FH Vorarlberg
University of Applied Sciences

Masterthesis in the study program
Informatik – Software and Information Engineering

Influence of network-topologies on equilibrium in continuous double-auctions.

written by

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Dornbirn, June 2, 2015

Statuatory Declaration

I declare that I have developed and written the enclosed work completely by myself, and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. This Master Thesis was not used in the same or in a similar version to achieve an academic degree nor has it been published elsewhere.

Widmung

Ich widme diese Arbeit meinen beiden liebevollen Eltern, die den verlorenen Sohn nach 11 Jahren in Wien wie selbstverständlich wieder mit offenen Armen zu Hause in Vorarlberg aufgenommen haben und ihm so ein entspanntes Masterstudium ermöglichten und ihm dadurch halfen ein völlig neues Kapitel in seinem Leben aufzuschlagen.

Contents

Abstract

In the paper of [BSV13] a model for endogenous leverage in a continuous double-auction is introduced and it is shown under which circumstances holdings and trading prices approach an equilibrium. One main criteria is the trading network the agents use where Breuer et al. examine only two topologies and report that the prices come to an equilibrium only in the case of a fully connected network. They leave the question open on how the model behaves with different kind of networks and which network topology exactly allows an equilibrium to be reached for further research. This thesis builds upon this model and gives a hypothesis for a necessary condition a network must satisfy to allow the model to approach an equilibrium. Then a few network-topologies are examined in regard of their ability to allow equilibria to be reached or not through computer-driven simulation. As will be shown in this thesis through validation by computer-driven simulation the hypothesis turns out to be correct only after extending the simulation-model by an additional market. This result raises questions this thesis tries to answer about market-mechanisms and market-types when agents don't trade in a fully informed network.

Chapter 1

Introduction

TODO: überarbeiten, passt so noch nicht In 2008 the so called "Subprime Mortgage Crisis" struck the world. It was caused by declining house prices which rose during the US Housing Market Bubble in 2006 to an all-time high. Borrowers used their asset as collateral for the mortgage which constantly increased in value which guaranteed them a low payment-rate because the rate was coupled to the value of the asset. Banks granted "subprime" mortgages to more and more highly risky borrowers. In 2007 borrowers started to default which led to falling prices as the banks reclaimed the collateral and wanted to sell it again on the market to compensate for the loss. This led to a flood of assets which led to a decline of housing prices overall. As the prices fell dramatically the payment-rates rose dramatically to compensate for the cheaper asset. This in turn resulted in even more borrowers going default which resulted in a dramatic downward spiral. Even worse the banks were selling these collateralized products between each other and even insured themself against defaults of borrowers which led to an even more dramatic kick-back.

This mechanism of borrowing money to buy goods which in turn act as a security for the borrowed money is called leverage which was determined as the primary driving force behind systemic risk in the aftermath of the "Subprime Mortgage Crisis". See Chapter 2.1 "Leverage and Systemic Risk" for a more in-depth discussion.

Up until 2010 leverage was always exogenous in the literature on collateralized credit but recently Geanakoplos and Zame (TODO: cite) proposed theories which endogenized leverage within a general equilibrium framework.

[BSV13] developed a simulation on top of the model of Geanakoplos in which zero-intelligence agents trade assets and loans in a continuous double auction. They wanted to better understand the dynamic of such a theoretical process and how prices develop instead of being predicted through an equilibrium theory. They TODO: zitierne "ask whether the competitive theory of trade in leveraged assets has decriptive and predictive power in a double auction environment."

4 contributions: 1. double auctions for leveraged assets is new 2. details of institutional specification matter a lot 3. limits of the endogenous leverage model 4.

They could show that in their simulation trading prices and wealth-distribution approach the theoretical equilibrium of Geanakoplos. In their simulation only a fully connected network and a hub-network of agents was investigated where the equilibrium was only reached in the case of the fully connected network. See Chapter 3. "The Leverage Cycle" for a thorough description of the simulation-model of [BSV13].

This thesis investigates more topologies of networks and their states of equilibrium. Furthermore it presents a hypothesis about the necessary property a topology of a network must satisfy to reach the theoretical equilibrium predicted in the theory of Geanakoplos. Interestingly it is shown experimentally that the hypothesis alone does not guarantee the reach of the theoretical equilibrium but further mechanisms needs to be implemented. See Chapter 4 "Hypothesis" and Chapter 6 "Results" for an in-depth explanation of both the hypothesis and why it does not hold and needs to be extended by means of an additional market-mechanism.

For experimental investigation a software was built for this thesis which implemented the exact simulation model of [BSV13] but extended it further to be applicable to arbitrary topologies. See Chapter 5 "Implementation" on details of the software.

In Chapter 2 "Theory" the theoretical background involved with this thesis is presented. First Leverage and systemic risk and its implications are discussed. Then an introduction into the mechanics of Continuous Double Auction as market-mechanisms and equilibrium theory in economics is given. Finally an overview of abstract networks, network-generating algorithms and and their properties is given.

In Chapter 3 "The Leverage Cycle" the theoretical model [BSV13] built their simulation upon is discussed in-depth.

In Chapter 4 "Topologies and Hypothesis" all topologies which are investigated are introduced and the conjecture about the type of topology necessary to reach the theoretical equilibirum is presented and discussed whether the given topologies could ever approach it or not.

Chapter 5 "Implementation" gives an in-depth explanation of the implementation of the computer-driven simulation presented in [BSV13] including a description of the architecture, implementation of the markets and trading mechanisms.

Chapter 6 "Results" shows the results of simulations of all implemented topologies.

Chapter 7 "Interpretation and Discussions" connects the content of the previous chapters to show that the initial hypothesis of Chapter 4 does not satisfy the equilibrium and shows how it can be reached by introducing an additional market. Then results of simulations with this market are given and discussed where will be shown that using the additional market an equilibrium will be reached but that it is different from the theoretical predictions.

In Chapter 8 "Conclusions" a short sum-up of the thesis and questions left for further research are presented.

Chapter 2

Theory

TODO: der theorie-teil. Soll in die verwendete Theorie des Hauptteils einführen und darauf hinweisen, aber nicht völlig trocken und losgelöst vom hauptteil sein. Soll immer den kontext des hauptteils berücksichtigen und schon gewisse anwendungsfälle vorwegnehmen.

2.1 Systemic risk and Leverage

Both are tightly coupled in a way that leverage increases systemic risk dramatically as was the case in the "Subprime Mortgage Crisis".

Systemic Risk

WIKI: It refers to the risks imposed by interlinkages and interdependencies in a system or market, where the failure of a single entity or cluster of entities can cause a cascading failure, which could potentially bankrupt or bring down the entire system or market.

[Bor10]

Leverage

WIKI: In finance, leverage (sometimes referred to as gearing in the United Kingdom and Australia) is any technique to multiply gains and losses.

Accounting Leverage Notational Leverage Economic Leverage

2.2 Continuous Double Auction

Paper: gode and sunders auszüge aus dem Breuer et al. Paper und Everything you wanted to know about Continous Double-Auctions

2.3 Equilibrium Theory

theoretisches: utiliy-funktionen und clearing preis in der simulation: ungeklärt, immer individuell, "steckenbleiben" vs. gleichgewicht, am ende an theoretischem gleichgewicht orientiert

2.4 Complex Networks

small-world power-law distribution generation algorithms dient hauptsächlich zur kategorisierung

TODO: In "State of the art" an overview of abstract networks and their properties is given. Also network-generating algorithms are presented and discussed. Because continuous double-auctions are the type of market which is used for matchings a short introduction is given on this topic too.

TODO: ziel hier eine theoretische übersicht über netzwerk-theorie zu geben wobei hauptaugenmerk auf die entwicklungen der letzten jahre (scale-free, small-world, ...)

Regular Graphs: [AlB99, vgl.] [New03, vgl.]

Random Graphs: but since then, most large scale networks with no apparent design principle were described as random graphs introduced by two Hungarian mathematicians Paul Erdos and Alfred Renyi [ER59, vgl.] [ER60, vgl.] Have small-world properties.

Small World Graphs or Average Path Length: Stanley Milgram [TM69] [Mil67] [Kle00]

Clustering Coefficient or Transitivity [WS98]

Degree Distribution [AlB02] Generally, it was believed that the degree distribution in most networks follows a Poisson distribution but in reality, real world networks have a highly skewed degree distribution following power-laws. Power-laws are expressions of the form y / x, where is a constant, x and y are the measures of interest [152].

Small World and Scale Free Network: A small world network as deined by Watts and Strogatz [WS98], is a network with high clustering coeffcient and small average path length. A scale free network as deined by Barabasi and Albert [AlB02], is a network where the degree distribution follows a power law.

Complex Networks: are Small-World and/or Scale-Free [BW00] [ASBS00] [Kle02] http://www.cs.princeton.edu/ chazelle/courses/BIB/big-world.htm

Mathematical stuff [New06] [ACL01] [EMB02] [GP04]

2.5 Network-Generating Algorithms

- fully connected - ascending connected - ascending connected with shortcuts
- hubs - erdos-renyi - barbasi-albert - watts-strogatz

Chapter 3

The Leverage Cycle

Definition des Modells Märkte, Marktmechanismen, clearing, utiliy funktionen,.... alles theoretisch, um des dann in implementierung praktisch zu zeigen Bestehende Resultate mit Bezug auf paper Fully-Connected: prozess und endverteilung, erreicht theoretisches Gleichgewicht approximativ

Chapter 4

Topologies and Hypothesis

Eigentliche Fragestellung: Wie wichtig ist die Vollvernetzung? Allgemeine Netzwerkstrukturen untersuchen aber mit hauptaugenmerk auf Ascending-Connected d.h. reicht ascending-connected aus?

4.1 Hypothesis

hypothese vorstellen: jedes paar von agenten muss über einen kantenzug erreichbar sein, in dem der optimismusfaktor von agent zu agent monoton wächst.

Chapter 5

Implementation

5.1 Functionality

5.1.1 Inspection

5.1.2 Replications

5.1.3 Experiments

GUI

Command-Line

5.2 Architecture

5.2.1 Frontend

5.2.2 Controller

5.2.3 Backend

5.3 Agents

5.3.1 Utility

5.4 Markets

5.4.1 Asset/Cash

5.4.2 Loan/Cash

5.4.3 Asset/Loan

5.5 Simulation

5.5.1 Sweeping and Matching

5.6 Performance improvement

Chapter 6

Results

In this Chapter the results of the experiments are given. Each topology-type introduced in chapter 4 "Topologies and Hypothesis" is handled in a separate section where the hypothesis is put to test in the section regarding the Ascending-Connected topologies.

Note: The numbers in tables resemble always a median-value with the standard-deviation given in parentheses.

6.1 Replicating theoretical equilibrium

As a point-of-reference and as an experimental proof for the correctness of the implementation of the simulation the results of a replication of the theoretical equilibrium and the equilibrium found in [BSV13] are given. Because equilibrium differs across the number of agents and the type of loan traded to be comparable the same amount of agents and the same loan-type has to be used in the experiments which is 1000 Agents and a 0.5 loan because [BSV13] report their equilibria only for a count of 1000 Agents and loans between 0.1 to 0.5.

Table 1: Theoretical Equilibrium for 1000 Agents

Asset-Price p	0.715
Loan-Price q	0.374
Marginal Buyer i0	0.583
Marginal Seller i1	0.802

Table 2: Equilibrium in [BSV13] for 1000 Agents and 0.5 loan

Asset-Price p	0.716
Loan-Price q	0.375
Marginal Buyer i0	0.583
Marginal Seller i1	0.801
Pessimist Wealth	1.716
Medianist Wealth	4.578
Optimist Wealth	5.032

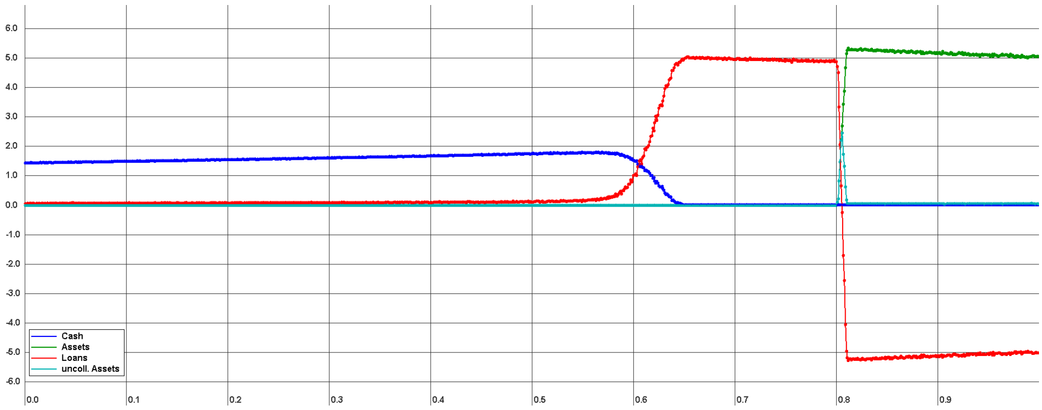

Figure 1: Wealth-Distribution of thesis-implementation of Fully-Connected topology

Table 3: Equilibrium of thesis-implementation

Asset-Price p	0.700 (0.005)
Loan-Price q	0.389 (0.002)
Marginal Buyer i0	0.616 (0.004)
Marginal Buyer i1	0.805 (0.001)
Pessimist Wealth	1.582 (0.01)
Medianist Wealth	4.578 (0.031)
Optimist Wealth	5.105 (0.025)

TODO: difference to breuer TODO: difference to theoretical equilibrium

6.2 Experiments configuration

In the following experiments 100 Agents were used, all markets (Asset/Cash, Loan/Cash, Asset/Loan) were enabled, as loan-type 0.5 was selected and the

Table 4: Performance of thesis-implementation with 1000 Agents and 0.5 loan

Successful TX	19,300.04 (101.68)
Total TX	29,606.82 (2938.82)
Failed TX	10,306.78 (2914.11)

number of replications run was 50. A replication was terminated after 1000 failed transactions in a row. Note that if trading is not possible any more before 1000 failed transactions have been reached in a row, the simulation is halted and thus it is possible that it terminates earlier as can be seen for the Ascending-Connected Importance Sampling topology.

[BSV13] showed that equilibrium can be reached already with 30 agents so this was the minimum number of agents to start with but for a smoother visual result 100 were chosen. Also one simulation-run takes not too much time with 100 as compared to the 1000 agents thus it is a very good match between visual accurateness and processing-power requirements.

The 0.5 loan was selected because its a risky one which is important as riskless loans (facevalue ¡= 0.2) the results are indifferent and wont show the characteristic progression.

Obviously the whole simulation-process is a random-process with an equilibrium (different for each topology) as the fixed-point solution thus one needs replications to reduce noise. The number of 50 replications was chosen because it is a good match between processing-power requirements and overall reduction of noise - increasing the number e.g. to 100 or 200 would not result in much better results but would need much longer to run. All facts can be seen and derived when using 50 replications thus for all figures 50 replications were used unless stated otherwise e.g. a single run.

Table 5: Configuration for all experiments

Agent-Count	100
Loan-Type	0.5
Replication-Count	50
Terminate after	1000 failed successive Transactions

Table 6: Theoretical Equilibrium for 100 Agents

Asset-Price p	0.716
Loan-Price q	0.384
Marginal Buyer i0	0.584
Marginal Seller i1	0.801

6.3 Fully-Connected Topology

This topology serves as the major point-of-reference for the other experiments as it reaches the theoretical equilibrium for 1000 agents as demonstrated.

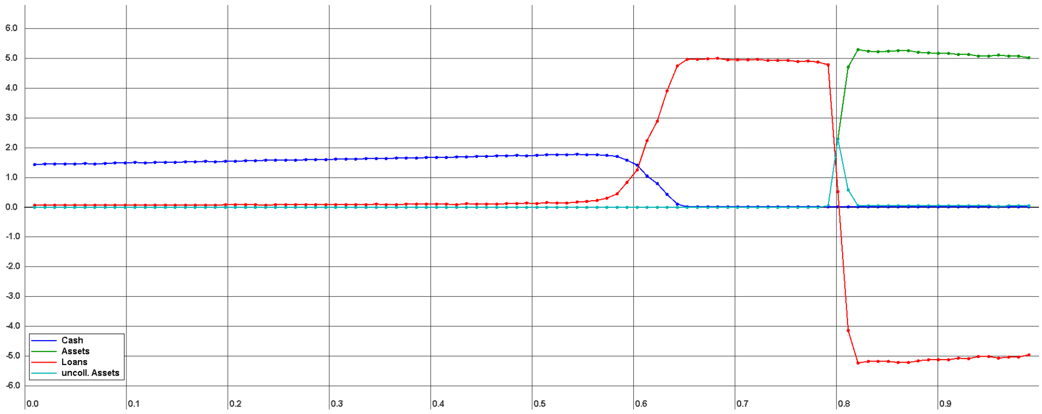

Figure 2: Wealth-Distribution of Fully-Connected topology

Table 7: Equilibrium of Fully-Connected topology

Asset-Price	0.689 (0.010)
Loan-Price	0.384 (0.004)
i0 (Marginal Buyer)	0.603 (0.007)
i1 (Marginal Seller)	0.803 (0.003)
Pessimist Wealth	1.597 (0.015)
Medianist Wealth	4.565 (0.113)
Optimist Wealth	5.021 (0.064)

Table 8: Performance of Fully-Connected topology

Successful TX	1916.14 (31.42)
Total TX	6364.8 (1679.21)
Failed TX	4448.66 (1668.93)

6.3.1 Half-Fully Connected

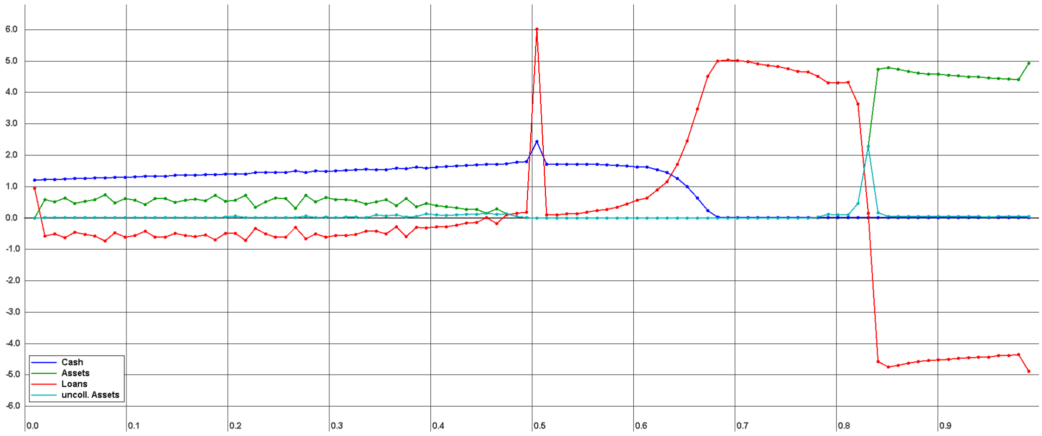

Figure 3: Wealth-Distribution of Half-Fully Connected topology

Table 9: Equilibrium of Half-Fully Connected topology

Asset-Price	0.651 (0.027)
Loan-Price	0.362 (0.013)
i0 (Marginal Buyer)	0.640 (0.015)
i1 (Marginal Seller)	0.833 (0.09)
Pessimist Wealth	1.22 (0.096)
Medianist Wealth	2.258 (0.409)
Optimist Wealth	4.526 (0.071)

Table 10: Performance of Half-Fully Connected topology

Successful TX	14,218.9 (4621.74)
Total TX	15,253.02 (4633.44)
Failed TX	1034.12 (22.99)

6.4 Ascending-Connected Topologies

6.4.1 Ascending-Connected

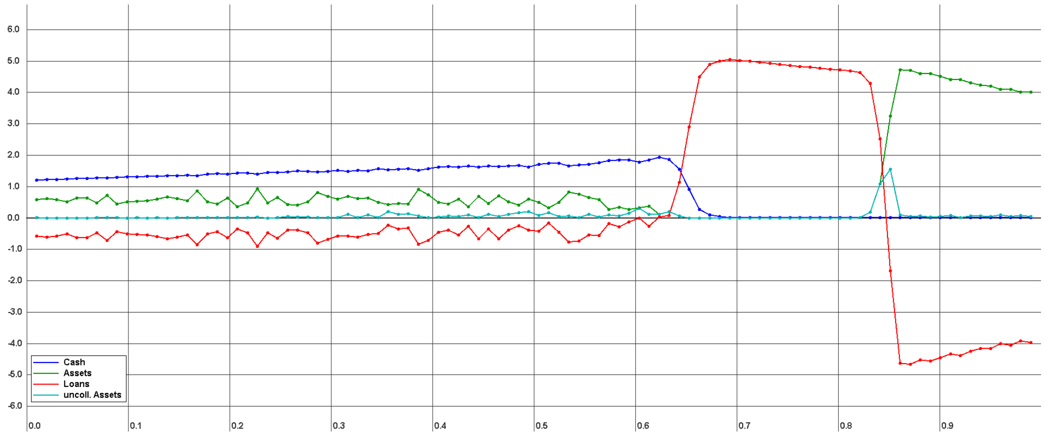

Figure 4: Wealth-Distribution of Ascending-Connected topology

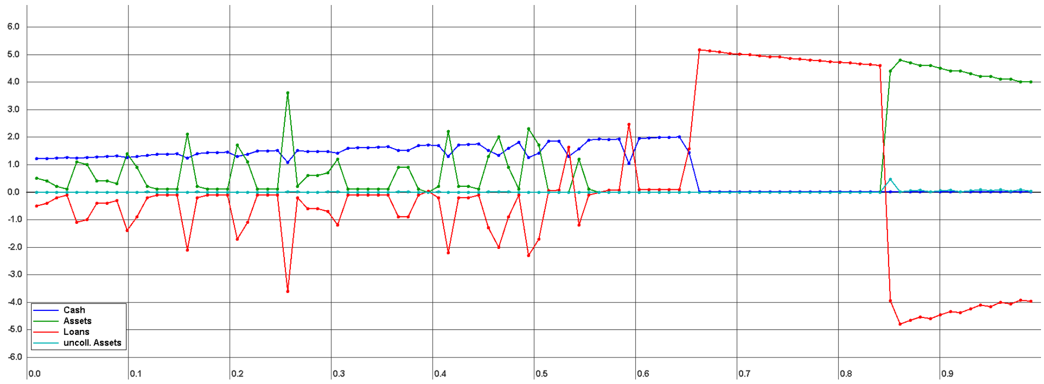

Figure 5: Wealth-Distribution of Ascending-Connected topology after single run

TODO: move to interpretation: As can be clearly seen the equilibrium is fundamentally different than the fully-connected one and thus the hypothesis is not satisfied.

Table 11: Equilibrium of Ascending-Connected topology

Asset-Price	0.711 (0.016)
Loan-Price	0.391 (0.005)
i0 (Marginal Buyer)	0.646(0.012)
i1 (Marginal Seller)	0.850 (0.008)
Pessimist Wealth	1.166 (0.072)
Medianist Wealth	1.869 (0.243)
Optimist Wealth	4.307 (0.070)

Table 12: Performance of Ascending-Connected topology

Successful TX	36,940.96 (1948.69)
Total TX	38,117.04 (1934.06)
Failed TX	1176.08 (98.01)

6.4.2 Ascending-Connected Importance Sampling

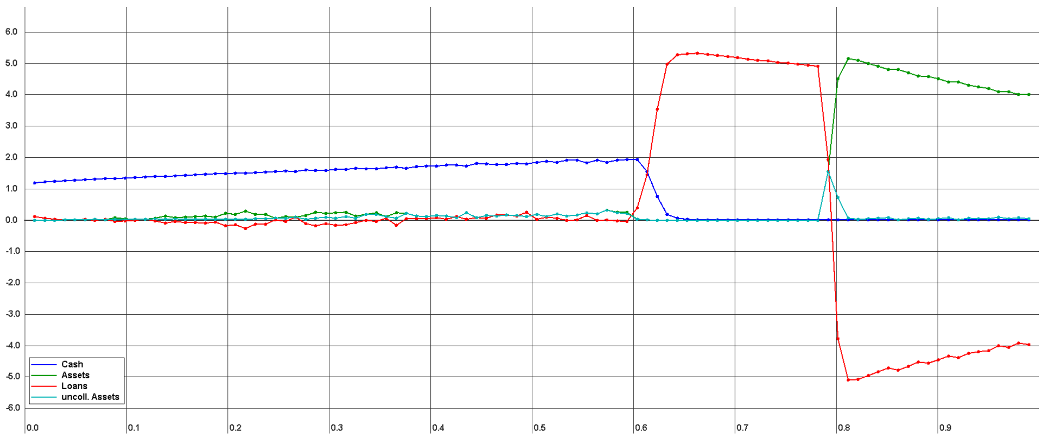

Figure 6: Wealth-Distribution of Ascending-Connected Importance Sampling topology

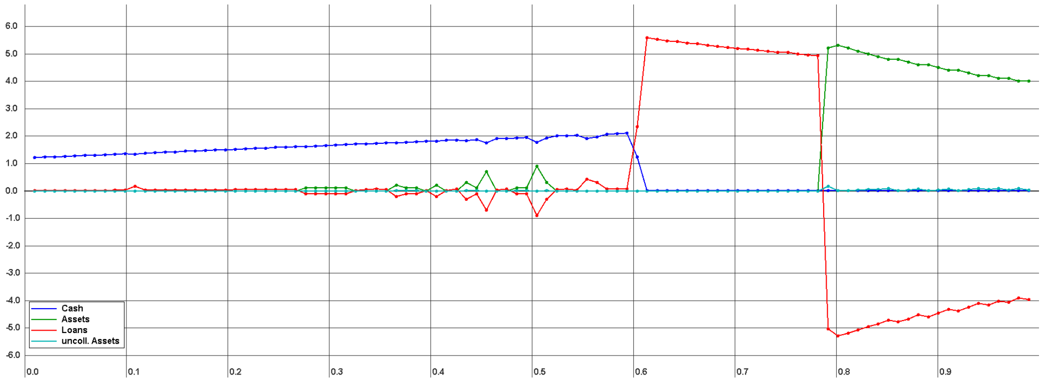

Figure 7: Wealth-Distribution of Ascending-Connected Importance Sampling topology after single run

Table 13: Equilibrium of Ascending-Connected Importance Sampling topology

Asset-Price	0.691 (0.009)
Loan-Price	0.383 (0.004)
i0 (Marginal Buyer)	0.614 (0.009)
i1 (Marginal Seller)	0.799 (0.006)
Pessimist Wealth	1.497 (0.072)
Medianist Wealth	3.934 (0.505)
Optimist Wealth	4.519 (0.051)

Table 14: Performance of Ascending-Connected Importance Sampling topology

Successful TX	49,881.6 (1733.33)
Total TX	49,882.6 (1733.33)
Failed TX	1.0 (0.00)

Note that in this case the matching-probabilities are such that upon the first failed transaction the equilibrium has reached as no agent can trade with each other anymore which results in just on single failed transaction.

TODO: move to interpretation: As can be clearly seen the equilibrium is fundamentally different than the fully-connected one and thus the hypothesis is not satisfied.

6.4.3 Ascending-Connected with short-cuts

6.4.4 Random short-cuts

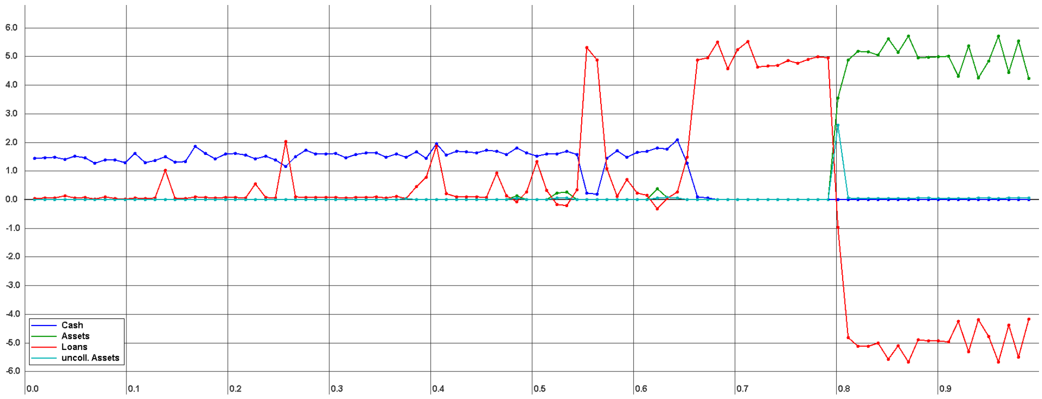

Figure 8: Wealth-Distribution of Ascending-Connected random short-cuts topology

Table 15: Equilibrium of Ascending-Connected random short-cuts topology

Asset-Price	0.731 (0.019)
Loan-Price	0.393 (0.009)
i0 (Marginal Buyer)	0.649 (0.005)
i1 (Marginal Seller)	0.804 (0.004)
Pessimist Wealth	1.441 (0.03)
Medianist Wealth	4.282 (0.278)
Optimist Wealth	4.974 (0.038)

Table 16: Performance of Ascending-Connected random short-cuts topology

Successful TX	8314.78 (229.85)
Total TX	9496.84 (228.23)
Failed TX	1182.06 (29.23)

2 short-cuts

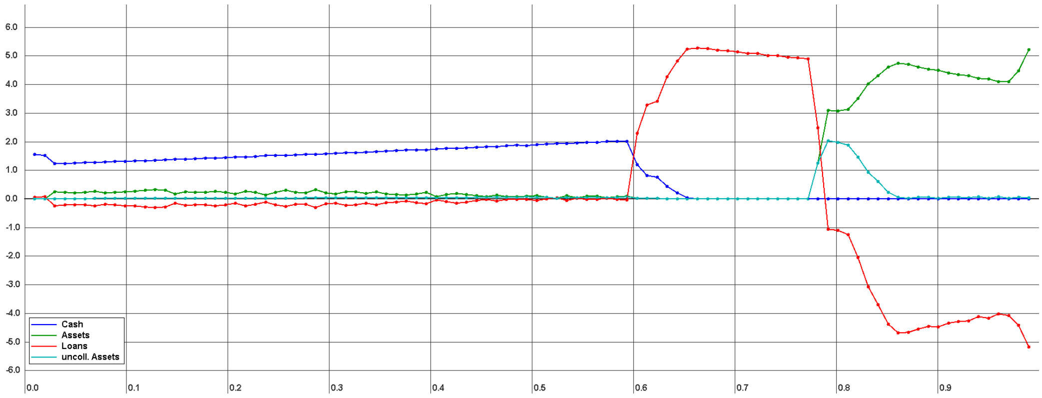

Figure 9: Wealth-Distribution of Ascending-Connected 2 short-cuts topology

Table 17: Equilibrium of Ascending-Connected 2 short-cuts topology

Asset-Price	0.662 (0.024)
Loan-Price	0.376 (0.006)
i0 (Marginal Buyer)	0.608 (0.018)
i1 (Marginal Seller)	0.805 (0.028)
Pessimist Wealth	1.441 (0.21)
Medianist Wealth	3.978 (1.442)
Optimist Wealth	4.514 (0.063)

Table 18: Performance of Ascending-Connected random short-cuts topology

Successful TX	37,093.64 (12,864.4)
Total TX	38,115.54 (12,851.53)
Failed TX	1021. (18.85)

5 full short-cuts

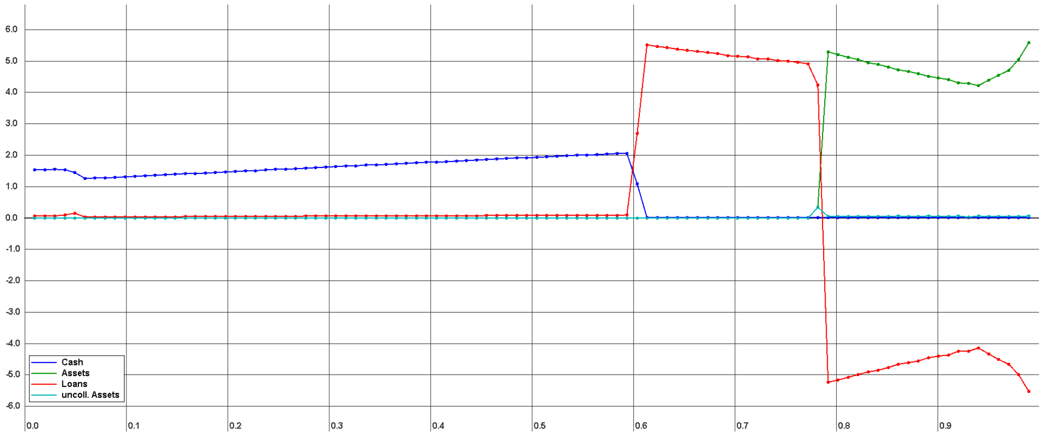

Figure 10: Wealth-Distribution of Ascending-Connected 5 full short-cuts topology

Table 19: Equilibrium of Ascending-Connected 5 full short-cuts

Asset-Price	0.656 (0.019)
Loan-Price	0.371 (0.003)
i0 (Marginal Buyer)	0.594 (0.0)
i1 (Marginal Seller)	0.792 (0.0)
Pessimist Wealth	1.649 (0.002)
Medianist Wealth	5.013 (0.018)
Optimist Wealth	4.746 (0.011)

Table 20: Performance of Ascending-Connected 5 full short-cuts topology

Successful TX	16,971.34 (228.0)
Total TX	17,998.26 (225.23)
Failed TX	1026.92 (22.68)

TODO: move to interpretation: As can be clearly seen 5 full shortcuts seem to be already enough to solve the inefficiencies seen in Ascending-Connected with/without Importance Sampling.

15 full short-cuts

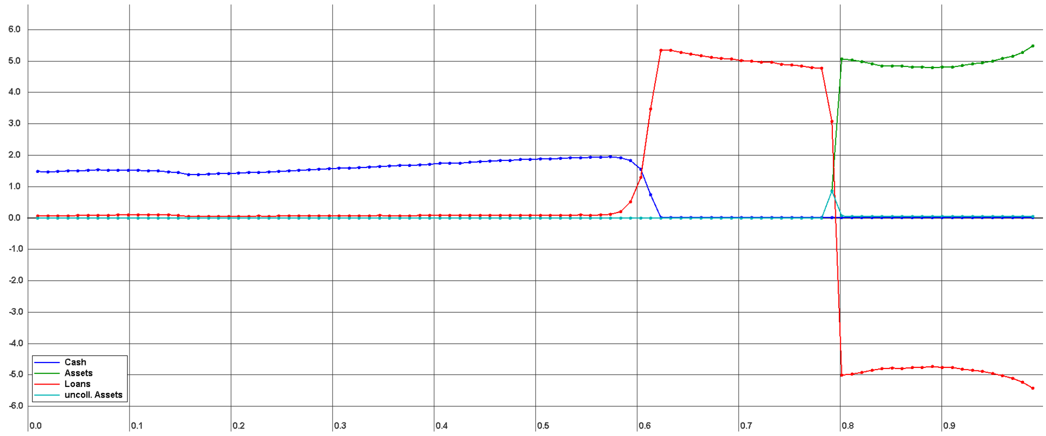

Figure 11: Wealth-Distribution of Ascending-Connected 15 full short-cuts topology

Table 21: Equilibrium of Ascending-Connected 15 full short-cuts topology

Asset-Price	0.658 (0.024)
Loan-Price	0.366 (0.009)
i0 (Marginal Buyer)	0.601 (0.004)
i1 (Marginal Seller)	0.802 (0.0)
Pessimist Wealth	1.649 (0.004)
Medianist Wealth	4.811 (0.092)
Optimist Wealth	4.957 (0.021)

Table 22: Performance of Ascending-Connected 15 full short-cuts topology

Successful TX	4498.08 (58.67)
Total TX	5522.860 (64.72)
Failed TX	1024.78 (17.3)

30 full short-cuts

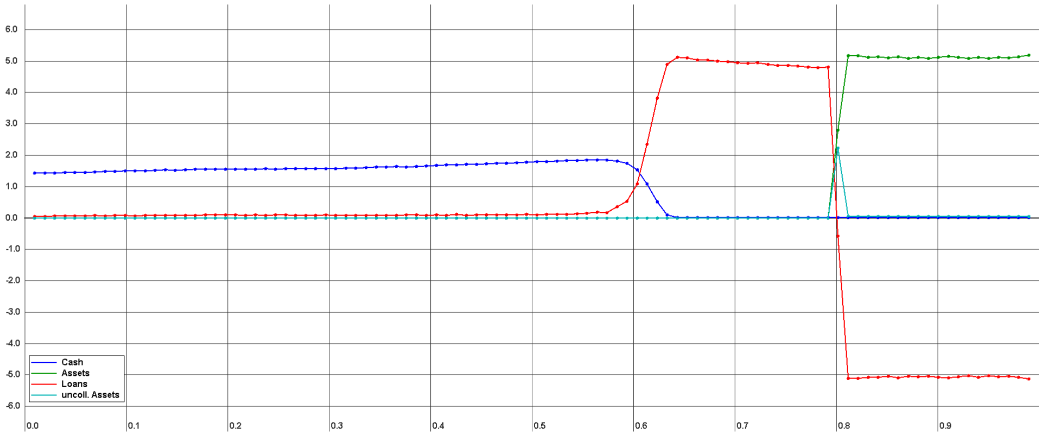

Figure 12: Wealth-Distribution of Ascending-Connected 30 full short-cuts topology

Table 23: Equilibrium of Ascending-Connected 30 full short-cuts topology

Asset-Price	0.681 (0.012)
Loan-Price	0.378 (0.006)
i0 (Marginal Buyer)	0.603 (0.006)
i1 (Marginal Seller)	0.802 (0.1)
Pessimist Wealth	1.649 (0.009)
Medianist Wealth	4.702 (0.112)
Optimist Wealth	5.004 (0.025)

Table 24: Performance of Ascending-Connected 30 full short-cuts topology

Successful TX	2211.08 (35.88)
Total TX	3225.76 (40.18)
Failed TX	1014.68 (10.55)

5 regular short-cuts

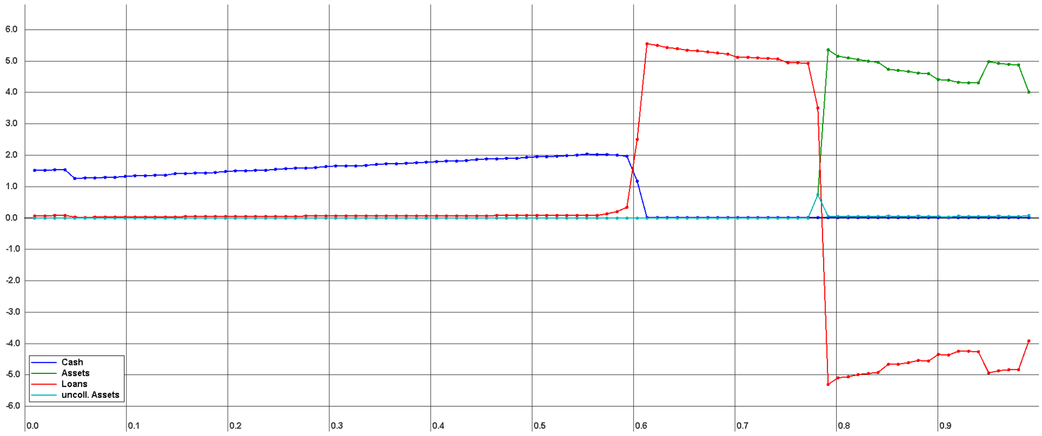

Figure 13: Wealth-Distribution of Ascending-Connected 5 regular short-cuts topology

Table 25: Equilibrium of Ascending-Connected 5 regular short-cuts topology

Asset-Price	0.665 (0.016)
Loan-Price	0.364 (0.007)
i0 (Marginal Buyer)	0.595 (0.003)
i1 (Marginal Seller)	0.792 (0.0)
Pessimist Wealth	1.649 (0.003)
Medianist Wealth	4.991 (0.045)
Optimist Wealth	4.727 (0.011)

Table 26: Performance of Ascending-Connected 5 regular short-cuts topology

Successful TX	14,570.44 (157.61)
Total TX	15,634.68 (166.21)
Failed TX	1064.24 (29.88)

15 regular short-cuts

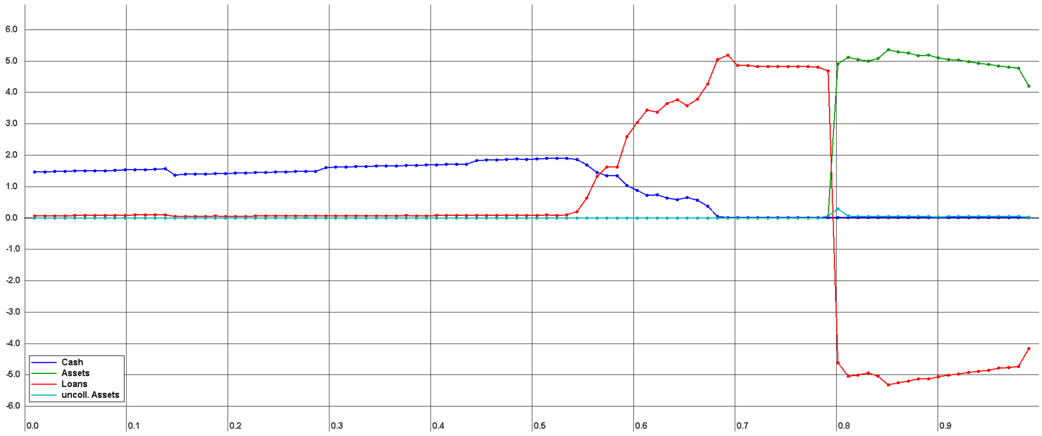

Figure 14: Wealth-Distribution of Ascending-Connected 15 regular short-cuts topology

Table 27: Equilibrium Ascending-Connected 15 regular short-cuts topology

Asset-Price	0.705 (0.020)
Loan-Price	0.357 (0.018)
i0 (Marginal Buyer)	0.586 (0.023)
i1 (Marginal Seller)	0.802 (0.0)
Pessimist Wealth	1.649 (0.051)
Medianist Wealth	4.146 (0.101)
Optimist Wealth	4.997 (0.007)

Table 28: Performance of Ascending-Connected 15 regular short-cuts topology

Successful TX	4373.28 (50.13)
Total TX	5502.52 (52.11)
Failed TX	1129.24 (19.2)

30 regular short-cuts

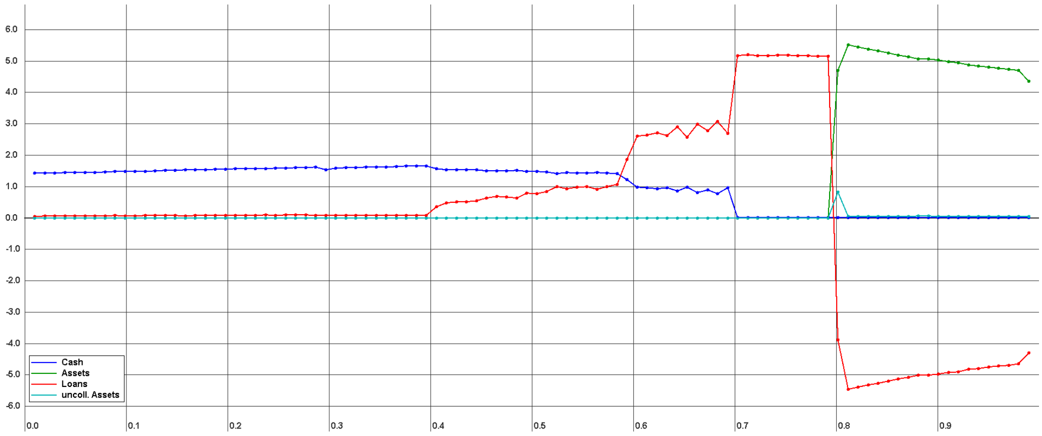

Figure 15: Wealth-Distribution of Ascending-Connected 30 regular short-cuts topology

Table 29: Equilibrium of Ascending-Connected 30 regular short-cuts topology

Asset-Price	0.710 (0.021)
Loan-Price	0.398 (0.008)
i0 (Marginal Buyer)	0.589 (0.021)
i1 (Marginal Seller)	0.802 (0.0)
Pessimist Wealth	1.479 (0.049)
Medianist Wealth	3.713 (0.125)
Optimist Wealth	5.0 (0.0)

Table 30: Performance of Ascending-Connected 30 regular short-cuts topology

Successful TX	5427.02 (90.82)
Total TX	6566.06 (96.04)
Failed TX	1139.04 (27.74)

Chapter 7

Interpretation and Discussion

In this Chapter interpretation of the results of Chapter 6 are given and discussed.

First the Hub-, Scale-Free and Small-World Topologies are handled as they turn out to fall far from satisfying the hypothesis. Then the Ascending-Connected topology is discussed as it is the most interesting one - both without and with importance sampling - because it is the most minimal network which satisfies the requirements for the hypothesis. As will be seen satisfying these requirements is not enough to reach equilibrium but an additional market is required which will be introduced too.

7.1 Ascending Connected topology

Es trifft hypothese offensichtlich nicht zu (resultate zeigen und interpretieren) Gibt es möglicherweise Marktmechanismen, die dies beheben können oder liegt es grundstäzlich in der natur der topologie? Entweder Vollvernetzung notwendig oder neuer markt für theoretisches gleichgewicht

Chapter 8

A new Market

neuer markt: Collateralisierte ASsets gegen Cash Neuer Markt: Collateralisierte Assets gegen Cash Käufer: bekommt Asset und Loan, zahlt Cash Verkäufer: bekommt Cash und gibt Asset und Loan limit-preis für diesen markt? Fläche unter P/M/O gleich bei Fully-Connected und Ascending-Connected obwohl unterschiedliche

Erweiterung mit zweiter Hypothese zweite Hypothese: erreicht ascending-connected nun mit dem neuen markt das gleichgewicht? ergebnis der zweiten hypothese: funktioniert

8.1 Results with the new market

As experiment-configuration the same as given in Chapter 5 "Results" is used.

Table 31: Configuration for all experiments

Agent-Count	100
Bond-Type	0.5
Replication-Count	50
Terminate after	1000 failed successive Transactions

8.1.1 Fully-Connected

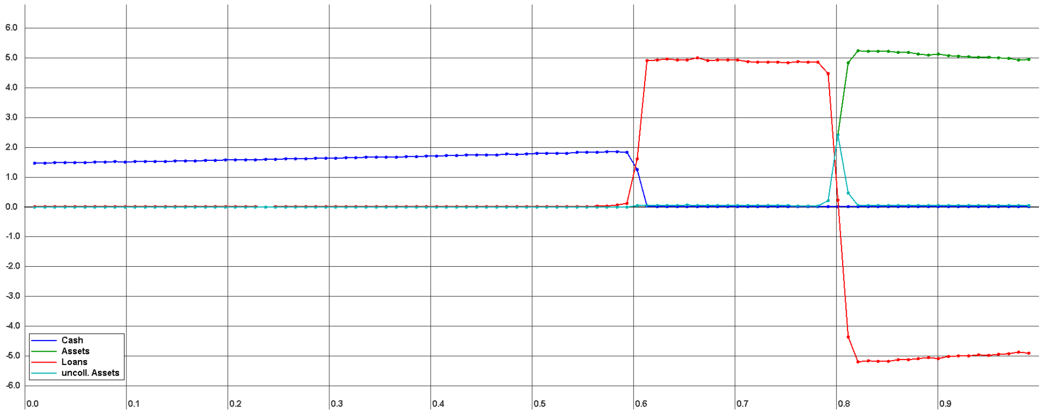

Figure 16: Wealth-Distribution of Fully-Connected topology

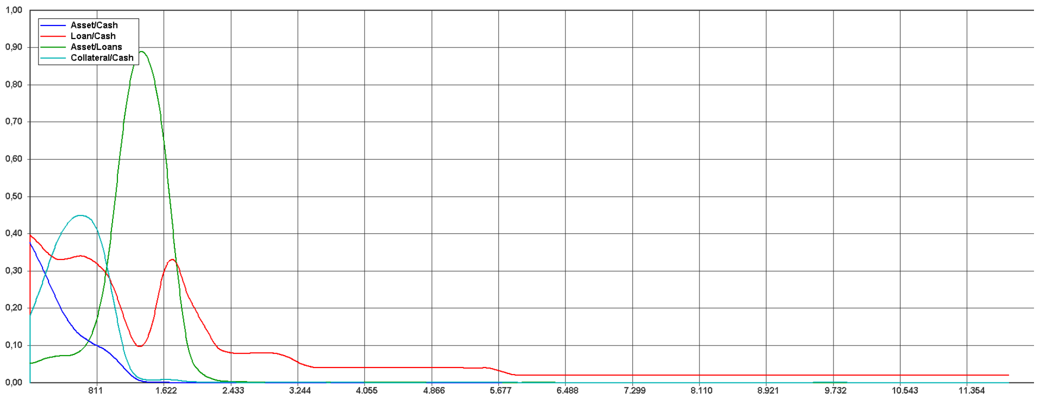

Figure 17: Market-activity over time of Fully-Connected topology

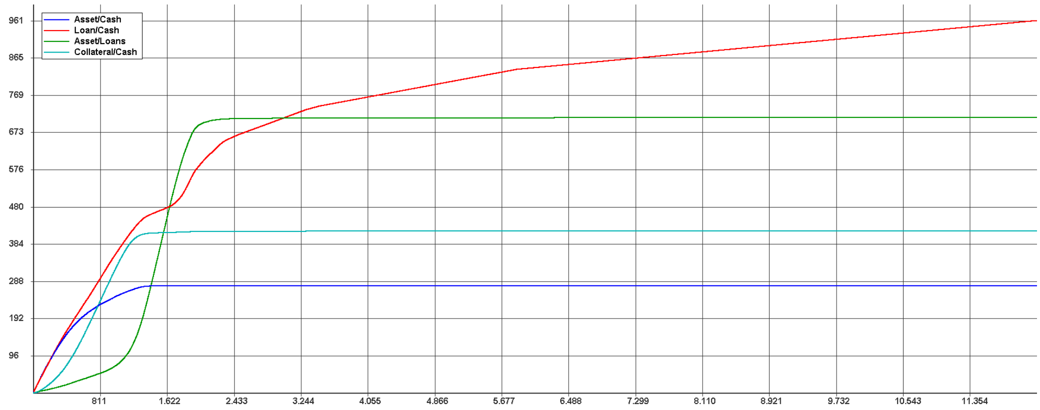

Figure 18: Market-activity accumulated of Fully-Connected topology

8.1.2 Ascending-Connected

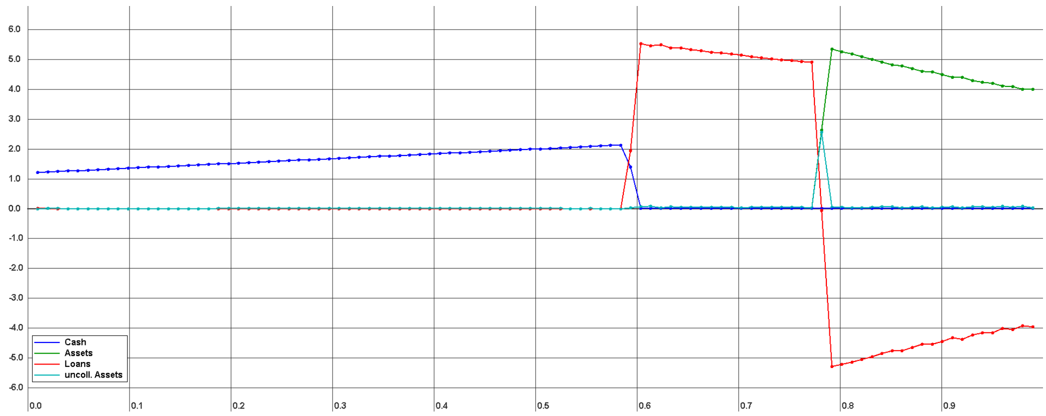

Figure 19: Wealth-Distribution of Ascending-Connected topology

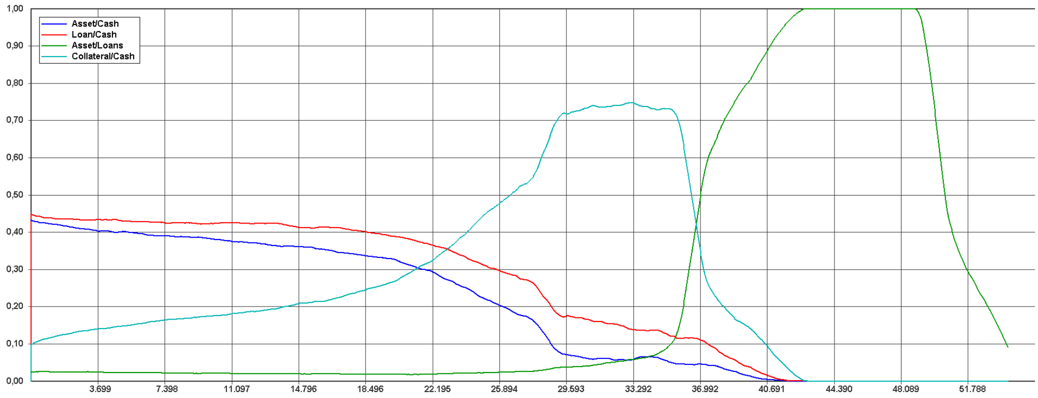

Figure 20: Market-activity over time of Ascending-Connected topology

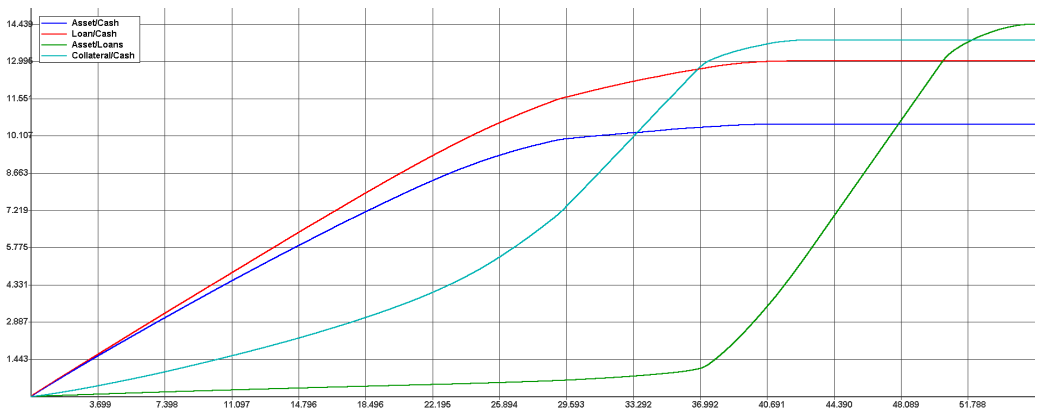

Figure 21: Market-activity accumulated of Ascending-Connected topology

Chapter 9

Conclusion, Summary and further Research

importance-sampling allgemein experimentelle simulationen mit echten menschen: einschränken der handelsbeziehungen wie lokal bzw. global muss die vernetzung sein (ascending-connected full shortcuts) beweisbarkeit der ascending-connected (MIT/OHNE neuem Markt)

9.1 Conclusion

9.2 Summary

9.3 Further Research

Appendix A

Topologies

All Topologies are demonstrated with 30 Agents only for better visibility and übersicht of edges. All topologies have connected-component of 1 (TODO: warum) except Erdos-Renyi can produce connected-component ¿ 1.

A.1 Fully-Connected

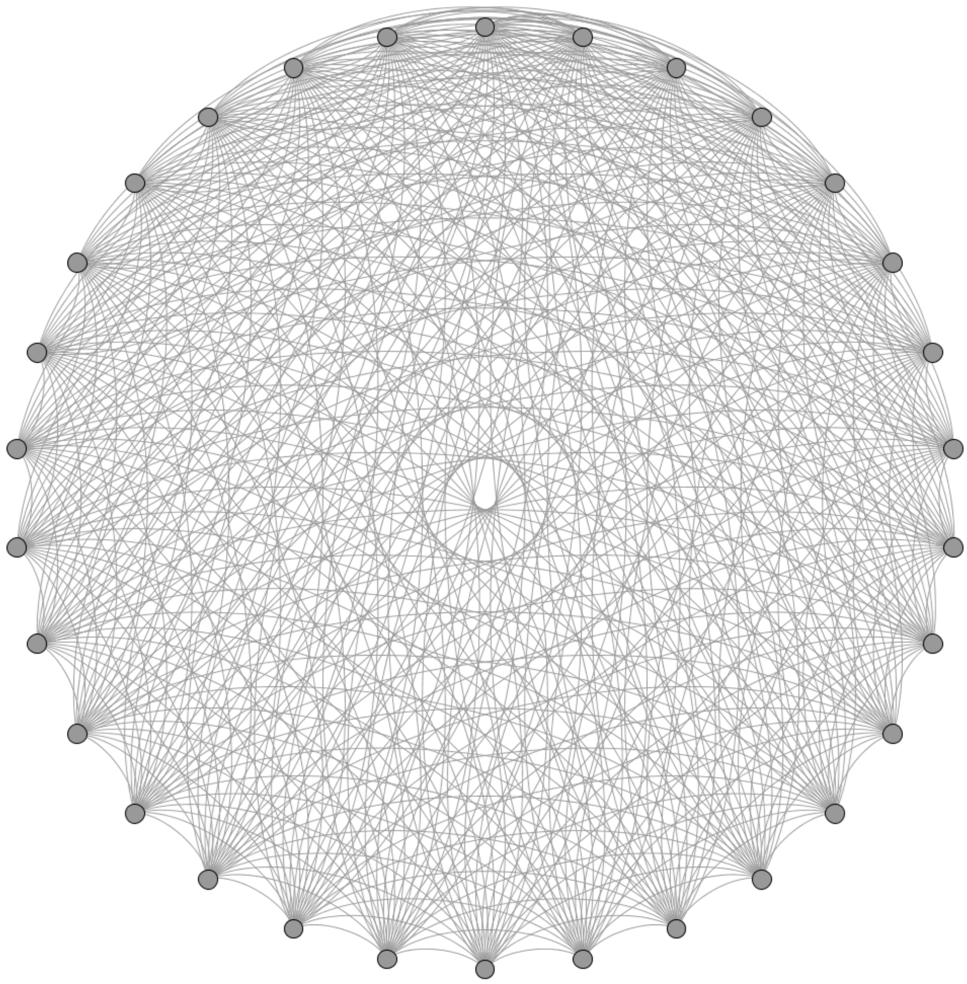

Figure 22: Fully-Connected topology

Table 32: Network metrics Fully-Connected topology

Avg. degree	29
Avg. path-length	1
Avg. clustering coefficient	1
Network diameter	1
Graph density	1

A.2 Half-Fully Connected

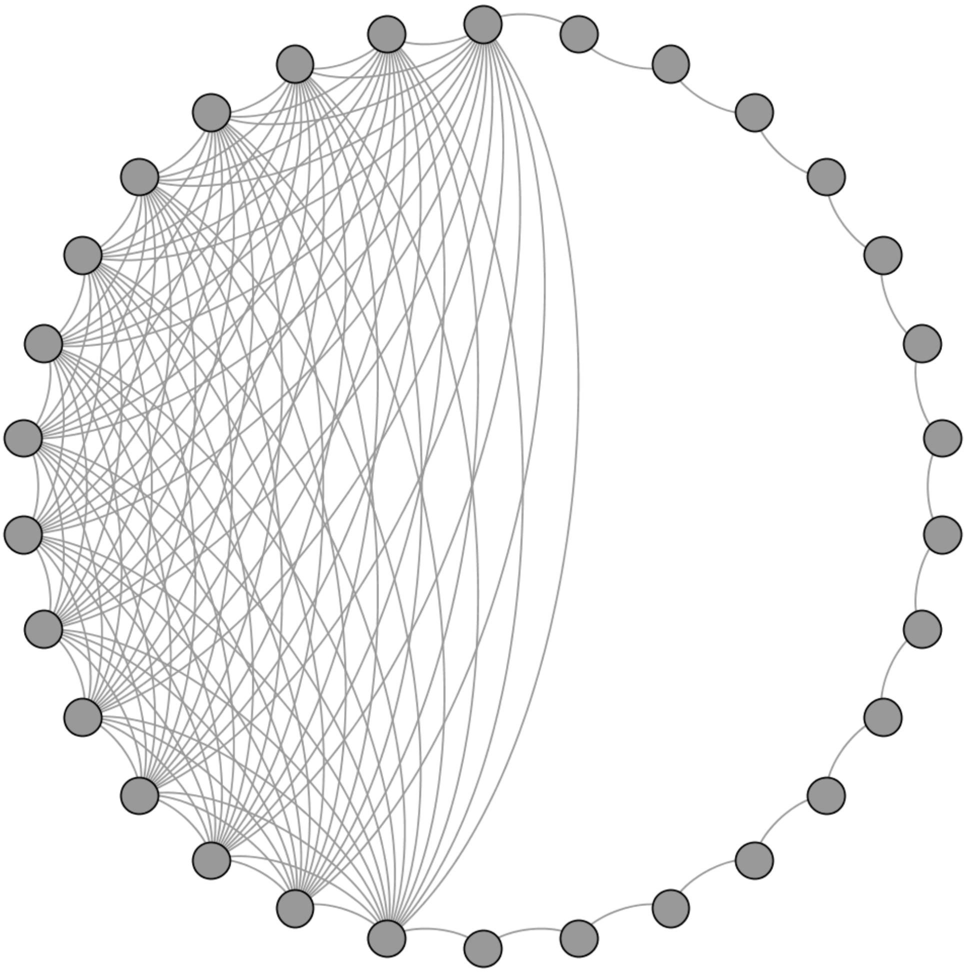

Figure 23: Half Fully-Connected topology

Table 33: Network metrics Half Fully-Connected topology

Avg. degree	8.067
Avg. path-length	4.007
Avg. clustering coefficient	0.491
Network diameter	9
Graph density	0.278

A.3 Ascending-Connected

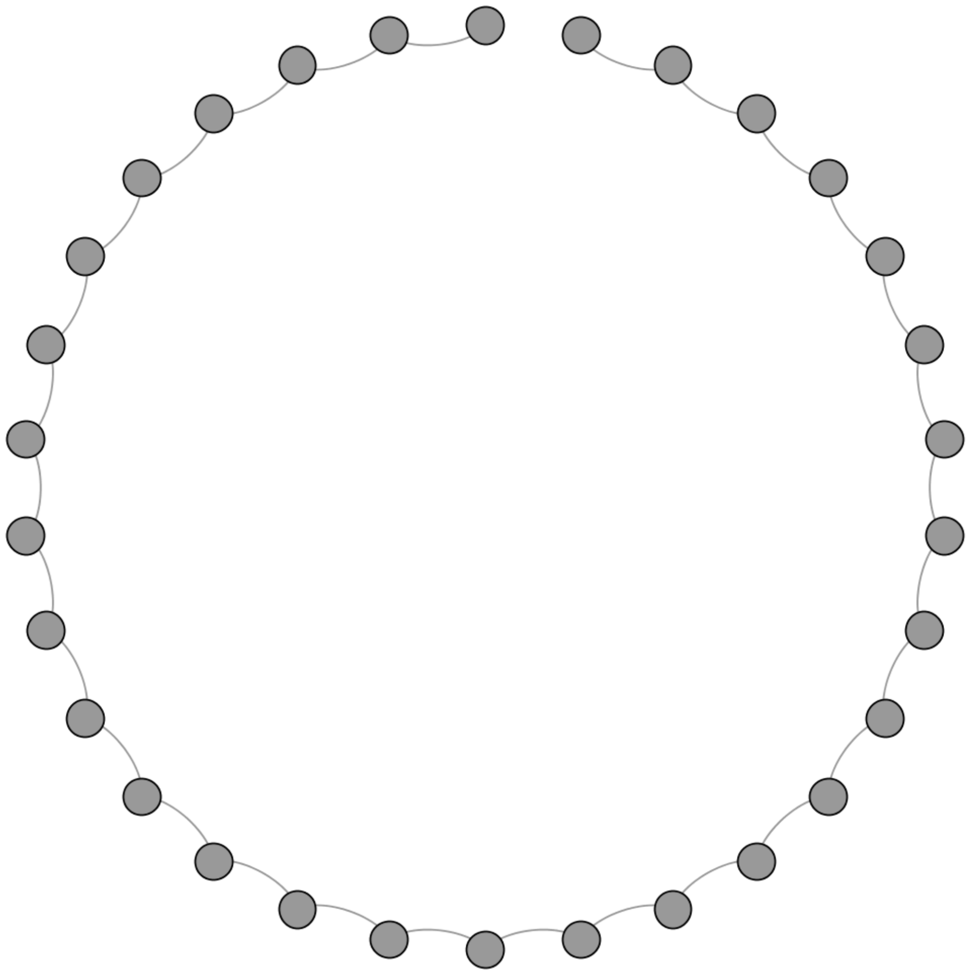

Figure 24: Ascending-Connected topology

Table 34: Network metrics Ascending-Connected topology

Avg. degree	1.933
Avg. path-length	10.33
Avg. clustering coefficient	0
Network diameter	29
Graph density	0.067

A.4 Ascending-Connected with short-cuts

A.4.1 Full short-cuts

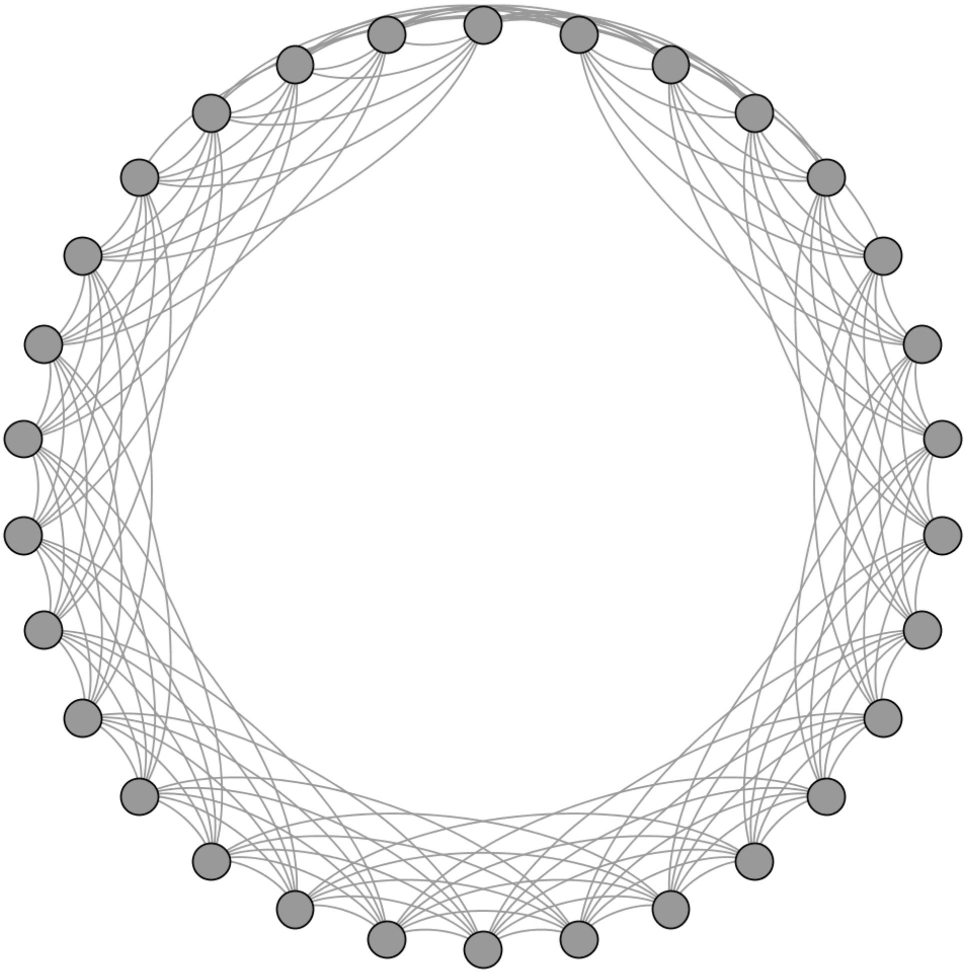

Figure 25: Ascending-Connected 5 full short-cuts topology

Table 35: Network metrics Ascending-Connected 5 full short-cuts topology

Avg. degree	10
Avg. path-length	1.966
Avg. clustering coefficient	0.667
Network diameter	3
Graph density	0.345

A.4.2 Regular short-cuts

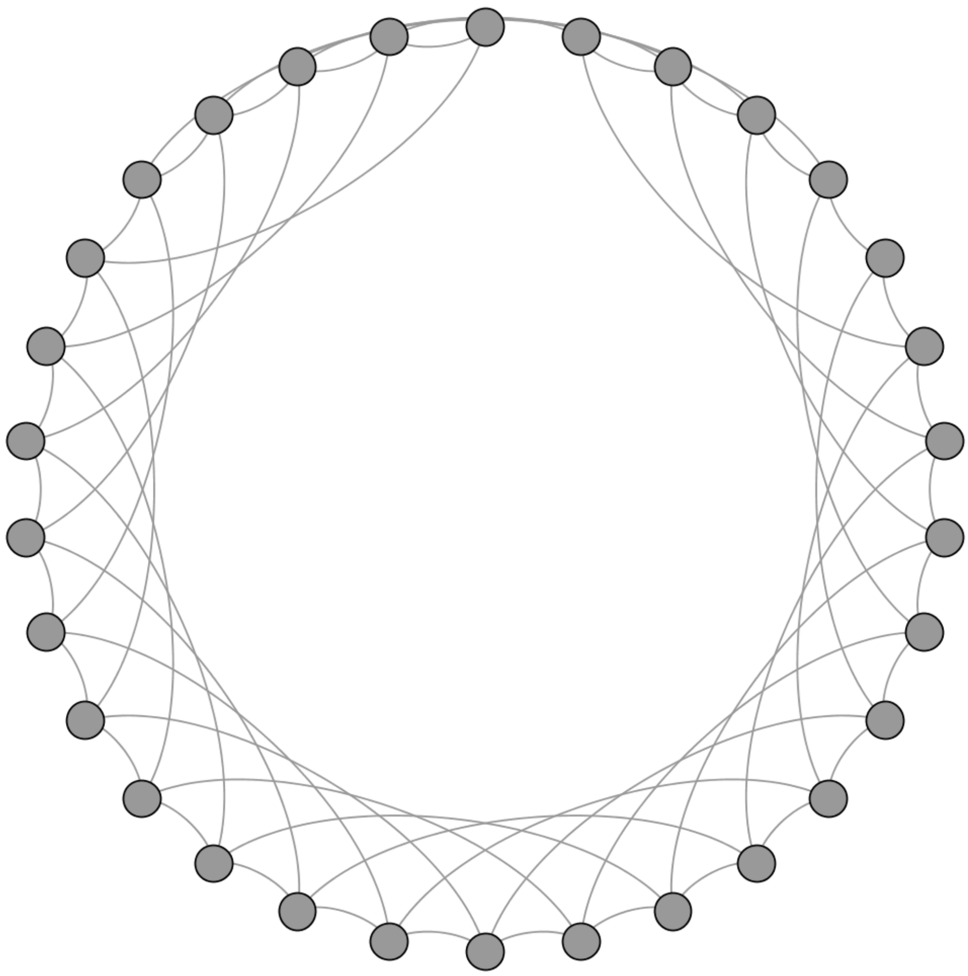

Figure 26: Ascending-Connected 5 regular short-cuts topology

Table 36: Network metrics Ascending-Connected 5 regular short-cuts topology

Avg. degree	3.867
Avg. path-length	2.839
Avg. clustering coefficient	0
Network diameter	6
Graph density	0.133

A.4.3 Random short-cuts

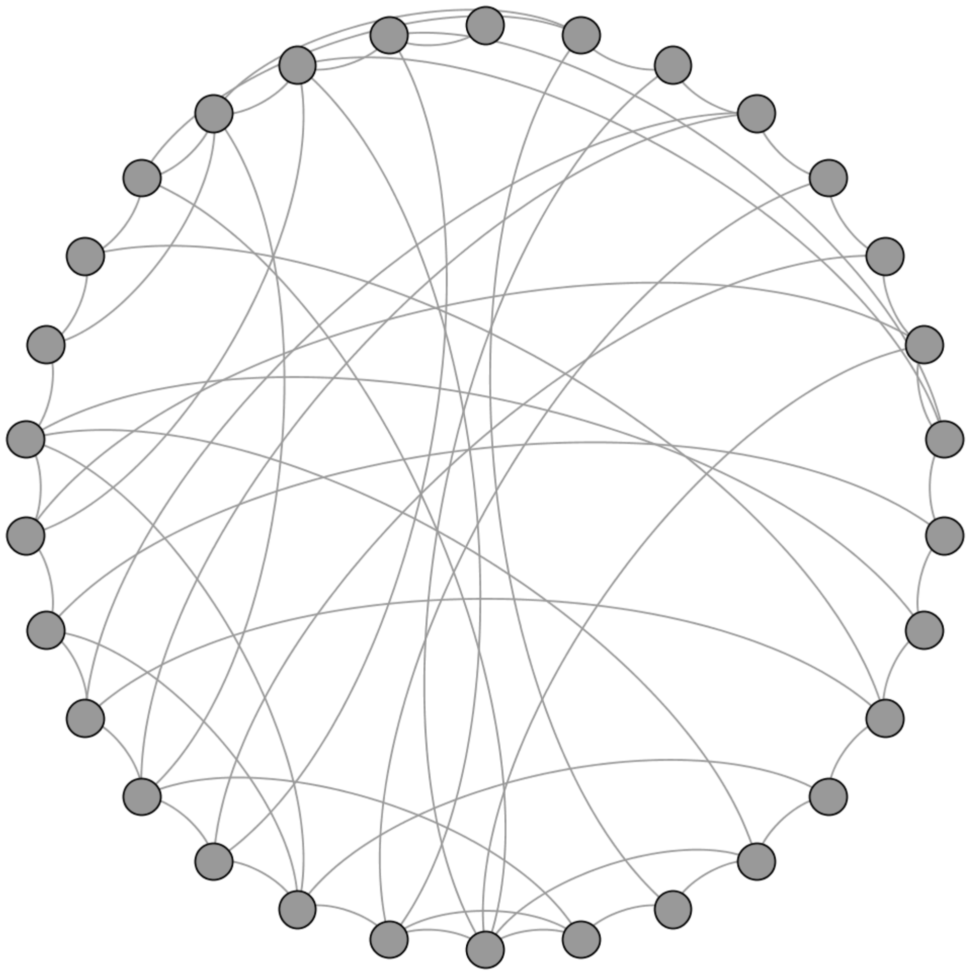

Figure 27: Ascending-Connected random short-cuts probability 1.0 topology

Table 37: Network metrics Ascending-Connected random short-cuts topology

Avg. degree	3.867
Avg. path-length	2.506
Avg. clustering coefficient	0.056
Network diameter	5
Graph density	0.133

A.5 Hub-based topologies

A.5.1 3 Hubs

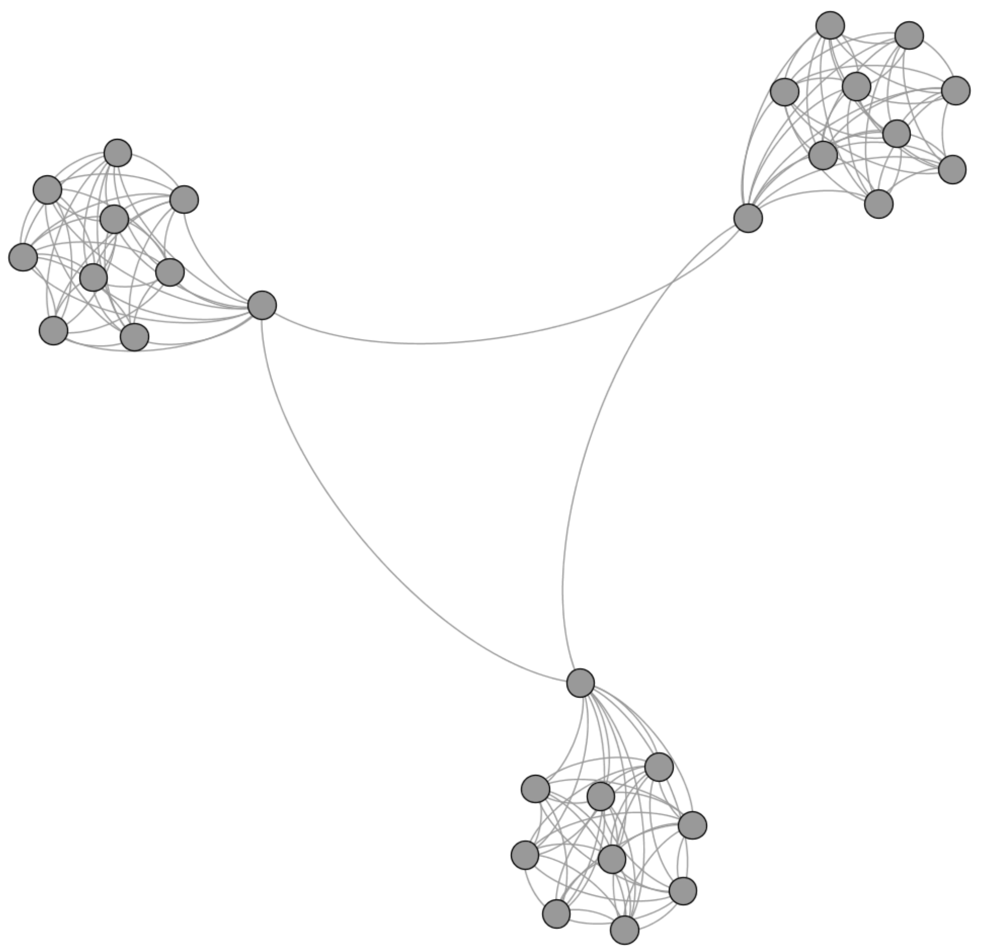

Figure 28: 3 Hubs topology

Table 38: Network metrics 3 Hubs topology

Avg. degree	9.2
Avg. path-length	2.241
Avg. clustering coefficient	0.976
Network diameter	3
Graph density	0.371

A.5.2 3 Median Hubs

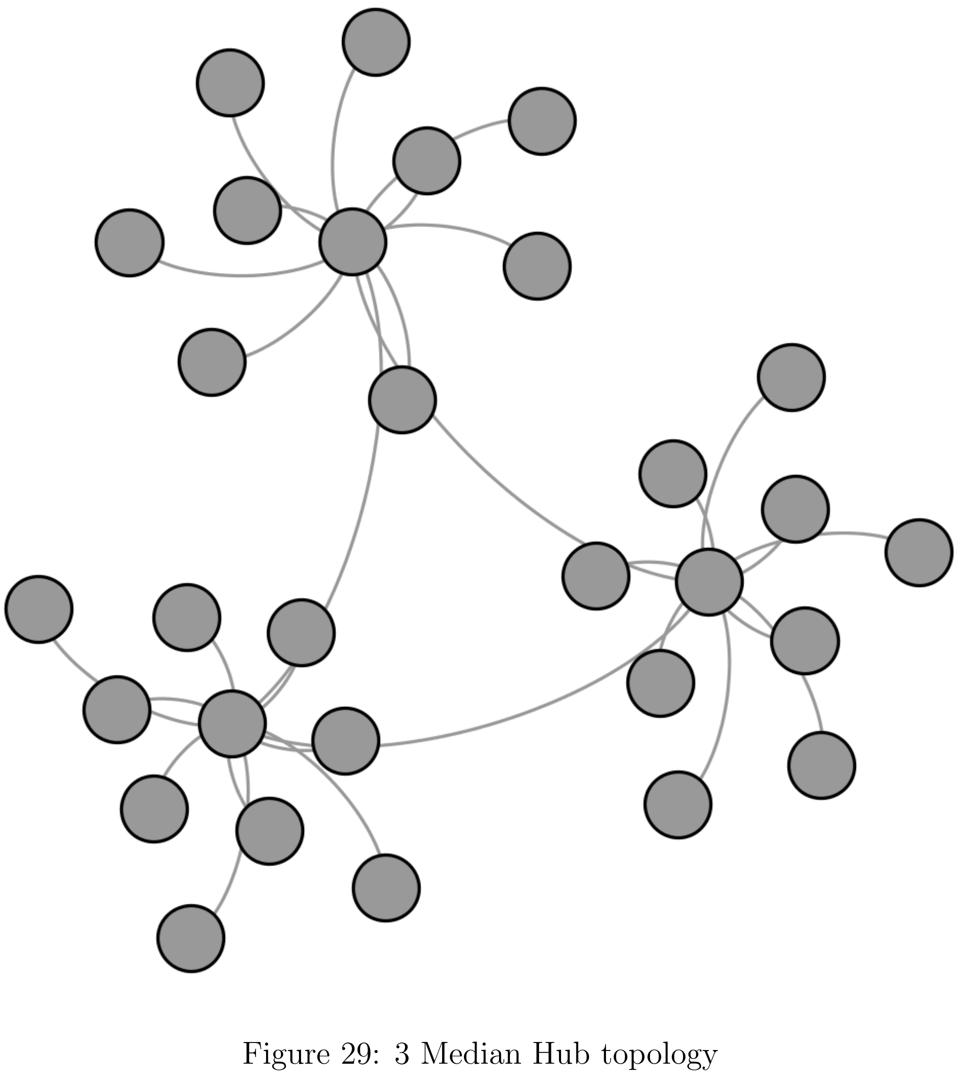

Figure 29: 3 Median Hub topology

Table 39: Network metrics 3 Median Hub topology

Avg. degree	2
Avg. path-length	2.49
Avg. clustering coefficient	0.018
Network diameter	3
Graph density	0.069

A.5.3 Median Hub

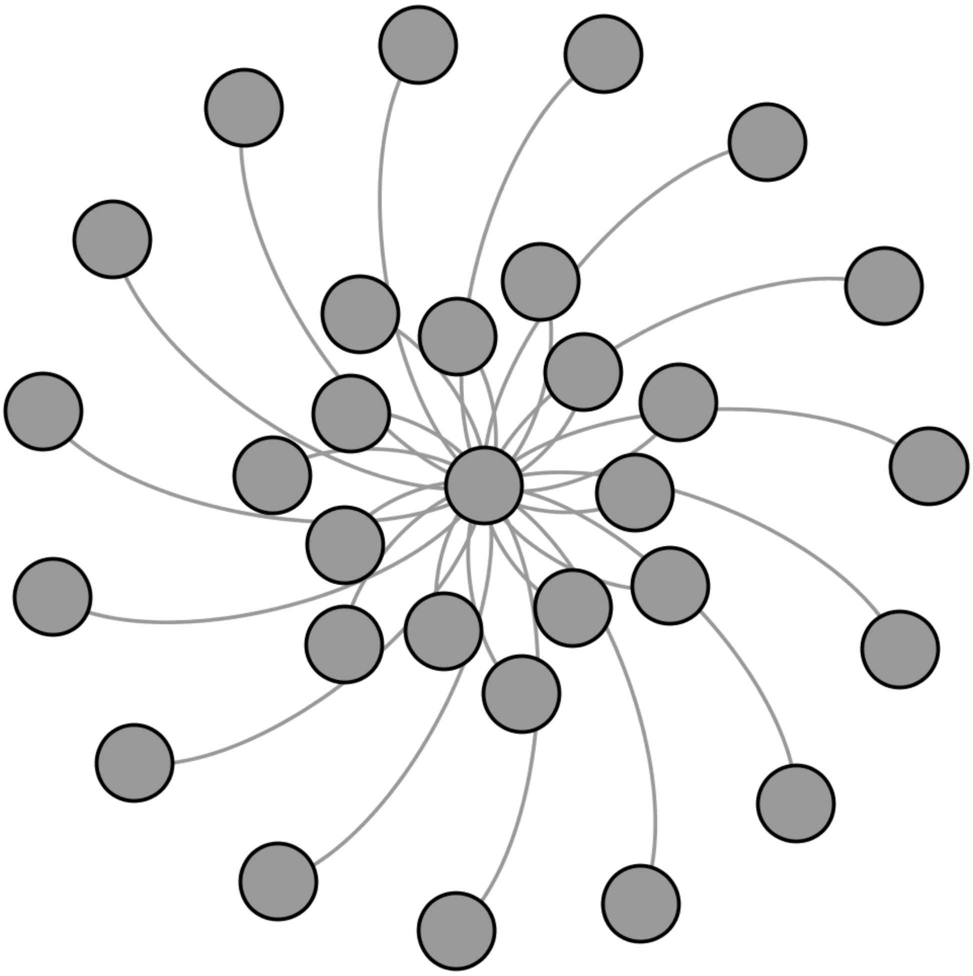

Figure 30: Median Hub topology

Table 40: Network metrics Median Hub topology

Avg. degree	1.933
Avg. path-length	1.933
Avg. clustering coefficient	0
Network diameter	2
Graph density	0.067

A.5.4 Maximum Hub

Looks the same as 1 Median Hub but all edges are connected to the agent with the highest optimism-value. Has thus also the same metrics as the optimism-values have no functional influence on the metrics.

A.6 Small-World and Scale-Free topologies

A.6.1 Erods-Renyi

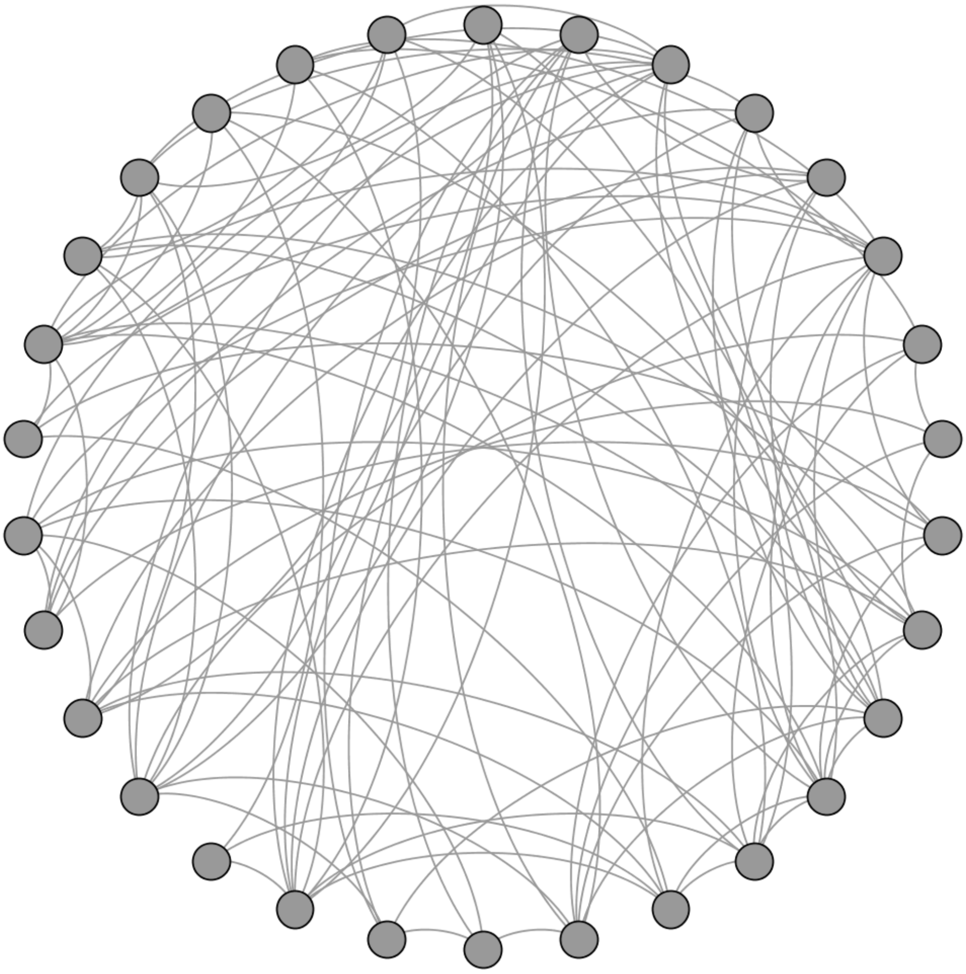

Figure 31: Erdos-Renyi topology with inclusion-probability of 0.2

Table 41: Network metrics Erdosy-Renyi 0.2

Avg. degree	6.8
Avg. path-length	1.913
Avg. clustering coefficient	0.266
Network diameter	3
Graph density	0.234
Connected component	1

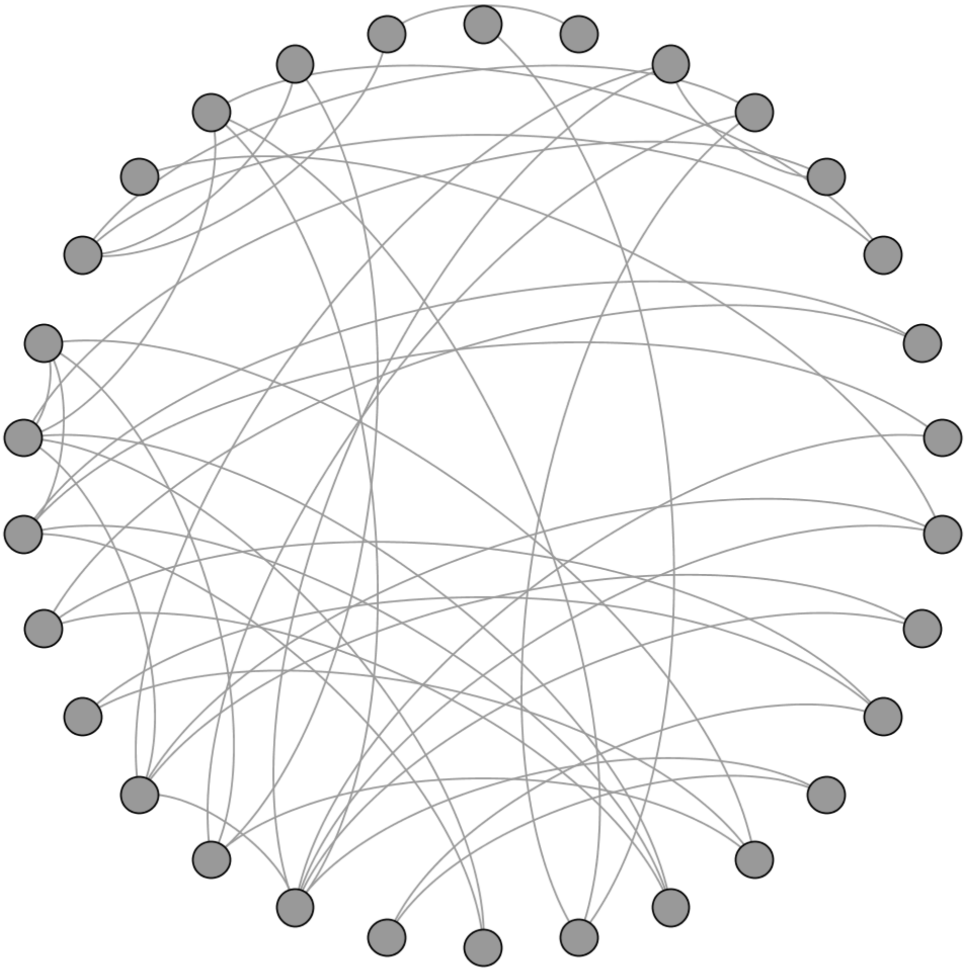

Figure 32: Erdos-Renyi topology with inclusion-probability of 0.1

Table 42: Network metrics Erdosy-Renyi 0.1

Avg. degree	2.933
Avg. path-length	3.262
Avg. clustering coefficient	0.103
Network diameter	7
Graph density	0.101
Connected component	1

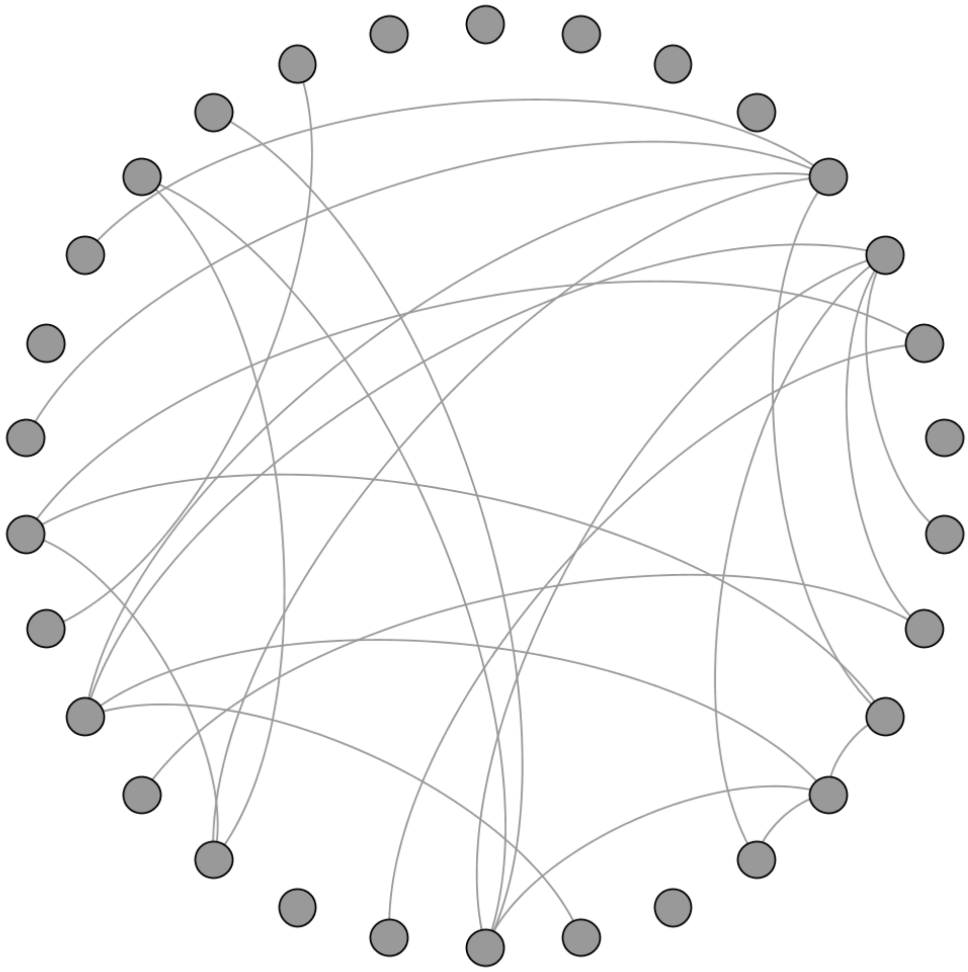

Figure 33: Erdos-Renyi topology with inclusion-probability of 0.05

Table 43: Network metrics Erdosy-Renyi 0.05

Avg. degree	1.6
Avg. path-length	3.052
Avg. clustering coefficient	0
Network diameter	8
Graph density	0.055
Connected component	11

A.6.2 Barbasi-Albert

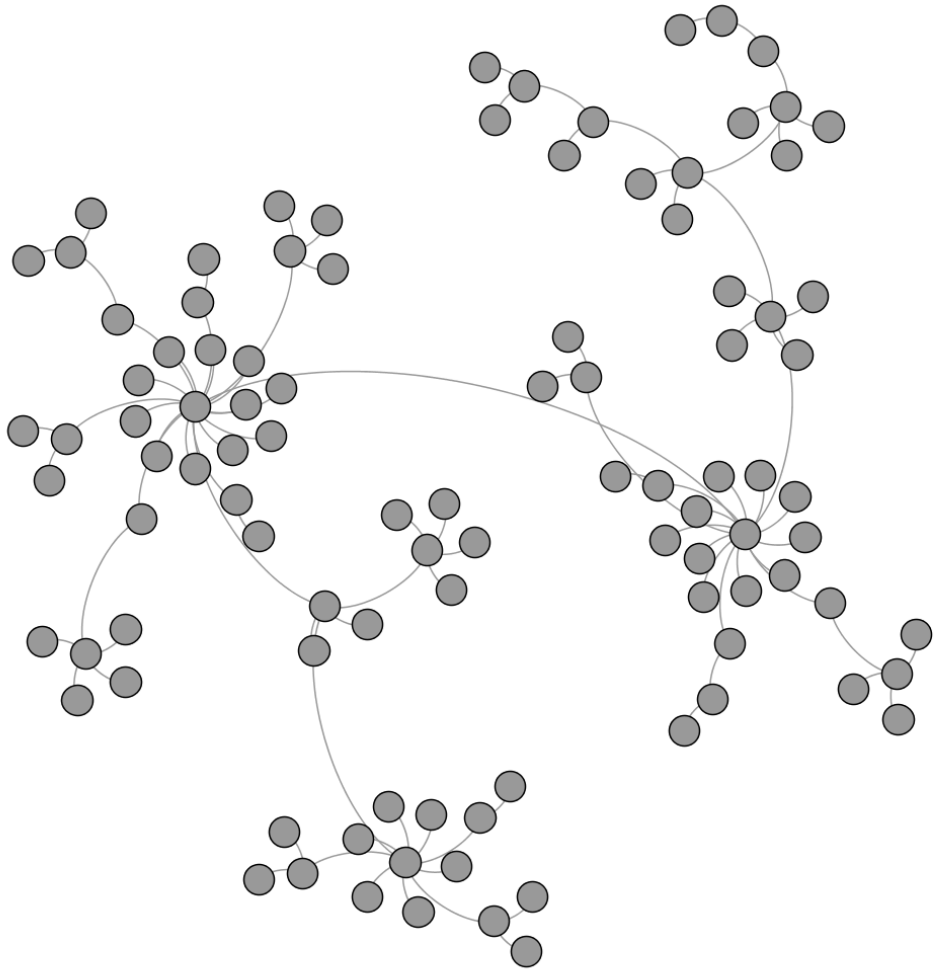

Figure 34: Barbasi-Albert topology with m0=3, m=1

Table 44: Network metrics Barbasi-Albert m0=3, m=1

Avg. degree	1.98
Avg. path-length	4.684
Avg. clustering coefficient	0
Network diameter	11
Graph density	0.02

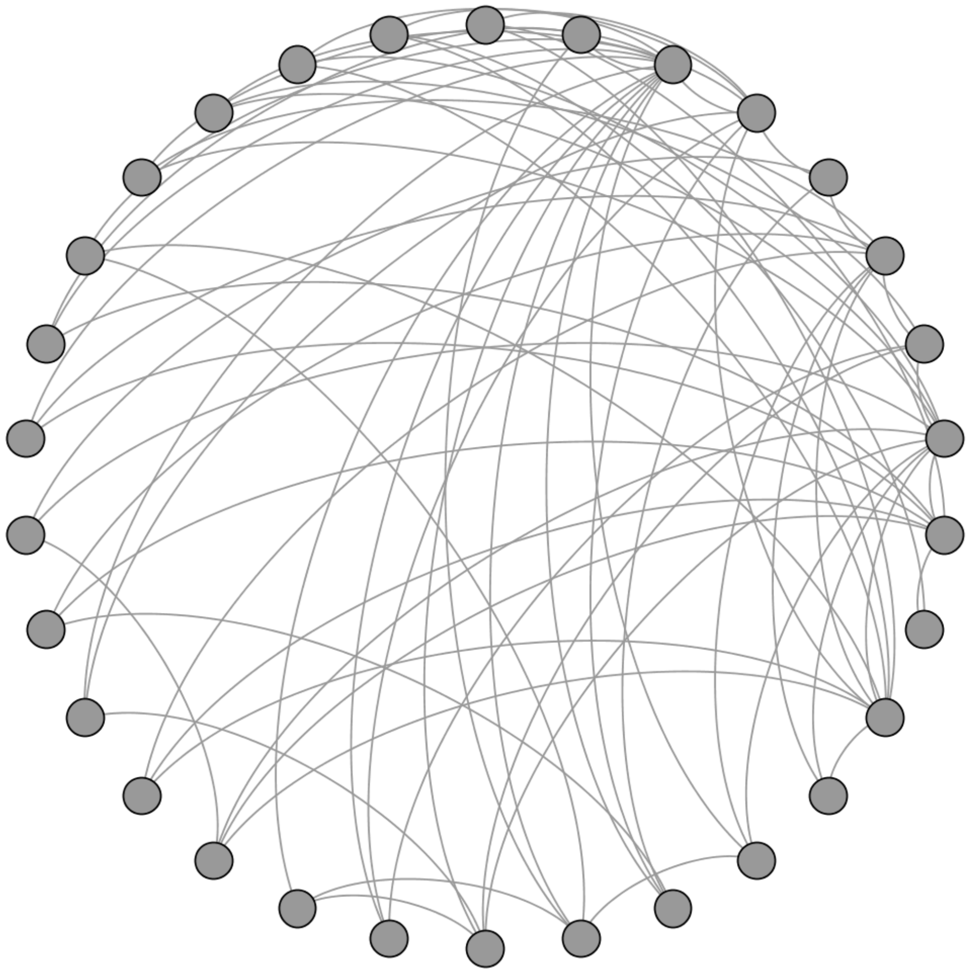

Figure 35: Barbasi-Albert topology with m0=9, m=3

Table 45: Network metrics Barbasi-Albert m0=9, m=3

Avg. degree	4.733
Avg. path-length	2.11
Avg. clustering coefficient	0.279
Network diameter	4
Graph density	0.163

A.6.3 Watts-Strogatz

Two params: k and p Creates N nodes and connects each to k neighbours and rewires each then existing edge with a probability of 0.2 to another node with lower id (younger).

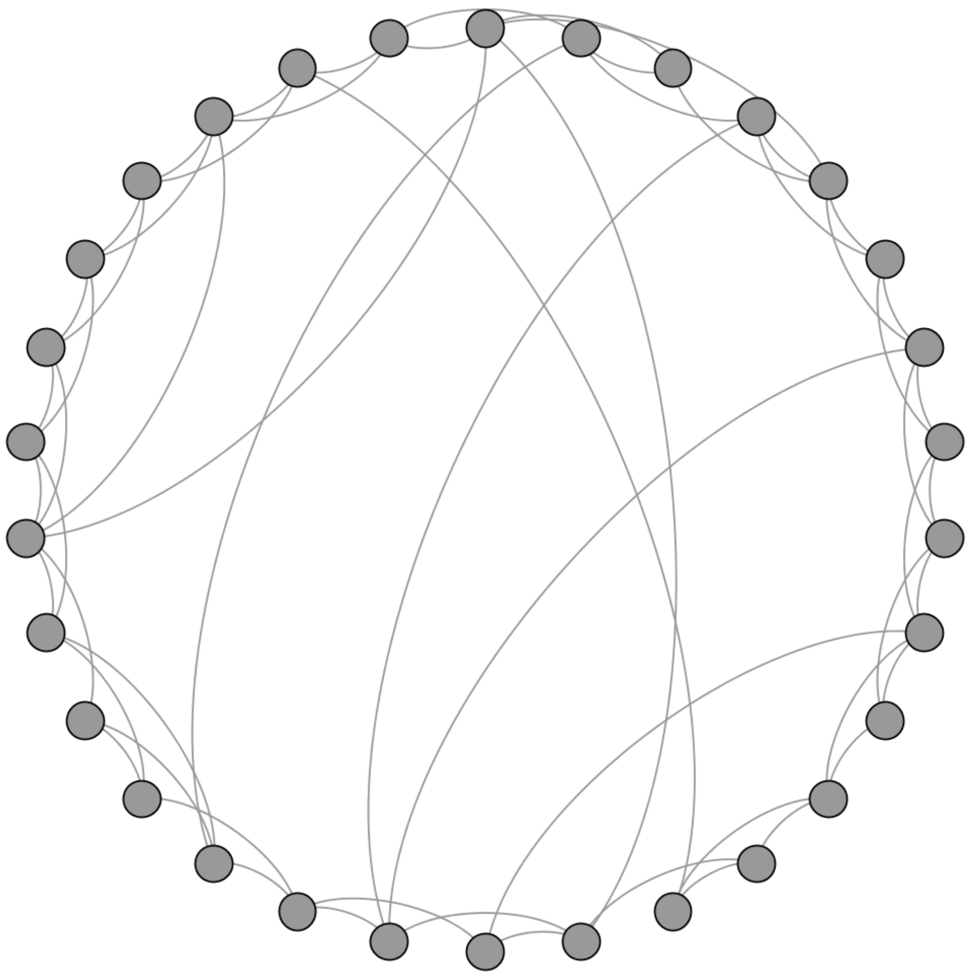

Figure 36: Watts-Strogatz topology with k=2, p=0.2

Table 46: Network metrics Watts-Strogatz k=2, p=0.2

Avg. degree	4
Avg. path-length	2.883
Avg. clustering coefficient	0.259
Network diameter	6
Graph density	0.138

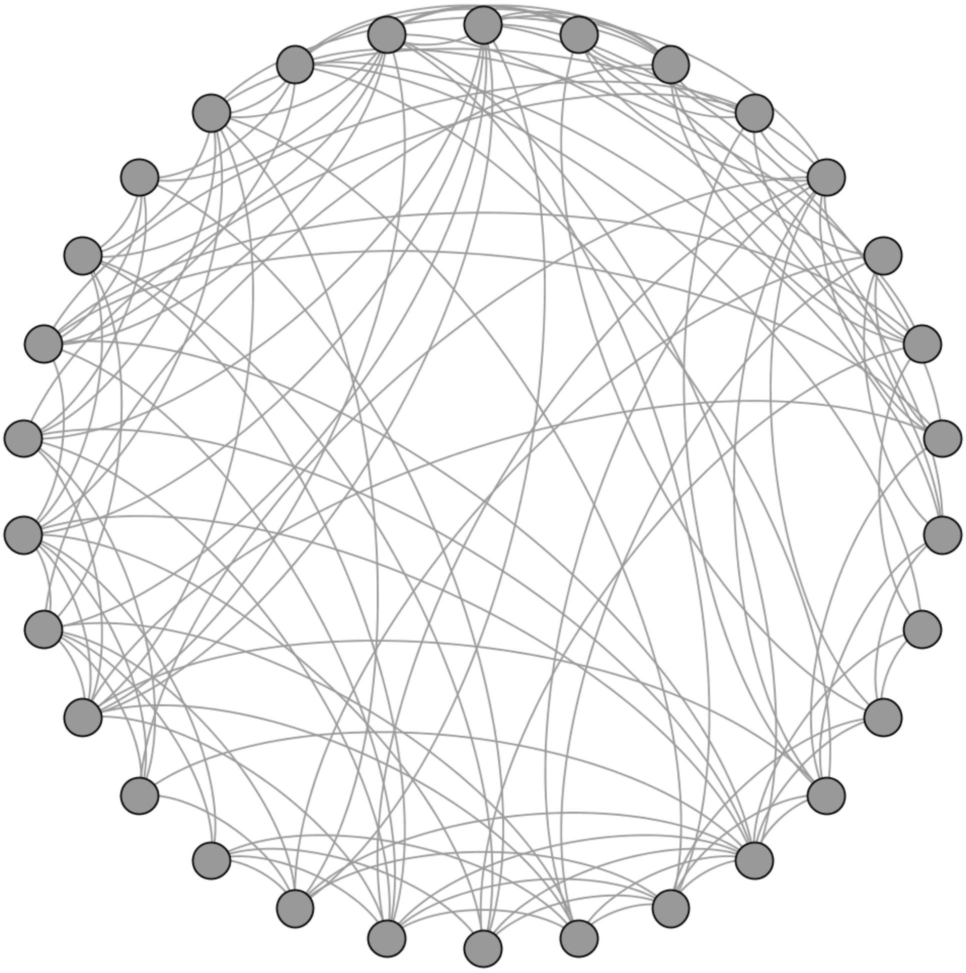

Figure 37: Watts-Strogatz topology with k=4, p=0.5

Table 47: Network metrics Watts-Strogatz k=4, p=0.5

Avg. degree	8
Avg. path-length	1.823
Avg. clustering coefficient	0.241
Network diameter	3
Graph density	0.276

Appendix B

Visual Results for Hub-Based, Scale-Free and Small-World Topologies

B.1 Hub-Based topologies

The Hub-Based Topologies fail to come even close to equilibrium due to reasons given in Chapter "Topologies and Hypothesis". This can be seen also very clearly in the visual results and thus no performance- and equilibrium-tables are listed as they would not make any sense.

B.1.1 3-Hubs

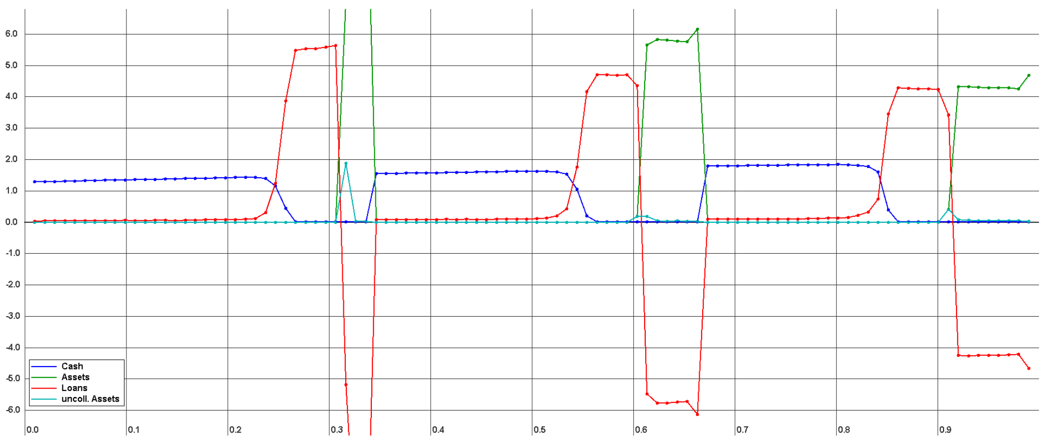

Figure 38: Wealth-Distribution of 3-Hubs topology

B.1.2 1-Median Hub

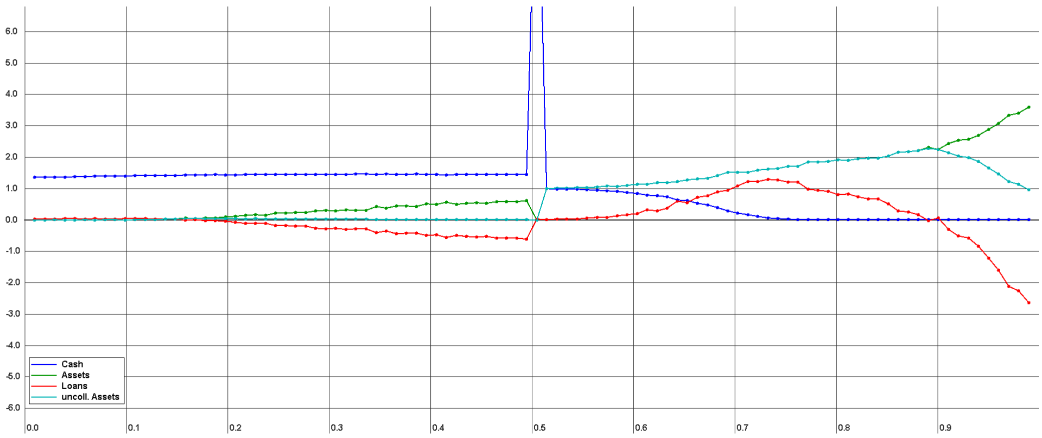

Figure 39: Wealth-Distribution of 1 Median-Hub topology

B.1.3 3-Median Hubs

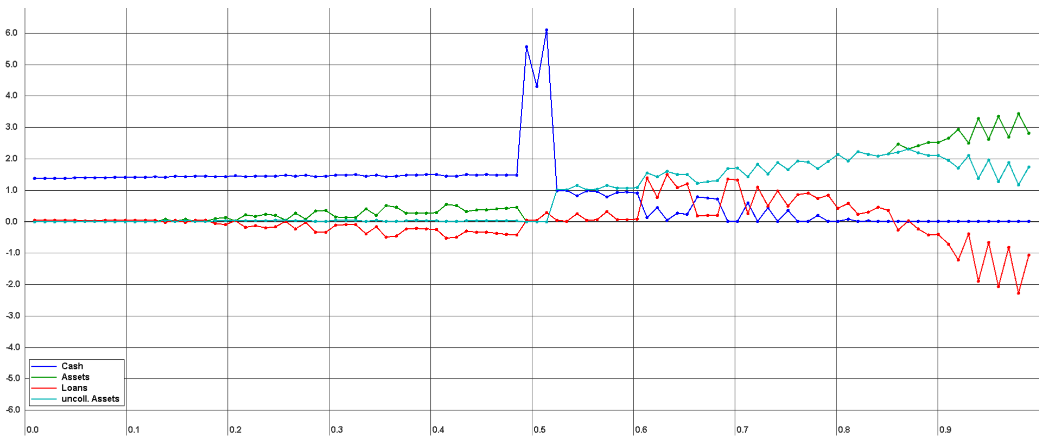

Figure 40: Wealth-Distribution of 3 Median-Hubs topology

B.1.4 Maximum Hub

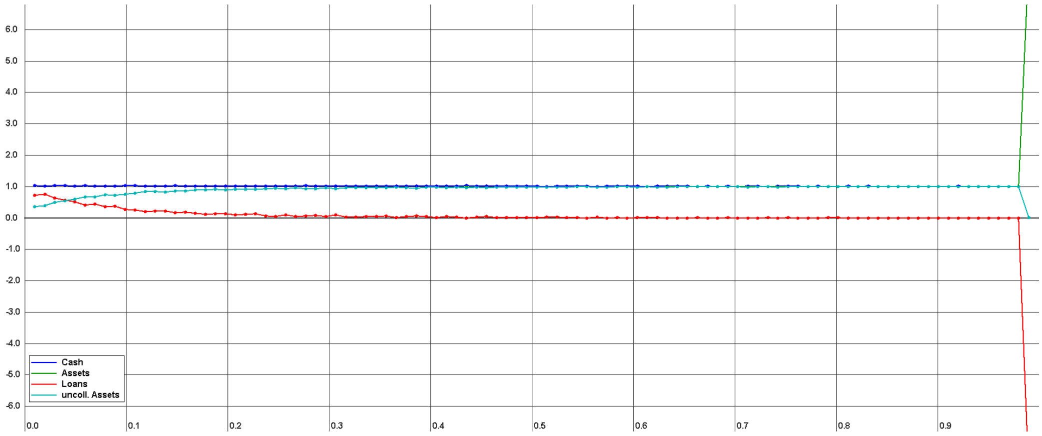

Figure 41: Wealth-Distribution of Maximum-Hub topology

B.2 Scale-Free and Small-World topologies

This topologies fail to come even close to equilibrium too due to reasons given in Chapter "Topologies and Hypothesis". This can be seen also very clearly in the visual results and thus no performance- and equilibrium-tables are listed as they would not make any sense.

B.2.1 Erdos-Renyi

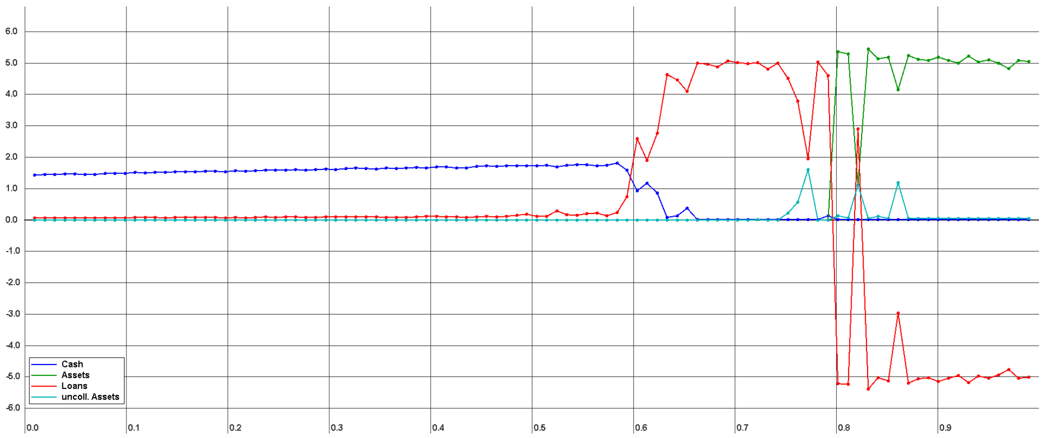

Figure 42: Wealth-Distribution of Erdos-Renyi 0.2 topology

need to show network too because random ?

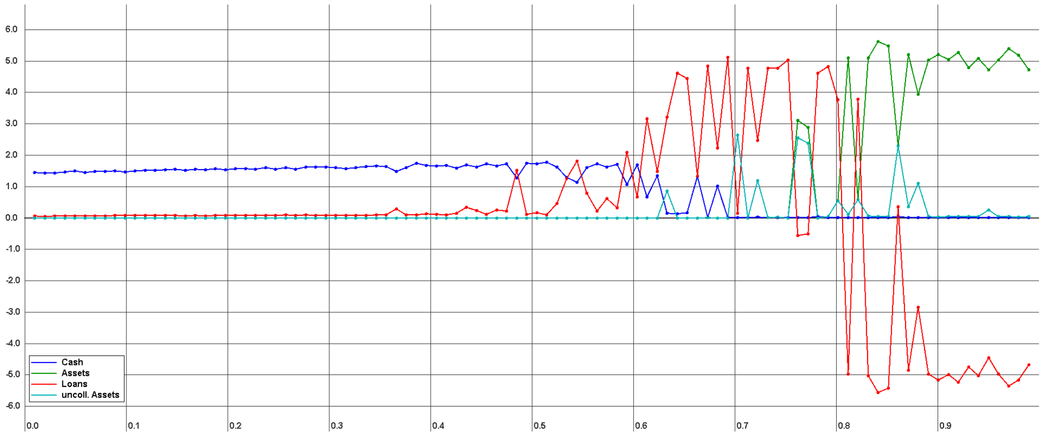

Figure 43: Wealth-Distribution of Erdos-Renyi 0.1 topology

need to show network too because random ?

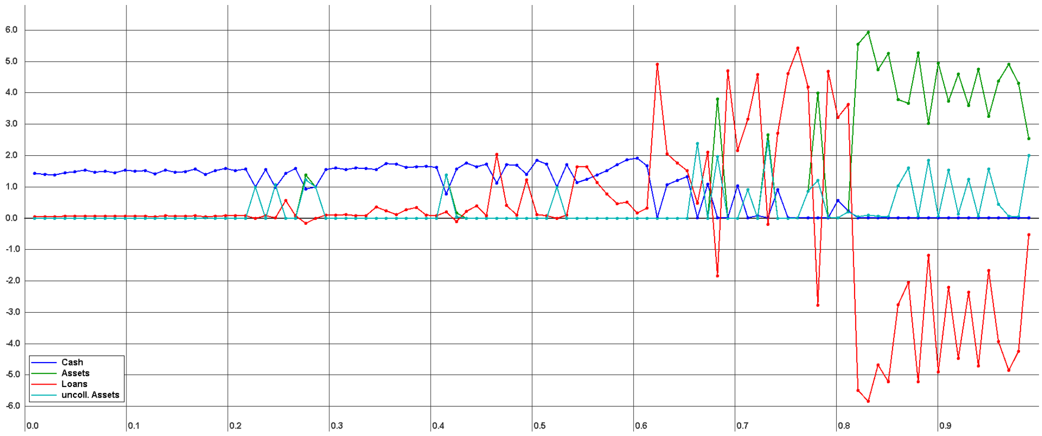

Figure 44: Wealth-Distribution of Erdos-Renyi 0.05 topology

need to show network too because random ?

B.2.2 Barbasi-Albert

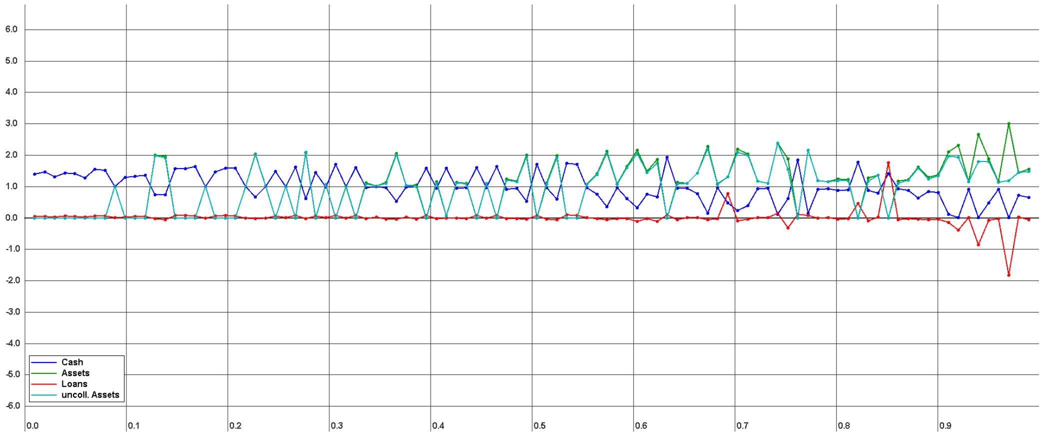

Figure 45: Wealth-Distribution of Barbasi-Albert m0=3, m=1 topology

need to show network too because random ?

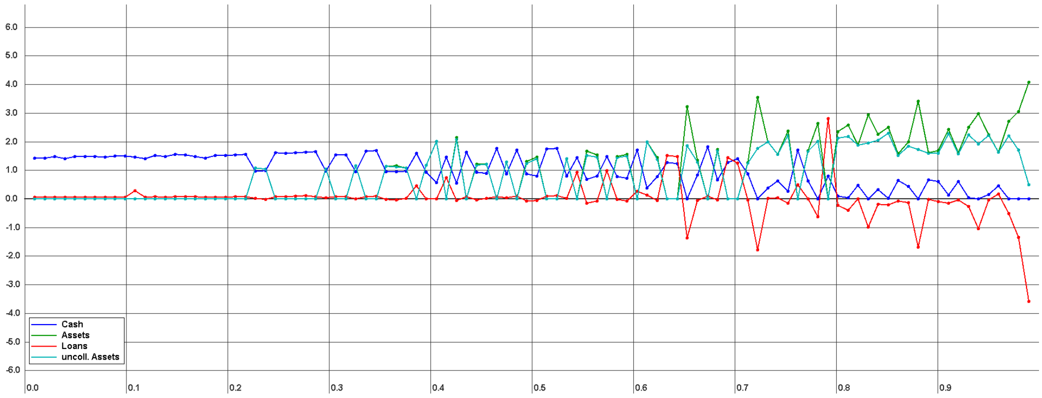

Figure 46: Wealth-Distribution of Barbasi-Albert m0=9, m=3 topology

need to show network too because random ?

B.2.3 Watts-Strogatz

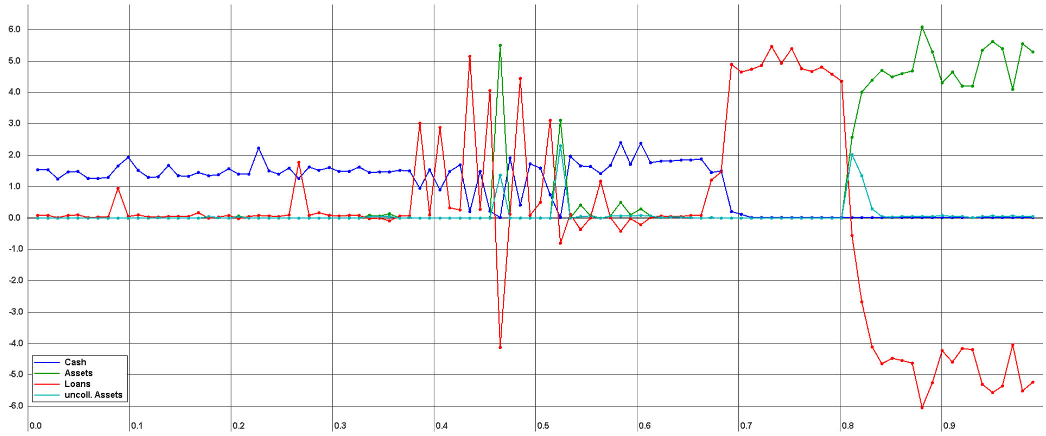

Figure 47: Wealth-Distribution of Watts-Strogatz k=2, b=0.2 topology

need to show network too because random ?

Appendix C

Interpretation of results of Hub-, Scale-Free and Small-World Topologies

C.1 Hub Topologies

C.1.1 3-Hubs

C.1.2 1-Median Hub

C.1.3 3-Median Hubs

C.1.4 Maximum Hub

C.2 Scale-Free and Small-World topologies

C.2.1 Erdos-Renyi

C.2.2 Barbasi-Albert

C.2.3 Watts-Strogatz

Figures

List of Tables

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