Elimination of systemic risk in financial networks by means of a systemic risk transaction tax

Sebastian Poledna[1] and Stefan Thurner[1,2,3*]
[1]Section for Science of Complex Systems; Medical University of Vienna; Spitalgasse 23; A-1090; Austria
[2]Santa Fe Institute; 1399 Hyde Park Road; Santa Fe; NM 87501; USA
[3]IIASA, Schlossplatz 1, A-2361 Laxenburg; Austria

Financial markets are exposed to systemic risk (SR), the risk that a major fraction of the system ceases to function and collapses. Since recently it is possible to quantify SR in terms of underlying financial networks where nodes represent financial institutions, and links capture the size and maturity of assets (loans), liabilities, and other obligations such as derivatives. We show that it is possible to quantify the share of SR that individual liabilities in a financial network contribute to the overall SR. We use empirical data of nation-wide interbank liabilities to show that a few liabilities carry the major fraction of the overall SR. We propose a tax on individual transactions that is proportional to their contribution to overall SR. If a transaction does not increase SR it is tax free. With an agent based model (CRISIS macro-financial model) we demonstrate that the proposed Systemic Risk Tax (SRT) leads to a self-organized re-structuring of financial networks that are practically free of SR. ABM predictions agree remarkably well with the empirical data and can be used to understand the relation of credit risk and SR.

Keywords: systemic risk, DebtRank, agent based model, self-organized criticality, multiplex network

INTRODUCTION

Failure to manage systemic risk (SR) has been proven to be extremely costly for society. The financial crisis of 2007-2008 and its consequences demonstrated the importance to reduce it. The threat of collapse of large parts of the financial system forced national governments to bail out hundreds of banks [1]. As a result one observed falling global stock and real estate markets[2–4], a severe and global credit crunch [5], skyrocketing and prolonged unemployment rates [6–8], and several Western governments at the verge of bankruptcy [6]. Bank bailouts caused dangerously high levels of sovereign debt around the world, and it becomes necessary to find alternatives to finance bailouts. The International Monetary Fund proposed a tax on banks, called the "financial stability contribution" (FSC) that can be seen as a contribution of the financial sector to the public costs of the financial crisis, and to create reserves for future crises. Bank taxes have been implemented in many countries around the world, such as the "Financial Crisis Responsibility Fee" in the US. The European Commission proposed an EU-wide bank tax under the "Single Resolution Mechanism". In addition to bank taxes a financial transactions tax (FTT) is considered by many countries. FTT is not a tax on financial institutions *per se*, but a levy placed on specific types of financial transactions. Its main purpose, besides generating revenue for governments, is to curb volatility of financial markets [9, 10]. Empirical studies are generally inconclusive, and a causal relation between volatility and FTTs remains ambiguous [11, 12]. In response to the financial crisis of 2007-2008 a consensus for the need of new financial regulation emerged. New financial regulation should be designed to mitigate the risk of the financial system as a whole. This approach to financial regulation is known as *macroprudential regulation*, and is currently put in place around the globe [13–15]. The Basle III framework recognizes systemically important financial institutions (SIFI) and recommends increased capital requirements for them, the so called "SIFI surcharges" [16, 17]. Basle III further introduces *countercyclical buffers* that allows regulators to increase capital requirements during periods of high credit growth.

No matter how well intended these developments might be, they miss the central point about the nature of SR, and might not be suitable to improve stability of the financial system in a sustainable way. SR is tightly related to the *network structure* of financial assets and liabilities in a financial system. Management of SR is essentially a matter of re-structuring financial networks such that the probability of cascading failure is reduced, or ideally eliminated.

Credit risk is the risk that a borrower will default on a given debt by failing to make the full pre-specified repayments. It is usually seen as a risk that emerges between two counterparties once they engage in a financial transaction. The lender is the sole bearer of credit risk, and figures the likelihood of failed repayments into a risk premium. Lenders usually charge higher interest rates to borrowers that are more likely to default (risk-based pricing). Credit risk is relatively well understood, and can be mitigated through a number methods and techniques [18]. The Basle accords provide an extensive framework dealing foremost with the mitigation of credit risk [19–21].

When two counterparties are part of a financial system, for example as nodes in a financial network, the situation changes, and their transaction may affect the financial system as a whole. The lender no more is the sole bearer of credit risk, nor does credit risk depend on the financial conditions of the borrower alone. The impact of a default of the borrower is no longer limited to the lender, but it may affect the other creditors of the lender (who also lend to the same borrower) as well as their creditors, and so on. Similarly, the lender is not only vulnerable to a default of the borrower but also to defaults from all debtors of that borrower as well as their debtors, etc. In financial networks credit risk loses the local character between two counterparties, and becomes *systemic*.

SR is the risk that the financial system as a whole or a large fraction of it can no longer perform its function as a credit provider and collapses. SR is a result of the network nature of financial transactions and liabilities in the financial system. It unfolds as secondary cascades of credit defaults, triggered by credit defaults between individual counterparties. These cascades can potentially wipe out the financial system by a de-leveraging cascade [22–29]. It is obvious that lenders have a strong incentive to mitigate credit risk. In the case of SR the situation is less clear, since the loss-bearers will in general not be directly involved in those transactions that trigger systemic damage. It is not obvious which players in the financial system have a true interest to mitigate SR. Management of SR is foremost in the public interest.

It is important to note that SR spreads by lending. If a systemically risky node lends to a systemically non-risky one, the later inherits SR from the risky node, since if the non-risky borrower should (for whatever reason) not repay the loan, the risky node would trigger systemic damage. In this sense SR spreads from the risky through lending.

SR is predominantly a network property of liability networks. Different financial network topologies will have different probabilities for systemic collapse, given the link density and the financial conditions of nodes being the same. The management of SR becomes a technical problem of managing the network topology of financial networks. The goal is to do this in a way that does neither reduce the credit provision capacity, nor the transaction volume of the financial system. Data on the topology of credit networks is available to many central banks. Several studies on historical data show typical scale-free connectivity patterns in liability networks [30–35], including overnight markets [36], and financial flows [37].

As a network property, SR can be quantified by using network metrics [38, 39]. In particular a relative risk measure (DebtRank) can be assigned to all nodes in a financial network that specifies the fraction of SR they contribute to the system (institution- or node-specific SR) [39]. As shown later, it is natural to extend the notion of node-specific SR to individual liabilities between two counterparties (liability-specific SR), and to individual transactions (transaction-specific SR).

The central idea of this paper is to introduce an incentive structure in form of a transaction tax that dynamically structures liability networks such that SR is minimized. Since every transaction in a financial network has an impact on the overall SR of a system, we suggest a transaction tax on all transactions between any two market participants that increase the SR of the entire system. The size of the tax is proportional to the SR contribution of the particular transaction. Market participants looking for credit will try to avoid this tax by looking for credit opportunities that do not increase SR and are thus tax free. As a consequence the network arranges toward a topology that, in combination with the financial conditions of individual institutions, will lead to a *de facto* elimination of SR, meaning that cascading failures can no longer occur. In the spirit of risk-based pricing as it is used for credit risk, here we propose a *systemic risk premium*. It was shown in [39] that SR can be drastically reduced by reducing borrowing *from* systemically risky nodes. This is achieved by distributing SR evenly over the network and by preventing the emergence of systemically super-risky nodes. The mechanism works in a self-organized way: risky nodes reduce their SR because they are blocked from lending, non-risky nodes become more systemically risky through their lending. A SR premium encourages borrowers to borrow from safer lenders (since the borrower pays the tax). Further, lenders have an incentive to become systemically safe so that no (or only little) SRT is added to their loan offers, and they can offer competitive rates. Since mitigation of SR is foremost in the public interest we propose to charge a systemic risk tax as a margin on every financial transaction that increases global SR.

We test the proposed SRT within the framework of the CRISIS macro-financial model[1]. In this ABM we run the financial system in three modes. The first reflects the situation today, where banks don't care about their systemic impact, and where interbank credits are traded with an "inter bank offer rate". This interest rate reflects only the creditworthiness of the borrowing counterparty, and does not contain any information on SR. The second mode introduces the SRT. In this mode the interest rate reflects both the creditworthiness of the borrowing counterparty and the SR change associated with each transaction. For comparison, in a third mode we implement a transaction tax on *all* transactions (Tobin tax) that does not have any network re-structuring effect.

SYSTEMIC RISK TAX

The systemic risk tax (SRT) is a levy placed on a financial transaction to offset the SR increase associated with that transaction. We show that SR of a transaction can be quantified by the so-called DebtRank that was

[1] http://www.crisis-economics.eu

suggested originally as a recursive method to determine the systemic relevance of nodes within financial networks [38]. It is a quantity that measures the fraction of the total economic value in the network that is potentially affected by the default and distress of a node or a set of nodes. For simplicity in the following let us think of the nodes in financial networks as banks. By L_{ij} we denote the liability (exposure[2]) network of a given financial system at a given moment. $L_{ij} = \sum_k l_{ijk}$ is the sum of all loans l_{ijk} that bank j currently extends to bank i. C_i is the capital of bank i. If bank i defaults and can not repay its loans, bank j loses the loans L_{ij}. If j has not enough capital available to cover the loss, j also defaults. Given L_{ij} and C_i, the DebtRank $R_i(L_{ij}, C_i)$ of node (bank) i can be computed, see SI.

DebtRank has the precise meaning of economic loss (in dollars) that is caused by the distress or default of a node [38]. This precise meaning of the DebtRank allows us to define the *expected systemic loss* for the entire economy, which is the size of a possible loss times the probability of that loss occurring. For a single node i it is

$$EL_i^{\text{syst}} = P_i^{\text{def}} \, V \, R_i \quad , \tag{1}$$

with P_i^{def} the probability of default of node i, and V the combined economic value of all nodes. R_i measures the fraction of the total economic value that is potentially affected by node i. Assuming that we have a number of B banks in the system, the total expect systemic loss is

$$EL^{\text{syst}} = \sum_{i=1}^{B} EL_i^{\text{syst}} = \sum_{i=1}^{B} P_i^{\text{def}} \, V \, R_i \quad , \tag{2}$$

which has the precise meaning of the expected economic loss within a given timespan (dollars per year).

To calculate the contribution of an individual interbank liability L_{mn}, to the expected systemic loss for the whole economy (marginal systemic effect), we define a liability network without that specific liability L_{mn} by

$$L_{ij}^{(-mn)} \equiv L_{ij} - \sum_{m,n} \delta_{im} \delta_{jn} L_{mn} \quad , \tag{3}$$

where δ_{ij} is the Kroneker symbol. The marginal effect of the particular L_{mn} on the expected systemic loss is

$$\Delta^{(-mn)} EL^{\text{syst}} = \sum_{i=1}^{B} P_i^{\text{def}} V \left(R_i(L_{ij}^{(-mn)}, C_i) - R_i(L_{ij}, C_i) \right) , \tag{4}$$

where $R_i(L_{ij}^{(-mn)}, C_i)$ is the DebtRank of the liability network without the specific exposure L_{mn}. Clearly, a negative $\Delta^{(-mn)} EL^{\text{syst}}$ means that L_{mn} increases the total SR.

Finally, the marginal effect of a single loan (or a transaction leading to that loan) can be calculated. The liability network without a specific loan l_{ijk} is

$$L_{ij}^{(-k)} = L_{ij} - \sum_{m,n,\kappa} \delta_{im} \delta_{jn} \delta_{k\kappa} l_{mn\kappa} \quad , \tag{5}$$

where the sum over m and n runs over all B banks, and κ runs over all transactions that exist between i and j. The marginal systemic effect of a single loan (transaction) $\Delta^{(-k)} EL^{\text{syst}}$, is obtained by substituting $L_{ij}^{(-mn)}$ by $L_{ij}^{(-k)}$ in Eq. (4).

Obviously, the marginal systemic effect of adding a loan to an existing liability network L_{ij} leads to $L_{ij}^{(+k)} = L_{ij} + \sum_{m,n,\kappa} \delta_{im} \delta_{jn} \delta_{k\kappa} l_{mn\kappa}$, i.e. by changing the minus to plus signs in Eq. (5). In this way every existing loan in the financial system as well as every hypothetical one can be evaluated with respect to its marginal systemic effect.

The central idea of the SRT is to tax every transaction between any two counterparties that increase SR in the system. The size of the tax is proportional to the increase of expected systemic loss that this transaction adds to the system per time unit. The SRT for transaction l_{ijk} between two banks i and j can now be expressed by appropriate discounting of Eq. (4) and taking the lifetime T of the loan into account[3],

$$SRT_{ij}^{(k)} = \zeta \max \left[0, \int_0^T dt V v(t) \times \right.$$
$$\left. \times \sum_i \hat{p}_i(t) \left(R_i(L_{ij}^{(+k)}, C_i) - R_i(L_{ij}, C_i) \right) \right] \tag{6}$$

Here $\hat{p}_i(t)$ is the default probability density[4] of node i at time t, and $v(t)$ the present value of \$1 received at time t. R_i is computed at $t = 0$. ζ is a proportionality constant that specifies how much of the expected systemic loss is taxed. $\zeta = 1$ means that 100% of the expected systemic loss will be charged. $\zeta < 1$ means that only a fraction of the true SR increase is passed on to the tax for the causing institution. Ideally, it is chosen such that the efficiency of the financial system is kept the same as in the untaxed world. We show that this is indeed possible.

[2] Note that the entries in L_{ij} are the liabilities bank i has towards bank j. We use the convention to write liabilities in the rows (second index) of L. If the matrix is read column-wise (transpose of L) we get the assets or loans, banks hold with each other.

[3] Valuation is done similar to credit risk models as for example for credit default swaps [40–42]

[4] The default probability density is defined as $\hat{p}_i(t) = h(t) \exp^{-\int_0^\tau h(\tau) d\tau}$, where $h(t)$ is the hazard rate.

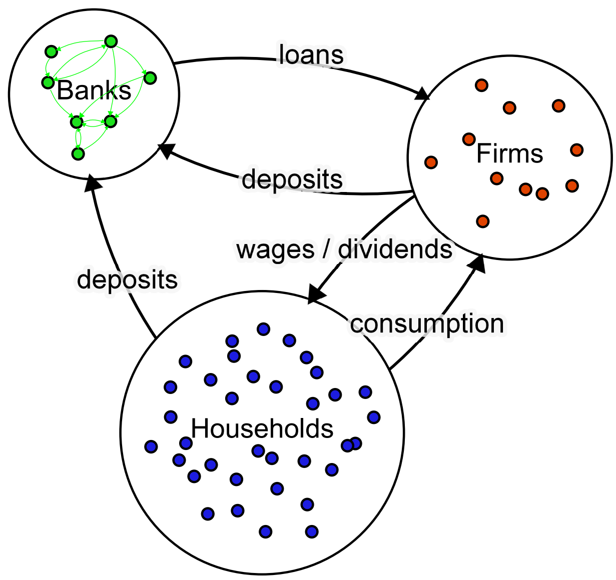

FIG. 1. Schematic overview of the model structure showing the three agent types (banks, firms, and households), and their interactions. Firms pay dividends to their owners, and wages (financed through income and loans) to their workers. Households consume goods produced by the firms. Households and firms deposit money in banks, banks grant loans to the firms.

THE MODEL TO TEST THE EFFECT OF SRT

To test the economic and financial implications of the SRT we use the CRISIS macro-financial model[5]. This is an economic simulator that combines a well-studied macroeconomic ABM [43–45] with an ABM of financial markets. We use a slightly modified version of the model in [44] that includes an interbank market, and that is a *closed* economic system that allows no in- or out-flows of cash. For a comprehensive description of the model, see [44, 46], for the modifications, see SI.

The agents

The model features three types of agents: households, banks, and firms, as depicted in Fig. 1. They interact on four markets

(i) Firms and banks interact on the credit market.

(ii) Banks interact with banks on the interbank market.

(iii) Households and firms interact on the job market.

(iv) Households and firms interact on the consumption goods market.

(v) Banks interact a second time on the interbank market (in case they need additional liquidity for deposit withdrawals).

We give a short description of the agents, for more details on the agents and their interactions, see [44, 46] and SI[6].

Households. There are H households of which there exist two types, firm owners, and workers. Each of them has a personal account $A_{j,b}(t)$ at one of the B banks. j indexes the worker, b the bank. Household accounts are randomly assigned to banks. Workers apply for jobs at the F different firms. If hired, they receive a fixed income w per time step, and supply a fixed labor productivity α. Firm owners receive their income through dividends from their firm's profits. At every time step every household spends a fixed percentage c of its current account on the goods market. They compare prices of goods from z randomly chosen firms and buy the cheapest.

Firms. There are F firms producing perfectly substitutable goods. At every time step firms compute an expected demand $d_i(t)$, and an estimated price $p_i(t)$ (subscript labels the firm), based on a rule that takes into account both excess demand/supply and the deviation of the price $p_i(t-1)$ from the average price in the previous time step [44]. Each firm computes the number of required workers to supply the expected demand. If the wages for the respective workforce exceed the firm's current liquidity, it applies for a credit. Firms approach n randomly chosen banks and choose the credit with the most favorable rate. If this rate exceeds a threshold rate $r^{\max}$, the firm only asks for ϕ percent of the originally desired loan volume. Based on the outcome of this credit request, firms re-evaluate the needed workforce, and hire or fire the needed number of workers. Firms sell the goods on the consumption goods market. Firms go bankrupt if they have negative liquidity after the goods market closes. Each of the bankrupted firm's debtors (banks) incurs a capital loss in proportion to their investment in the company. Firm owners of bankrupted firms are personally liable, their account is divided by the debtors *pro rata*. They immediately start a new company, with initially zero equity. Their initial estimates for $d_i(t)$ and $p_i(t)$ equal the respective current averages in the population.

Banks. There are B banks that offer firm loans at rates that take into account the individual specificity of banks (modeled by a uniformly distributed random variable), and the firms' creditworthiness. Firms pay a credit risk premium according to their creditworthiness that is modeled by a monotonically increasing function of their financial fragility [44]. Banks try to provide requested firm loans and grant them if they have enough liquid resources. If they do not have enough cash, they approach

[5] `http://www.crisis-economics.eu`

[6] `http://www.complex-systems.meduniwien.ac.at/people/sthurner/SI/S`

other banks in the interbank market to obtain the needed amount. If a bank does not have enough cash and can not raise the full amount for the requested firm loan on the IB market it does not pay out the loan. Interbank and firms loans have the same duration. Additional refinancing costs of banks remain with the firms. Each time step firms and banks re-pay τ percent of their outstanding debt (principal plus interest). If banks have excess-liquidity they offer it on the interbank market for a nominal interest rate. The interbank relation network is modeled as a fully connected network and banks choose the interbank offers with the most favorable rate. Interbank rates r_{ij} offered by bank i to bank j take into account the specificity of bank i, and the creditworthiness of bank j. If a firm goes bankrupt the respective creditor bank writes off the respective outstanding loans as defaulted credits. If the bank has not enough equity capital to cover these losses it defaults. Following a bank default an iterative default-event unfolds for all IB creditors. This may trigger a cascade of bank defaults. For simplicity, we assume no recovery for IB loans. This assumption is reasonable in practice for short term liquidity [47]. A cascade of bankruptcies happens within one time step. After the last bankruptcy is taken care of the simulation is stopped.

Implementation of systemic risk tax and "Tobin tax"

A systemic risk premium in form of the SRT is imposed on all interbank transactions. The SRT is calculated according to Eq. (6). Before entering a desired loan l_{ijk}, the credit seeking banks i can get quotes of the $SRT_{ij}^{(k)}$ rates from the Central Bank, for various banks j. They choose the IB offer from bank j with the smallest total rate, which is composed of $r_{ij}^{\text{total}} = r_{ij} + SRT_{ij}^{(k)}$. All other transactions are exempted from SRT. This makes borrowing from banks with large systemic impact more expensive and does not affect lending activities of non-risky banks. In contrast to current market practice, with the SRT banks do have a clear incentive to borrow from systemically non-risky banks. The SRT is collected in a bailout fund.

For comparison we implement a financial transaction tax (Tobin tax [10]) for interbank loans. We impose a constant tax rate of 0.2% of the transaction (this is about 5% of the IB interest rates) on all offered interbank rates. Other transactions are not taxed. The FTT makes lending less attractive for firms that borrow from banks that need liquidity from the interbank market since refinancing costs remain with the firms.

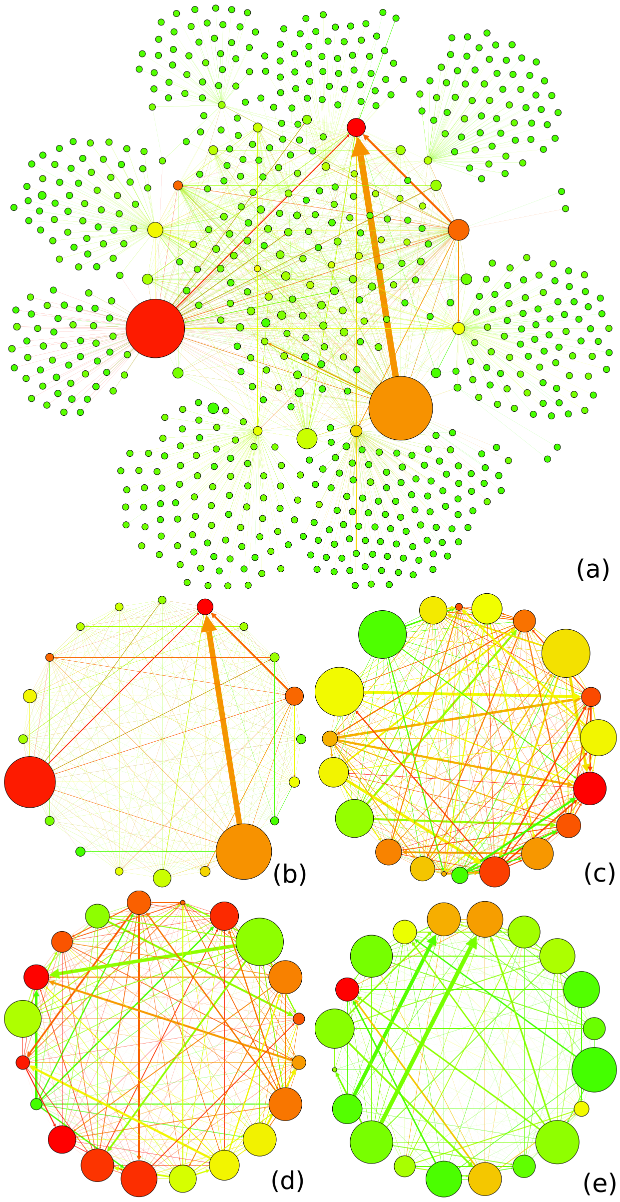

FIG. 2. Banking network. (a) Austrian IB network at the end of the first quarter of 2006, (b) only the 20 largest banks of the Austrian IB network, (c) banking network of the model without tax, (d) with FTT, and (e) with SRT. Nodes are colored according to their systemic impact R_i, from risky banks (red) to unrisky (green). The node size represents the capitalization of the banks. Width of the links are the exposures of the banks in the IB network and the color is according to the source.

RESULTS

We implement the above model in Matlab code for $B = 20$ banks, $F = 100$ firms, and $H = 1300$ households. The model is run in three modes, without any tax, with SRT, and with a Tobin-like financial transaction tax. Results are averages over $10,000$ indepen-

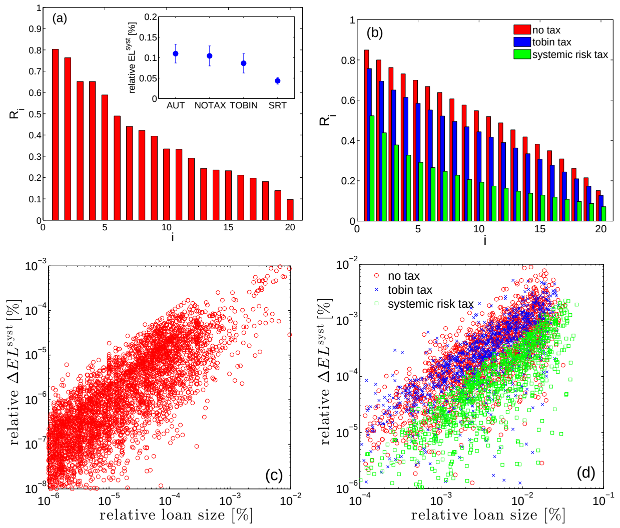

FIG. 3. Expected systemic loss as measured by DebtRank, $EL_i^{\text{syst}} \propto R_i$. (a) DebtRank, R_i of the 20 largest banks of the Austrian banking sector at the end of the third quarter of 2008. Banks are ordered by DebtRank, the most risky being to the very left. Inset: Expected systemic loss from all banks for the Austrian-IB data and the three model modes. Here the SR measure is the size of a possible loss for the entire economy times the probability of that loss occurring as defined in 4. (b) Model results for R_i: without tax (red), with FTT (blue), and with SRT (green). Clearly, SRT drastically reduces the SR contributions of individual banks. The situation without tax resembles the empirical distribution. (c) Marginal effects on expected systemic loss $\Delta^{(-mn)}EL^{\text{syst}}$ of individual IB liabilities L_{mn} vs. the relative size of IB loans in double logarithmic scale. Every data point represents an interbank liability L_{mn}^{data}. The loan size captures the credit risk for lenders, whereas $\Delta^{(-mn)}EL^{\text{syst}}$ is the SR of the liability. (d) Marginal effects for the simulations in the three modes. SRT reduces SR but leaves contract sizes unchanged.

dent, identical simulations across 500 time steps. We set $P_i^{\text{def}} = 0.01$, $V = \sum_{i=1}^{B}\sum_{j=1}^{B} L_{ij}$, and $\zeta = 0.02$. For different tax rates for the Tobin-like financial transaction tax and an alternative mode in which the SRT is set to the true increase in SR associated with the transaction ($\zeta = 1$), see SI.

We compare model results to historical, anonymized, and linearly transformed interbank liability data provided by the Austrian Central Bank (OeNB), see Data and Methods. The data does not contain credit ratings of banks. Therefore we assume $P_i^{\text{def}} = 0.025$[7] for all banks. In Fig. 2(a) we show a snapshot of a the Austrian IB network at the end of the first quarter of 2006. Clearly, the 20 largest contribute most of the SR (red dots), see also Fig. 2(b). Fig. 2(c) shows the situation of the model without tax, (d) with FTT, and (e) with SRT. The SRT effectively reduces spreading of SR by preventing systemically risky nodes from lending. This can be seen from the fact that there are only green links in Fig. 2(e). In the snapshot of the Austrian IB network and in the model without the SRT numerous red links are clearly visible. In Fig. 3 (a) we show SR as measured by the DebtRank R_i. In particular we show R_i for the 20 largest banks (according to total assets) of the Austrian banking sector at the end of the third quarter of 2006. Banks are ordered by DebtRank, the most risky is to the very left, the safest to the very right. The ABM results for R_i are presented in Fig. 3 (b): without tax (red), with FTT (blue) and with SRT (green). The shown distributions are averages over 10,000 independent simulation. Clearly, SRT drastically reduces the SR contributions of individual banks. The situation without tax resembles the empirical distribution (a). In Fig. 3 (c) the marginal effects on expected systemic loss from Eq. (4) are presented for all individual IB liabilities L_{mn}^{data}, as a function of the relative size of IB loans. Every data point represents a single interbank liability L_{mn}^{data} from bank m to n. IB loans are themselves power-law distributed (not shown), which is known empirically [34]. The loan size captures the credit risk for lenders, whereas $\Delta^{(-mn)}EL^{\text{syst}}$ is the SR contribution of the liability. Figure 3 (d) shows the marginal effects for the ABM simulations for the three modes. It is clearly visible that SRT reduces the SR contribution of liabilities by about an order of magnitude (log scale!), but leaves contract sizes practically unchanged.

The effects of the SRT and the FTT on total losses to banks $\mathcal{L}$ (see Data and Methods for definition) that occur as a consequence of bank defaults are shown in Fig. 4 (a). Clearly, the mode without tax (red) produces fat tails in the loss distributions of the banking sector. The Tobin tax slightly reduces losses (almost not visible). The SRT gets completely rid of big losses in the system (green). The remaining losses are from firm defaults. This elimination of losses on the IB market is due to the fact that under the SRT the possibility for cascading defaults is largely reduced. This is seen in Fig. 4 (b), where the distributions of cascade sizes $\mathcal{L}$ (see Data and Methods for definition) for the three modes are compared. While the untaxed mode produces considerable cascade sizes of up to 20 banks, the maximum cascade sizes under the SRT is about 10. The Tobin tax basically follows the untaxed case. As mentioned above the IB loan sizes are practically unchanged under the SRT. This is also true for the total transaction volume $\mathcal{V}$ (see Data and Methods for definition) in the IB market, as is seen in Fig. 4 (c), where the distributions of transaction volumes at time step 100 are shown. Obviously, the situation for the SRT (green) is very similar to the untaxed case (red), whereas the transaction volume is drastically reduced in

[7] This corresponds approximately to Standard & Poor's One-Year Global Corporate Default Rates for Rating Categories A+, A, and BBB+ in 2008 [48]. Representative Austrian banks are in the Rating Categories A+, A and A-.

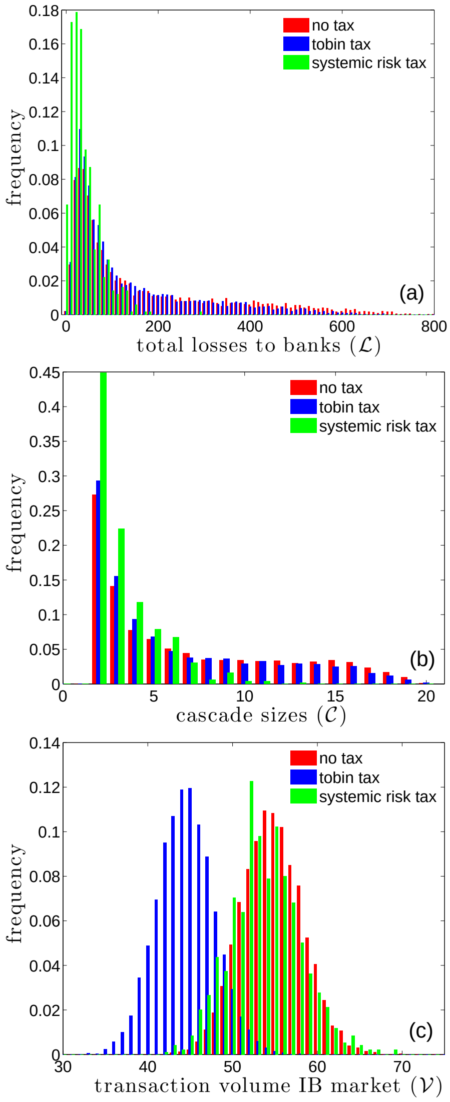

FIG. 4. Comparison of no transaction tax (red) on IB loans, with systemic risk tax (green), and Tobin tax (blue). (a) Distribution of total losses to banks $\mathcal{L}$, (b) distribution of cascade sizes $\mathcal{C}$ of defaulting banks, and (c) distribution of total transaction volume in the IB market $\mathcal{V}$. 10,000 independent, identical simulations, each with 500 time steps, 20 banks.

the FTT scenario (blue), as expected.

DISCUSSION

We extend the notion of SR to individual liabilities within a financial network, and show with empirical data of nation-wide interbank liabilities that this is indeed feasible. The notion of liability-specific SR allows us to quantify the SR that every financial transaction adds to a financial network. We propose a tax on every SR-increasing transaction proportional to the true expected systemic losses. This forces financial institutions to avoid systemically risky transactions and to look for saver ones on the market. Effectively this leads to a re-configuration of financial networks.

We test the SRT within the framework of the CRISIS macro-financial model. The model produces SR profiles of banks that are practically identical with the real IB exposure data. Even on the level of individual transactions the model is fully compatible with empirical data. The SRT drastically reduces the probability for financial collapse due to restructured liability networks that minimize the size of cascading failure. The tax is implemented in a simple way: an agent would like to make a transaction (with a given counterparty) and expresses this interest by announcing it (and the envisioned counterparty) to the Central Bank. The later computes the SR increase of the transaction, based on the knowledge of the present state of the entire asset-liability network and the capitalization of its agents. The SR-increase is then multiplied by the default probability of the agent, discounted, and presented to the agent as a tax (SRT) for that particular transaction. If the SR-increase is zero, there is no tax. The agent can now look for other counterparties to do exactly the same transaction. If the new counterparty is systemically less risky, the tax will be lower. The agent will therefore screen all possible counterparties and decide on the one with the lowest tax. Once the agent decides to do the transaction, is is executed and the tax is payed to the CB or the government.

We show explicitly that SR is to a large extend a NW property. We show that the SRT is able to rearrange financial liability networks without loss of credit volume in the financial markets. For the explicit demonstration we implement and test a Tobin tax which taxes all transactions regardless of their SR contributions. The Tobin tax does not restructure networks and only reduces SR because it also drastically reduces credit volume in the system. This is damaging as it makes the system less efficient; the loss of efficiency materializes as expensive credit for the real economy. We tested an alternative mode in which the SRT is set to the true increase in SR associated with the transaction, and not only a fraction ($\zeta = 1$). This alternative leads to much more homogeneous SR-spreading across all agents, and makes the system even safer, see Fig. 3(b) and SI.

The proposed SRT is a macroprudential regulation aimed to reduce SR and the macroeconomic costs of financial instability. In the classification of [49] credit risk mitigation, including risk-based pricing, is a microprudential measure limiting distress of individual actors. The SRT in this classification is a macroprudential approach that reduces system-wide distress. Since SRT depends both on the interbank liability network and the equity capital, SRT has pro- and counter-cyclical effects. The pro-cyclical side arises through the fact that SRT can bring systemically risky banks even more under stress by reducing their possibilities for lending. However, the dependence of SRT on the density of the liability network has a strong counter-cyclical effect. It is easy to see that the denser the IB network, the higher the SRT rate becomes in general. The SRT rate increases with the demand of interbank loans, and decreases by holding more capital. It is an intriguing research question under which circumstances the counter-cyclical effects will dominate the pro-cyclical ones in times of crisis and credit squeeze.

We finally stress that the current market practice of not pricing SR into transaction costs effectively amounts to a subsidy for those running the highest systemic impact and a tax on those with the lowest.

DATA AND METHODS

Data

Data provided by the Austrian Central Bank (OeNB) contains fully anonymized, and linearly transformed interbank liabilities/exposures $L_{ij}^{\mathrm{data}}(t)$ from the entire Austrian banking system, comprised of about 800 banks over 12 consecutive quarters from 2006-2008. The dataset additionally includes the total assets, total liabilities, due from banks, due to banks, and liquid assets (without due from banks) for all banks again in anonymized form.

Measures for losses, default cascades and transaction volume

We use the following three observables: (1) the *size of the cascade*, $\mathcal{C}$ as the number of defaulting banks triggered by an initial bank default ($1 \leq \mathcal{C} \leq B$), (2) the *total losses to banks* following a default or cascade at t_0, $\mathcal{L} = \sum_{i \in I} \sum_{j=1}^{B} L_{ij}(t_0)$, where I is the set of defaulting banks, and (3) the transaction volume in the IB market at a particular time $t = T$ in a simulation run,

$$\mathcal{V} = \sum_{j=1}^{B} \sum_{i=1}^{B} \sum_{k \in K} l_{jik}(t) \quad , \tag{7}$$

where K represents the new IB loans at time step T. We set $T = 100$.

We acknowledge financial support from EC FP7 projects CRISIS, agreement no. 288501 (65%), LASAGNE, agreement no. 318132 (15%) and MULTIPLEX, agreement no. 317532 (20%).

* stefan.thurner@meduniwien.ac.at

[1] http://www.economist.com/news/finance-and-economics/215
[2] http://www.economist.com/node/10134118.
[3] http://research.stlouisfed.org/fred2/series/SPCS20RSA.
[4] http://research.stlouisfed.org/fred2/graph/?id=SP500.
[5] http://www.economist.com/node/9972489.
[6] http://epp.eurostat.ec.europa.eu/portal/page/portal/eur
[7] http://data.bls.gov/timeseries/LNU04000000?years_option
[8] http://research.stlouisfed.org/fred2/graph/?id=UNRATE.
[9] L. H. Summers and V. P. Summers. When financial markets work too well : A cautious case for a securities transactions tax. Technical Report 12, 1989.
[10] J. Tobin. A proposal for international monetary reform. Technical Report 506, 1978.
[11] N. McCulloch and G. Pacillo. The tobin tax a review of the evidence. Technical Report 1611, 2011.
[12] T. Matheson. Security transaction taxes: issues and evidence. *International Tax and Public Finance*, 19 (6): 884-912, 2012.
[13] D. Aikman, A. G. Haldane, and S. Kapadia. Operationalising a macroprudential regime: Goals, tools and open issues. *Financial Stability Journal of the Bank of Spain*, 24, 2013.
[14] Bank of England. Instruments of macroprudential policy. Technical report, Bank of England, 2011.
[15] Bank of England. The financial policy committee's powers to supplement capital requirements: a draft policy statement. Technical report, Bank of England, 2013.
[16] Bank for International Settlements. *Basel III: A global regulatory framework for more resilient banks and banking systems*. Bank for International Settlements, 2010.
[17] C.-P. Georg. Basel III and systemic risk regulation - what way forward? Technical Report 17-2011, Jan 2011.
[18] D. Duffie and K. Singleton. *Credit Risk: Pricing, Measurement, and Management*. Princeton Series in Finance. Princeton University Press, 2012.
[19] B. J. Balin. Basel I, Basel II, and emerging markets: A nontechnical analysis. Available at SSRN: http://ssrn.com/abstract=1477712, 2008.
[20] Bank for International Settlements. *International convergence of capital measurement and capital standards*. Bank for International Settlements, Basel, 1988.
[21] Bank for International Settlements. *International Convergence of Capital Measurement and Capital Standards: A Revised Framework Comprehensive Version*. Bank for International Settlements, Basel, 2006.
[22] H. P. Minsky. The financial instability hypothesis. The Jerome Levy Economics Institute Working Paper 74, 1992.
[23] T. Adrian and H. S. Shin. Liquidity and leverage. Tech. Rep. 328, Federal Reserve Bank of New York, 2008.
[24] M. Brunnermeier and L. Pedersen. Market liquidity and funding liquidity. *Review of Financial Studies*, 22 (6): 2201-2238, 2009.
[25] F. Caccioli, J.-P. Bouchaud, and J. D. Farmer. Impact-adjusted valuation and the criticality of leverage. http://arxiv.org/abs/1204.0922, 2012.
[26] A. Fostel and J. Geanakoplos. Leverage cycles and the anxious economy. *American Economic Review*, 98(4): 1211–44, 2008.
[27] J. Geanakoplos. The leverage cycle. In D. Acemoglu, K. Rogoff, and M. Woodford, editors, *NBER Macroeconomics Annual 2009*, volume 24, page 165. University of Chicago Press, 2010.
[28] S. Poledna, S. Thurner, J. Farmer, and J. Geanakoplos.

Leverage-induced systemic risk under basle II and other credit risk policies. arXiv:1301, 2013.

[29] S. Thurner, J. D. Farmer, and J. Geanakoplos. Leverage causes fat tails and clustered volatility. Quantitative Finance 12, 695-707, 2012.

[30] K. Soramäki, M. L. Bech, J. Arnold, R. J. Glass, and W. E. Beyeler. The topology of interbank payment flows. *Physica A: Statistical Mechanics and its Applications*, 379: 317-333, 2007.

[31] C. Upper and A. Worms. Estimating bilateral exposures in the German interbank market: Is there a danger of contagion? Technical Report 2002, Deutsche Bundesbank, Research Centre, 2002.

[32] M. L. Bech and E. Atalay. The topology of the federal funds market. *Physica A: Statistical Mechanics and its Applications*, 389(22):5223-5246, 2010.

[33] M. Boss, M. Summer, and S. Thurner. Contagion flow trough banking networks. *Lecture Notes in Computer Science*, 3038:1070-1077, 2004.

[34] M. Boss, H. Elsinger, M. Summer, and S. Thurner. The network topology of the interbank market. *Quantitative Finance*, 4: 677-684, 2005.

[35] D. O. Cajueiro, B. M. Tabak, and R. F. S. Andrade. Fluctuations in interbank network dynamics. *Phys Rev E*, 79: 037101, 2009.

[36] G. Iori, G. De Masi, O. V. Precup, G. Gabbi, and G. Caldarelli. A network analysis of the italian overnight money market. *Journal of Economic Dynamics and Control*, 32: 259-278, 2008.

[37] F. Kyriakopoulos, S. Thurner, C. Puhr, and S. W. Schmitz. Network and eigenvalue analysis of financial transaction networks. *The European Physical Journal B*, 71 (4): 523-531, 2009.

[38] S. Battiston, M. Puliga, R. Kaushik, P. Tasca, and G. Caldarelli. Debtrank: Too central to fail? financial networks, the FED and systemic risk. *Sci. Rep.*, 2, 08, 2012.

[39] S. Thurner and S. Poledna. Debtrank-transparency: Controlling systemic risk in financial networks. *Sci. Rep.*, 3, 05, 2013.

[40] J. Hull. *Options, Futures, and Other Derivatives*. Prentice Hall PTR, 2012.

[41] J. C. . Hull and A. D. White. Valuing credit default swaps i: No counterparty default risk. *The Journal of Derivatives*, 8 (1): 29-40, 2000.

[42] J. C. . Hull and A. D. White. Valuing credit default swaps II: Modeling default correlations. *The Journal of Derivatives*, 8 (3): 12-21, 2001.

[43] D. Delli Gatti, E. Gaffeo, M. Gallegati, G. Giulioni, and A. Palestrini. *Emergent Macroeconomics: An Agent-Based Approach to Business Fluctuations*. New economic windows. Springer, 2008.

[44] D. Delli Gatti, S. Desiderio, E. Gaffeo, P. Cirillo, and M. Gallegati. *Macroeconomics from the Bottom-up*. Springer Milan, 2011.

[45] E. Gaffeo, D. Delli Gatti, S. Desiderio, and M. Gallegati. Adaptive microfoundations for emergent macroeconomics. Technical Report 0802, 2008.

[46] S. Gualdi, M. Tarzia, F. Zamponi, and J.-P. Bouchaud. Tipping points in macroeconomic agent-based models. *arXiv preprint arXiv:1307.5319*, 2013.

[47] R. Cont, A. Moussa, and E. Santos. Network structure and systemic risk in banking systems. http://ssrn.com/abstract=1733528, 2011.

[48] http://www.standardandpoors.com/servlet/BlobServer?blobl

[49] C. Borio. Towards a macroprudential framework for financial supervision and regulation? *CESifo Economic Studies*, 49(2):181–215, 2003.