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Sovereign default contagion: an agent-based model approach

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Abstract

Sovereign default contagion in Eurozone has been under attention since the first problems in Greece at the end of 2009. Despite the improvements in the situation, in particular after several European Central Bank non- conventional monetary policy measures, the roots of the problem and policy prescriptions are still fiercely debated today. Using an agent-based model adapted from Tirole (2015), we simulate sovereign default contagion in a world where countries have random incomes, heterogeneous borrowing behaviors and risk aversion levels and where governments have the possibility to enter in *ex-ante* agreements to protect against default. We conclude that default contagion can be a very fast and 'destructive' process, higher spending countries tend to have lower disposable incomes and higher risk aversion levels are associated with lower default rates.

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1 – INTRODUCTION

Government bond yields in Eurozone countries were almost the same during the first ten years of European Monetary Union (EMU). This was, simultaneous, a surprising and a worrying behavior. Every country has virtually a German sovereign risk premium level, independently of its specific fundamentals, and investors consider it normal and price almost equally all the government bonds. The financial crisis was a trigger to review this risk levels. Debt sustainability was questioned in many Eurozone countries after the first Greek problems in late 2009.

Hesitations, sloppy reactions and very high debt-GDP ratios were the perfect ingredients to the financial turmoil that followed: four bailed-out countries (Portugal included), several new instruments created to strengthen EMU firepower against financial turbulence and a 'real' economy that still tries to recover several years after 2009´s Great Recession.

On the main stage of the Eurozone sovereign debt crisis debate were – and still are – two opposing political views about the nature and the solution of the problem. It is a liquidity crisis that should be addressed by liquidity providing mechanism such as the ECB´s long-term refinancing operations or the more recent asset purchase program? Or, on the contrary, it is a solvency problem and countries should instead embark in fiscal tightening policies to assure the investors that debt will be fully payed?

We have, on one corner, the 'German' vision – this is of course an oversimplification – defending fiscal consolidation and, on the opposite corner, the vision that austerity measures are self-defeating. In fact, this kind of sudden stop in debt markets has profound roots on the market sentiment but have also, of course, less immediate causes on the fundamentals of the economies. And it has also roots on the EMU design itself. Namely, the (in)existence of mechanisms to deal with this sort of turbulence and to cope with asymmetric shocks in general.

Technicalities about the intervention mechanisms are, probably, the easiest part to deal with. The hardest part, in the multiple steps taken since 2010, was always to have enough agreement between all the governments. Because the diagnosis was often blurred by simplistic formulations such as creditors *versus* debtors; hard working countries *versus* lazy countries or

spenders *versus* savers. Different concepts of guilt also play an important role in the debate: some countries believe that the 'crisis countries' are responsible for their own faith and should pay to avoid moral hazard; and other instead think that this is a systemic problem that must be addressed in a systemic way and not by simply putting all the effort in some countries.

In fact, beyond further considerations about solidarity or Europeanism, there are good reasons for a country to share the risk of default of its neighbors. First, because it is probably affected by the default of its neighbor. This can happen directly - if the country (its companies, households or even public entities) is a net creditor of its neighbor – or indirectly by traditional economic and financial linkages.

Even for very large and resilient economies, it is not very likely that a 'bad neighborhood' has no consequences at all. Financial and economic linkages, such as trade or investment (direct investment and portfolio investment), tend to be stronger for geographically closer countries.

At the same time, frequently a region is seen from outside – large global investors, for instance - as an almost homogeneous block. The Asian crisis in late 90´s is a very good example of how financial turmoil can spread rapidly between neighbor countries, due precisely to the fact that large institutional investors – mutual funds, in particular – withdraw their investments in block from that region.

The second good reason for sharing the default risk is the possibility to be bailed-out too, if necessary. This assistance mechanism can be an *ad hoc* solution or a predefined arrangement in which the necessary tools are always in place to be triggered. The European Union attitude towards the crisis have different phases and different solutions, which are a good illustration of the different options. The first Greek bail-out (2010) - when the financial envelope was gathered, in part, with bilateral loans from other countries – was an *ad hoc* solution but, after that, new instruments were created and now exists a permanent European bailout mechanism – the European Stability Mechanism (ESM).

The flipside of the creation of these new mechanisms were further rules and economic conditionality (namely in terms of fiscal targets and structural reforms, inspired in International Monetary Fund programs). It is a normal feature in this kind of institutional arrangements and also a

feature in current Eurozone fiscal policy rules. Because those who share the risk are interested not only in the 'selfish' view of paying a cost that, indirectly, could be their cost (by contagion). But also, because they want to have a word to say about the policies of their neighbor countries. Fiscal compact treaty in the euro area is an example of such requirements.

In this paper, we will try to evaluate some of these questions within an agent-based model framework. Beginning with the crisis contagion - or serial defaults – and finishing with the institutional mechanisms and how they affect the contagion. We intend to analyze the problem in abstract terms, for different scenarios, and to draw some conclusions that may be useful in understanding some of the problems in Eurozone.

The starting point is the model presented by Jean Tirole (Tirole, 2015) in which he tries to find optimal behavior of countries in this kind of situation. In particular, he attempts to determine the optimal strategies of countries and optimal contract design that maximizes utility in default scenarios for different frameworks.

Our model is adapted from Tirole´s model. The idea is to simulate sovereign default and its contagion process for different institutional architectures, different prevalence of symmetric/asymmetric countries and different government attitudes towards spending.

2 – RELATED LITERATURE

Since 2007/2008 crisis, several articles were published addressing topics related with financial contagion using computational economics. Nevertheless, it is very difficult to find examples of agent-based models or other computational tools dealing directly with sovereign default. Credit flows and financial system itself are the most frequent subjects.

Steinbacher *et al* (2013), for example, used a network system to assess the credit contagion channel in financial markets and concluded that the effects are non-linear and shocks transmission depends heavily on the financial system structure and on the functioning of the interbank market. Zedda (2014) used simulations to test not only the ‘pure’ financial contagion but also the consequences for public finances and real economy, which he calls the “side effects" of systemic crises. Galliani and Zedda (2015) also look to the “vicious circle" between banks and public debt. They conclude that this

is a “real threat” and that the shock tends to disappear only if the bank collapses are not severe or if the system is strong enough to absorb the impact.

Klimek, Poledna, Farmer and Thurner (2015) used an agent-based model to simulate the bail-out and/or bail-in of distressed financial institutions in an environment where governments can choose between three alternatives: closing the bank, bail-in it or bail-out it. Simulations was performed in CRISIS macromodel.

Bookstaber, Paddrik, and Tivnan (2014) simulate a fire sales scenario in order to understand the mechanism behind stop phenomena, for example. Bookstaber (2012) tested financial vulnerabilities.

Caporale, Serguieva and Wu (2009) used ABM models to test different strategies in a financial crisis scenario. Simulations performed can be used to define parameter values and characteristics useful for early detection of financial contagion or powerful financial crisis. Caporale, Serguieva and Wu (2008) had already used an ABM model for simulating financial contagion.

Lengnick and Wohltmann (2013) present a synthesis between ABM models and new-keynesian macroeconomics. In particular, they use a NK model mixed with financial markets ABM model features, namely the fundamentalist-chartist model.

There are, in recent years, some examples in the literature about sovereign debt and fiscal policy simulation. But not about sovereign default, in particular. Raberto, Teglio and Cincotti (2011) use Eurace simulator to understand linkages between financial sector and economic performance. Thurner (2011) presents an extensive review about the use of ABM to evaluate and assess risks related with nation-level leverage and economic indicators. Pick and Anthony (2006) applied a simulation model to assess UK debt strategy. Gande and Parsley (2005) analyses the rating downgrades contagion on neighbor countries and it concludes that it is highly asymmetric: downgrades have negative impact; upgrades don’t have any.

Another different stream of research targets financial contagion itself, away from simulation or ABM models. For instance, Allen and Gale (2000) presents one of the classic approaches to financial contagion through liquidity preference shocks. This kind of turbulence can be easily used to interpret sovereign debt crisis in Eurozone and the flight to quality

phenomena experienced by countries like Portugal, Greece or Ireland in the run up to their respective bail-outs.

On a more empirical basis, Kaminsky and Reinhart (2000) look to trade and financial links as contagion channels based on the data for 80 currency crisis between 1970 and 1998. In order to assess the role of international lending, cross-market hedging and trade, they find that contagion is a non-linear process and contagion channels are not always the same in different crisis.

Dornbusch, Park and Claessens (2000) present a taxonomy of the financial crisis contagion based on specific examples, literature analysis and empirical results.

Full understanding of traditional propagation mechanisms are also useful to anticipate crisis contagion, as done by Schimmelpfenning, Roubini and Manasse (2003). The three authors proposed a logit model and a binary recursive tree that are effective early warning mechanisms in, respectively, 74% and 89% of the crisis.

Some papers, like Lizarazo (2009), use a theoretical framework to evaluate crisis contagion, namely a DSGE model of default risk to identify endogenous foundations of the contagion. Theoretical results were in line with empirical evidence of Argentina-Uruguay contagion and suggested that: a) sovereign spreads and capital flows are correlated; b) economic fundamentals affect sovereign spreads and capital flows; and c) financing conditions in one economy are less favorable after other countries defaulted.

Constâncio (2012) and Kalbaska and Gatkowski (2012) used credit-default swap (CDS) spreads in Eurozone to detect financial contagion. Constâncio argue that contagion played a more important role than fundamentals in sovereign debt crisis in EMU. Kalbaska and Gatkowski concluded that contagion exists but it is different among countries and that Portugal is one of the most fragile economies.

Mink and De Haan (2013) analyzed bank returns across Europe in response to news about Greece in 2010 and found that both news about Greek economy or Greek bailout had an impact. Beirne and Frarzscher (2013) found that, more than a contagion *per se*, sovereign debt crisis in Europe propagated across continent because economic agents – investors, in particular – decided to consider fundamentals in their decisions.

Sudden stops literature is another useful field to consider when studying EMU debt crisis. In some aspects, flight to quality phenomena and external reluctance to maintain investments in some specific countries is a sudden stop phenomena. Merler and Pisani-Ferry (2012) consider that the massive capital outflows of some Eurozone countries can be qualified as sudden stops and that demonstrates that balance of payment crisis are still possible in the context of a monetary union.

Cavallo and Frankel (2008) used a gravity model for Latin America and find that openness is associated to less sudden stop and currency crashes risks. A result that is not applied to European countries but should be considered in any future institutional revisions.

Other paper about sudden stops is Mendonza (2010) which explores the linkages between sudden stops and economic crisis looking to the role of the collateral constraints. It argues that this kind of phenomena has non-linear and asymmetric features.

Argentinian crisis is the object of Calvo, Izquierdo and Talvi (2003) paper where the three authors offer an explanation of the collapse of peso-dollar peg based on a sudden stop problem. Calvo, Izquierdo and Mejia (2004) present an empirical analysis of sudden stop crisis based on a sample of 32 developed and developing countries and concluded that sudden stops with large real exchange rate fluctuations are an emerging market phenomena and seem to come in bunches - grouping countries that are apparently different. Calvo (1998) presents the “simple economics of sudden stops”.

In this paper, our aim is to simulate sovereign default contagion in a regional context where one country default has implications in its neighbors and where it is possible to establish *ex-ante* or *ex-post* agreements for risk sharing and for some kind of transfers and fiscal rules. An environment similar to the one faced by Eurozone.

3 – THE MODEL

This model is a version of Jean Tirole´s model with some modifications: a) Tirole´s model is a game theory model aiming to define optimal behaviors while our model intends to simulate contagion; b) Tirole´s model has only two countries, two periods and considers two different cases and our model have a large number of periods and different countries.

The general dynamic of Tirole´s model is the following. In the scenario without *ex-ante* agreements (laissez-faire), country A (the Agent) decides how much to borrow (b) in period 1. In period 2, it has an income y and decides to pay an amount d of the loan. If this payment d is not the full repayment, the country has a penalty (or cost) c which, in turn, indirectly affects the other country P (the Principal) in an amount Rc (R is a value between 0 and1). Income y depends on the state of nature and it is only observable by the country itself.

In this general framework, the two countries can make bilateral agreements where both can have utility gains. In *ex-ante* agreements, country A, in exchange for a transfer τ, commits to a contract that limits its borrowing level and determines a penalty for the case of partial or total default. In *ex-post* agreements, after the state of nature materializes in period 2, country P transfers a value to assure the loan repayment.

The model we intend to simulate is simpler than the original Tirole´s model but it is wider in terms of countries and periods. For example, in the original model country A chooses how much to repay and has a penalty based on that value. In our model, the country simply pays all or nothing and this action depends only on the income received. Governments don´t have the possibility of discretionary default and only default when they don´t have enough money to do it.

The penalty of a default is being out of the markets until the 'end of times'. This means that, after that period, this country have to live only with the income received and without the possibility of borrowing. Spillover effects of a default are a cost that depends on the number of countries in default.

The main characteristics of our model are:

- N countries
- S small countries and $(N - S)$ large countries

- Small countries have an income $y_S = [y_S^{min}, y_S^{max}]$
- Large countries have an income $y_L = [y_L^{min}, y_L^{max}]$
- $y_L \gg y_S$, which means that $y_L^{min} > y_S^{max}$
- Each country i borrows $b_{i,t}$ in period t and pay $d_{i,t+1}$ in period t_{i+1} (it is assumed that each credit has a maturity of only one period)
- $d_{i,t}$ depends on the income $y_{i,t}$ in period t; country pays all (if its income is enough) or nothing; strategic default is impossible
- y_i depends on the state of nature: it has a value uniformly distributed in the intervals $[y_S^{min}, y_S^{max}]$ and $[y_L^{min}, y_L^{max}]$, respectively for Small and Large countries (in the original model, income was y with probability α and 0 with probability (1-α))
- Countries have two different behaviors: X are Spenders and $(N - X)$ are Savers regarding their borrowing levels
- Borrowing is used to compensate income volatility in the intervals: Spenders compensate an higher part of the difference to maximum income ($b_{i,t} = \gamma\ (y^{max} - y_{i,t})$; Savers compensate a lower part ($b_{i,t} = \emptyset(y^{max} - y_{i,t})$ with $0 < \emptyset, \gamma < 1$ and $\gamma > \theta$
- When the 'neighbor' don´t pay, the country has a cost Rc, with different R values for different countries based on the linear distance to the defaulting country. In the simplest form, the model considers $R = 1$ for all countries.

In each period, countries decide how much to borrow but also if they want to enter in agreements. *Ex-ante* agreements transform Spenders in Savers, which means that default risk decrease in exchange of a transfer τ (lower than c). *Ex-ante* agreements with Savers transform them in Ultra-Savers (with a lower borrowing parameter $\mu < \emptyset$). When defaulting, countries with agreements are implicitly bailed-out and will keep on the markets borrowing normally.

Countries can decide to engage in agreements in each period. Each country has a risk aversion level and, depending on it, it will decide whether or not to protect against default. Higher risk-averse countries decide to enter in agreements when their income is lower than the midpoint of the income interval for the first time. Low risk-averse countries have a higher threshold (3/4 of the interval).

The cost of agreements, i.e. the transfers made to participant countries, are equally divided by all the remaining countries. In our simpler form, this cost

is not imputed to any country, but this doesn´t change the general conclusions.

4 – SIMULATION

For the simulation, we considered 100 periods and 20 different countries. It is an arbitrary choice that can be, of course, changed. Our goal is to generate sufficient decisions and interactions between countries to artificially create an environment of sovereign default contagion.

In each of these 100 periods, each country receives an income $y_{i,t}$ randomly generated in two different intervals [10,20] and [25,50], respectively for Small and Large countries. Countries with individual income lower than the sum of previous period debt and contagion cost of other countries default enter, themselves, in default. This means that they will be out of market until the last period, living only with their 'natural income' randomly generated.

However, countries with an agreement – that imposes a limit on their borrowing – may default in financial terms (their income being lower than their financial needs) but stay in the market normally. For the sake of simplicity, there are no creditors of this debt, which is the same of saying that there is no financial system supplying funds to the countries. This is a research avenue for future developments of this paper. In this stage, the only financial consequence of a default for neighbor countries is the impact c of each default and this impact is the same for Small and Large countries. This means that, for a constant contagion cost, Small countries suffer most.

After that, the countries that are not in default or don´t have previous agreement, decides if they want to enter an agreement –exchanging a transfer τ for a more frugal behavior. Only then, the country will decide how much to borrow depending on their specific spending stance.

In simple terms, the process is divided in four basic steps:

1) Countries have an income $y_{i,t}$
2) Income is compared with previous period borrowing ($b_{i,t-1}$) added to default contagion impact (measured by the sum of c factor divided by the numbers of countries not in default; we are assuming that countries in default have already enough impact). If income is

enough, country pays. Otherwise, the country will default which means that, if it has no prior agreement, it will be out of the markets forever.

3) Countries that are not in default and have no previous agreement decide if they want to adopt one. This decision depends on their individual risk aversion level – that determines a specific threshold to trigger a decision – and on their income.
4) Countries decide how much to borrow and this decision depends on their propensity to borrow. Borrowing is used to compensate income volatility. In practice, they borrow an amount depending on the distance between current income and maximum possible income. Spenders have a larger borrowing parameter while Savers have a lower parameter. Countries with ex-ante agreements change their behavior: Spenders become Savers and Savers become Ultra-savers.

4.1 Scenarios and parameters

Simulation was performed for four different scenarios. All have the same number of periods (100) and countries (20) but different partitions in terms of Small/Large countries, Spenders/Savers and High/Low risk averse countries. Agreement transfer (τ) and contagion cost (c) are set, respectively, to 10 and 100. Borrowing parameters are set to 1, 0.9 and 0.5, respectively for Spenders, Savers and Ultra-savers.

Table 1 summarizes the four scenarios:

Table 1 – Simulation scenarios

SCENARIO	P	N	L	X	R	g	s	u	τ	c
Baseline	20	100	5	10	5	1	0.9	0.5	10	100
2			2	10	5					
3			5	5	5					
4			5	10	10					

Note: Scenario 2 have less large countries (2); Scenario 3 have less spenders (5); Scenario 4 have higher risk aversion (10)

In Baseline scenario we have 5 Large countries, 10 Spenders and 5 High-risk averse countries. The other three scenarios are variations among these three dimensions. Scenario 2 depicts a world with less Large countries (2 instead of 5). Scenario 3 have less Spenders (5 instead of 10) and Scenario 4 have more High risk aversion countries (10 instead of 5).

To evaluate economic performance, we compute individual country disposable income *per period* ($YD_{i,t}$) that is simply the difference between receipts (income, borrowing and agreement transfers) and spending (previous debt and financial impact of defaults). It is given by the following expression for country i in period t:

$$YD_{i,t} = y_{i,t} + b_{i,t} - b_{i,t-1} + \tau - \frac{D_{t-1}.c}{(N - D_{t-1})}$$

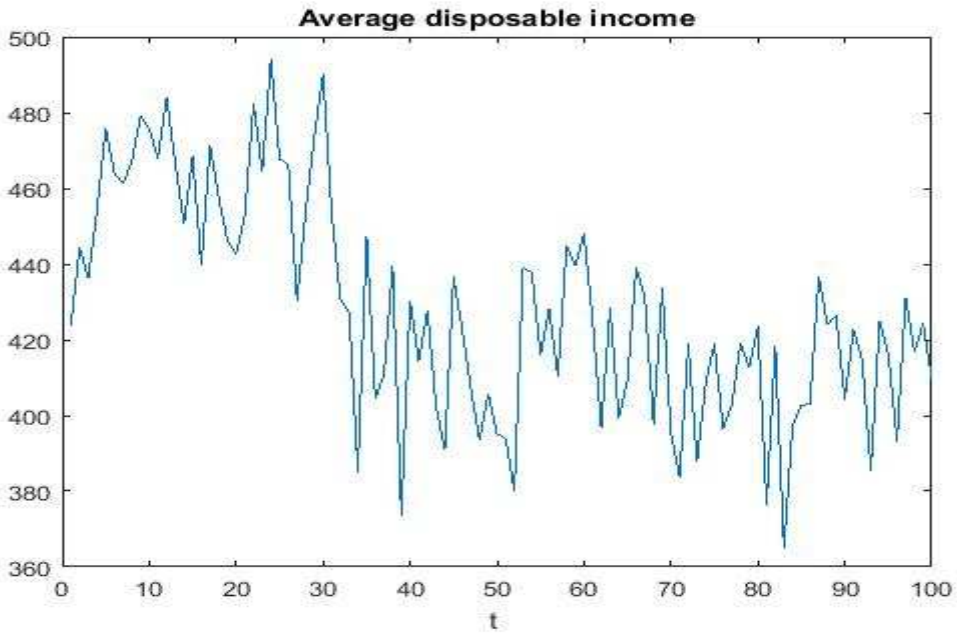
where D_{t-1} is the number countries defaulting in period t-1 and the other variables are the same used previously.

6. RESULTS

Several conclusions can be drawn regarding sovereign default propagation and income volatility in a world with different countries and different behaviors towards borrowing. Baseline scenario results provide very interesting and revealing results.

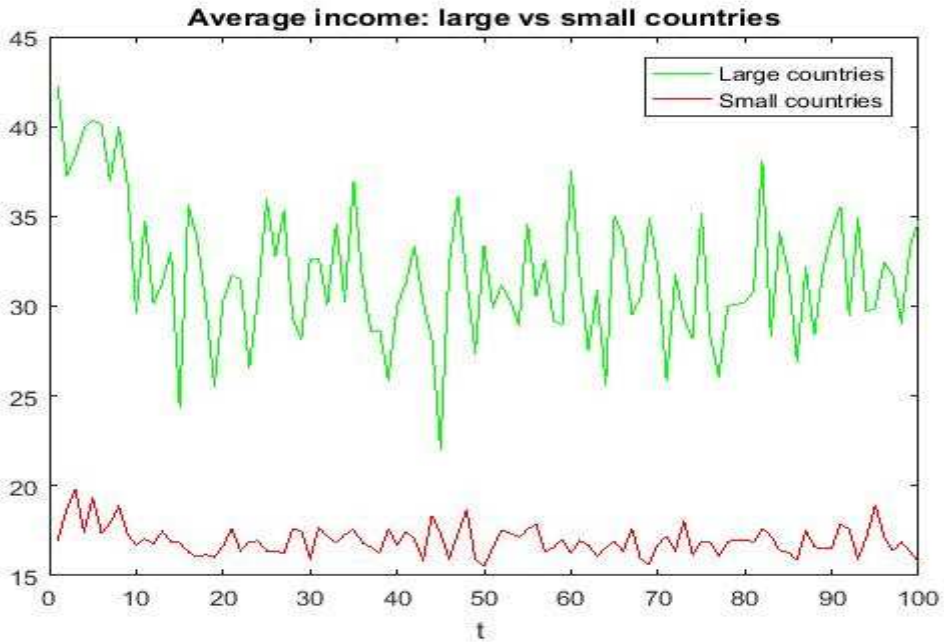
First, average income is highly volatile, which is a direct result of its own nature – it is randomly generated – and to the fact that countries change their borrowing attitudes after defaulting or after an agreement. This can be easily seen in Figure 1 that depicts the evolution of the average disposable income.

Figure 1 – Baseline: average income



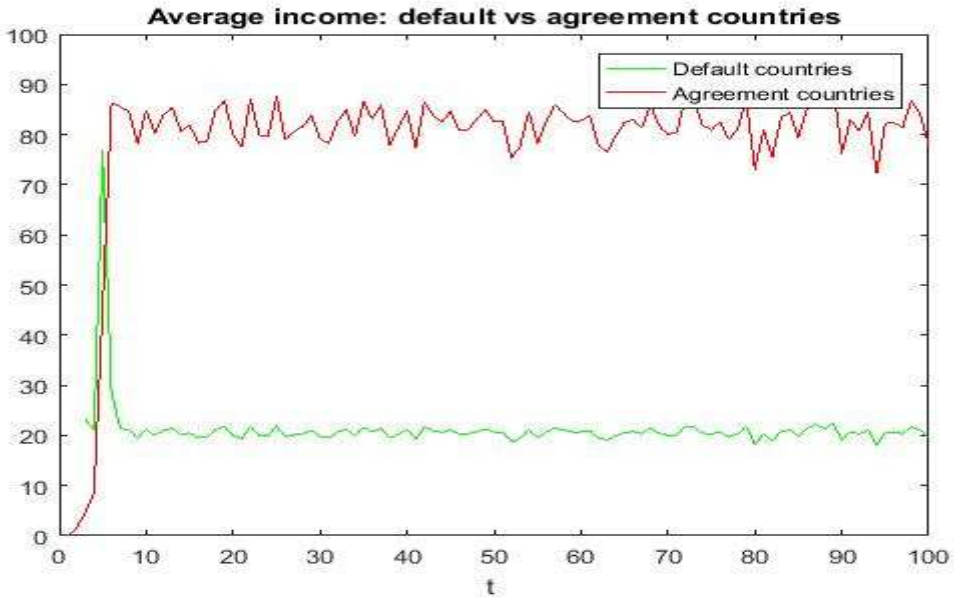
Second, Large countries have larger average incomes. That is normal considering that, by definition, large countries have always larger incomes, as we can see in Figure 2.

Figure 2 – Baseline: large versus small countries



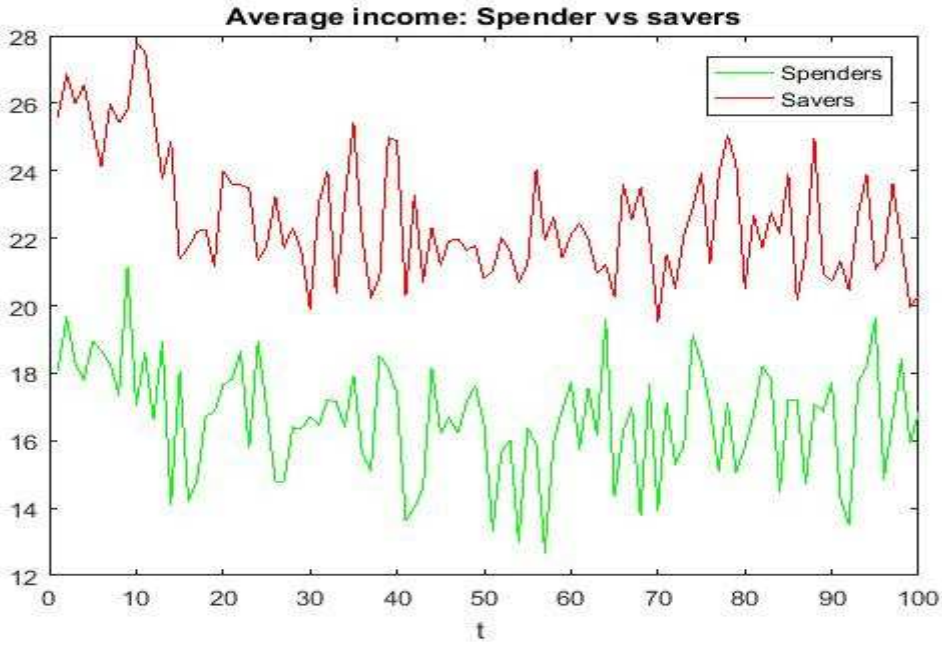
Third, defaults have harsh consequences for disposable income and, in this particular, agreement countries performed better. After the first defaults, default countries average income tends to decrease very fast while agreement countries have a relatively stable income. Figure 3 depicts this opposing pattern.

Figure 3 – Baseline: default versus agreement countries



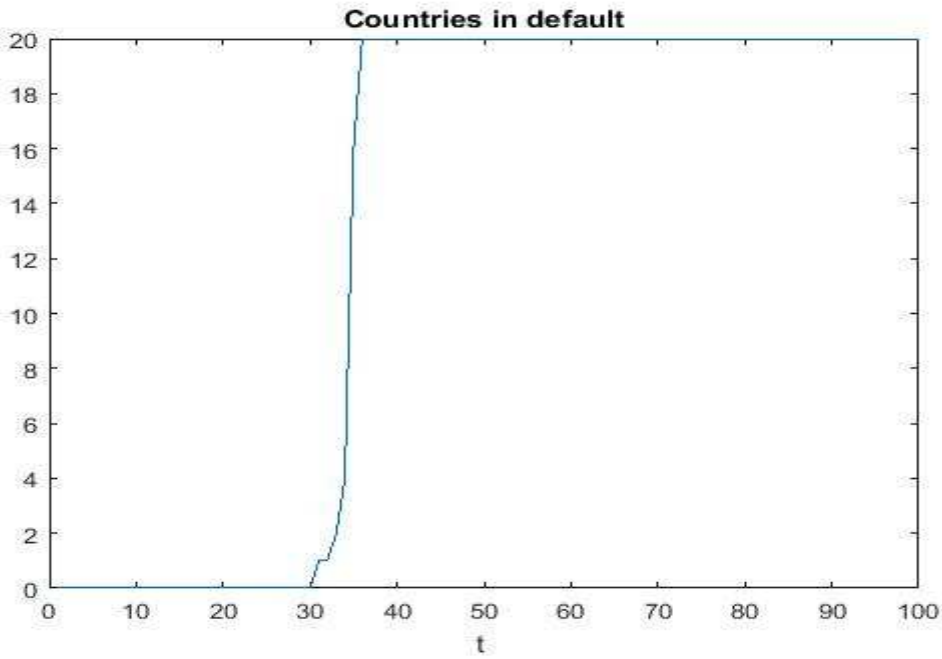
Four, Savers tend to have higher disposable incomes. This must be analyzed in further detail before definitive conclusions. But it is probably due to the fact that Savers have lower default rates and can stay in the market borrowing normally. On the contrary, Spenders tend to have earlier defaults with consequences for their future income. This pattern can be easily recognized in Figure 4.

Figure 4 – Baseline: spenders versus savers



In the Baseline Scenario, all countries default during the 100 periods time span. In the example presented in Figure 5, it happens between periods 30 and 40. This acceleration is, precisely, the contagion effect.

Figure 5 – Baseline: number of defaults

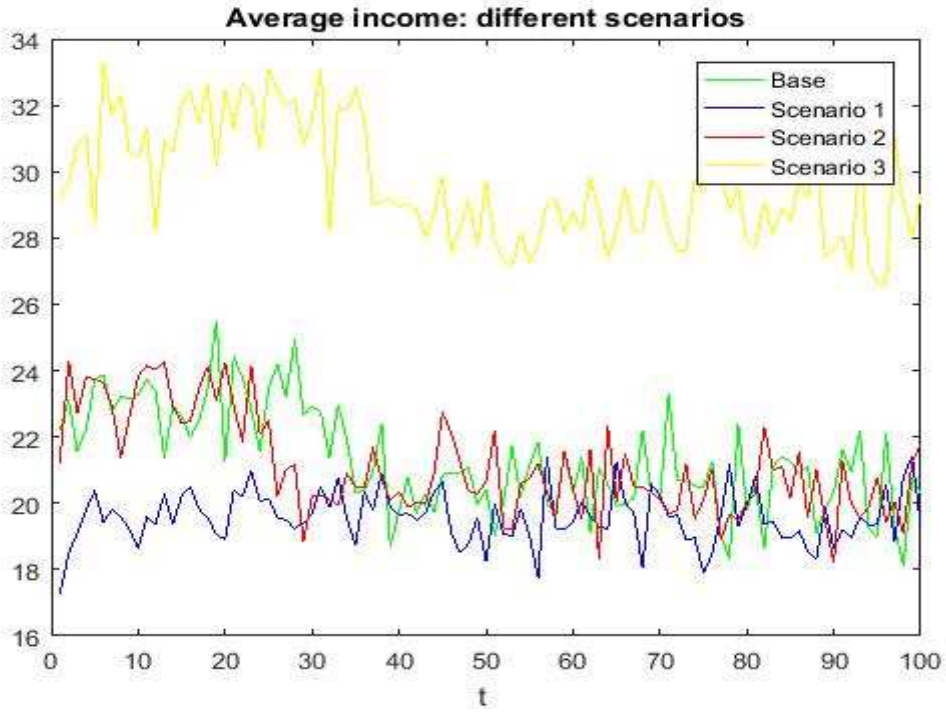


6.1 Scenario comparison

Economic performance of Scenario 3 surpasses, clearly, all the others. It has a simple explanation: less Spenders are associate with lower default levels and contagion, so more countries stay in the market borrowing normally.

On the other extreme, Scenario 2 has the lowest average income. It has less Large countries which have a direct scale effect. All the average disposable incomes for the four scenarios is depicted in Figure 6.

Figure 6 – Scenarios average income performance



7 – CONCLUDING REMARKS

In this paper we simulate sovereign default contagion in an environment where countries have random incomes and different borrowing behaviors and risk aversion levels. Countries can decide to enter in *ex-ante* agreements with other countries in order limit their borrowing in exchange for a transfer and a hedge against default.

The model was based on Jean Tirole´s (Tirole, 2015) framework, with some extensions and departures. In particular, we considered a larger number of countries and periods as well as modifications in the borrowing procedure and in the contagion process.

The main conclusions are:

a) higher risk aversion is associated with lower default levels but also with lower disposable incomes
b) countries with higher propensity to borrow (Spenders) tend to have lower average disposable incomes
c) agreements are an obvious good option, in terms of average income
d) default contagion is a very rapid process and can affect all the countries in a small number of periods

This work is only a first step to simulate sovereign default contagion. Several improvements can be made in the future along two main roads of research. First, the model specification itself. For example: improving the contagion process to consider bilateral distance between countries or even more complex bilateral relations based on economic ties; consider different contagion effect for large and small countries; consider time-depending risk aversion or other time-depending variables.

The second road of improvement is related to the perimeter of the model – introducing a banking sector as the creditor of the countries, for instance - and with the introduction of external shocks – to simulate financial crises periods for example.

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