RURAL-URBAN MIGRATION: AN AGENT-BASED SIMULATION

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Introduction

As the title might suggest, the following work has the purpose of describing the basic dynamics of the phenomenon of migration from rural areas to urban ones by mean of an agent-based simulation. The main underlying idea has been taken from Todaro and Smith (2009), as the model created by the first (along with its diagrammatic presentation, named the "Harris-Todaro Migration Model") has widely inspired the construction of the simulation.

As the Authors do, the focus of this work is in the urbanization process taking place in most of the developing and poorest countries of the world, which "are far more urbanized than today's developed countries were when they were at a comparable level of development, as measured by income per capita; and LDCs[1] are urbanizing at a faster rate." (Todaro and Smith 2009, p321). This trend goes together with the increasing size of slums surrounding the major cities, which is caused both by an high birth rate and by the stream of migrants coming from rural areas, since this kind of migrants represents from 35% to 60% of the urban population growth (*ibidem*, p326).

What drives the migrants in their resettlement decision seems to be mainly the desire to escape from rural areas hoping to achieve, in big cities, better life conditions. But it is not clear the reason why people keep on moving to urban areas that, actually, do not guarantee them such better conditions. In simpler words: why do they migrate when they will likely be unemployed (or underemployed) and will live in dramatically poor slums? This question represents a challenge for development economists, mainly because it violates the classic assumption of rationality of economic agents. The first development models concerning migration (as the Lewis Model[2]) had as starting point the historical path occurred in western countries, where economic development had been tightly associated with the rural-urban migration which, through the decades, has re-allocated human resources from agriculture to manufacture sector, supplying labour-force to rising industries. The problem is that these models were designed considering a developed and industrialized context, thus using the underlying assumption off full, or nearly-full, employment, while instead in LDC's the urbanization process, that has led to streams of migrants from rural areas to cities, have continued despite an increasing rate of unemployment and underemployment among the urban population (*ibidem*, pp. 344 – 345).

The aim of the Todaro Model is to resolve this overwhelming contradiction between

1 Least Developed Countries. These countries are identified according three criteria: low income per capita, low level of human resource development and high level of economic vulnerability (see UN-CDP 2004).
2 For more details about Lewis Model, see Todaro and Smith (2009), Chapter 3.

the theoretical framework and the empirical evidence. What the Authors suggest, is that the decision on whether to migrate or not must be restated in terms of expected income, rather than of actual earnings. Quoting the examples used in the text, let us suppose that a worker can earn 50 units of real annual income working as farmer, while in the city, with his current skills and education, he could receive a salary of 100 annual units. Obviously, from the perspective of income differentials, to migrate would be a perfectly rational choice; but, as mentioned before, this argument seems unlikely to hold: if the probability of finding a well-paid job (as in developing countries cities environment) is very low, the income differential has little to do with the migration choice. In Authors opinion, it seems hence more realistic to assume that individuals compare the risks of being underemployed or unemployed, against the income difference considered above. Consequently, if the probability of getting an high-paid job, let's say within one year, is of the 20%, then the expected income the migrants shall consider will be of just 20 units: the choice would be not to migrate. If instead the same probability was of the 60% (the expected income being of 60 units), thus it would be rational to leave the land in search of a better wage, even though an high rate of unemployment may affect the urban area. Considering, furthermore, that the larger part of migrants is quite young, it seems realistic that people face a time horizon far larger than one year in deciding to move towards cities; this choice can be indeed motivated by expectations concerning permanent earnings. What will happen is that people will move even if their destination suffers from very high unemployment or underemployment rate: "As long as the present value of the net stream of the expected urban income over the migrant's planning horizon exceeds that of the expected rural income, the decision to migrate is justifiable." (*ibidem*, pp. 345-347).

For what concerns the simulation model, there are some similarities and some differences with respect to Todaro Model. In the former, the world is divided, for matter of simplicity, in three parts. The widest is the green one, which represents the land occupied by farmer. There is then a red square representing a city, the place where formal jobs can be found, surrounded by a blue area which is the suburbs, ideally the spatial representation of informal jobs and underemployment. Agents, represented by turtles, freely move in the space by following certain decision rules. These latter have been designed differently from what is assumed by the Harris-Todaro Model, where people will migrate until the prevailing agricultural wage will not equate the expected urban wage (i.e. the urban wage is multiplied by the probability of obtaining a job). This choice have been made considering the fact that agents, in order to compute the probability of getting an employment in the formal manufacturing sector, should know the total labour-force in the urban area and the amount of it employed in the industrial sector[3]. This kind of knowledge seems unlikely to be at people disposal, since national statistics are not (and hardly can be) carefully elaborated in LDCs, mainly because of a big lack of reliable data. Thus, to

3 The probability of obtaining a formal job is computed as the ratio between the total urban labour-force and the labour-force which actually has this kind of job. For more details, see Todaro and Smith (2009), pp. 347- 349.

make the simulation more “agent-based” (Harris-Todaro Model has a more “macro” perspective), the decision rule is simply: how much do I earn? Would it be better in another place? If is it so, agents will then move towards the areas that guarantee them more wealth, at least in theory. Therefore, if income is greater in the city than in the land, they will move to the former.

As in the theoretical model, this time, the dynamics taking place in the city are influenced by a limited number of work places available: the Harris-Todaro Model considers as exogenously given the wage in the urban context, following the argument that salary of jobs in the formal sector are institutionally set up. Considering these assumptions, the simulation model presents a limited number of jobs available in the red area, which can change only by decision of the observer. Those who, coming from the land, manage to get one of these jobs, earn a wage large enough that they are no longer induced to move following the income differential. Those instead who are left without employment in the red area, are relocated in the suburbs (blue area), where the income they earn (according to the rules explained in details in the next section) has to be shared with the agents occupying their same place. If, after this division, agents' income is less than that prevailing in the agriculture, they move back to the green area.

In all these movements, agents follow what they expect to be their future wealth; what they will actually get depends on the situation in which their destinations are (e.g if there is room for everybody or not, or how many agents are already occupying that place). The aim of the simulation is to check whether an emergent behaviour arises when agents follow such simple decision rules, and to check the differences affecting this behaviour when some conditions are changed, for instance when income is assigned using different probabilistic distributions, when agents are allowed to imitate others or when single locations are endowed with the possibility of “producing” output according to a certain productivity function. This last case is also considered in Todaro-Smith (2009), since: “The informal sector is characterized by a large number of small-scale production and service activities that […] use a simple, labor-intensive technology” (p336).

Code Instances

```
to setup
...
 ask turtles
       [ifelse normal? = true
    [ if pcolor = red
     [set income random-normal income-from-city 10]
   if  pcolor = green
```

```
   [set income random-normal income-from-land 10]]
    [if pcolor = red [set income random income-from-city]
       if pcolor = green [set income random income-from-land]]]
   ask turtles [set friend one-of turtles in-radius 3]
```

These lines of code decide the income of which turtles are endowed at the very beginning of the program. In the program's interface, there are two sliders, namely “income-from-city” and “income-from-land”, on which the observer can act in order to set the income differential. So, when the program starts to run, turtles on the green area are averagely endowed with the income set by “ income-from-land”, the same happens to those on red patches using the slider “income-from-city”. “normal?” is referred to a switcher in the user interface. If it is on, the income is randomly assigned according to a normal distribution, with mean equal to the income of the sliders and a standard error of 10; otherwise the distribution is a uniform distribution, and the income is randomly assigned with an integer value that can go from 0 up to the number set by the slider.

The last line assigns to every turtles a friend, which will be imitated whenever the procedure “mimic” is called.

```
to migration

  ask turtles [if income-from-land > income-from-city and
                  income-from-land > income
                 [move-to one-of patches with [pcolor = green]]

               if income-from-land <= income-from-city and
                  income-from-city > income
               [move-to one-of patches with [pcolor = red]]]
```

This piece of code set the decision rule which the turtles follow. The program asks each turtle to compare the prevailing income in the city and in the land (decided by the sliders mentioned above) and the bigger of them is compared with the actual income the agent has. If, let's say, “income-from-land” is bigger of both “income-from-city” and that owned by the single turtle, this last will search a new location on the green patches. When the last condition fails, agents will have no incentive to move from their current position, thus they will stay where they are. The same process happens when the first conditions fails, i.e. when “income-from-city” is bigger than (or equal to) “income-from-land”.

```
to patches-output

    ask patches
```

```
[if patches-output? = true and pcolor != red and inhabitants != 0
[set output (( 3 * inhabitants ^ 1.2) / inhabitants) + constant]]

end
```

These lines run when the switcher called "patches-ouput?" in the user interface is on. When this is the case, then the program asks to each patch which is not red (thus to blue and green patches) to set the output, which is a variable globally owned by them, according to a specific production function that has as independent variable the number of inhabitants (i.e. the turtles located on the same patch). To the value computed in this way, a constant (again set by the observer in the interface) is added[4]. The result is then divided by the number of inhabitants, since it will be assigned as income to the agents located on the patch, as further explained.

```
to city-movements

     if n-of-neighbours  > work-place
                   [move-to one-of patches with [pcolor = blue ]]
     if turtles-on-my-patch >= 2
                  [fd 1]
     if n-of-neighbours <= work-place and turtles-on-my-patch <= 1
            [set income 110
            move-to patch-here]
end
```

These lines of code, called by the procedure "reallocation" whenever turtles are on red patches, set the behaviour followed by agents in the city. When they arrive, they are asked to count the number of turtles in the surrounding patches. If they exceed the number "work-place" (set in the observer interface through a slider), they are forced to move to one of the blue patches, since there is no room for them. If, instead, this is not the case, than it can be the situation in which another turtle is already occupying the same patch; if is it so, they do one step ahead looking for a free location. If both of the previous conditions fail, then the turtle receives an income of 110 units, more than what is obtainable in any other part of the program's world. Thus there cannot be any incentive for them to change their position.

```
to slum-movements
```

4 This constant has been added mainly for practical reasons, otherwise the output would have a size not comparable to that of incomes set by the sliders. The advantage of a constant is that the function gets shifted, while its shape remains the same.

```
  ifelse patches-output? = true
  [ set income output]
  [set income (income-from-city / turtles-on-my-patch) ]
  if income < income-from-land
[move-to one-of patches with [pcolor = green]]
   move-to patch-here
end
```

These lines, called by the procedure "reallocation" whenever turtles are on blue patches, set the behaviour followed by agents in the suburbs. When they are in this area, there are two possibilities: if the switcher "patches-output" is on, then they earn an income equal to the output generated by the patch on which they are situated, according to the "patches-output" procedure seen above; if instead the switcher is turned off, agents receive an income equal to that set by "income-from-city", divided by all the occupants of the same patch. In both cases, when the income given to the turtles becomes lower than "income-from-land", they move to a green patch. If the income is set by a single factor production function, then it will increase with the number of "inhabitants" (according to the shape of the function, see also footnotes 5 and 6) by marginally decreasing proportions; if the income is set in the other way, it will simply decrease as the number of turtles on that patch increases.

```
to land-movements
 ifelse patches-output? = true [ set income output ]
 [ ifelse normal? = true
    [set income random-normal income-from-land 10]
    [set income random income-from-land]]
end
```

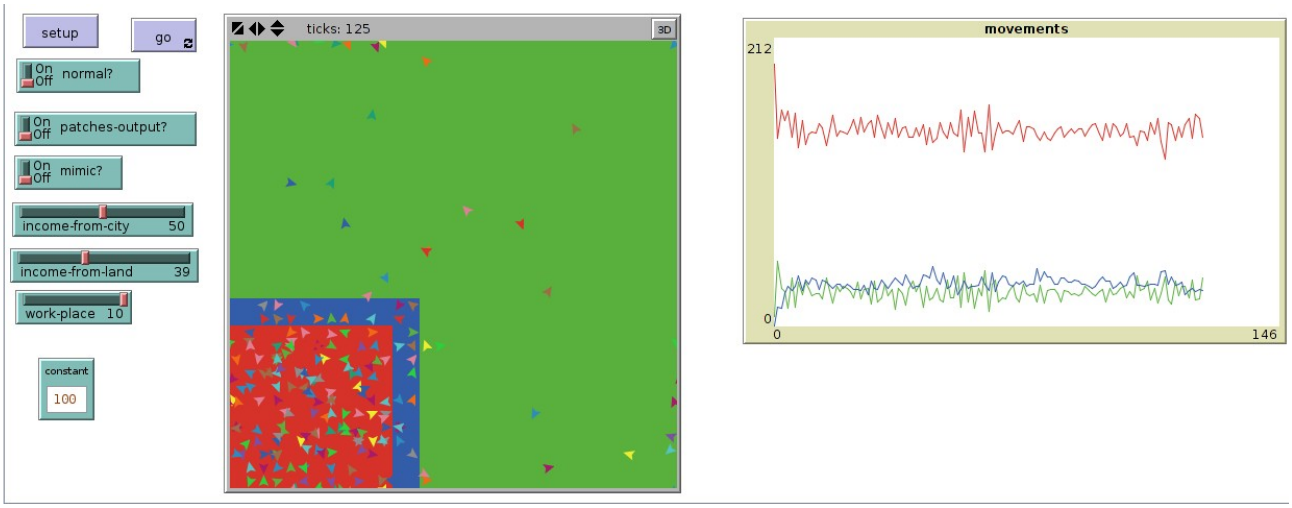
This last piece of code, called by the procedure "reallocation" whenever turtles are on green patches, set the behaviour followed by agents in the land. It consists in two nested boolean conditions, since two switchers are involved. The first sets that, if "patches-output?" is on, turtles will receive an income equal to the output generated by the patches in the same way explained above. If it is off, then the switcher "normal?" is called. As described at the beginning of this section, on the "on" position, turtles will receive a randomly assigned income following a normal probability distribution. Otherwise, they will get a random value following a uniform distribution.

Experiments

Let's now try to see how the program works using different settings of variables modifiable by the observer.

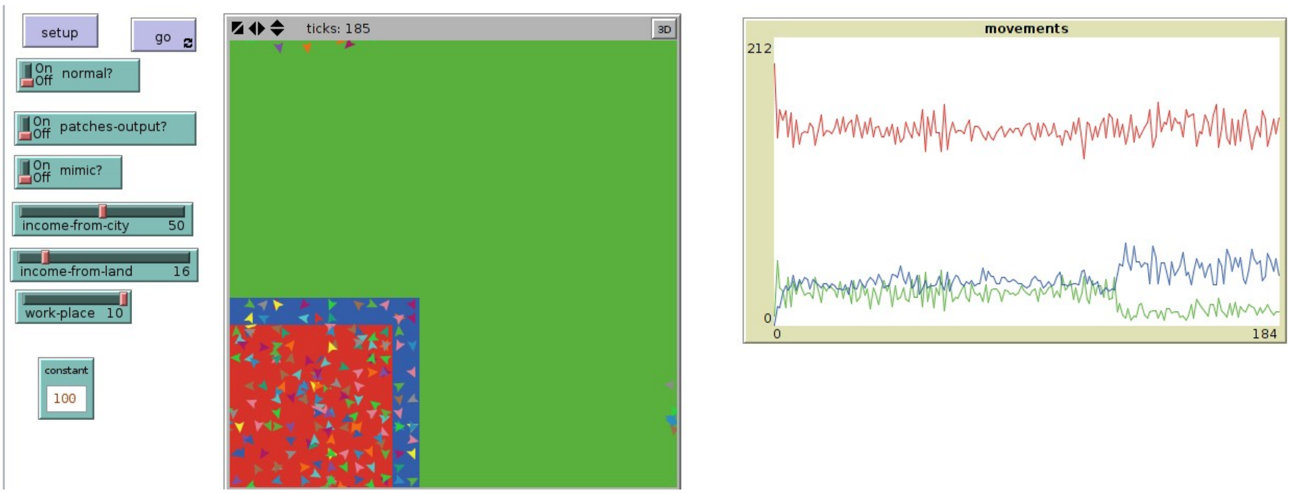
1.

Turning off all the switchers, holding at the same level of 50 units the slider "income-from-city" and moving below and above that level the slider "income-from-land", let's inspect how turtles react to income differential. The slider "work-place" is kept at 10.



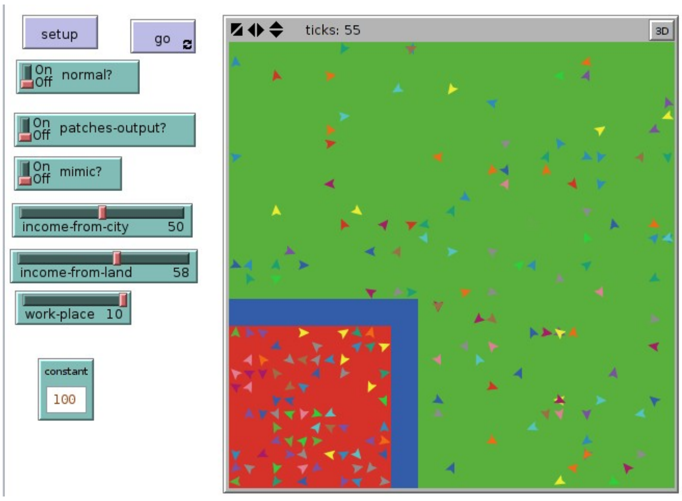
As it can be seen, turtles actually follows the income differential, since the biggest part of them can be found on the red area (the lines in the graph counts how many turtles there are on the area of the lines' colour).

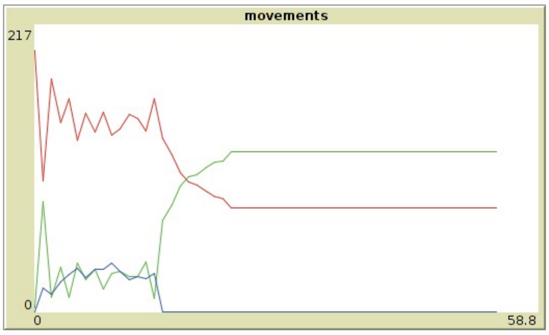
What if the differential gets bigger?



An interesting dynamic features appears when the slider is brought further below: what increases is the number of turtles on the blue area. This happens, likely, because of the limited number of place available on red patches; more turtles are pushed to move by the increased income differential, but there is no room for them. Thus, they are relocated onto the blue area. The number of turtles on green patches reduces consequently.

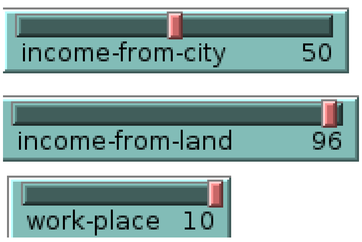
Let us now see what happens when “income-from-land” is above “income-from-city”.

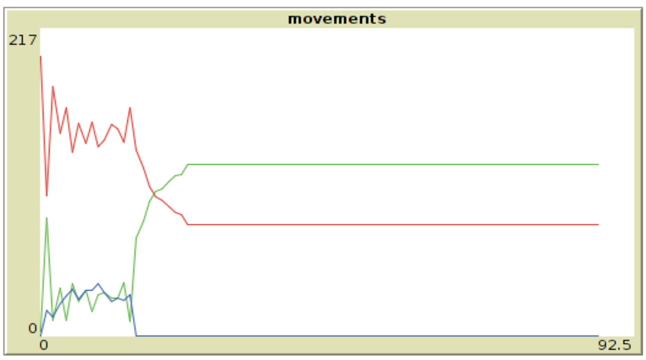




As it could be expected, now the majority of the turtles are on green patches. Interestingly, there are no turtles on blue patches; this phenomenon can be explained considering that the maximum income level that turtles in the suburbs can receive is equal to the level set by “income-from-city”: they are better off if they move to the land.

With a wider income differential in the same direction, this figure does not change, as all the agents that were already located on red patches have an income of 110 units, greater than what is offered by the green ones (as shown by the image below).

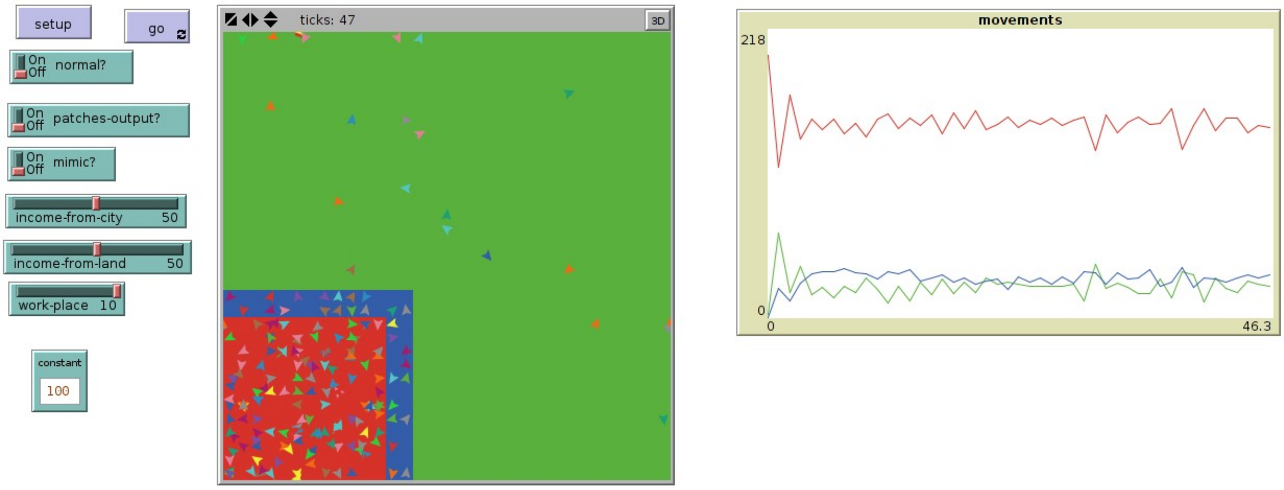




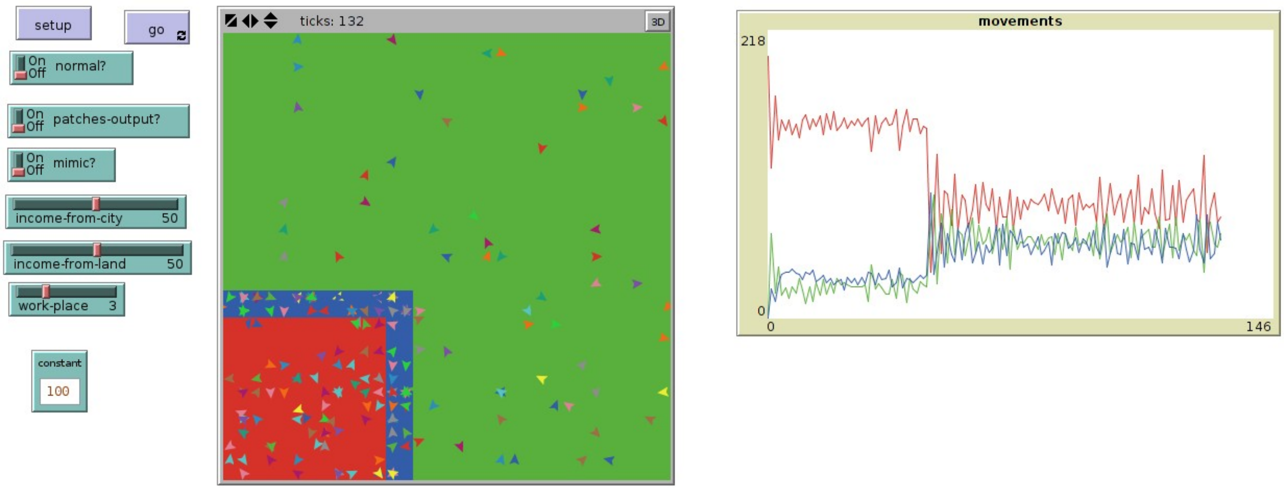
2.

Turning off all the switchers, holding at the same level of 50 units the slider "income-from-city" as well as the slider "income-from-land", what happens by lowering the slider "work-place"?

The starting situation is the following:



Lowering the value of "work-place", this is what happens:

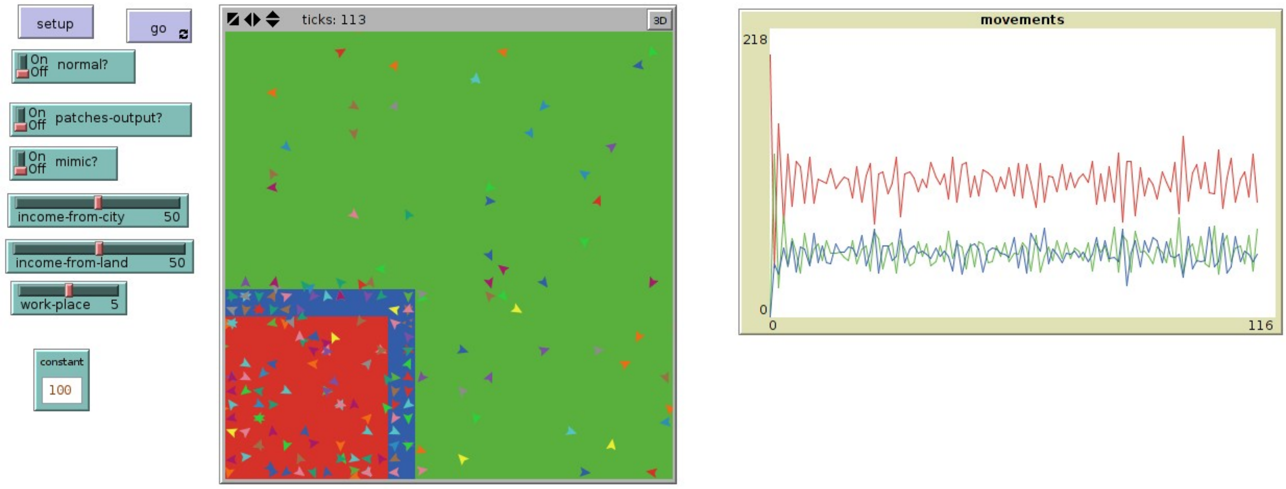


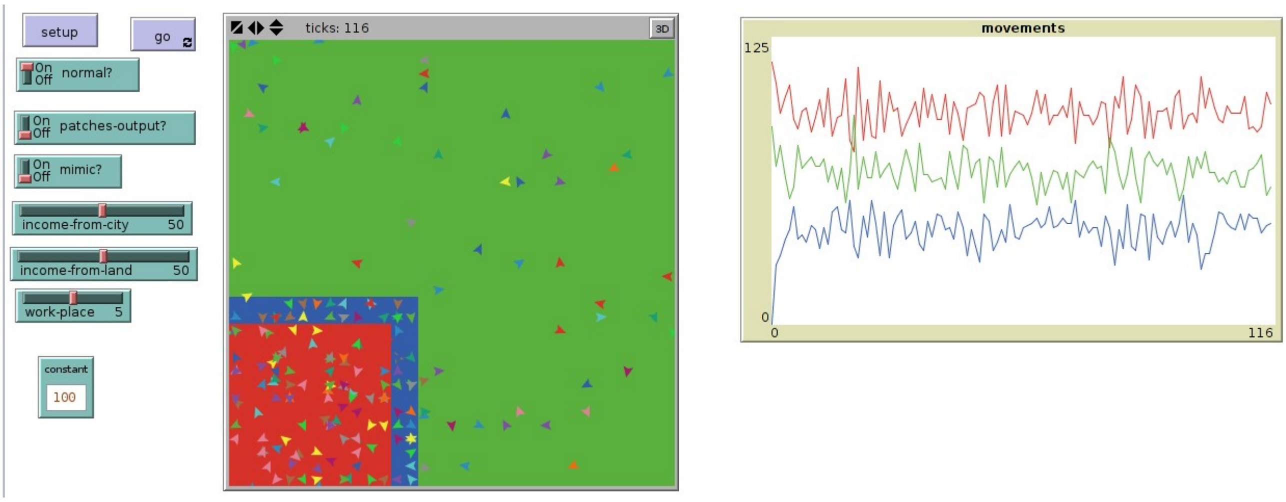
As expected, lowering the slider, the number of turtles which can be allocated in the city decreases (as it actually happens); consequently the number of agents on blue patches increases.

The higher number of turtles on the green area can be explained considering that the income earned by each turtle in the suburbs is divided by the amount of agents on the same patch: the more they are, the lower becomes their income. Hence, for a limited number of agents, it is better to move to a green patch, which guarantees them an higher income.

3.

Let's now see what changes turning the switcher “normal?” on. To appreciate possible differences, the program will be run, *ceteris paribus*, first with the switcher turned off and then turned on.
What follows are the two results.

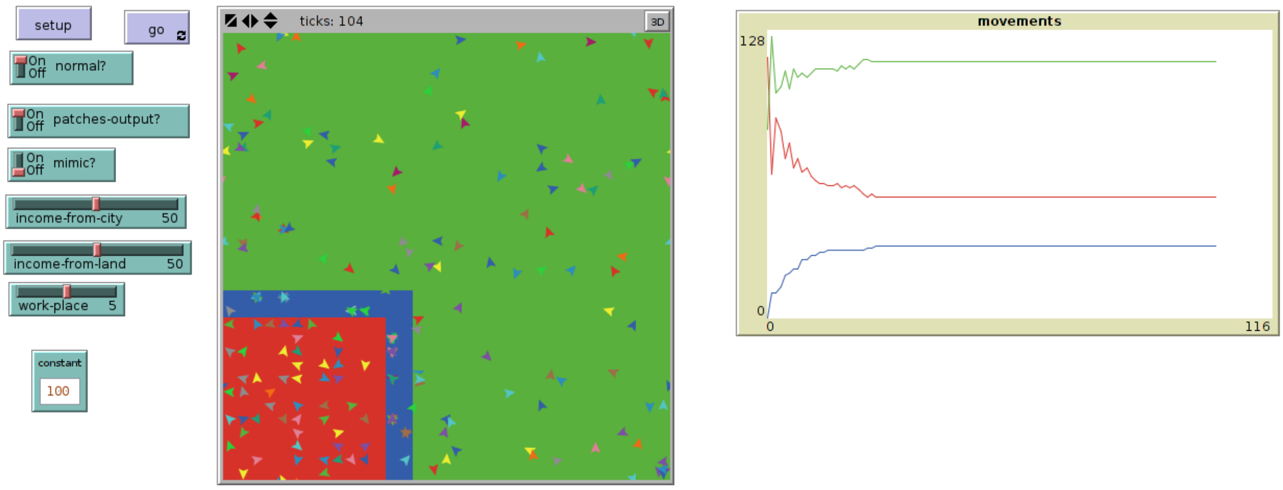




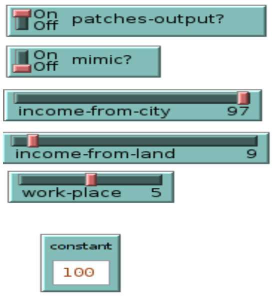
Once the program has been run for a period of time of 110 ticks average,the main difference between the two situations appears to be a neater division among turtles situated on the same areas (mainly between the blue and the green ones). Why is it so? A possible explanation can rely on the fact that, when the income is assigned by a normal probability distribution, the actual value received can be either higher or lower than the mean value (with a variability linked to the standard error), while in a uniform distribution it can be only lower, since the value sets by the slider works as a maximum point, and 0 as a minimum. If a turtle has an income lower than that of the city, it will move towards a red patch in both cases, while with a normal distribution it happens that some turtles have an income greater than what is set by the slider. To make these lasts move, an increase of “income-from-city” is required. This consideration can also explain the relatively higher number of turtles on green patches when the switcher is on, since a part of them has an income greater than “income-from-city”. Anyway, this behaviour is clearly observable mainly when the values of the two sliders are close.

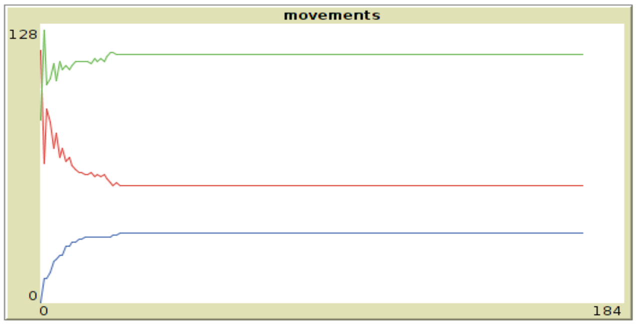
4.

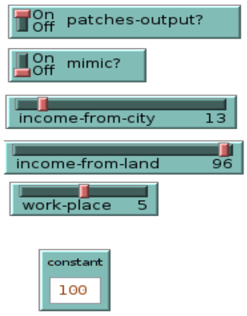
Let's now pass to examine how could the switcher “patches-output” work and its relation with the input “constant”. The following picture shows a simple case, keeping everything as in the previous experiment but the switcher “patches-output”, which will be now turned on (noting that the switcher “normal?” is now useless since, in this phase, it is called only by the procedure “land-movements” and only when “patches-output” is off).

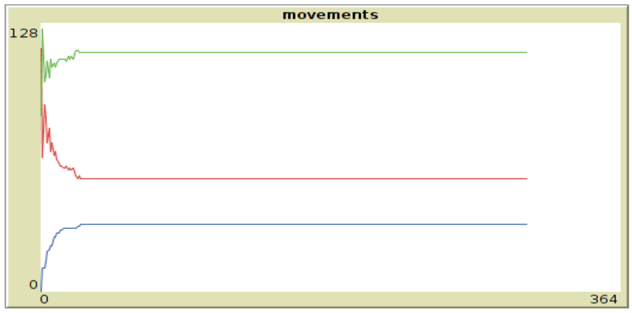


The result is that, after a while, the turtles do not move any more. This happens, likely, because of the new way of attributing incomes, which follows a production function with the formula (3L^1.2/L) + K (see the section *Code Instances*). Thus, when L=1, i.e. when there is only one inhabitants on a blue or green patch, the output generated (which is equal to the income earned) is equal to 3 + K, that in this case is set equal to 100: with an income not lower than 103, no turtles can have incentives to move. This hypothesis can be proved by fact that, moving the incomes sliders, nothing changes:

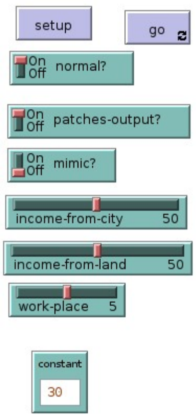


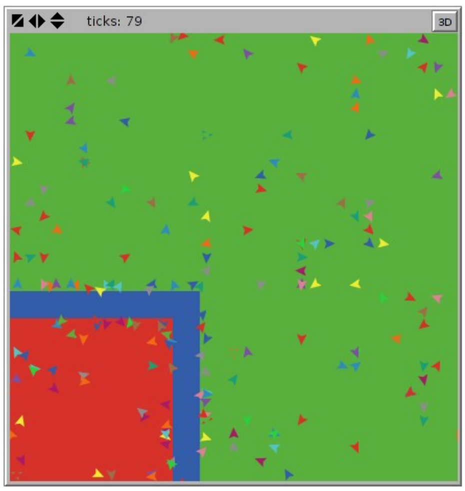


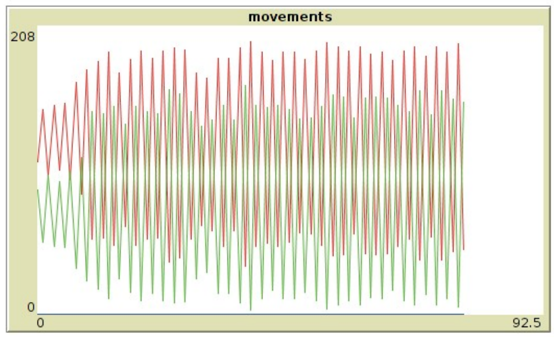




What happens then with a lower constant?







It appears that no equilibrium is reached, and no agent is located on blue patches. A reasonable explanation could be that, now, a single turtle located on the blue area earns an income of 33 units, less than the "income-from-land", thus it will immediately move to a green patch. There, anyway, it will earn the same and thus it will go to the red area, where there is no space enough for everybody and, consequently, will return to the blue area, from where it will immediately go to the green one ... a kind of loop is then affecting the program. That could explain the high variability of turtles moving directly from the city to the land.

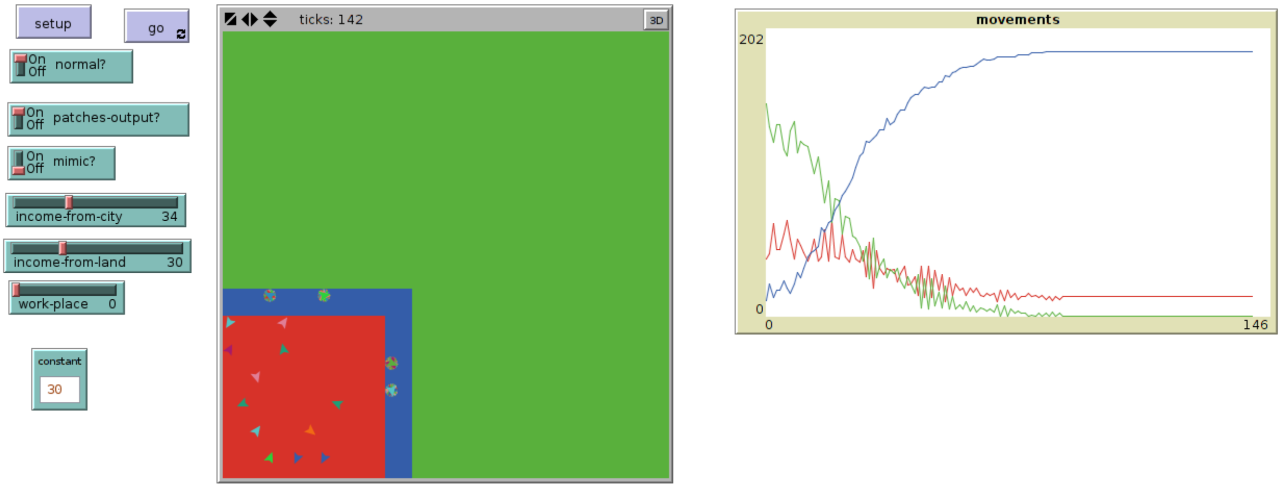
What if more than one turtle is located on the same area? Likely, they will earn more, but in progressively reducing proportions[5]. Because of the shape of the production

5 The function 3*L^0.2 has negative second derivative with respect to L.

function, these marginal extra proportions, since they sharply decrease, might not be sufficiently large to compensate the income difference[6].

A rather interesting case, is when the constant is set to a value slightly lower than that of the slider “income-from-city”. In the following picture, the constant is held at 30, while “income-from-city” at a value of 34, meaning that at least 5 turtles are required on the same patch in order to produce an output greater than that. “income-from-land” is kept to a value lower than 34 and “work-place” is set to 0[7], in order to obtain a greater concentration of turtles on the blue area.

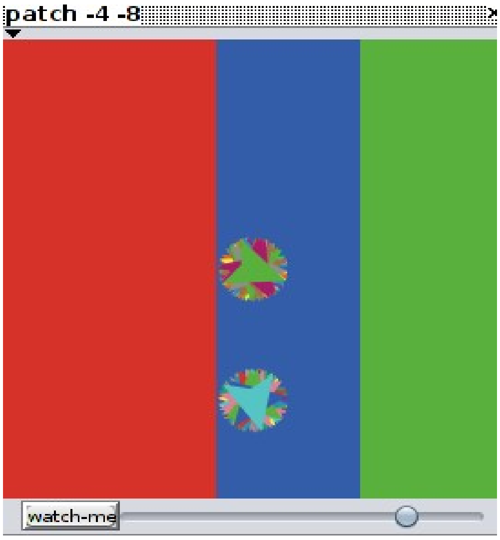
This is the result:

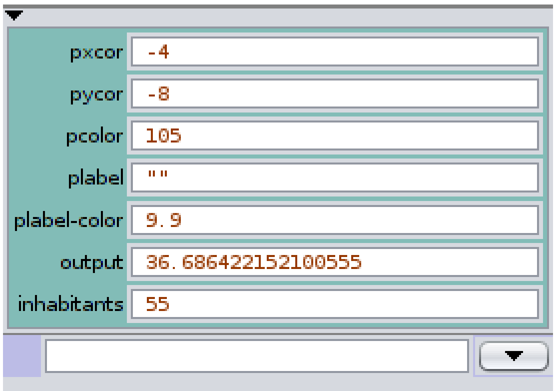


As it is observable, after a while a stable equilibrium is reached, where turtles are no longer moving. An interesting feature of this equilibrium is that agents on blue patches are all situated on four aggregation points (this number can variate a bit running the program several times, but not too much), while no turtle is located on green patches. A possible explanation could be the following: at the beginning agents move towards the city following the income differential. Since there is room just for few of them, the most part will try to find a location in the suburbs. At a certain point five of them choose randomly and simultaneously the same patch and there the output (income) will increase above 34 units, thus they will not have any incentive to change position. As the time goes by, more turtles will find by chance a location on those kinds of centre, getting, therefore, an income greater than “income-from-city”. Inspecting the single patch, that is what appears:

6 Numerically, when K=30 and L=1, output=33. When k=30 and L=5, output=34,14.

7 Anyway, the result of the experiment can be achieved also with an higher value.



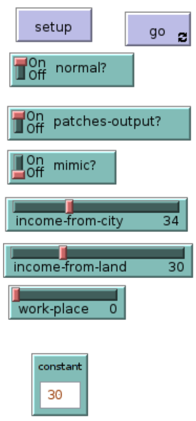


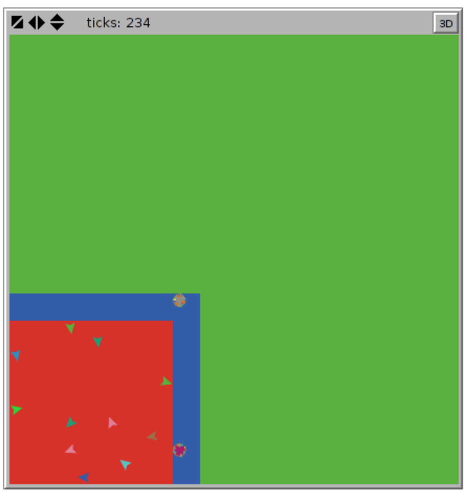
The result is that green patches will be empty, and the majority of the turtles will be found in the suburbs on those kind of "aggregation centres" (as matter of brevity, the calibration tries occurred to achieve this result will be omitted, since they generate quite the same dynamics seen at the beginning of this experiment).

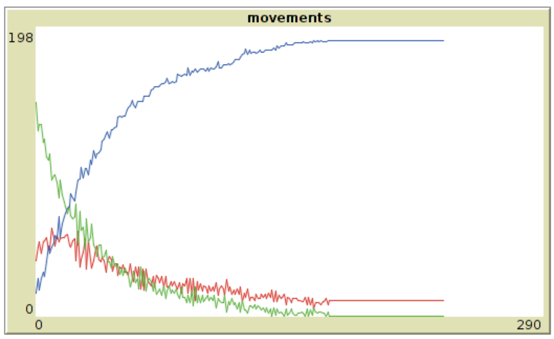
5.

Finally, let's inspect how the switcher "mimic?" works. This switcher asks to a random number of agents to move where another turtle (named "friend" in the code) is. This turtle is assigned in the procedure "setup".

Let's run the same experiment as before:

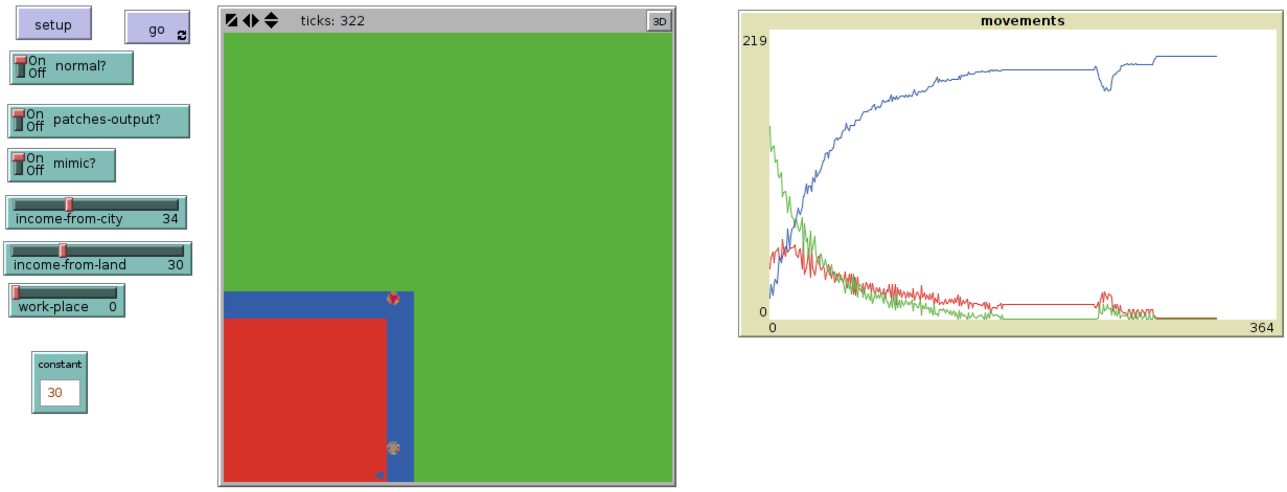






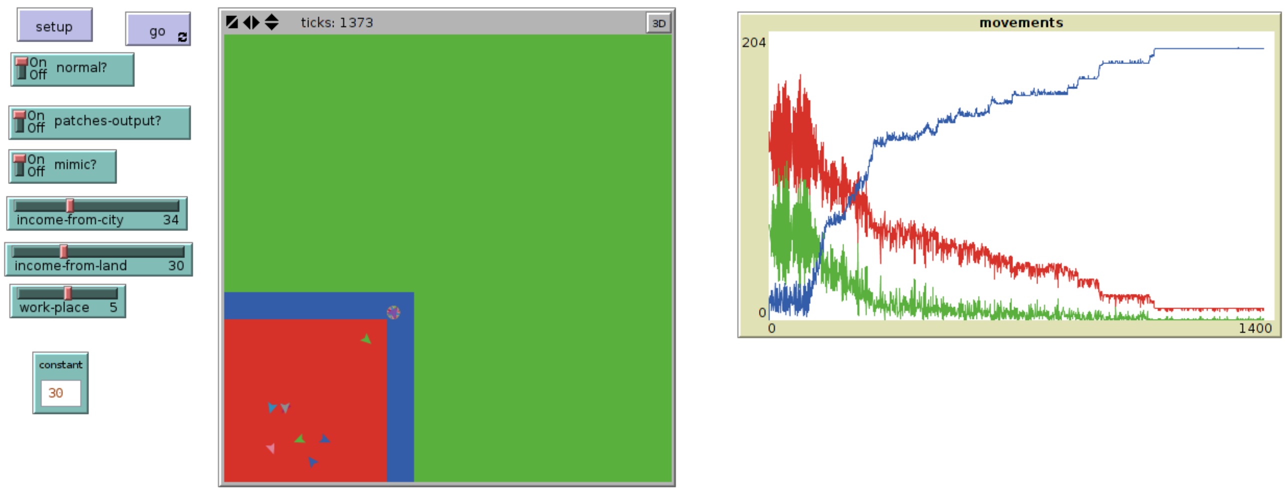
The results are: no turtles on green patches, few turtles on red patches (due to the value 0 of “work-place” and all the others located on two aggregation centres in the suburbs.

What happens by switching-on “mimic?” ?



This result shows that, in the new equilibrium, all turtles but one are located on the aggregating centres. This means that they have no longer followed the income differential in their location procedure (they would be better-off in the city), but they chose their position by looking where their “friends” were.

This behaviour can be checked by running again the same experiment with an higher value of “work-place”:



Turtles on red patches are far less than their capacity and the equilibrium, which is less stable (in the simulation few turtles are still moving on the red areas), took far more time to be reached. The reason could be found considering that there cannot be two turtles on the same red patch. Thus only those few who are not following their “friend” are able to find a place in the city.

Conclusions

As told at the beginning of this short paper, the aim of this simulation was to discuss the Todaro Model from an agent-based perspective. Agents in the simulation, following expected income differentials, seem to behave more or less as predicted by original model and the results of the different experiments seem to consistent with the program's settings.

Anyway, a couple remarks could be done. First, this program does not consider a lot of non-monetary variables, which are actually mentioned in Todaro and Smith (2009), such as those psychological and social costs which most of the migrants have to face, like the loss of cultural roots or the condition of outsiders. These costs are likely to be quite relevant in the migration choice and can complicate a lot the process: as matter of fact, each man is different from another and reacts in a different way to the same stimulus. Second, migration can be also caused by dramatic events, like wars, famines, epidemics ... but no such a possibility has been included in the simulation. The forces driving the agents movements follow a kind of “pulling” mechanism, while also other “pushing” factors work in reality.

This simulation is thus far from being realistic, but the hope is that it could decently work for its purpose of analysing the rural-urban migration described by Todaro from an agent-based point of view.

References

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United Nations, Committee for Development Policy, “Report on the Sixth Session (29 March-2 April 2004) ”, Economic and Social Council Official Records, 2004