


Figure A.6: Scenario A_4 ($r = 0.03, \lambda_2 = 0.0001$)

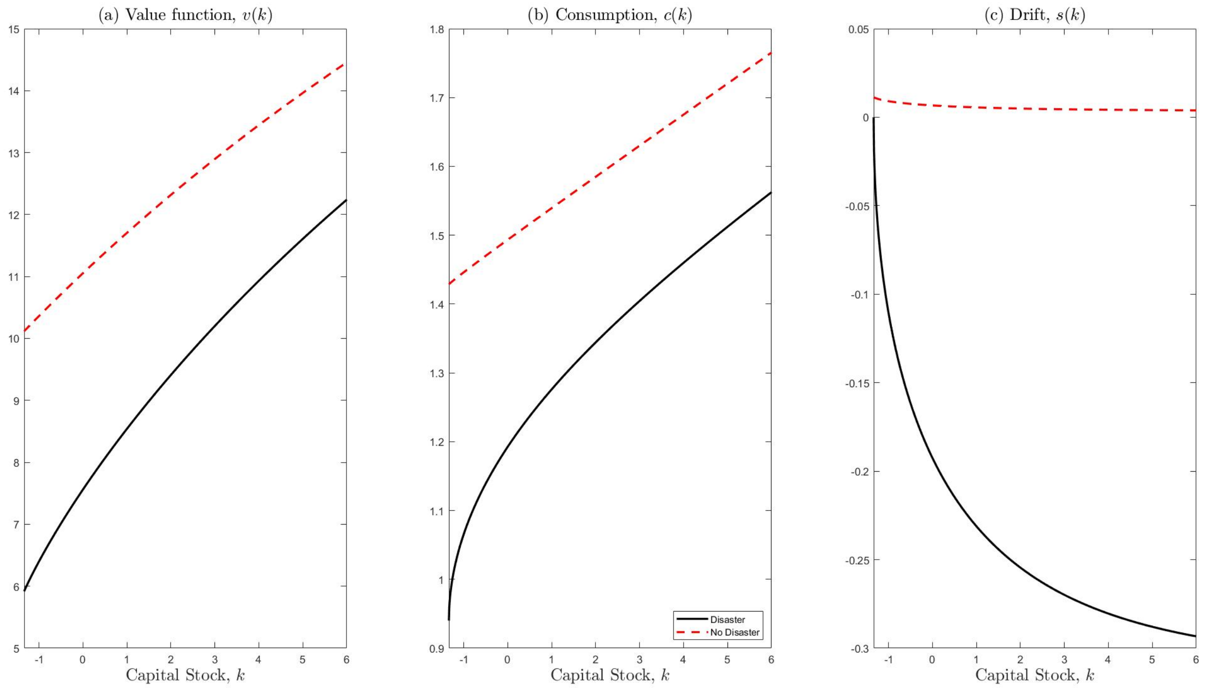
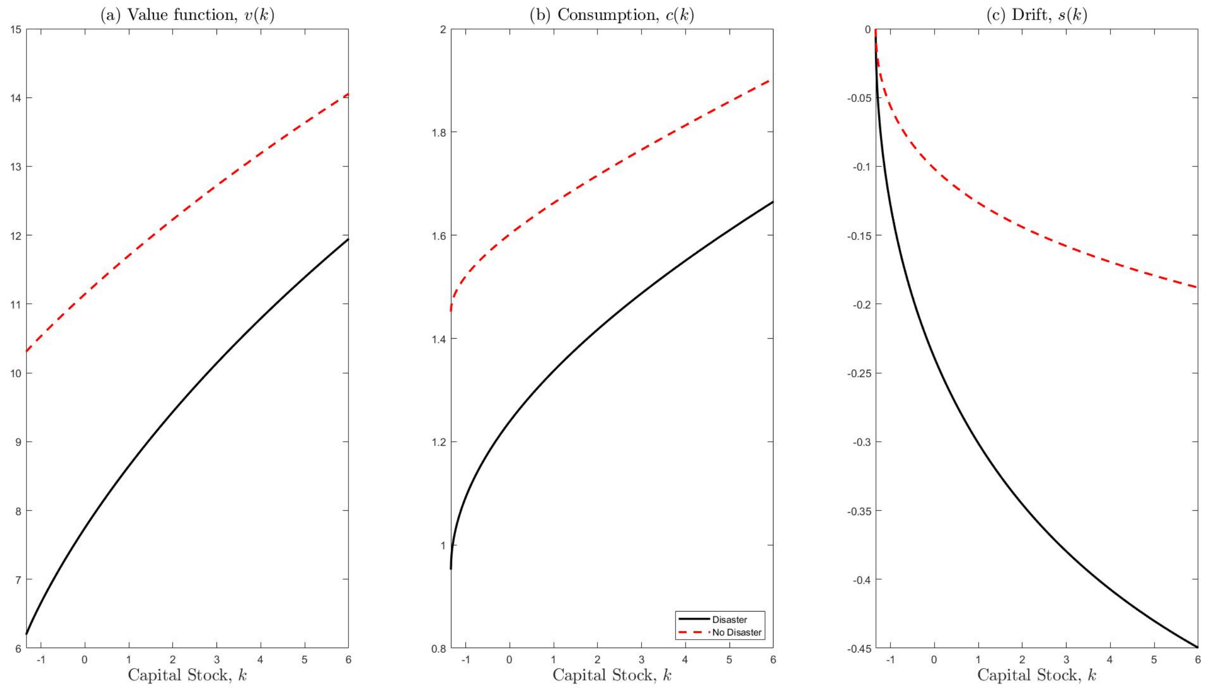


Figure B.7: Scenario B_0 ($r = 0.3, \lambda_2 = 0.0005$)

Appendix C. Scenario Analysis



(a) Value function, $v(k)$

(b) Consumption, $c(k)$

(c) Drift, $s(k)$

Figure B.8: Scenario B_1 ($r = 0.024, \lambda_2 = 0.0005$)

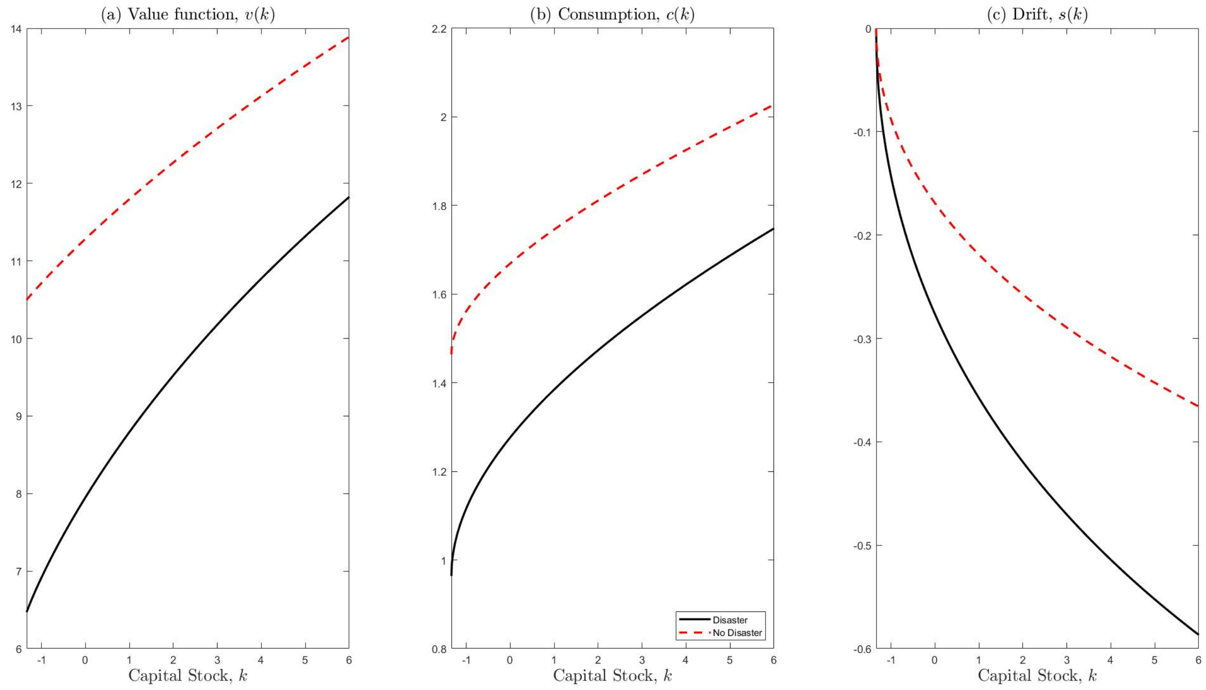


Figure B.9: Scenario B_2 $(r = 0.018, \lambda_2 = 0.0005)$

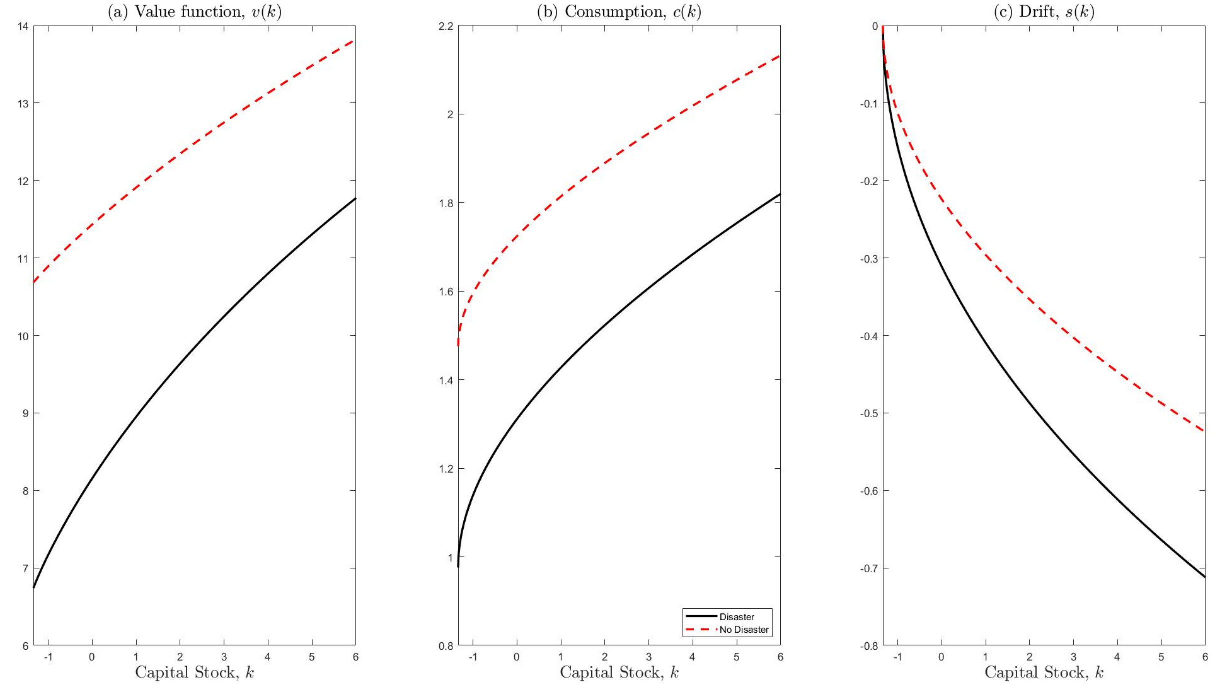
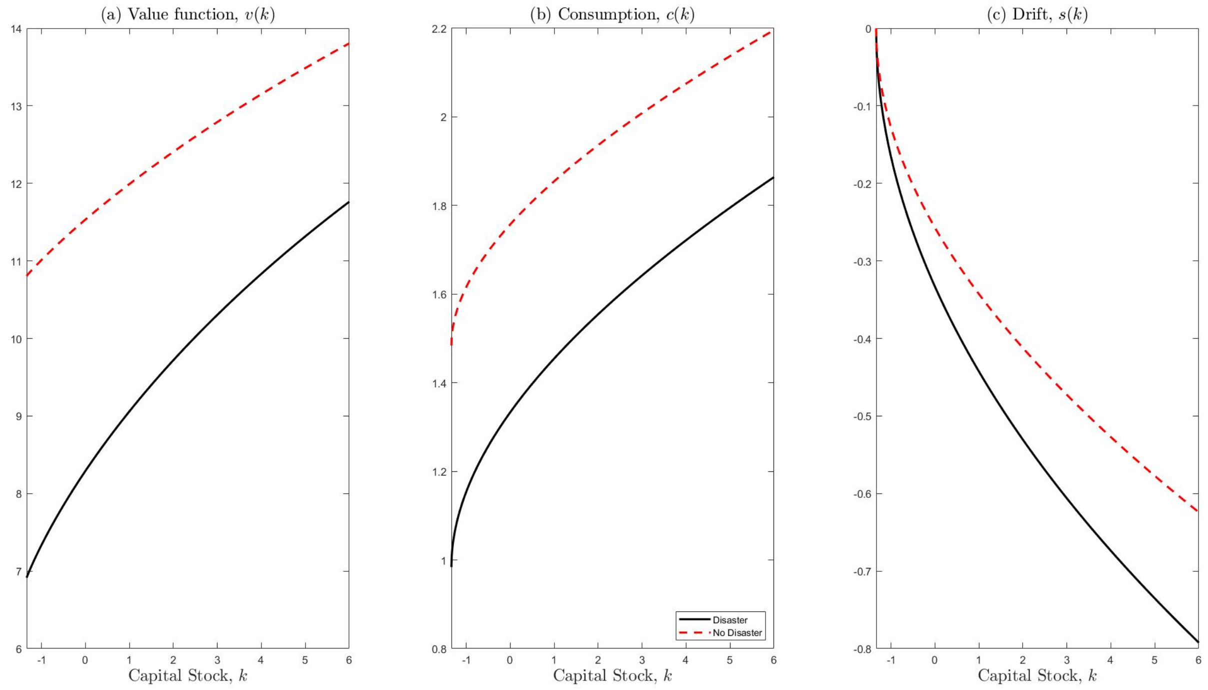


Figure B.10: Scenario B_3 $(r = 0.012, \lambda_2 = 0.0005)$



(a) Value function, $v(k)$

(b) Consumption, $c(k)$

(c) Drift, $s(k)$

Figure B.11: Scenario B_4 ($r = 0.006, \lambda_2 = 0.0005$)

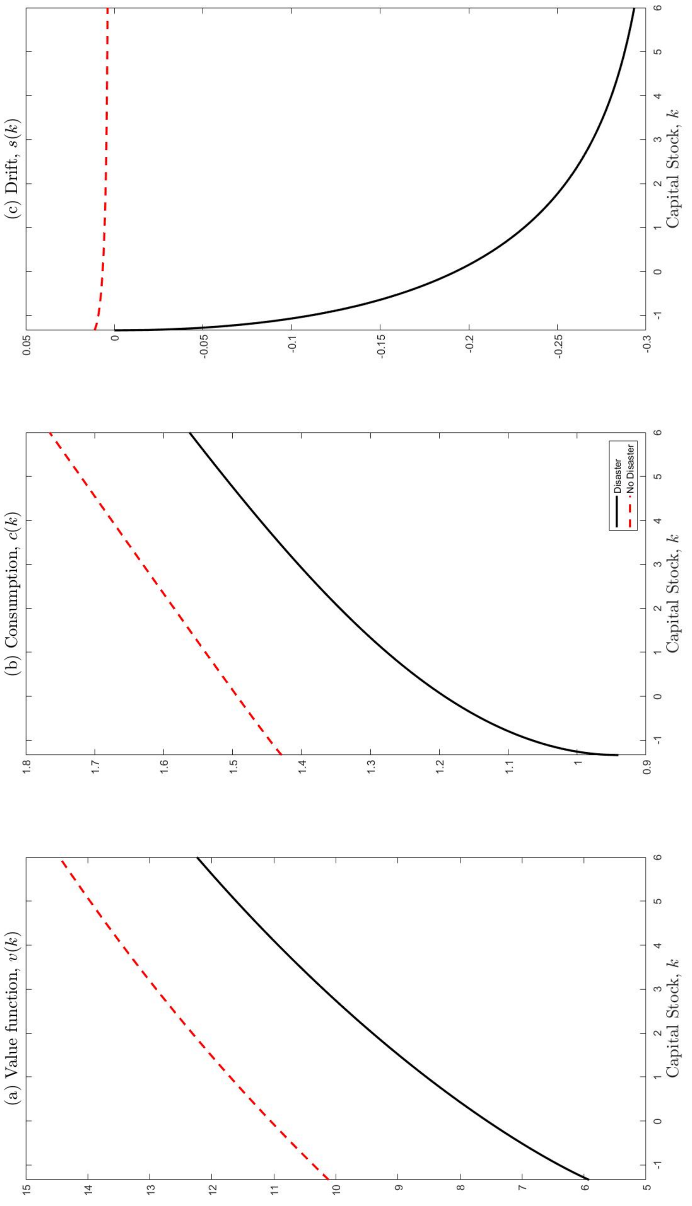
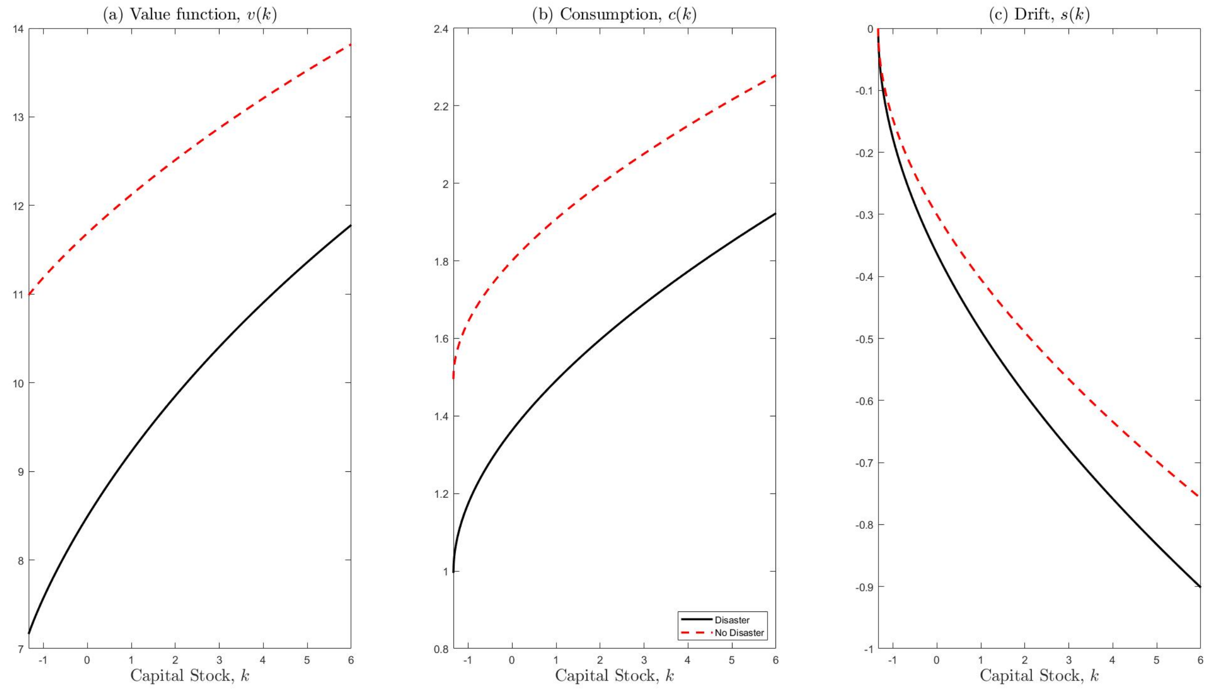


Figure C.12: Scenario C_0 ($r = 0.03, \lambda_2 = 0.0005$)


(a) Value function, $v(k)$

(b) Consumption, $c(k)$

(c) Drift, $s(k)$

Figure C.13: Scenario C_1 $(r = 0.024, \lambda_2 = 0.0004)$

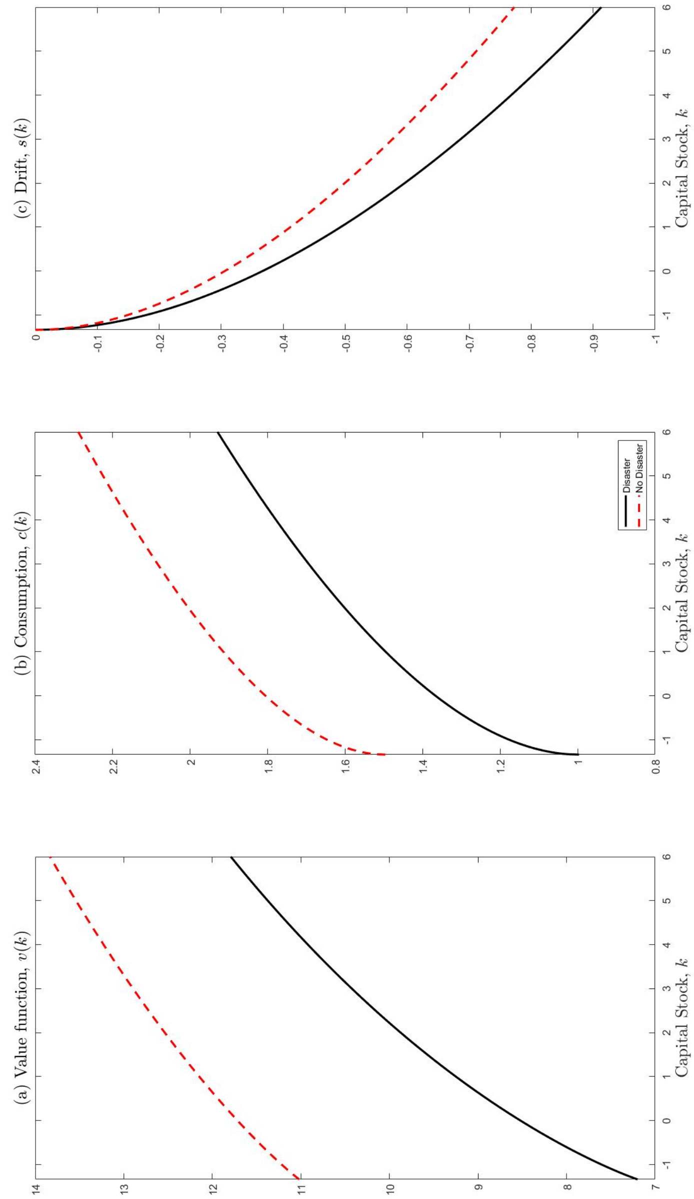


Figure C.14: Scenario C_2 ($r = 0.018, \lambda_2 = 0.0003$)

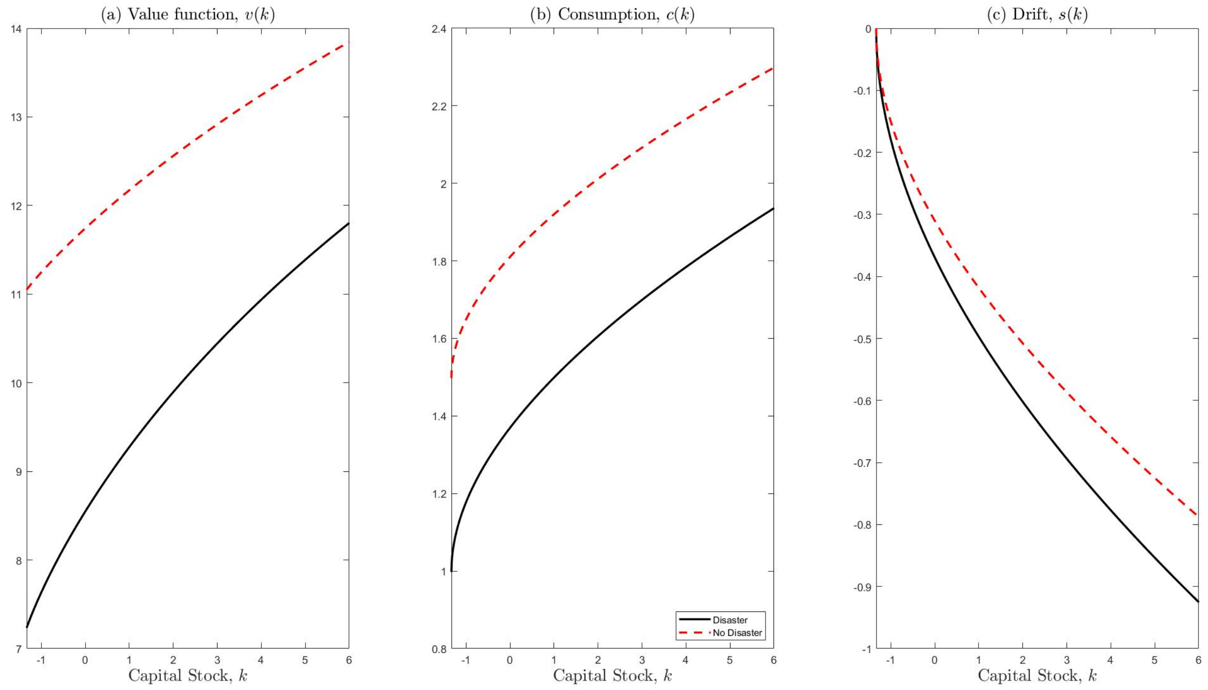


Figure C.15: Scenario C_3 $(r = 0.012, \lambda_2 = 0.0002)$

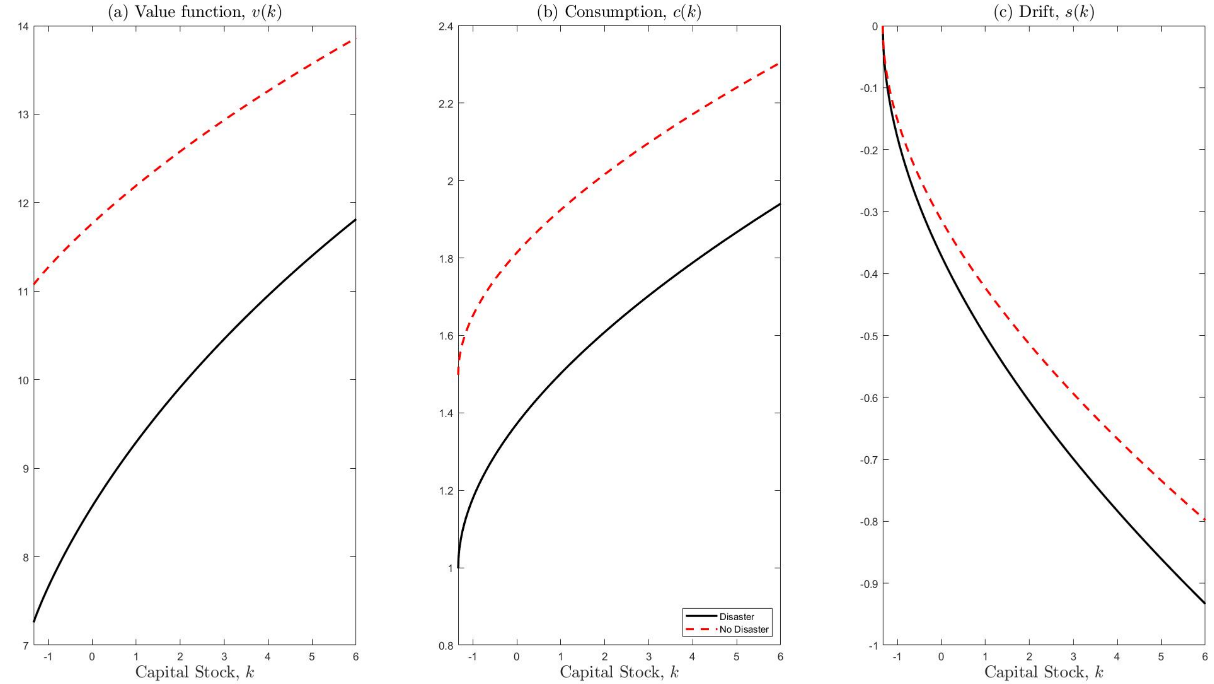


Figure C.16: Scenario C_4 ($r = 0.006, \lambda_2 = 0.0001$)