**Using the Solow model to study Climate Change**

**Deadline:**

**15 March, 08:30 (.pdf report and spreadsheet)**

**Must be submitted via Canvas**

Group information

Group #:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ANR | Email | First name | Family name |
| Student 1 |  |  |  |  |
| Student 2 |  |  |  |  |
| Student 3  Student 4 |  |  |  |  |

*Instructions*: For this assignment you are asked to numerically simulate the extended Solow model in a spreadsheet. Then, you are asked to submit a report with the main numerical results and their interpretation. The report consists of the questions marked with **[R]** in this file, they should be answered here [as indicated below] and should be submitted as a .pdf.

The points for each question are provided in the rubric of report in Canvas.

The spreadsheet is not graded, but you must submitted as a separate file. **If you do not submit a spreadsheet with all the calculations required for the report by assignment’s deadline, your report will not be graded.**

**Model setup**

The Solow model with technological progress is given by:

Aggregate output (1)

Productivity (2)

Population (3)

Consumption (4)

Physical capital accumulation (5)

Where:

investment rate

population growth rate

initial pop in 2022 (mill.)

initial physical capital stock in 2022 (mill. 2017 USD, PPP)

initial productivity index in 2022

Throughout this assignment we assume the following parameter values:

0.25 investment rate

0.03 population growth rate

0.33 elasticity of output to physical capital

0.03 depreciation rate of physical capital

g 0.023 rate of technological progress

and the following initial values

45

1035000

9900

You have access to a spreadsheet with the parameter and initial values presented above. These correspond to a hypothetical Upper Middle Income Country. It is your task to perform different simulations of the Solow model in the spreadsheet. Based on these simulations you will analyze the economic implications of climate change and climate policy scenarios the report.

*\*Note: For the simulation of the evolution of variables and the computations of their growth rates use the exponential formulation. For any variable this is:*

*where is the growth rate of variable between year and year .*

* Use the information above to simulate the population up to 2102 (*column B*). Take as given the initial level . You will use this population series in all the scenarios of this assignment.

Now we will perform a simulation exercise to obtain a baseline scenario without the effects of climate change.

**Scenario 1 - Baseline scenario**

* Levels (*columns E-G*): Simulate the GDP per capita (), aggregate capital (), and the productivity index () up to 2102. Take as given the initial capital stock , the initial productivity , (*column B*), and use equations (1), (2) and (5). (Present your answers with 3 decimals)
* Compute the annual growth rate of GDP per capita that you obtain in this simulation for each year between 2023 and 2102 (*column H*).

1. **[R]** Based on the results of the previous steps, present two separate line charts of the following variables as a function of time for the 2022-2102 period:
   1. level of GDP per capita (use a log scale)
   2. growth rate of GDP per capita

[Insert figures here]

1. **[R]** Based on the figure, is GDP per capita in 2022 below or above its steady state level. Justify your answer by explicitly referring to how the growth rate GDP per capita evolves over time. Approximately, in which year does the economy reach the steady state?

[Answer here]

1. **[R]** Is the growth rate that you find in the long run in this model in line with the theoretical prescription of the Solow model? Explain

[Answer here]

**Scenario 2 – Extreme weather events in the Solow model**

Every year different economies around the world are hit by extreme weather events. For instance, in 2023 the US registered 28 weather/climate disasters with damages exceeding $1 billion including, for instance, the Hawaii firestorm of August 8.[[1]](#footnote-1)

One channel to incorporate extreme weather events in the Solow model is as negative productivity shocks. To do this, assume that one extreme weather event causes a productivity loss of rate , and that multiple extreme weather events can occur per year (i.e., productivity decreases by percent in a year where ‘W’ extreme **W**eather events occur).

In this case, the (*ex post*) realizations of the evolution of productivity is described by an adjusted version of (2):

, (2’)

where is the number of extreme weather events that occur in year .

1. **[R]** Explain why an extreme weather event can affect the level of productivity in the economy? Provide concrete examples.

[Answer here]

Assume that the number of extreme weather events occurring in any given year is independent of the number of occurrences in other years. Furthermore, assume that the number of events is a random variable following a Poisson distribution, with the expected number of extreme events occurring per year being *ex ante* known and equal to the constant parameter ; i.e., from the perspective of the initial year 2022, the expected value of for any year after 2022 is .

Assume that productivity in year 2022 is unaffected by weather events and the initial levels of capital and productivity are given by and .

Let us first analyze the expected path of the economy. For this, assume that each year after 2022 the number of extreme events is exactly equal to .[[2]](#footnote-2)

1. **[R]** Show that under this assumption, the expected productivity in year is given by

. (2e)

[Answer here]

The expected level of output is given by

, (1e)

and the expected capital accumulation by

(5e)

Assume that and in all years after 2022. The rest of parameter values are as in *scenario 1*.

* Use equation (2e) and the relevant parameter values, to simulate the expected productivity series up to 2102 (*column O*). Take as given the initial productivity level .
* Expected levels (*columns M-N*): Simulate the expected GDP per capita (), and the expected aggregate capital (), up to 2102. Take as given the initial capital stock , (*column B*), and use the expected productivity level computed in the previous step; use equations (1e) and (5e) and the relevant parameter values.
* Expected growth (*column P*): Compute the annual growth rate of the expected GDP per capita () for each year between 2023 and 2102.
* Choose **one** of the 10 series with random simulations of the number of extreme weather events , i.e., a series of with the number of extreme weather events per year, between 2022 and 2102. You can find these series in the “Events” sheet; for these event series it is assumed that , and for the rest of the years the number of events are randomly generated from a Poisson distribution with mean . Copy and pastethe values of (only) the column of choice in ‘Events’ sheet in *column Q* of the ‘Data’ sheet.

1. **[R]** Write the name of the random series of events that you chose (events1, events2…). For this series, count the total number of years in which the following number of extreme events occur in the series to complete the table below.

Chosen series:

|  |  |  |  |
| --- | --- | --- | --- |
|  | X | | |
| 2 or less | 4 | 8 or more |
| Number of years with ‘X’ events |  |  |  |

* Use the random simulation of extreme events you chose in the previous step (*column Q*) and equation (2’) to simulate the corresponding productivity series up to 2102 (*column T*). Take as given the initial productivity level .
* Random simulation levels (*columns R-S*): Use the random simulation of productivity computed in the previous step to simulate the corresponding GDP per capita () and aggregate capital (), up to 2102. Take as given the initial capital stock , (*column B*); use equations (1) and (5) and the relevant parameter values.
* Random growth (*column U*): Compute the annual growth rate of the random GDP per capita () for each year between 2023 and 2102.

**Scenario 3 - Effect of Climate Change**

1. **[R]** Justify why an increase in or can be a potential effect of climate change. Cite recent **scientific** evidence (e.g., IPCC reports) to substantiate your answer, and link this to the interpretation of these parameters in the model (Make sure to properly cite your references, use APA citation style).

[Answer here]

1. **[R]** Use equation (2e) and assume is constant, as it is assumed in *scenario 2*, to show that: for a sufficiently high value of , productivity is expected to remain stagnant: for all .

[Answer here]

Assume now that, as consequence of climate change, for all periods; the rest of parameter values are as in scenario *2*.

* Use equation (2e) and the relevant parameter values, to simulate the expected productivity series up to 2102 (*column Z*). Take as given the initial productivity level .
* Expected levels (*columns X-Y*): Simulate the expected GDP per capita () and the expected aggregate capital (), up to 2102. Take as given the initial capital stock , (*column B*), and use the expected productivity level computed in the previous step; use equations (1e) and (5e) and the relevant parameter values. (Present your answers with 3 decimals).
* Expected growth (*column AA*): Compute the annual growth rate of the expected GDP per capita () for each year between 2023 and 2102.
* Given that is unchanged, we can use the same random simulation of extreme events as in *scenario 3* (set *column AB = column Q*). Use this and equation (2’) to simulate the corresponding productivity series up to 2102 (*column AE*). Take as given the initial productivity level .
* Random simulation levels (*columns AC-AD*): Use the random simulation of productivity computed in the previous step to simulate the corresponding GDP per capita () and aggregate capital (), up to 2102. Take as given the initial capital stock , (*column B*); use equations (1) and (5) and the relevant parameter values. (Present your answers with 3 decimals).
* Random growth (*column AF*): Compute the annual growth rate of the random GDP per capita () for each year between 2023 and 2102.

**Comparisons across scenarios**

Let us examine the expected economic implications of climate change through the extreme weather events channel that we have studied in this assignment.

* GDP per capita relative to *scenario 1* (*columns AI-AL*): For each scenario with extreme events (*2*, *and 3*) compute the expected GDP per capita relative to GDP per capita in *scenario 1 ()*, and the random simulation of GDP per capita relative to GDP per capita in *scenario 1* *().*

1. **[R]** Present a line chart depicting the following 4 variables relative to GDP per capita in *scenario 1,* as function of time, for the 2022-2102 period: expected GDP per capita in *scenarios 2 and 3*; random simulation of GDP per capita in *scenarios 2 and 3*. Use dashed lines for the expected; continuous lines for the random simulations; blue for *scenario 2*, red for *scenario 3*.

[Insert figure here]

1. **[R]** According to what you observe in the previous figure, and considering the evolution of GDP per capita in *scenario 1*, describe and explain the main differences when comparing the following (relative to GDP per capita in *scenario 1*)
   1. Expected GDP per capita in *scenario 2* Vs. *scenario 3*
   2. Expected GDP per capita in *scenario 3* Vs. random simulation in same scenario

[Answer here]

1. **[R]** Present a line chart depicting the following 4 variables*,* as function of time, for the 2023-2102 period: growth of expected GDP per capita in *scenarios 2 and 3*; growth of random GDP per capita in *scenarios 2 and 3*. Use dashed lines for the expected; continuous lines for the random simulations; blue for *scenario 2*, red for *scenario 3*.

[Insert figure here]

1. **[R]** According to what you observe in the previous figure describe and explain the main differences when comparing the following
   1. Growth of expected GDP per capita in *scenario 2* Vs. *scenario 3*
   2. Growth of expected GDP per capita in *scenario 3* Vs. growth in random simulation in same scenario
   3. Growth of GDP per capita in random simulation in *scenario 2* Vs. in random simulation in *scenario 3*

[Answer here]

Climate science suggests that climate change can cause and to increase; let us assess the long-run economic impact of climate change, through the impact of extreme weather events on productivity.

1. **[R]** According to the results of the Solow model augmented with extreme weather events that we have developed up to this point in the assignment analyze the following:
2. If extreme weather events affect productivity (), is climate change expected to have positive, negative, or no effect on the level of GDP per capita in the long run? Use the elements of the model to justify your answer.

[Answer here]

1. If extreme weather events affect productivity (), is climate change expected to have positive, negative, or no effect on the growth rate of GDP per capita in the long run? Use the elements of the model to justify your answer.

[Answer here]

1. Compute the average annual (exponential) growth rate of GDP per capita () for the last 10 years of your scenarios (2092-2102). Do this for GDP per capita under *scenario 1*, and for the expected GDP per capita under *scernarios 2 and 3*. Complete the following table (Use 3 decimals).

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | 1 | 2 | 3 |
|  |  |  |  |

**Taking stock – Climate policy and model assessment**

1. **[R]** If Lower and Lower Middle Income countries are more vulnerable to the impacts of climate change via the extreme-events channel than Higher income countries, what do your results suggest about the effect of this channel on the evolution over time of the distribution of GDP per capita between countries? Explain.

[Answer here]

1. **[R]** How could the model be adjusted to represent this higher vulnerability of Lower and Lower Middle income countries (i.e., higher vulnerability to extreme weather events for lower levels of income per capita)? What do you think this would imply for the long term outcomes of the model (e.g., emergence of poverty traps).

[Answer here]

1. **[R]** What are the main limitations of the model that we developed in this assignment to study the economic implications of climate change? Propose a direction in which you would extend/alter the model to think of the implications of (climate) policy in the context of extreme weather events.

[Answer here]

1. Billion-Dollar Weather and Climate Disasters. [National Centers for Environmental Information NCEI - NOAA](https://www.ncei.noaa.gov/access/billions/) [↑](#footnote-ref-1)
2. This assumption provides an ‘approximation’ of the ‘exact’ expected path. However, this is a good approximation for small values of and (as the ones that are used in this assignment). [↑](#footnote-ref-2)