# Wealth Distribution and Inheritance: A Agent-Based simulation analysis

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## Abstract

The main objective of this work is in the first place to analyze the evolution of inequality in the distribution of wealth throughout history. Second, determine the fiscal policies and economic behavior that best explain the inequality in the distribution of wealth observed in recent decades. On the other hand, this work also focuses on analyzing the properties of Agent-Based models, focusing especially on the NetLogo software and its wealth distribution simulator, Wilensky, U. (1998). NetLogo Wealth Distribution model. We will modify the code of this simulation firstly in order to add the conclusions drawn from our previous analysis and perform a more realistic simulation and secondly to observe the effects of implementation a progressive tax in the simulation.

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## 1 Introduction

For centuries, the distribution of wealth has been an interesting field of study for sociologists, economists or philosophers. Over time, different theories have developed trying to explain the nature of this phenomenon with the aim of predict the future situation. David Ricardo, Simon Kuznets or Karl Marx are some of the names that we can highlight in this field. Thanks to the successes and errors of their work, we have a better acknowledge of this phenomenon and of the variables that are involved in it. For example, Ricardo prediction in Principles of Political Economy and Taxation(1817) said that the landlords share of the national income would increase over the time once the output and population grew steadily. Land would tend to scarce related to other goods and due to the supply and demand law the price of land would increase steadily. This prediction was wrong because Ricardo did not think about the importance of the industrial and technological progress.

In this work we assume that the errors or inaccuracies of the works developed times ago may have are linked to the tools available at each time. Over the time, the evolution of humanity and the technological progress that derives from it have provided human beings with better tools for data analysis and estimation. Today we have large databases that authors in the past did not had at their disposal. This is why current works on the distribution of wealth should be more complete and accurate.

Based on the comments in the previous paragraph, in this work we defend the importance of Capital in twenty-first century, Piketty (2014), as the most important study on income and wealth inequality developed in this century. On the one hand, Piketty's definition of inequality, $r > g$, seems to explain this phenomenon more precisely than studies of the past. His work argues that the rate of return on capital, $r$, can be higher than the growth of income and output, $g$, for long periods of time throughout history. According to Piketty's work, over the time the entrepreneur inevitably tends to become a

rentier who is increasingly dominant over those who do not have more than their own workforce.

In section 2 of this paper, we will present two basic tools for the analysis of wealth inequality, the Lorenz curve and the Gini coefficient, which will be important to develop our conclusions about the results obtained in the second part of the work, where we will work the computer simulation. In the section 3 of this paper we focus on analyzing and comparing the evolution of income distribution and the evolution of wealth distribution over time, delving into the concept of income and focusing specially in the EEUU case. With the conclusion of this section we introduce the first ideas that we defend in this work. In section 4 we will analyze the importance of inheritance in the distribution of wealth. We will comment the examples of Sweden and France. In this section we will also comment on the importance of the behavior of consumption in the distribution of income.

The first part of this paper concludes with section 5, in this section we first comment on the ideas that emerge from the neoliberal doctrine. Secondly we study the effects that the fiscal policies associated with this field of economic thought could have generated. We have based our conclusions mainly on the study of the United States, where since 1970 this type of policy has taken place, especially in the Ronald Reagan era. Thirdly, in this section we will also comment on the role that progressive taxes can have on the distribution of wealth. Finally, we will develop an analysis of the ideas collected throughout this first part of the work that will serve as the basis for the second part.

On the other hand, the evolution of humanity and the technological development linked to it has not only facilitated the creation of large databases and more accurate estimations. It also provides us with the possibility to perform large mathematical calculations in seconds or build virtual simulations to analyze projects related to the different fields of knowledge. With virtual simulations we have at our disposal hundreds of tools that scholars of years ago did not have. It is obvious that the results obtained in the simulations related with field such as engineering or physics and the predictions or conclusions that emerge from these will have more consistency with respect to the results that can be obtained in virtual simulations developed in fields such as social sciences. But the studies developed in the different fields of social science such as economics provide us an empirical evidence of the variables and factors that we must consider when we develop a research. This fact encourages the development of virtual

models since programming codes can be designed that take into account the relevant variables to study and provide realism to the simulations.

In this paper we have worked with the Agent-based wealth distribution model provided by NetLogo, as mentioned above. This type of simulation aims to recreate virtual worlds where different agents participate. In the case of the social sciences, these virtual worlds simulate in a simple way observable situations in real life with the aim of analyze the behavior and interactions of the participating agents. First, in section 6 we will comment on the essential characteristics of the agent-based models provided by Netlogo, guiding the reader towards the model used in this work. Secondly, in section 7 we will study more in depth the characteristics of the wealth distribution model used and we will comment on the similarities that we find in it with reality.

Finally, in section 8 we will make modifications to the simulation programming code in order to implement the ideas extracted from the first part of the work and obtain more realistic results. We will introduce a bequest in the code simulation and an progressive tax on the inheritance on wealth. We will analyze the results obtained and provide the graphics of our simulation. We assume that there are parts of the simulation that cannot be interpreted in a realistic way and we observe how certain parameters can be very useful to configure simulations that try to explain consumption, the accumulation of wealth or the distribution of income. Above all, in this work we highlight the importance of developing the simulation code to improve results.

## 2 Measuring wealth inequality

A simple tool we can use to know the level of inequality in a certain region is to know how much wealth the first percentile possesses or to say with respect to the total wealth of the region. If 1% or 10% of the richest inhabitants of a region accumulate a very high percentage of the total wealth of this region, we will have evidence that there is a problem of wealth inequality. This logic is what Lorenz (1905) followed when he designed a function that aimed to detail the participation of each percentile or say of the population. To draw this function we will only use the first quadrant of the Cartesian plane. On the

vertical axis (Y) we indicate the percentages of total wealth of a region. On the horizontal axis (X) we indicate each say or percentile of this population so that if a certain population has a perfect distribution of wealth where the 20th percentile has 20% of the wealth and the 60th percentile has 60% of the wealth. wealth and the same happens with each percentile, we will draw a perfect 45 degree line that will go from point (0,0) to point (1,1). In reality, a perfect distribution of wealth is not observed in any population, therefore the resulting Lorenz function for each population is a kind of inverted "L" as we observe below.
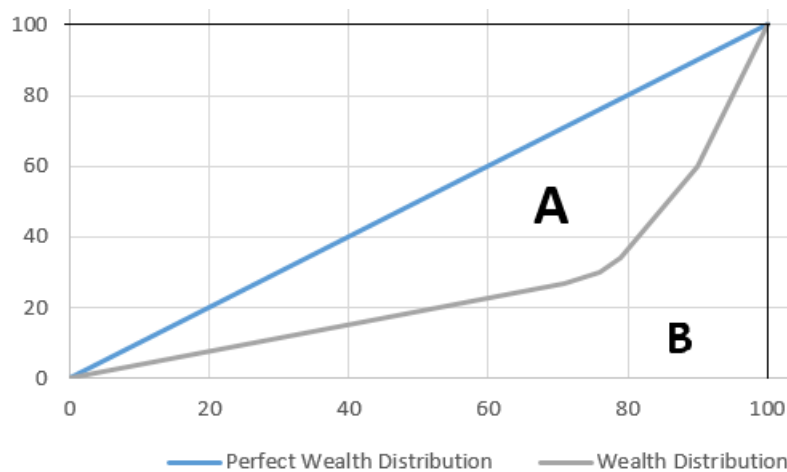


Figure 1 : Perfect Lorenz curve

The Gini coefficient is derived from the Lorenz curve, designed by the Italian economist Corrado Gini (1884-1965). This is obtained through the values of the areas A and B shown in the previous figure. We could say that the Lorenz function allows us to carry out a visual analysis of the distribution of wealth in a certain population, while the Gini coefficient allows us to carry out a numerical analysis of this distribution. Through operation (1) we calculate the value of the Gini coefficient. The result of this operation is always a number between 0, which indicates a perfect distribution of wealth, and 1, which indicates a maximum inequality in the distribution of wealth.

(1)     A/(A+B)

The Lorenz curve, the Gini coefficient and the concepts that emerge from both are essential when making an analysis of the distribution of wealth, we can find the Gini coefficients for each country in different databases and official statistics as in the Central Bank or the Federal Reserve. These tools have been used especially in the last part of this work to analyze the results obtained in the simulations.

## 3 Income and Wealth Inequality

It is easy to intuitively think that income is an important variable in explaining a person's wealth. Piketty and Saez (2014) distinguished two types of income. On the one hand, capital income, which generates rentals, shares, royalties and other income derived from the possession of capital assets after taxes or transfers. On the other hand, labor income, which comes from the performance of labor services also after taxes and government transfers. Within the labor income we can find very different ranges, depending on the type of work that the required training is carried out. The same occurs with the capital income, where there are large differences between shareholders or landowners. Economic history has shown us how, in general terms, capital income has been a third of national income, while labor income corresponded to the remaining two-thirds. In the first figure of our appendix A, we observe how the share of labor income has decreased in favor of capital income in the last decades in Britain. This trend began in 1970, at the same time that we observed the beginning of a growing trend of wealth inequality in this same region, as we can see in the second figure of our appendix A.

As explained in the introduction, a decrease in inequality in the distribution of wealth has been observed in Europe from 1910 to 1970 where a growing trend is once again observed as shown in the appendix A. In the commented work by Piketty and Saez we can observe how the trend of income inequality in Europe follows a similar trend. We can observe a similar trend in the case of the United States, although in this region the growing trend of income and wealth inequality begins earlier than in Europe, later we will try to explain the causes of this situation. This information and the commented in the first paragraph of this section strengthens the intuitive idea that we discussed at the

beginning of this section. The wealth of a person is related to his the level of income so a variation in the share of income of the productive forces will have effects on the distribution of the wealth.

Delving deeper into the evolution of income inequality, we comment on the evolution of this phenomenon in the United States. Based on the study carried out by Piketty (2014), we observe how at the end of the 20's of the last century, the participation of the richest decile in the total national income was almost 50%. As discussed in this study, the two world wars resulted in a sharp reduction in income and wealth. After the end of the WWII, this percentage is below 35% and we observe how from the 70's of the last century the trend is growing again as we also observe in the evolution of wealth inequality in this country despite the fact that it has not returned to pre-World War I levels. However, the participation of the top percentile in total national income has reached levels higher than those reached in the period prior to WWI.

The work of Piketty and Saez stated that "the reason is that modern American inequality is based more on a large rise in peak earnings than on the extreme levels of wealth concentration that characterized the "patrimonial" (wealth-based) societies of the past". This fits with the concepts that emerge from the definition of inequality discussed in the introduction, r > g, also with what was discussed in this same section about the decreasing trend of the labor share in national income. Based on the rest of our reviewed bibliography, we can suggest that one of the main causes of this rise in peak earnings in the USA are the economic policies required since the 70's of the last century. In section 5 this type of policies based on the neoliberal doctrine, specifically those applied during the mandate of Ronald Reagan, that generates what is known as trickle-down economies and where inequality is assumed as one of the bases of economic growth will be analyzed in greater depth. It could also reinforce this idea by comparing the share of the top decile in total income in the United States and in Europe, where the economic policies carried out have generally been different. We observe how in the United States the participation is close to 50% in Europe it does not reach 35%. This is available in the appendix A

At this point we have defined the concepts of income and distinguished labor income from capital income. We have commented on the evolution of income inequality in the United States and highlighted its similarities with the evolution of inequality in the distribution of wealth. Through the comparison between the United States and Europe.

Finally we propose the idea that neoliberal policies are related to the growth of income inequality and therefore to the growth of inequality in the distribution of wealth.

## 4 Inheritance and Wealth inequality

In the previous section, we began by commenting that it is logical to think that income is an important variable when determining a person's level of wealth. In this section we add the idea, also logical, that saving levels should explain to some degree the participation of a part of the population in the total wealth of the region, for example the richest top decile that has been analyzed in the previous section. Economic theory has shown us through different mathematical formulas that saving can be explained in terms of consumption. Also, throughout history consumption behaviors have been studied between different social classes, different generations, different family structures or cultures.

In our work we will assume the conclusions drawn from the work of Zou (1995) in which the possibility that capitalist society continues to accumulate wealth even after retirement is discussed. This reinforces our initial argument that saving is related to the accumulation of wealth and also makes us consider what role the transfer of intergenerational wealth has in the accumulation of wealth and in the inequality of its distribution. Elinder, Erixon and Waldenström (2018) analyzed in their work the population register on inheritances and wealth in Sweden, and they commented that inheritances generated a reducing effect on the Gini coefficient but also generated a greater absolute dispersion. The authors argued that this could be due to the difference in consumer behavior between rich and poor as well as the difference in inherited wealth between social classes. Karagiannaki's (2011) study provides us with a similar conclusion. In the first place, there is a wide inequality between the inheritances received. Second, despite the fact that inheritance may have a certain equalizing character, differences in behavior end up causing inheritances to have a final unequal effect on the distribution of wealth.

Piketty (2014) study is the most comprehensive in this field. Starting with the graph that shows the evolution of the share of bequests and donations on national income throughout history, 1900-2010, for Germany, France and the United Kingdom, which follows trends similar to those observed in the inequality of distribution of wealth for that period and also in those observed in the income distribution. According to Piketty's estimations for France, inheritance will account for about a quarter of total resources throughout life for generations born in the 1970s of the last century onwards. His analysis adds that "almost one sixth of each cohort has an inheritance greater than the amount that the bottom half of the population earns through their lifetime work."

At this point in our work, adding the information discussed in this section to the previous section, we continue to reinforce the idea that neoliberal thought and the economic policies that emerge from it are not valid to try to reverse the trends in the accumulation of income and wealth. In the first place because, as has been commented before, the nature of this economic doctrine assumes the existence of inequality of wealth. And secondly, observing the data in areas where the role of the state is relatively important in the economy, such as in Europe and especially in France, we can affirm that we agree with Stiglitz (2015) that in order to reduce economic and social inequalities, the role of the sector public must be decisive. With this, we refer to the role of the central institution of the State with the capacity to regulate and intervene in different fields of the economy and to its capacity to modify the marginal tax rates in order to reduce the effects of the equalizers observed previously.

We end this section with the proof that inherited wealth plays a very important role in the economy, especially in the levels of inequality in the distribution of wealth, and we have evidence that the role of inheritance will be even more decisive in the economy in the future if the national institutions do not work to reverse this trend being aware that the growth of the role of inheritance in the economy represents a great danger for the meritocracy. This is why in the second part of this work, given this dangerous role of inheritances in the economy, we will work with inheritance in virtual simulations in order to reduce their equalizing effect, adapting a tax based on the ideas previously discussed by Stiglitz and the ideas of Capital in the twenty-first century. This will be discussed in the next section.

## 5. Neoliberalism, trickle-down economics and progressive taxes.

A great amount of economists, historians, and sociologists agree that the term "neoliberalism" was coined in the late 1930s by the German economist Alexandre Rüstow. There are different aspects of neoliberalism but in general terms we could highlight that the main ideas that emerge from this field of economic and political thought are the defense of the free market and the reduction of the role of the State in the economy, as well as the assumption of inequality as a part of economic growth. Privatization of public services, with health and education being the most affected areas, reduction of taxes or loss of strength unions are some of the measures and effects of neoliberal policies. In this paper we highlight as neoliberal policies those carried out in the United States since the 1960s, with greater emphasis on the mandate of Ronald Reagan in the 1980s, and those carried out in the United Kingdom by Margaret Thatcher, especially the one known as poll tax. which led to her resignation as Prime Minister.

The idea that inequality is part of growth justifies reducing taxes on the richest by creating a regressive tax system. Piketty (2014) classifies taxes into three groups. Simplifying, we could say that a proportional tax is one that applies the same rate to all people regardless of the amount of wealth they have, this type of tax is commonly known as a flat tax. On the other hand, a progressive tax is one that has a different rate depending on the amount of wealth that a person has, the greater the wealth of a person, the higher the tax rate. Finally, a regressive tax is the exact opposite of a progressive tax. The measures by the governments of Thatcher and Reagan converge towards a regressive tax system, next we will analyze what happened in the economy of the United States in the last decades.

Neoliberal ideas defend that implementing a regressive tax system would encourage large fortunes to innovate and develop new goods and services. This will suppose the creation of employment and new businesses generated by the economic trickle that supposes the initial measure of implementation of regressive taxes. In other words, implementing tax policies that make the rich richer will mean creating jobs and services that the poorest will benefit from. This is what is known as the trickle-down economy.

Akinci (2018), reviewing the effects of trickle-down economies in 65 countries, showed that increasing the income of the rich the income of the poor is also increased and vice versa, but he affirmed that the trickle-down effect was invalidated since the transfer of

income from poor to rich is more dominant than vice versa. Also Stiglitz (2015) affirms the failure of regressive policies as a measure aimed at achieving a higher level of well-being. Analyzing deeply the failure of this type of economic policy, the work by Greenwood and Holt (2010) comments that the effect produced is a "negative trickle" that affects different fields of the economy. First, looking at the effects of these policies, the United States, his study comments that the middle class was clearly affected by these policies, with the passage of time fewer and fewer people had the necessary income to be considered middle class. According to a survey by the Pew Research Center (2008), during the years 2007-2008 the median family income was slightly above $ 50,000, while the median needed to be considered middle class was $ 70,000. From 1975 to 2008, average income growth grew very slightly, creating a trend in which fewer and fewer families have the necessary wealth to consume according to what is understood as a middle-class standard of living.

Another negative effect related to these policies is education. The reduction of taxes is linked to a reduction of public services and their privatization. In the case of education and especially in a country like the US, public education services are necessary for the poorest people, if public education services are reduced, these people must resort to granting loans to finance their academic training . The previously mentioned work by Greenwood and Holt reports that an increase in interest rates on student loans is observed in the period studied. In addition, they also inform us that for the period between 1970 and 2000, the average family income grew by 33% while housing prices increased by 83%, evidencing another problem derived from this type of policies, the level of access to housing is inevitably reduced given these differences between the increase in average income and that of house prices.

The effect on health is similar to that commented on education, but in this paper it will not be commented on since we consider that enough has already been commented on what neoliberal policies are based on and the effects they have had on society, specifically on the wealth distribution. We end the first part of this section with a literal statement by Joseph Stiglitz in an article written for the Project Syndicate organization in 2019: "For the past 40 years, the United States and other advanced economies have been pursuing a free market agenda of low taxes, deregulation, and cuts to social programs. There can no longer be any doubt that this approach has failed spectacularly, the only question is what will and should come next".

On the other hand, we begin the last part of this section by analyzing the ideas that we extract from what has been commented above. This paper seeks to offer ideas about how to reduce wealth inequality and observing all the comments, first of all, we assume that a regressive tax system favors the growth of inequality. Second, the idea of building a tax system does not seem like a good idea if what we are looking for is to reduce economic inequalities. As we have commented in the previous section, consumption behaviors have an influence on the final distribution of wealth. Third, we assume that the best solution to reduce economic inequalities is, on the one hand, the provision of quality public services by the state to cover the health and education needs, among others, of the poorest. These public services must be financed with taxes and, according to what has been observed, their character must be progressive, they must be paid based on the wealth that is possessed.

To strengthen this idea, we turn to the revised bibliography where, on the one hand, Piketty (2014) comments that to achieve the new economic objectives for the 21st century, among which the objective of reducing inequality in the distribution of wealth stands out, the best option is to establish a progressive tax system. On the other hand, Stiglitz (2015) comments that increasing the 5 percent in the income tax rate to the richest percentile of the US population would suppose additional income of between 1 and 1.5 trillion dollars during the next 10 years also adds " To put this in perspective: for every additional $ 50,000 taxed for every million dollars of income of a wealthy person, the United States could make all public college education free and fund universal preschool education. "

We end this section and the first part of this study with the assumption that reducing inequalities in the distribution of wealth requires the intervention of the state as the central regulatory entity. The state must orient its fiscal policies as a whole towards a more progressive character. These policies must cover the important effect that inheritance has on wealth inequality, which also endangers the system of meritocracy on which a large part of the world's countries are based. We will seek to adapt these ideas in the second part of this study dedicated to computer simulation.

# 6 Introduction to Agent-Based models and Netlogo

In this part of our work we will first discuss the fundamentals and general concepts of an agent-based model, what it consists of and its composition. In addition the model that has been used in this study will be briefly explained. In the section 7, It will delve into the most relevant properties of this, such as parts of the simulation code that we have found interesting or characteristics the most remarkable characteristics of the agents that intervene in it. Finally, in section 8 we will introduce changes in the code and will analyze the results obtained. The objective of this section is to guide the reader so that they are well acquainted with the context in which the simulator has been used.

The main objective of an agent-based model is to virtually recreate a scenario where a large part of the elements that appear in it act autonomously based on the parameters assigned through the programming code with which the model is designed. Today virtual simulations are used in a large number of disciplines such as the social sciences, engineering or health sciences. The elements that make up each simulation are called agents, Wilensky and Rand (2016) defined the term agent as "an autonomous individual element of a computer simulation". In this work, simulations have been carried out using the software Wilensky, U. (1999). NetLogo. In this software we can distinguish four types of agents: Patches, turtles, the observer and links. In the next lines, the essential characteristics of the agents will be discussed and we will use some of the properties of Wilensky, U. (1998) NetLogo Wealth Distribution model as an example. The reader have to know that the simulations reproduced by this model are in 2D, so the examples and explanations that will be provided below are based on a 2D simulation context.

As commented above, in the NetLogo wealth distribution model we can observe three agents, patches, turtles and the observer participate. The patches are distributed throughout this virtual world so that each one has its coordinates, at the point (0,0) is the central patch. Through the programming language we can determine the number of patches that each simulation has. Patches remain fixed in the simulation, cannot be moved, and turtles moves over them. Although they do not move, the patches actively participating in the simulation performing certain actions. In the case of the Wilensky, U. (1998). NetLogo Wealth Distribution model, the patches hold a certain amount of grain that is collected by the turtles. When a patch runs out of grain, it generates it again until it reaches the amount of grain that that patch can support, through the programming

code of the simulator, the amount of grain that each of the patches can support is randomly established that form the simulation.

On the other hand, turtles could be interpreted as the inhabitants of the simulated world, so it will be from the context of our model. The turtles, as already mentioned, move on the patches following previously set parameters that determine the patterns of their movements, the actions to be carried out and the reasons that justify a certain action. Continuing with the example of NetLogo wealth distribution model, a tortoise may to collect or may not collect grain, which in programming terms is known as a binary state. The turtle can also perceive the amount of grain in a patch, which we would call a multivalued state. In the simulation provided by NetLogo, the turtles have a grain limit that they can accumulate, therefore the amount of grain they have at any given time will justify the turtle's action of catching or not catching more grain. On the other hand, the turtle can know the amount of grain that the patches around it have, which will justify the turtle movement towards a certain patch.

We will not analyze the links because it are not relevant for our study and we will end this section describing the role of the observer. The observer does not have a location within the simulated world, he has the possibility of altering the simulation code, which means introducing changes in it such as increasing the number of patches that appear in the simulation, creating or eliminating turtles or changing the properties of these. He can also order a group of turtles to perform a certain action by following instructions. We have been the observer during our study, we have changed parameters, we have modified the code and we have observed the results.

## 7 NetLogo Wealth Distribution model and reality.

Through the multi-agent programmable modeling environment NetLogo and its model library we can get access to Wilensky, U. (1998). NetLogo wealth distribution model, adapted from Epstein and Axtell's sugarscape model. This simulation provide a virtual world where there is a quantity of grain and a finite number of turtles distributed throughout it. Turtles collect grain and accumulate as much as possible while consuming

it. Patches that contain grain are colored yellow, the more intense the yellow color in a patch, the more grain it contains. Patches without grain are black. The turtles in this simulation are colored according to the amount of grain they have. Turtles that have less than a third of the grain accumulated than the turtle that has the most grain are colored red. The turtles that have between one third and two thirds of this same quantity are colored green and the rest, the turtles that have more grain, are colored blue.
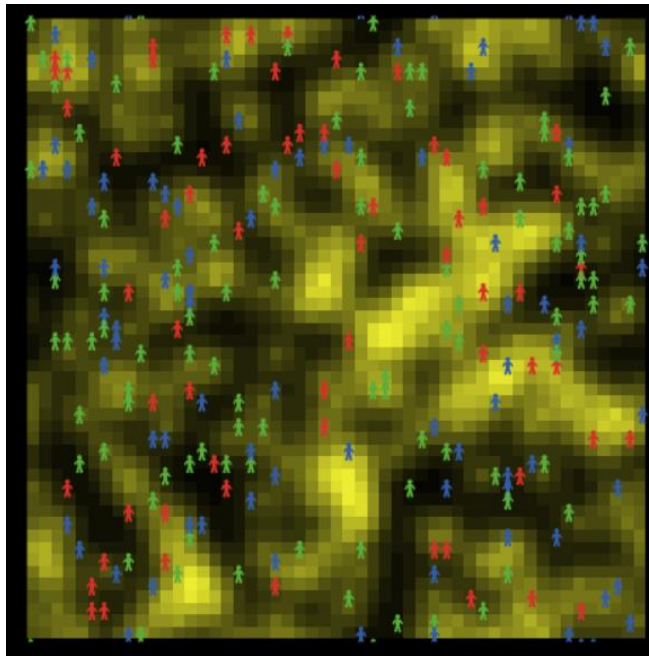


Figure 2: 2D view of Wilensky, U. (1998). NetLogo Wealthl Distribution model

The simulation code also determines the vision of the turtles. In the code provided by NetLogo, turtles can analyze the amount of grain in the patch in front of them, to a specified number of patches. In the default code, the vision of each turtle is different, everyone can see at least one patch forward and a maximum of 5. The capacity of each turtle is set randomly. The turtle has the ability to turn 90 degrees, 180 or 270 but the turtle does not have the ability to see diagonally.

In the two previous paragraphs we observed three properties of the simulation that we can extrapolate to reality. In the first place, the division of turtles by colors based on the

amount of grain they possess is perfectly extrapolated to the division of society into social classes based on the wealth they possess. In the simulation, the turtles are divided into three classes, red green and yellow, and in reality we can also divide citizens into three classes, low or poor, middle class and upper class or top income class. This is the idea that follows the simulation. On the other hand, in the vision of turtles we have another property that we have considered that can also be extrapolated to reality. One of the conclusions of Balboni, Bandiera, Burgess, Ghatak and Heil (2020) was "people are poor because of a lack of opportunity". As mentioned before, a turtle has a reduced visibility, it means that it cannot know the amount of wealth that exists in the entire simulated world and therefore there is the possibility that the turtle does not access to areas with greater wealth and improve its social status. In this simulation we can see rich areas, areas with great amount of grain, and poor areas, areas without grain. Also here we find a parallelism with the real world where there are regions with more wealth than other regions and regions where there is no wealth.

The next section will show the evolution of the Gini index and the number of turtles that form each social class over time. In the virtual world with which we work, time passes discreetly, and the unit of measurement of time is the tick. We rely on the tick to measure the time that has passed in the simulation. The default life expectancy of turtles is 83 ticks, a turtle can only remain in the virtual world 83 tick and then it will be replaced by another that will have a random amount of grain, which means that a turtle does not leave an economic legacy after its death. As will be shown later, the life expectancy and other parameters can be modified.

As previously mentioned briefly, turtles, in addition to collecting grain, consume it. Turtles have a metabolism that determines the amount of grain they consume at any given number of ticks. Turtle metabolism varies and is determined randomly at the start of each simulation and at the birth of a new turtle. Metabolism is another interesting variable of this code because can be interpreted as the human consumption. The default code provided by NetLogo presents the following interface, where the previously mentioned parameters can be modified.

# 8 Observations and modifications

The simulation generated by the code and predetermined parameters shows cycles in the number of turtles that make up each class, the Gini index and the total wealth of turtles, but we do not observe decreasing or increasing trend. Although the Gini index that we obtain is high, it is similar to that of countries such as Brazil or Mozambique, and a change in the number of turtles or others parameters can reduce the Gini Index. We could also consider that there is a certain similarity between reality and the graph that details the amount of population that belongs to each class. However, economic theory has taught us that throughout history the level of total wealth has an increasing trend. The economies grows over the time. Also, the reviewed bibliography has shown us how the level of inequality in the distribution of wealth has increased in recent decades.
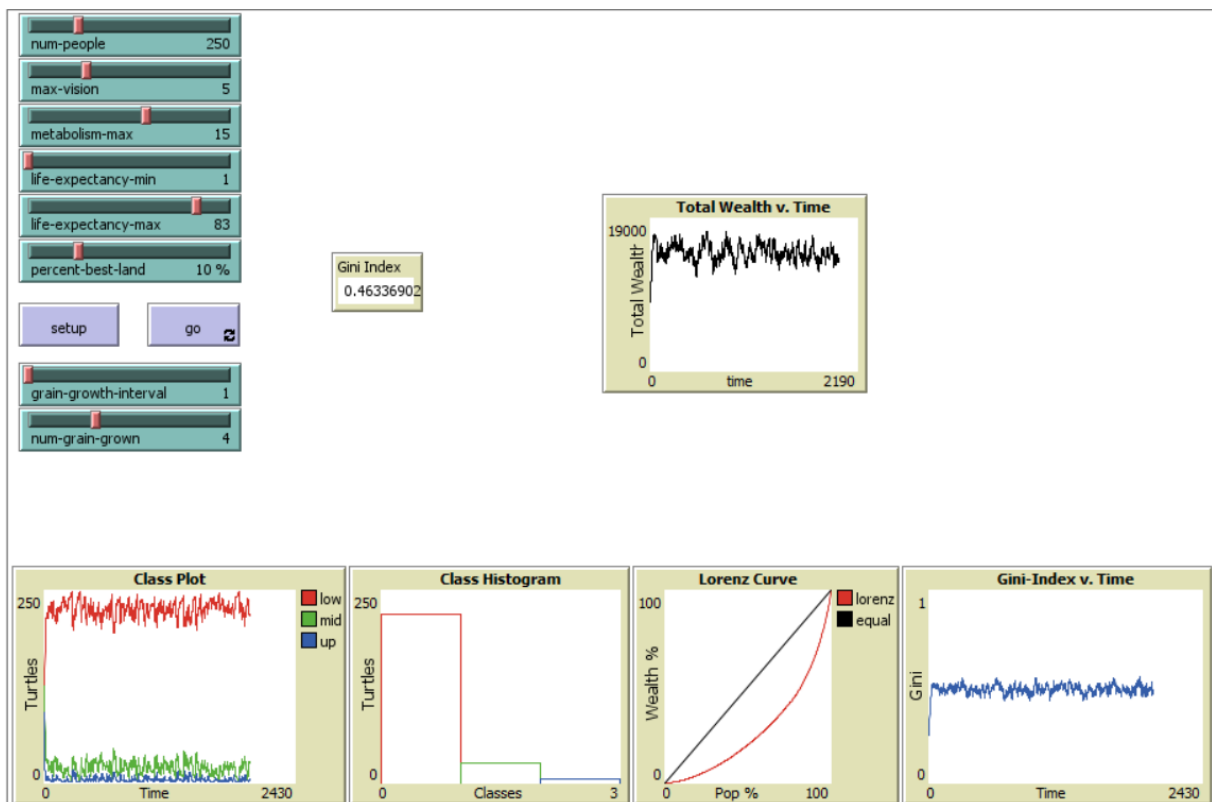


Figure 3: Observations with predetermined code and parameters

With the aim of obtain an increasing trend over time in the Gini Index and the total wealth, we modified the simulation code by adding a bequest. As mentioned before, when a turtle dies it is replaced by another that has a random amount of grain that must be at least equal to its metabolism, since if it were lower it could not survive. With our modification, when a turtle dies it transfers its wealth to the turtle that replaces it. In this way, the wealth accumulated by the turtles will not be eliminated and will continue among the population generation after generation. The results after this modification show increasing trends in both graphs. The growth of the Gini index over time makes it reach values that we do not observe in reality, so we will have to give up obtaining realistic values of the Gini index in favor of obtaining a realistic trend of its evolution over time.

In addition to modifying the code, we have added indicators to know the percentage of turtles that make up each social class and the total wealth accumulated by each of these classes. As shown in the following image, the turtles that belong to the top class represent 1.6% of the total population and the total wealth accumulated by this social class is 14,106. On the other hand, the middle class represents 6% of the total population and its total accumulated wealth is 25799. Knowing that the total wealth of our virtual world is 87111. We add both percentages and the total wealth of both social classes we obtain that 7.6% of the richest population of our simulated universe owns 45.81% of the total wealth. This last percentage obtained is among the values that Piketty (2014) shows us of accumulated wealth by the top 1% and the top 10% in France, the United States and Sweden from 1970 to 2010. Figures showed in the appendix A
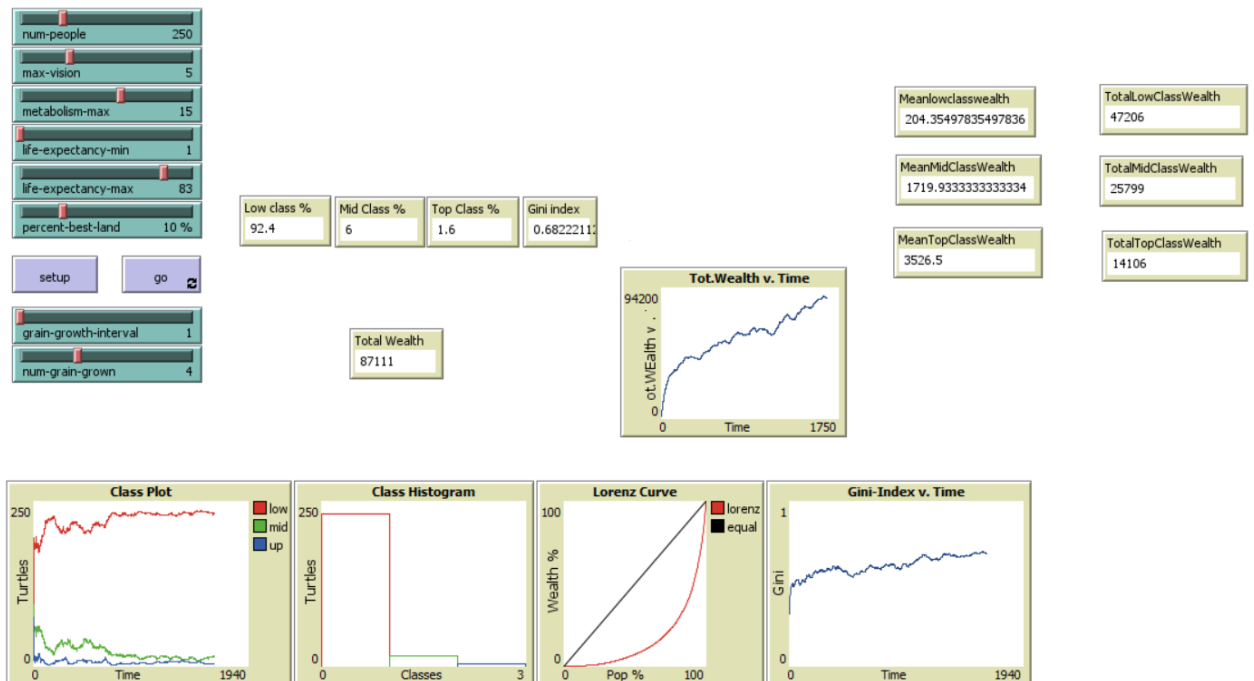
Figure 4: Results observed with adding inheritance to the code

The bibliographic resources discussed above also showed us the relevance of taxes on the level of inequality in the distribution of wealth. Following the idea of Piketty (2014), we added a progressive inheritance tax to the code in order to reduce the Gini index of the simulation. First, we add a tax rate to the code, which we can regulate from the simulator interface, and which we multiply the previously added bequest. The result of this multiplication is subtracted from the bequest and creates a new variable that we have called inheritance. For the tax to have a progressive character, we add the following operation to the code in the section where the initial characteristics of a turtle at birth are determined.

**totalwealthtax * (1 - (wealth / sum [wealth] of turtles))**

With this tax now each turtle has a different inheritance depending on the wealth it has at its birth. After the introduction of the tax, we observed a decrease in the Gini index. As expected, this decline is not prolonged over time. The index tends to stabilize over time and remain constant. In the following image we see the data that emerges from the simulation once the 5% tax has been added. The evolution of the Gini index is shown in red after the tax has been set.
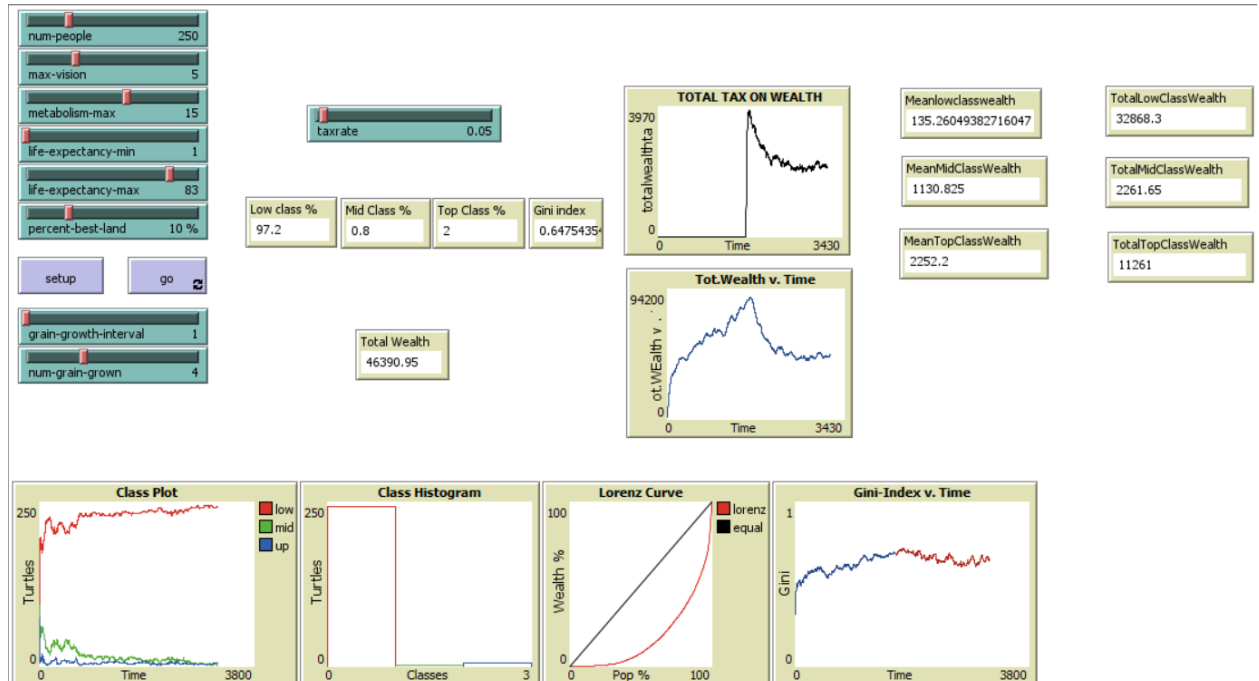
Figure 5: Results observed with inheritance and tax on inheritance wealth (color red).

Apart of the decrease in the Gini index, we observe how total wealth tends to decrease until it finally stabilizes. This is explained by the context of our simulation. We understand by total wealth the sum of the grain of all the turtles, therefore, when introducing the tax, the amount of grain retained by it ceases to be part of the total wealth. In reality, this wealth would become part of the public treasury. We also observe changes in the number of turtles that make up each social class. This is justified by the decrease in the Gini index itself and by the parameters to be followed when differentiating the social classes set in the simulation code. Given that the inequality of wealth distribution has been reduced and as the turtle with the most wealth is the one that determines the classification in the different classes, the growth of the number of turtles that form the lower class and the reduction of the number of turtles that form the middle and top classes is something totally expected.

On the other hand, we observe that the richest 2% of our virtual population owns 24.27% of the total wealth, that is, that accumulated among all the turtles. We observe how this percentage is clearly below that shown by Piketty (2014) in the graph that details

inequality in wealth in the United States, if we compare it with the levels from 1970 to 2010.

Given all the above, we can conclude that the effect of the introduction of a progressive tax on the distribution of wealth in our virtual world has had the effects that we expect to have in the real world with the application of a tax of a similar nature. As mentioned, the work carried out has had certain limitations due to the nature of the code used. The Gini index is the tool we use to analyze inequality in our virtual world. The Gini index that emerges from our simulations grows steadily once the bequest is entered into the code reaching figures that are very difficult to observe in reality. We consider more important for the study to work with a growing trend of inequality to try to reverse it with a progressive tax. Given the nature of the code used, the concept of total wealth has been established, which is no longer valid in the study once the tax is added for the reasons previously explained. It is possible that these aspects and others such as the criteria for classifying turtles into social classes could be defined with a higher level of development of the simulation code.

## 9 Conclusions

In reference to the first part of the work, in the first place we observe how the levels of inequality in the distribution of income and wealth begin to follow a trend similar to the observed during the 19th century and which stopped at the beginning of the last century, we can intuit this is largely due to the level of wealth destruction that occurred during the two world wars. On the other hand, Piketty's definition of inequality, r > g, does imply that this trend can be increasing over a long period of time and there is the possibility of reaching the levels of inequality observed before the First World War in countries such as USA or France for example.

Secondly, we have demonstrated the danger posed to the meritocracy of our society by the inheritance system implemented in most developed countries, specifically we have analyzed the example of Sweden and France, where we observe how inheritances favor the accumulation of capital and, due to the importance of consumer behavior between

social classes to inequality in the distribution of wealth. From this section we have drawn the conclusion that a progressive inheritance tax could be a very useful tool to combat wealth inequality.

Through the conclusions discussed in the previous paragraph we can intuit that the role of the state is essential to reduce inequalities. In the last section of this first part of our work we can affirm this idea. We have analyzed how the effects of neoliberal policies, mainly those carried out in the US, have meant an increase in inequality, negatively affecting fields such as health, education or housing, which are fundamental rights that any human should have. This work claim for a global change on the economic politics, mainly in the fiscal policies, and the need of the participation of the state and public institutions in the economy with the aim of reduce social inequalities that are linked to the wealth and income inequalities.

On the other hand, with reference to the second part of this work, we verify that the wealth distribution model provided by Netlogo has different interesting aspects for the study of this phenomenon. The metabolism and the vision of the turtles on the one hand, as we have verified, are variables necessary to understand the nature of the distribution of wealth. On the other hand, are two very interesting variables that can be used to develop other simulations or studies related to other fields of economics. We also find interesting the way in which wealth is generated in this simulation and the way it is distributed through the patches of the simulation, creating areas with great economic potential and areas with structural poverty as it seems to be observed in reality.

We end these conclusions by commenting on the results obtained and the limitations of our work. In reference to the results obtained, our modifications to the simulation code have managed to provide a growing trend to the total wealth of the simulated world through the inheritance of wealth. It has also been possible to reduce the inequality in the distribution of wealth in the simulation through a progressive tax. In general terms, our modifications to the code have created a more realistic simulation, with generational changes, a legacy of wealth and increasing trends in the growth of the economy and inequality as has been observed in reality. Where the application of the tax has a certain experimental character. On the other hand, the limits of this work are highly linked to the development of the simulation code. The increasing trend of inequality over the time once bequest is introduced forces us to give up realistic Gini coefficients, especially since once inheritance is introduced, changes in the population number or amount of grain in

the patches that previously reduced the Gini coefficient of simulations now produce less realistic results. As mentioned at the end of the previous section, the important thing for us is to achieve a growing trend in inequality and to work with it. Also although it is less important, we commented that when applying the progressive tax we should ignore the total wealth graph because the amount withheld by the tax was not shown.

With the comments in the previous paragraph, we affirm that in order to improve the results obtained and achieve greater harmonization between the different parameters and variables that make up the simulation, it is necessary to develop the simulation code more deeply. Our work has been based on studying the code to understand it and add some small modifications. The capacity of the simulator is considerably large and there is the possibility of making a large number of modifications in order to obtain more realistic results or to focus the simulations towards other contexts. Following the line of our study, it would be interesting to fix the metabolism of turtles according to the social class to which they belong. We know that consumption habits can explain the accumulation of wealth. Fixing the vision of the turtles according to their social class would also be interesting. Introducing the two changes discussed above at the same time could be even more interesting. These could be some of the aspects to improve in our code.

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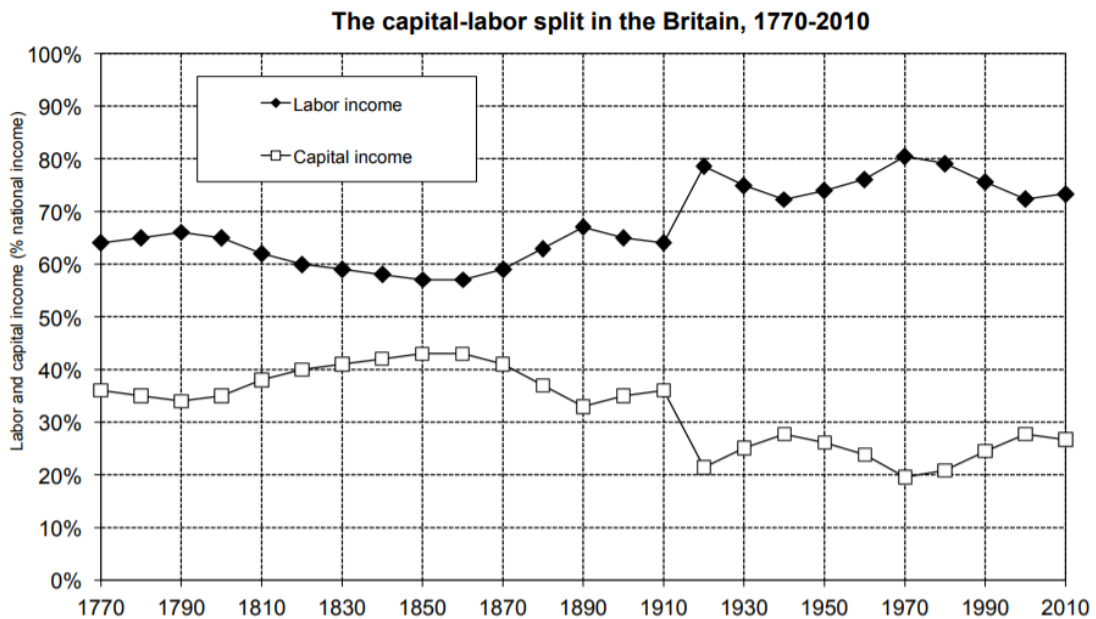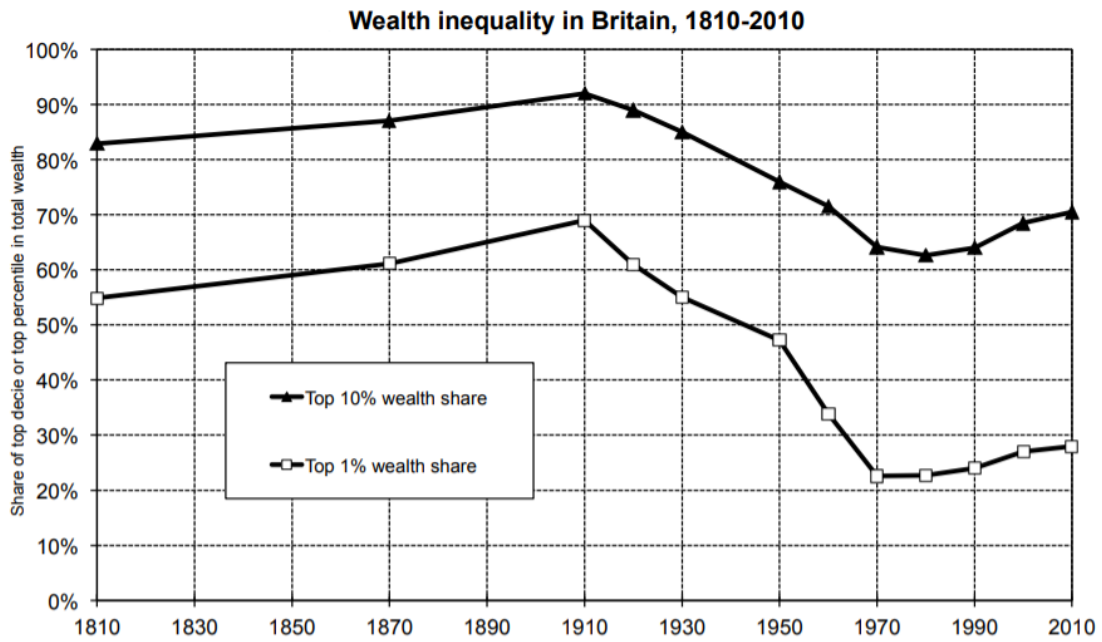
# 11 Appendix A
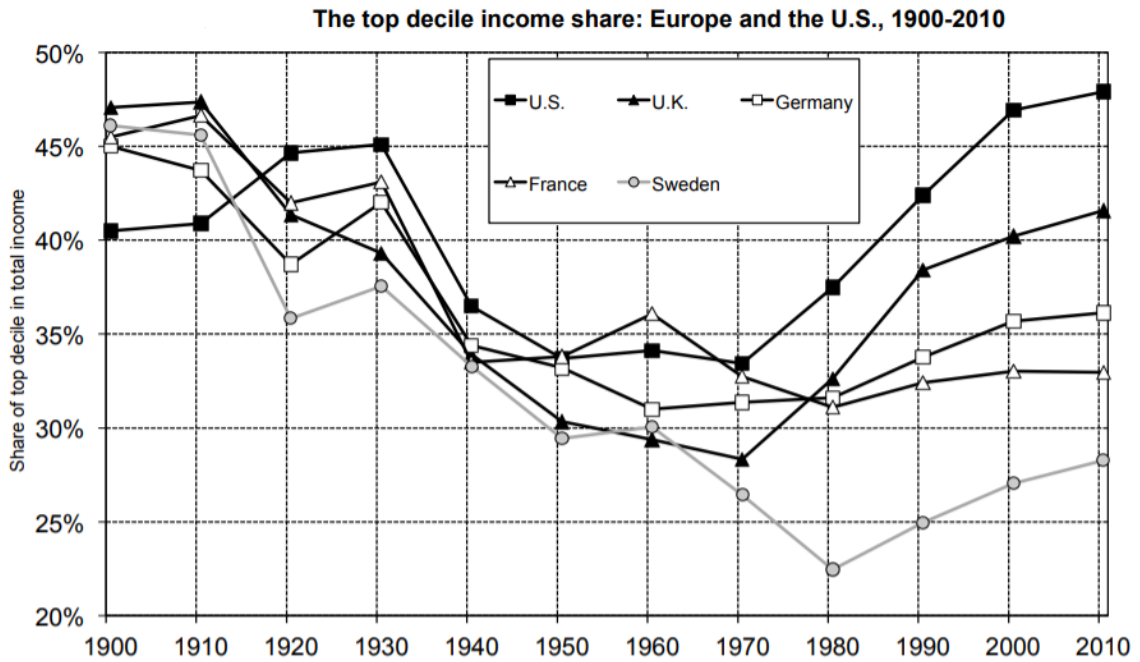
**The capital-labor split in the Britain, 1770-2010**

Figure available in: http://piketty.pse.ens.fr/files/capital21c/en/pdf/F6.1.pdf

## Wealth inequality in Britain, 1810-2010



Figure available in: http://piketty.pse.ens.fr/files/capital21c/en/pdf/F10.3.pdf

## The top decile income share: Europe and the U.S., 1900-2010

## Wealth inequality in the U.S., 1810-2010

**Wealth inequality in Sweden, 1810-2010**



Figure available in: http://piketty.pse.ens.fr/files/capital21c/en/pdf/F10.4.pdf

**The annual inheritance flow
as a fraction of national income, France 1820-2010**



Figure available in: http://piketty.pse.ens.fr/files/capital21c/en/pdf/F11.1.pdf
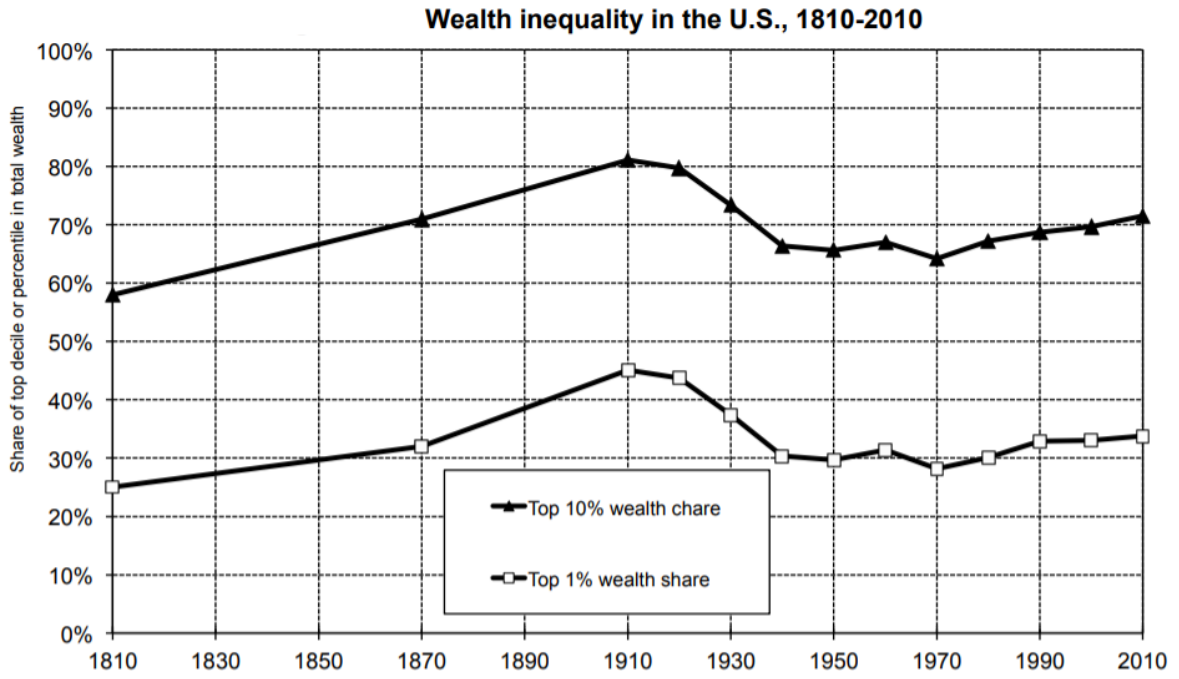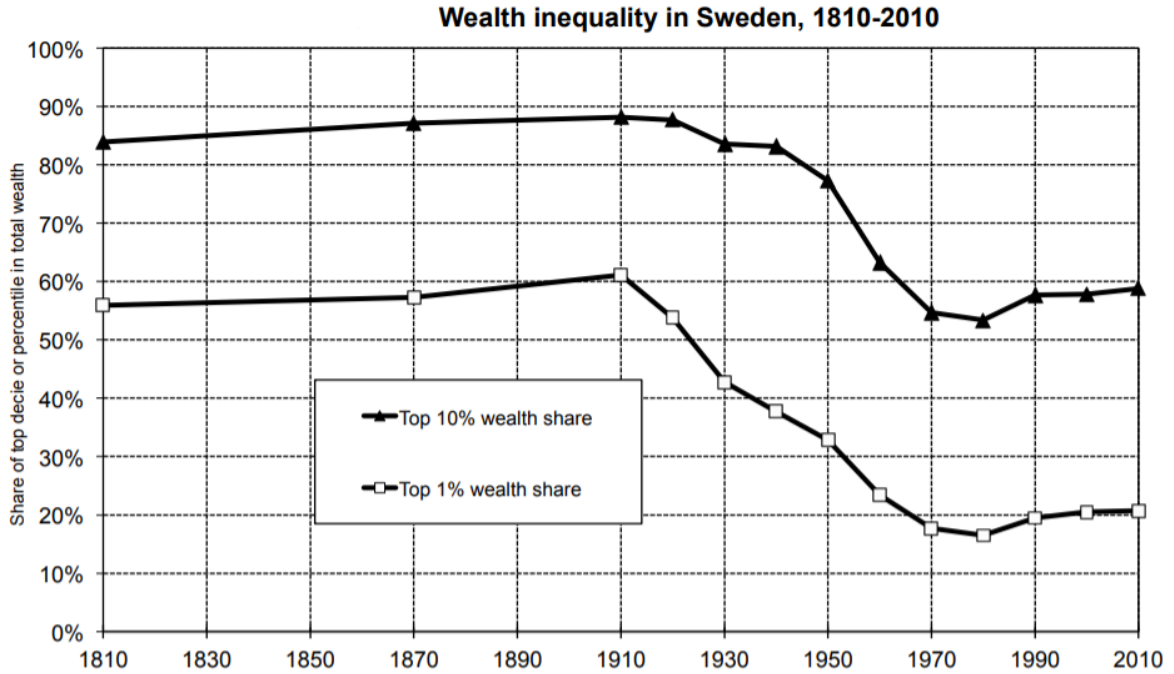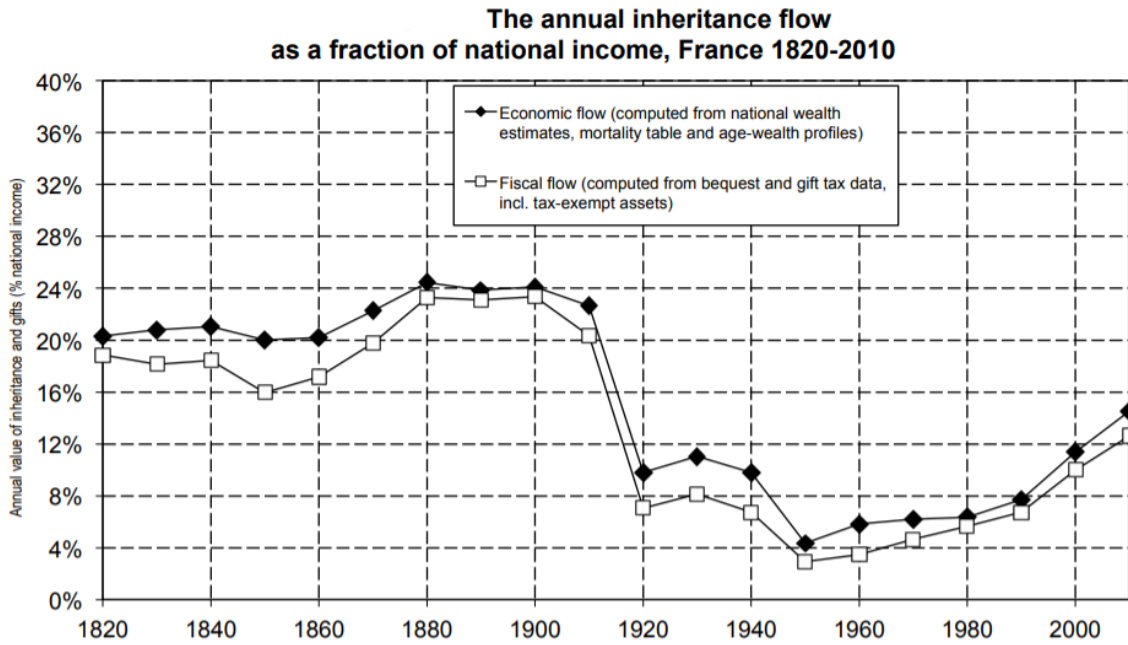
## 12 Appendix B

12.1 Predetermine code

```
globals
[
  max-grain     ; maximum amount any patch can hold
  gini-index-reserve
  lorenz-points
]

patches-own
[
  grain-here      ; the current amount of grain on this patch
  max-grain-here  ; the maximum amount of grain this patch can hold
]

turtles-own
[
  age               ; how old a turtle is
  wealth            ; the amount of grain a turtle has
  life-expectancy   ; maximum age that a turtle can reach
  metabolism        ; how much grain a turtle eats each time
  vision            ; how many patches ahead a turtle can see
]

;;;
;;; SETUP AND HELPERS
;;;

to setup
  clear-all
  ;; set global variables to appropriate values
  set max-grain 50
  ;; call other procedures to set up various parts of the world
  setup-patches
  setup-turtles
  update-lorenz-and-gini
  reset-ticks
end
```

```
;; set up the initial amounts of grain each patch has
to setup-patches
  ;; give some patches the highest amount of grain possible --
  ;; these patches are the "best land"
  ask patches
    [ set max-grain-here 0
      if (random-float 100.0) <= percent-best-land
        [ set max-grain-here max-grain
          set grain-here max-grain-here ] ]
  ;; spread that grain around the window a little and put a little back
  ;; into the patches that are the "best land" found above
  repeat 5
    [ ask patches with [max-grain-here != 0]
        [ set grain-here max-grain-here ]
      diffuse grain-here 0.25 ]
  repeat 10
    [ diffuse grain-here 0.25 ]              ;; spread the grain around some more
  ask patches
    [ set grain-here floor grain-here      ;; round grain levels to whole numbers
      set max-grain-here grain-here        ;; initial grain level is also maximum
      recolor-patch ]
end

to recolor-patch  ;; patch procedure -- use color to indicate grain level
  set pcolor scale-color yellow grain-here 0 max-grain
end

;; set up the initial values for the turtle variables
to setup-turtles
  set-default-shape turtles "person"
  create-turtles num-people
    [ move-to one-of patches  ;; put turtles on patch centers
      set size 1.5  ;; easier to see
      set-initial-turtle-vars ]
  recolor-turtles
end
```

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```
to set-initial-turtle-vars
  face one-of neighbors4
  set life-expectancy life-expectancy-min +
                      random (life-expectancy-max - life-expectancy-min + 1)
  set metabolism 1 + random metabolism-max
  set wealth metabolism + random 50
  set vision 1 + random max-vision
  set age random life-expectancy
end

;; Set the class of the turtles -- if a turtle has less than a third
;; the wealth of the richest turtle, color it red.  If between one
;; and two thirds, color it green.  If over two thirds, color it blue.
to recolor-turtles
  let max-wealth max [wealth] of turtles
  ask turtles
    [ ifelse (wealth <= max-wealth / 3)
        [ set color red ]
        [ ifelse (wealth <= (max-wealth * 2 / 3))
            [ set color green ]
            [ set color blue ] ] ]
end

;;;
;;; GO AND HELPERS
;;;

to go
  ask turtles
    [ turn-towards-grain ]  ;; choose direction holding most grain within the turtle's vision
  harvest
  ask turtles
    [ move-eat-age-die ]
  recolor-turtles

  ;; grow grain every grain-growth-interval clock ticks
  if ticks mod grain-growth-interval = 0
    [ ask patches [ grow-grain ] ]

  update-lorenz-and-gini
  tick
end
```

```
;; determine the direction which is most profitable for each turtle in
;; the surrounding patches within the turtles' vision
to turn-towards-grain   ;; turtle procedure
  set heading 0
  let best-direction 0
  let best-amount grain-ahead
  set heading 90
  if (grain-ahead > best-amount)
    [ set best-direction 90
      set best-amount grain-ahead ]
  set heading 180
  if (grain-ahead > best-amount)
    [ set best-direction 180
      set best-amount grain-ahead ]
  set heading 270
  if (grain-ahead > best-amount)
    [ set best-direction 270
      set best-amount grain-ahead ]
  set heading best-direction
end

to-report grain-ahead   ;; turtle procedure
  let total 0
  let how-far 1
  repeat vision
    [ set total total + [grain-here] of patch-ahead how-far
      set how-far how-far + 1 ]
  report total
end

to grow-grain   ;; patch procedure
  ;; if a patch does not have it's maximum amount of grain, add
  ;; num-grain-grown to its grain amount
  if (grain-here < max-grain-here)
    [ set grain-here grain-here + num-grain-grown
      ;; if the new amount of grain on a patch is over its maximum
      ;; capacity, set it to its maximum
      if (grain-here > max-grain-here)
        [ set grain-here max-grain-here ]
      recolor-patch ]
end
```

```
;; each turtle harvests the grain on its patch.  if there are multiple
;; turtles on a patch, divide the grain evenly among the turtles
to harvest
  ; have turtles harvest before any turtle sets the patch to 0
  ask turtles
    [ set wealth floor (wealth + (grain-here / (count turtles-here))) ]
  ;; now that the grain has been harvested, have the turtles make the
  ;; patches which they are on have no grain
  ask turtles
    [ set grain-here 0
      recolor-patch ]
end

to move-eat-age-die  ;; turtle procedure
  fd 1
  ;; consume some grain according to metabolism
  set wealth (wealth - metabolism)
  ;; grow older
  set age (age + 1)
  ;; check for death conditions: if you have no grain or
  ;; you're older than the life expectancy or if some random factor
  ;; holds, then you "die" and are "reborn" (in fact, your variables
  ;; are just reset to new random values)
  if (wealth < 0) or (age >= life-expectancy)
    [ set-initial-turtle-vars ]
end

;; this procedure recomputes the value of gini-index-reserve
;; and the points in lorenz-points for the Lorenz and Gini-Index plots
to update-lorenz-and-gini
  let sorted-wealths sort [wealth] of turtles
  let total-wealth sum sorted-wealths
  let wealth-sum-so-far 0
  let index 0
  set gini-index-reserve 0
  set lorenz-points []
```

```
  ;; now actually plot the Lorenz curve -- along the way, we also
  ;; calculate the Gini index.
  ;; (see the Info tab for a description of the curve and measure)
  repeat num-people [
    set wealth-sum-so-far (wealth-sum-so-far + item index sorted-wealths)
    set lorenz-points lput ((wealth-sum-so-far / total-wealth) * 100) lorenz-points
    set index (index + 1)
    set gini-index-reserve
      gini-index-reserve +
      (index / num-people) -
      (wealth-sum-so-far / total-wealth)
  ]
end
```

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## 12.2 Code with inheritance and progressive tax

```
globals
[
  max-grain       ; maximum amount any patch can hold
  gini-index-reserve
  lorenz-points
  totalwealthtax
]

patches-own
[
  grain-here      ; the current amount of grain on this patch
  max-grain-here  ; the maximum amount of grain this patch can hold
]

turtles-own
[
  age             ; how old a turtle is
  wealth          ; the amount of grain a turtle has
  life-expectancy ; maximum age that a turtle can reach
  metabolism      ; how much grain a turtle eats each time
  vision          ; how many patches ahead a turtle can see
  bequest         ; legacy that receive a new turtle
  inheritance     ; bequest after tax before progressive factor
  wealthtax       ; withhelded part of bequest
]

;;;
;;; SETUP AND HELPERS
;;;

to setup
  clear-all
  ;; set global variables to appropriate values
  set max-grain 50
  ;; call other procedures to set up various parts of the world
  setup-patches
  setup-turtles
  update-lorenz-and-gini
  update-aggregates
  reset-ticks
```

```
;; set up the initial amounts of grain each patch has
to setup-patches
  ;; give some patches the highest amount of grain possible --
  ;; these patches are the "best land"
  ask patches
    [ set max-grain-here 0
      if (random-float 100.0) <= percent-best-land
        [ set max-grain-here max-grain
          set grain-here max-grain-here ] ]
  ;; spread that grain around the window a little and put a little back
  ;; into the patches that are the "best land" found above
  repeat 5
    [ ask patches with [max-grain-here != 0]
        [ set grain-here max-grain-here ]
      diffuse grain-here 0.25 ]
  repeat 10
    [ diffuse grain-here 0.25 ]           ;; spread the grain around some more
  ask patches
    [ set grain-here floor grain-here     ;; round grain levels to whole numbers
      set max-grain-here grain-here       ;; initial grain level is also maximum
      recolor-patch ]
end

to recolor-patch ;; patch procedure -- use color to indicate grain level
  set pcolor scale-color yellow grain-here 0 max-grain
end

;; set up the initial values for the turtle variables
to setup-turtles
  set-default-shape turtles "person"
  create-turtles num-people
    [ move-to one-of patches  ;; put turtles on patch centers
      set size 1.5  ;; easier to see
      set-initial-turtle-vars ]
  recolor-turtles
end
```

```
to set-initial-turtle-vars
  face one-of neighbors4
  set life-expectancy life-expectancy-min +
                      random (life-expectancy-max - life-expectancy-min + 1)
  set metabolism 1 + random metabolism-max
  set wealth ifelse-value (sum [ wealth ] of turtles > 0)
    [metabolism + inheritance + totalwealthtax * ( 1 - (wealth /  sum [ wealth ] of turtles))]
    [metabolism + inheritance + totalwealthtax / num-people ]
  set vision 1 + random max-vision
  set age random life-expectancy

end

;; Set the class of the turtles -- if a turtle has less than a third
;; the wealth of the richest turtle, color it red.  If between one
;; and two thirds, color it green.  If over two thirds, color it blue.
to recolor-turtles
  let max-wealth max [wealth] of turtles
  ask turtles
    [ ifelse (wealth <= max-wealth / 3)
        [ set color red ]
        [ ifelse (wealth <= (max-wealth * 2 / 3))
            [ set color green ]
            [ set color blue ] ] ]
end
```

```
;;;; GO AND HELPERS
;;;;

to go
  ask turtles
    [ turn-towards-grain ]  ;; choose direction holding most grain within the turtle's vision
  harvest
  ask turtles
    [ move-eat-age-die ]
  recolor-turtles

  ;; grow grain every grain-growth-interval clock ticks
  if ticks mod grain-growth-interval = 0
    [ ask patches [ grow-grain ] ]

  update-lorenz-and-gini
  tick
end

;; determine the direction which is most profitable for each turtle in
;; the surrounding patches within the turtles' vision
to turn-towards-grain  ;; turtle procedure
  set heading 0
  let best-direction 0
  let best-amount grain-ahead
  set heading 90
  if (grain-ahead > best-amount)
    [ set best-direction 90
      set best-amount grain-ahead ]
  set heading 180
  if (grain-ahead > best-amount)
    [ set best-direction 180
      set best-amount grain-ahead ]
  set heading 270
  if (grain-ahead > best-amount)
    [ set best-direction 270
      set best-amount grain-ahead ]
  set heading best-direction
end
```

```
to-report grain-ahead   ;; turtle procedure
  let total 0
  let how-far 1
  repeat vision
    [ set total total + [grain-here] of patch-ahead how-far
      set how-far how-far + 1 ]
  report total
end

to grow-grain   ;; patch procedure
  ;; if a patch does not have it's maximum amount of grain, add
  ;; num-grain-grown to its grain amount
  if (grain-here < max-grain-here)
    [ set grain-here grain-here + num-grain-grown
      ;; if the new amount of grain on a patch is over its maximum
      ;; capacity, set it to its maximum
      if (grain-here > max-grain-here)
        [ set grain-here max-grain-here ]
      recolor-patch ]
end

;; each turtle harvests the grain on its patch.  if there are multiple
;; turtles on a patch, divide the grain evenly among the turtles
to harvest
  ; have turtles harvest before any turtle sets the patch to 0
  ask turtles
    [ set wealth floor (wealth + (grain-here / (count turtles-here))) ]
  ;; now that the grain has been harvested, have the turtles make the
  ;; patches which they are on have no grain
  ask turtles
    [ set grain-here 0
      recolor-patch ]
end
```

```
to move-eat-age-die   ;; turtle procedure
  fd 1
  ;; consume some grain according to metabolism
  set wealth (wealth - metabolism)
  ;; grow older
  set age (age + 1)
  ;; check for death conditions: if you have no grain or
  ;; you're older than the life expectancy or if some random factor
  ;; holds, then you "die" and are "reborn" (in fact, your variables
  ;; are just reset to new random values)
  if (wealth < 0) or (age >= life-expectancy)
    [set bequest max list 0 wealth
      set wealthtax taxrate * bequest
      set inheritance bequest - wealthtax
      set-initial-turtle-vars ]
end

;; this procedure recomputes the value of gini-index-reserve
;; and the points in lorenz-points for the Lorenz and Gini-Index plots
to update-lorenz-and-gini
  let sorted-wealths sort [wealth] of turtles
  let total-wealth sum sorted-wealths
  let wealth-sum-so-far 0
  let index 0
  set gini-index-reserve 0
  set lorenz-points []


  ;; now actually plot the Lorenz curve -- along the way, we also
  ;; calculate the Gini index.
  ;; (see the Info tab for a description of the curve and measure)
  repeat num-people [
    set wealth-sum-so-far (wealth-sum-so-far + item index sorted-wealths)
    set lorenz-points lput ((wealth-sum-so-far / total-wealth) * 100) lorenz-points
    set index (index + 1)
    set gini-index-reserve
      gini-index-reserve +
      (index / num-people) -
      (wealth-sum-so-far / total-wealth)
  ]
end




      to update-aggregates
        set totalwealthtax sum [wealthtax] of turtles
      end
```